ENERGY FOUNDATION
能源基金会

International Best Practices for Congestion Charge and Low Emissions Zone

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PREFACE

China is the global largest new vehicle market and is expected to exceed the United States as having the world's largest vehicle fleet in coming ten years. In addition to the fast growing oil consumption in China because of the increasing vehicle population, local cities are facing the challenges to deal with the deteriorating traffic and urban air quality. One hand, municipal governments and national government are exploring improving the urban function and space planning so that the transportation demand could be reduced, promoting public transportation system so that trips growth made by private vehicles could slow down, and developing electric vehicles so that technically vehicles could meet zero emissions. On the other hand, in order to control the new vehicle sales, plate auction, lottery system, and the policies combing the two are enforced in Beijing, Shanghai, and Guangzhou etc.. In a whole, top-down administrative rules are the preferred options. And there is much space for economic policies to regulate vehicle usage and reduce the intensity.

During the winter season in 2012 and 2013 serious air pollution episodes happened widely in China and continued for quite a long time. As a result, both national government and local governments adopted a series of policies to address this challenge. For example, Beijing adopted its *'2013-2017 Clean Air Action Plan'*, in which the tasks, 'conducting researches on low emissions zone and congestion charge, promoting intelligent vehicle identification and toll collection system, and reducing vehicle usage intensity in the city center', are included. Following that, *'Important Tasks Allocation Plan for the Clean Air Action Plan'* required Beijing Municipal Commission of Transport and Beijing Environmental Protection Bureau to lead the development of policies on low emissions zone and congestion charge. Besides, other mega cities are also showing growing interests in congestion charge. In order to support the interests, especially the efforts of Beijing, with the guidance from the Ministry of Transportation (MOT) and the Ministry of Environmental Protection (MEP) and the support from the Energy Foundation China (EFC), China Academy of Transportation Sciences under MOT, Vehicle Emissions Control Center under MEP, and Department of Transportation in Zhejiang Province organized an *International Forum on Economic Policies for Traffic Congestion and Tailpipe Emissions Control* on December 12 and 13, 2013 in Hangzhou, Zhejiang Province. International experts from London in U.K., Stockholm in Sweden, Milan in Italy, Singapore, and Minnesota and New York in U.S. presented the their own experiences on the research, development, and enforcement of congestion charge and low emissions zone. Feedbacks from the forum were very positive and based on the requests from the participants, EFC invited the six experts for papers to systematically summarize their experiences and lessons in more details and they all accepted the invitations. Consequently, all these papers are combined together and lead to this report, *'International Best Practices for Congestion Charge and Low Emissions Zone'*.

It took about half year to write, translate, proof reading, format, and print this report. EFC appreciates a lot to the support and contributions from Mr. Steve Kearns (Transport for London, U.K.), Mr. Gunnar Soderholm (Environment and Health Administration, City of Stockholm, Sweden), Dr. Jonas Eliasson (KTH Royal Institute of Technology in Stockholm, Sweden), Ms. Silvia Moroni (Mobility, Environment and Land Agency, City of Milan, Italy), Mr. Goh Shou Xian (Land Transport Authority of Singapore), Mr. Kenneth R. Buckeye (Minnesota Department of

Transportation, U.S.), and Mr. Charles Komanoff (the Nurture Nature Foundation, New York, U.S.). We are also appreciated of the help from Dr. Michael Wang (Senior Scientist, Argonne National Lab, DOE, U.S.) during the process of developing this report and organizing the international forum.

Constrained by the limited time and resources, the report may still have some mistranslation and errors, please contact the EFC by china@efchina.org for your comments and inputs.

Transportation Program & Sustainable Cities Program of EFC
August 2014

Bio of Writers

Steve Kearns has worked for Transport for London for the past 12 years, including seven years on the Central London Congestion Charging project. His job involved managing the concept, design and implementation of traffic and transportation measures to support the Charging scheme.

From 2008-2012 he worked in Transport for London's Technology Delivery Group, promoting new technology initiatives such as trialing reservations of on-street booking facilities for freight vehicles and usage of electronic devices for traffic management purposes.

Prior to working for Transport for London he spent 15 years as a transport planner in local authorities and community organizations in London where major projects included promoting the new Cross rail link and preparing the transport and business case for international rail station at Stratford, East London (used extensively during 2012 Olympic Games).

He has a Master of Science degree in Transport Planning from University of Westminster, is a member of the Chartered Institute of Highways and Transportation and also a member of the European Union's ITS Urban Experts Group.

Dr. Jonas Eliasson is Professor of Transport Systems Analysis at the KTH Royal Institute of Technology in Stockholm and director of the Centre for Transport Studies.

Prof. Eliasson has a long involvement in analyzing, developing and applying transport policies and appraisal methodologies. He directed the design and evaluation of the Stockholm congestion charges, introduced 2006, and has acted as expert advisor to many city leaders and national governments around the world on strategic transportation issues, often involving sustainable transport planning, transport pricing and social and economic appraisal.

He is a frequent advisor to the Swedish Government in transport policy issues, has chaired the national committee for analysis of the National Transport Investment Plan, is a member of the standing expert advisory board to the National appraisal guidelines committee, and has been responsible for forecasts and evaluations of several major infrastructure investments. He has published over 50 scientific papers on various topics such as cost-benefit analysis, transport modeling, transport pricing, acceptability of transport policies and social valuation of travel time and reliability.

Goh Shou Xian has been the Assistant Manager, Policy Division at the Land Transport Authority since 2011. He is involved in private transport policy formulation and his work focuses on vehicle ownership and usage policies, as well as policies relating to land transport emissions.

The Land Transport Authority (LTA) is a statutory board under the Ministry of Transport that spearheads land transport developments in Singapore. 'To provide an efficient and cost-effective land transport system for different needs' is our mission statement.

Ken Buckeye is Program Manager for Value Pricing with the Office of Policy Analysis, Research and Innovation with the Minnesota Department of Transportation (Mn/DOT). Ken has more than 20 years of experience in transportation planning and project management covering nearly all modes of travel.

Most recently his work at Mn/DOT has focused on value pricing alternatives as a means to manage demand and to help finance transportation systems. He currently is leading the department in implementation of its telework initiative created through the national Urban Partnership Agreement. Ken has a BA in Urban Affairs and Business Management from St. Cloud State University and a Master Degree in City and Regional Planning from Southern Illinois University.

Charles Komanoff is widely known for his work as an energy-policy analyst, transport economist and environmental activist in New York City. He “re-founded” NYC’s bike-advocacy group Transportation Alternatives in the 1980s, co-founded the pedestrian-rights group Right Of Way in the 1990s, and wrote or edited the landmark reports Subsidies for Traffic, The Bicycle Blueprint, and Killed By Automobile.

Earlier, Komanoff gained prominence for deconstructing the disastrous economics of nuclear power in the United States as author-researcher and expert witness for states and municipalities across the U.S. He wrote his visionary oil-saving report, Ending The Oil Age, after witnessing at close range the traumatic events of 9/11. Komanoff's current work includes modeling and advocacy for traffic pricing and free transit in New York City in partnership with renowned civic activist Ted Kheel. He also directs the Carbon Tax Center, a clearinghouse for information, research and advocacy on behalf of revenue-neutral carbon taxes to address the climate crisis. A math-and-economics graduate of Harvard, Komanoff lives with his wife and two sons in lower Manhattan.

Silvia Moroni achieved her PhD in Environmental Engineering at Politecnico di Milano in 2002 with a thesis titled ‘Vehicular Traffic emissions and Air quality: elements for the management in a large urban area’ concerning the City of Milan case study. She has been employed for over a decade by the Milan Local Agency for Mobility, Environment and Land Use Planning as Responsible for the Air quality Planning Sector, part of the Environment and Energy Department.

Mrs. Moroni manages the development of several research projects about air quality assessment with special focus on environmental effects of planned measures or new technologies, air pollution monitoring and emissions inventory with particular reference to vehicular emissions, theme on which she has also collaborated for several years with specialized Research Centers. In recent years, hers interest and researches focus on health effects related to air pollution.

Mrs. Moroni is author of several papers and presentations held at national and international conferences and experienced in teaching at University Master Courses and at the Training Courses organized by the Venice International University - TEN (Thematic Environmental Networks) Center in cooperation with the Municipality of Beijing, the Italian Ministry of Environment and the Chinese Environmental Protection Bureau.

CONGESTION CHARGING IN LONDON

Steve Kearns

Transport for London

February 2014

Abstract

This report deals with the history of road pricing policy in London from its first serious consideration in the 1960s through to the introduction of the Central London Congestion charging scheme in 2003. It describes the key operational features of the current scheme, the communications strategy that was used to promote the scheme to as a wide range of stakeholders as possible and the Complementary Measures programme of traffic management and public transport initiatives introduced to support the scheme and the role they played in its successful implementation.

The report also deals with distinct features relating to the Congestion Charging scheme such as the process behind the introduction of the Western Extension in 2007 and its subsequent removal in 2010 and also the introduction of the London-wide Low Emission Zone.

The impacts of the Congestion Charging scheme, both traffic related and wider economic and societal effects are outlined followed by a final appraisal of the lessons learnt chapter, which it is hoped might have a wider implications and relevance for people who are interested in introducing road pricing in other urban areas.

Contents

1. INTRODUCTION

1.1 The History of Congestion Charging Policy in London

The concept of congestion charging or 'road pricing' as it is often known is not new. In the early 1960s, the Ministry of Transport appointed a panel under the chairmanship of Reuben Smeed. Their remit was to report on the technical feasibility of various methods for improving the pricing system for the use of roads. They concluded that contemporary methods of vehicle taxation (which have changed little since) did not restrain people from making journeys which impose high costs upon others. The panel recommended the use of direct road user charges which they believed would achieve far superior results than other forms of tax or charge because they took the large differences in congestion costs between different journeys into account.

In 1967 the Ministry of Transport reported on a study of 'Better Towns with Less Traffic'. This reinforced the findings of the Smeed report, again suggesting that direct road pricing was the most effective means of traffic restraint. This report recognised that there was no current workable system to implement such a scheme and recommended further research and development into the concept.

In the early 1970s the Greater London Council commissioned studies to investigate methods of traffic restraint in response to concern about the impact of congestion on the quality of life and urban efficiency. They concluded that the best method of achieving this was to introduce a Supplementary Licence system whereby a paper licence would have to be purchased and displayed on any vehicle which was in the designated area during the day. It was expected that this scheme would generate substantial economic and environmental benefits and produce more revenue than was needed to meet the set up costs of the scheme and associated measures. However, concerns were expressed about the impacts of the scheme upon lower income groups, the economy, the problems caused by diverted traffic and the practicalities of enforcement. For these reasons the proposals were never taken forward.

In the 1980s the London Planning Advisory Committee (LPAC) commissioned research into a number of transport strategies as part of its work in providing the Government with strategic planning advice for London. This work concluded that the management of congestion was central to transport policy in London. The improvement of public transport by itself was not seen as sufficient; there was a need for direct measures to restrain road traffic and to obtain a better balance between the demand and supply of road space. Various possibilities were suggested as methods of achieving this, again with Congestion Charging seen as the most favourable. Consequently, Congestion Charging was recommended as an appropriate policy for London in LPAC's 1998 Strategic Advice to the Secretary of State.

In 1991 increasing concern about congestion led the Department of Transport to commission the London Congestion Charging Research Programme. The study was published in 1995 and reported that the introduction of Congestion Charging in London would reduce congestion, yield net revenues and provide a rapid payback on the initial costs in both financial and economic terms. The study also concluded that it seemed unlikely to have a significant impact on the economic strength of London, and may even improve it. However, it noted that there would be some losers and a need to protect some of the more vulnerable individuals and groups of society.

1.2 The Road Charging Options for London (ROCOL) Study

The Government Office for London set up an independent working group of experts in 1998 to prepare a report on how a congestion charging scheme in central London could be put into practice. The Road Charging Options for London report (ROCOL) examined a range of options for a charging system in London, ranging from a paper licence to electronic road pricing. It concluded that an area licensing system, enforced by Automatic Number Plate Recognition (ANPR) technology with a £5 daily charge, could have a significant impact on traffic conditions in central London, reducing traffic by around 12%. Improvements would be seen in terms of journey speed, reliability and economic benefits of reducing congestion would help businesses.

In contrast, the ROCOL report concluded that an area licence, based on a paper permit displayed in the windscreen and checked visually by inspectors could lead to a high level of non-compliance, such that the system might fall into disrepute. With more sophisticated electronic road pricing requiring in-vehicle equipment, the ROCOL report found that it was unlikely that such a scheme could become operational in central London within four years.

The recommendations of the ROCOL report form the basic design of the central London congestion charging scheme.

1.3 Greater London Authority Act 1999

In 1999, Parliament passed the Greater London Authority Act which created a unique form of strategic citywide government in London. This Act formed the Greater London Authority (GLA) which is made up of an elected Mayor who has an executive role, making decisions on behalf of the GLA and a separately elected London Assembly which has a scrutiny role. Along with transport, the GLA has responsibilities in a number of areas, including economic development planning, policing, and fire and emergency planning.

The GLA Act (as amended by the Transport Act 2000) is also the legislative instrument which gives the Mayor the powers to introduce Congestion Charging schemes in London. It sets out that:

• The charging authority is Transport for London, whose role is to implement the Mayor's transport strategy and manage the transport services for which the Mayor is responsible.

• The Mayor will have considerable discretion over the design of a charging scheme. However the Government has powers to intervene on issues such as the maximum level of penalty charges, exemptions or discounts in line with national policy, or ensuring value for money in terms of how the proceeds from a scheme can be spent.

• As with decriminalising penalties for parking enforcement within London, the Act allows for secondary legislation making failure to pay a congestion charge or penalty a civil liability, falling on the registered keeper, rather than a criminal offence.

• For at least ten years all net proceeds from a scheme must be spent upon improving transport in accordance with the Mayor's transport strategy.

Regulations were also made by central Government in 2001 to deal with matters such as penalty charges, vehicle clamping and removal processes, adjudication, representation and appeals processes and the recovery of penalty charges.

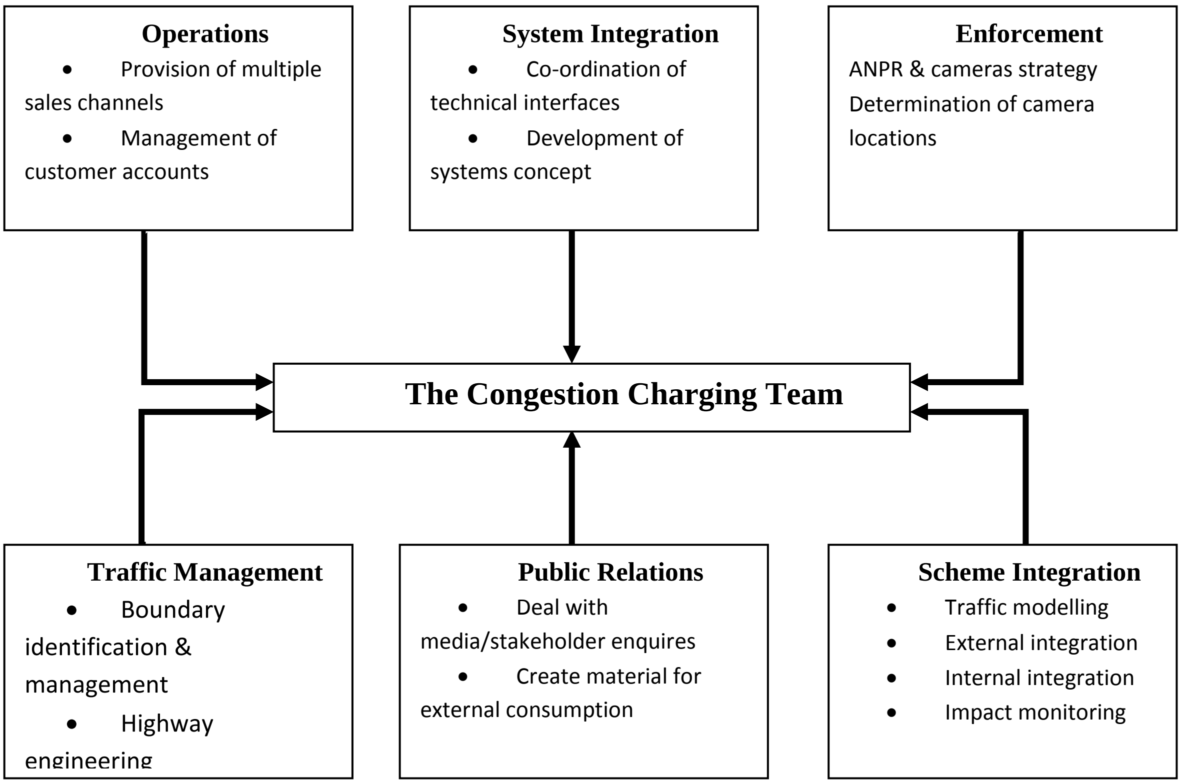
1.4 The Mayoral Elections

The campaign for Mayor of London began in 1999 with four main candidates from each of the main political parties and an independent, Ken Livingstone. Of these candidates three made election promises to introduce a Congestion Charging scheme in Central London. Although this was a brave decision because Congestion Charging was seen as a notoriously difficult policy to sell to voters, at the same time it demonstrated the high level of political commitment to the policy. However, for Ken Livingstone, this political gamble paid off and in May 2000 he was elected as Mayor of London.

Ken Livingstone had set himself a significant challenge. Of the one million people that work in central London one in seven travelled by car. At peak times over 50,000 vehicles per hour came into central London resulting in an average speed of 9 miles per hour throughout the working day. It was anticipated that the Congestion Charging scheme would reduce the traffic in the central zone by 10-15%. This would reduce queueing delays by 15-30% within the central zone and improve conditions on main roads into the zone.

1.5 The creation of a Transport for London Congestion Charging team

In July 2000 the Mayor asked Transport for London to investigate the options for implementing a congestion charging scheme in London. This led to the creation of a team committed to fulfilling the Mayor's election promise. The team was also supported by a dedicated project management function and general procurement capability.



2. KEY FEATURES OF THE SCHEME

2.1 Where do the charges apply?

The scheme covers the very heart of central London (21 square kilometres), the area is bounded by the Inner Ring Road. There is a charge for use of vehicles on roads within the charging zone, but not for using the Inner Ring Road itself.

2.2 How much is the charge and when does it apply?

The standard charge was originally £5 per vehicle per day. This has since risen incrementally to £10 with a consultation currently taking place with a view increasing the charge to £11.50. Charges can be paid weekly, monthly or annually. Charging hours apply from 7:00am to 6:30pm, Monday to Friday. There is no charge on public and bank holidays.

2.3 When do charges have to be paid?

To drive or park (unless in a residents bay) on the street within the central zone during hours of operation, the registration number of each vehicle (unless exempt) has to be notified to TfL as the charging authority and unless subject to a 100% discount, the charge paid. The majority of users pay in advance of the vehicle being in the central zone, through the Auto Pay system. However, vehicle registration numbers can be notified up to midnight on the day after travel. For payment on the day after travel, the charge will be £12 (a surcharge of £2) to encourage pre-payment, better planning of journeys and to assist enforcement.

2.4 Which vehicles are charged?

The Congestion Charge applies to all motor vehicles except exempt vehicles and those registering for a 100% discount. Examples of vehicles that are fully exempt include:

• Motorcycles and mopeds;
• Vehicles classified as emergency vehicles by the Driver and Vehicle Licensing Agency;
• National Health Service vehicles which are not liable for Vehicle Excise Duty (e.g. patient transport vehicles);
• Buses and coaches (Public Service Vehicles) with 9 or more seats;
• Vehicles used by disabled persons and disabled carrying vehicles (e.g. Dial-A-Ride that are not liable for Vehicle Excise Duty (VED))
• London licensed taxis ('Black Cabs') and licensed mini-cabs.

Some vehicles are eligible for a 100% discount from the Congestion Charge though it is required to pre-register these vehicles and verify their status. Examples of these vehicles include:

• Certain categories of military vehicle;
• Additional operational vehicles used by the emergency services (e.g. vehicles used to attend incidents, such as those used by police forensic teams);
• Key vehicles used by central London Boroughs – such as refuse vehicles, 'meals on wheels' and street maintenance vehicles;
• Community mini-buses.

Some vehicles are eligible for a 100% discount but that an annual registration fee of £10 is required to cover the costs of administration and verification. Examples of these vehicles include:

• All alternative fuel (i.e. gas, electric and fuel cell) vehicles (including bi/dual fuel vehicles). Vans and lorries were originally required to meet Euro III emission standards. Initially cars that would be expected to achieve emission savings 40% above Euro IV standards; - these standards have since become stricter.
• Specially adapted recovery vehicles (e.g. those used by motoring organisations for break down removals);
• Breakdown vehicles in use to provide roadside assistance or recovery services operated by independently accredited organisations (e.g. AA, RAC, Green Flag);
• Vehicles driven by or being used for driving disabled persons in receipt of a European Union Blue Badge

Private vehicles registered to a keeper within the central zone are eligible for a 90% discount of the congestion charge. This discount is subject to confirmation of residency status, vehicle ownership, and payment of an annual £10 registration fee. This discount applies to a minimum of one week's charge (£5.00). Residents with a relevant parking permit, living inside the central zone can park all day in a residents' on-street parking place within their local parking zone without paying the charge. However, if they move their vehicle within charging hours they are liable to pay the discounted charge.

2.5 How does the scheme work?

Drivers using a vehicle in the central zone pay the charge in advance or on the day of travel, to have the registration number of their vehicle entered into a database. TfL maintains the database of the vehicle registration numbers. Inclusion of an individual's vehicle registration number on the database could be for a day, a week, a month, or on an annual basis. Drivers could originally pay the charge and notify their vehicle registration numbers at retail outlets, by post or phone or over the internet. Following its introduction in 2011 Auto Pay quickly became the most popular means of payment for users. It involves a permanent record of a nominated vehicle being kept on TfL database. It is also operationally efficient for TfL because it significantly reduces the back office costs associated with Penalty Charge Notice processing. Auto Pay involves motorists giving TfL their credit card or debit card details; they then pay the charge a month in arrears, similar to Pay As You Go mobile phone accounts.

Auto Pay payment accounts are also available for certain fleet operators. In total over 70% of users now pay the charge via Auto Pay or Fleet Payment. No permit or equipment has to be displayed in the vehicle.

2.6 How is the scheme enforced?

The number plates of vehicles entering or moving in the central zone are 'inspected' by a network of fixed cameras. (Mobile cameras were also initially used). Parked vehicles can also be 'inspected' by foot patrols. The registered keeper of any vehicle, which has been identified within the central zone without an appropriate congestion charge having been paid, is liable to a penalty charge of £120. This is discounted to £60 for payment within 14 days. If a penalty charge has not been paid and there are no representations or appeals, a charge certificate will be issued after 28 days and the registered keeper will be liable for a penalty charge of £180.

- There was also originally a system of vehicle clamping and/or removal to deal with persistent evaders, i.e. when there are three or more penalty charges with respect to the vehicle. The system of clamping and/or removal applied within Greater London and not just within the central zone. This form of enforcement has now been discontinued.
- Bailiffs are used to recover the debts of persistent evaders and foreign registered vehicles, for which no charge payment is recorded. In addition, the charging scheme has a system of appeals and independent adjudication comparable to the existing arrangements that were in place for adjudication of disputed parking penalty charges.

2.7 Monitoring the Impacts of the Scheme

An extensive programme of impact monitoring was put in place by TfL so that any necessary or desirable adjustments to the scheme could be identified and introduced, both in the short and long term. The monitoring covered operational traffic and transport impacts but the potentially more subtle impacts on, for example households, different social groups, businesses, schools, public services, tourism, leisure and the environment. The Congestion Charging monitoring programme commenced in Spring 2001 and continued until the 6th Annual Monitoring Report, which was published in 2008. Monitoring since that time has been carried out as part of overall London traffic monitoring with results being published in TfL's annual *Travel in London* reports.

3. COMMUNICATIONS STRATEGY

3.1 The Mayor's Consultation Process

In July 2000, the Mayor began the process of consulting on his plans for introducing Congestion Charging in central London through publication of a discussion paper *'Hearing London's Views'*. This paper was sent to nearly 400 key stakeholders such as the London boroughs, London Members of Parliament (MPs), Members of the European Parliament (MEPs), business groups, transport operators, motoring organisations and disabled groups. The results of this exercise revealed that six times as many stakeholders supported the concept of introducing a congestion charging scheme in central London, as opposed the initiative.

The next step in the consultation process was the publication of the Mayor's draft Transport Strategy in January 2001. This document set out the Mayor's plans for transport in London. The proposed central London Congestion Charging scheme was an integral part of this Strategy and is one element of a package of measures which would be instrumental in achieving the Mayor's objective of providing London with a Transport system fit for the 21^{st} century. The consultation on the Strategy generated some 8,000 written responses which demonstrated that the public, stakeholders and other interested parties were broadly in favour of the proposed congestion charging scheme and the Mayor's plans for Transport in London more generally. In July 2001, the Mayor published his Final Transport Strategy, which, after taking into account the response to the Draft Transport Strategy consultation, confirmed proposals to introduce the congestion charging scheme in early 2003.

On 23 July 2001, TfL made the Scheme Order; this document provides the legal basis for the implementation of the scheme and sets out in detail its key aspects. The Scheme Order was sent to more than 500 stakeholders to consult them on the finer details of the Mayor's proposals.

Opinion polls conducted throughout the consultation period demonstrated significant support for the Mayor's scheme. For example, a poll conducted by Mori in April 2001showed that 51% of people are in support of the Mayor's scheme, with only 35% against, though there was evidence of support for the scheme waning approaching the go-live date and increasing once again post-implementation.

Having listened to people's views, a number of modifications were suggested by TfL to the original congestion charging scheme proposals. Londoners were consulted again in January 2002 on these suggested modifications.

Following this, the Mayor of London decided in February 2002 to go ahead with the scheme.

3.2 Communications Strategy on Details of the Scheme

Once the Mayor had the decision to proceed with the scheme, there followed a significant challenge to communicate the details of Congestion Charging to the general public and a range of major stakeholders.

There was no history of road pricing in London and level of awareness among the travelling public when Mayor Ken Livingstone assumed office was effectively non existent.

TfL drew up a communications strategy that was aimed at reaching as wide a range of the travelling public as possible, using many media channels.

The Order describing the scheme was published on the TfL website and a number of regional newspapers and periodicals. The Order invited comments from the general public but was very much a legal document and whilst the publication of the order resulted in responses from major stakeholders such as the London Borough Councils, motoring organisations, business representative groups etc., it was clear that this was not the optimum means of engaging with the general public on such a radical project and a further, more widely reaching form of consultation would need to be initiated.

The Communications Strategy was predicated on the need to both inform and persuade the travelling public of the rationale underpinning the introduction of Congestion Charging.

The major elements of the Communications Strategy consisted of ;

a) Information about Congestion Charging being published in the **London-wide evening newspaper** (Evening Standard). This information was primarily factual; eg geographical area of CC zone, start date, hours of operation, exemptions and discounts, how to register your vehicle, means of payment etc.

b) Similar information to the above published in **local newspapers**. These newspapers tend to focused at borough level (London consisting of 32 boroughs plus the City of London). Each borough council also has its own newspaper or publication, many of which are distributed free to their local residents.

c) **Radio adverts**; the majority giving factual information about Congestion Charging while others highlighted the reasoning behind the introduction of the scheme.

d) **Television adverts**; as radio adverts above. Senior TfL staff appearing on television programmes to explain why Congestion Charging was being introduced in Central London and how the scheme would operate.

e) **Road Shows** ; TfL personnel staffing a caravan at a range of locations such as shopping centres, local high streets, town squares, town halls, sports centres, swimming pools, theatres, cinemas etc. Staff would disseminate information about the scheme to passers-by and people approaching the caravan. A video about Congestion Charging was played on a continuous loop, which was used to engage people's interest. The locations were chosen to reflect those areas which had been evaluated as being most likely to experience changes in traffic flow due to the introduction of Congestion Charging; they were focused particularly on areas between the zone boundary and some 2-3 miles outside the zone boundary, as modelling results had indicated that these would be the areas which could experience some changes in traffic patterns and possible increases in traffic flows.

f) Regular meetings with and presentations to the **Greater London Authority (GLA)**, whose elected members, have a scrutiny function in relation to the Mayor of London. Some members of the GLA were very supportive of Congestion Charging, others were extremely hostile.

g) Regular meetings with **London Councils** (the representative body for London's 32 borough councils plus the City of London). These tended to be technically focused meetings with professional transport staff representing the boroughs.

h) Meetings with **local borough councils**; these included regular meetings with all boroughs inside and straddling the zone boundary. These consisted of technical meetings with council officers (professional staff) and sometimes elected members. Many borough councils also requested presentations at their full council meetings where all elected members would be present and would quiz TfL staff about any conceivable aspect of the project. Such meetings would also be open to members of the public.

i) Meetings with **commercial representative bodies;** These included London-wide, generic organisations such as the London Chamber of Commerce, London First and the London Branch of the Confederation of British Industry. The remit of these organisations was to protect the interests of business and commerce and to endeavour to influence the design and operation of Congestion Charging to minimise any detrimental impact for businesses and maximise potential commercial benefit.

These organisations ideally wanted an exemption from the charge for commercial vehicles but when that was not offered, they lobbied strongly that commercial vehicles should not pay a higher charge than private cars.

j) Meetings with **trade specific representative bodies**; Many specific trades initially expressed reservations about the perceived impact Congestion Charging would have on their business performance. These included a wide range of trades and professions who were concerned about the perceived impacts of Congestion Charging. These included:

- **medical professions** (doctors, nurses, midwives) who were concerned about having to pay the charge when driving vehicles whilst on duty and patients would have to pay if attending appointments at medical institutions inside the zone.
- **teachers** who would have pay to pay the charge when driving their own vehicles to/from their place of employment if within the Congestion Charging zone – this was a particular issue for music teachers who would often have to transport bulky musical instruments and art teachers who similarly would transport artistic materials;
- **wholesale market traders** – Central London still has a wholesale meat market and wholesale fruit and vegetable market, to which many retailers from across the UK travel to purchase food. There was concern about wholesalers and retailers having to pay the charge to access the markets.
- **tradespeople** such as plumbers and electricians – they were concerned about incurring extra costs when working inside the Congestion Charging zone.
- **undertakers** ; they viewed the charge as immoral as they would have to charge more to conduct funerals inside the Congestion Charging boundary.

As a result of these meetings TfL did agree to exempt medical staff whilst on duty and patients attending medical appointments from paying the charge but did not agree to exempt any other categories of users from the charge.

k) Information about the introduction of Congestion Charging in London was included when the UK's Driver Vehicle Licensing Agency sent out **Vehicle Excise Duty (Car Tax) payment reminders,** which they do either once or twice a year to every vehicle owner in the UK. This took the form a small paper slip, with a website address for further information, included with the vehicle tax reminder.

l) **Public Meetings** ; These were often requested by community and resident associations in areas immediately outside or up to 3 miles outside the zone boundary , where residents were especially concerned about the impact of the scheme on their journeys and on their residential areas. It was not possible for TfL to agree to every meeting request. However TfL staff did attend a significant number of these meetings, at which there was almost invariably opposition expressed to the idea of Congestion Charging by local people. The main reasons for this opposition were;

- Additional costs to be incurred by local residents driving into the CC zone.
- Perceived detrimental environmental and traffic impact of vehicles from outside the local area using local roads to park, thereby avoiding paying the charge.

This was successfully addressed by creating residents' only on-street Controlled Parking Zones in areas immediately outside the zone, which proved very popular with local residents.

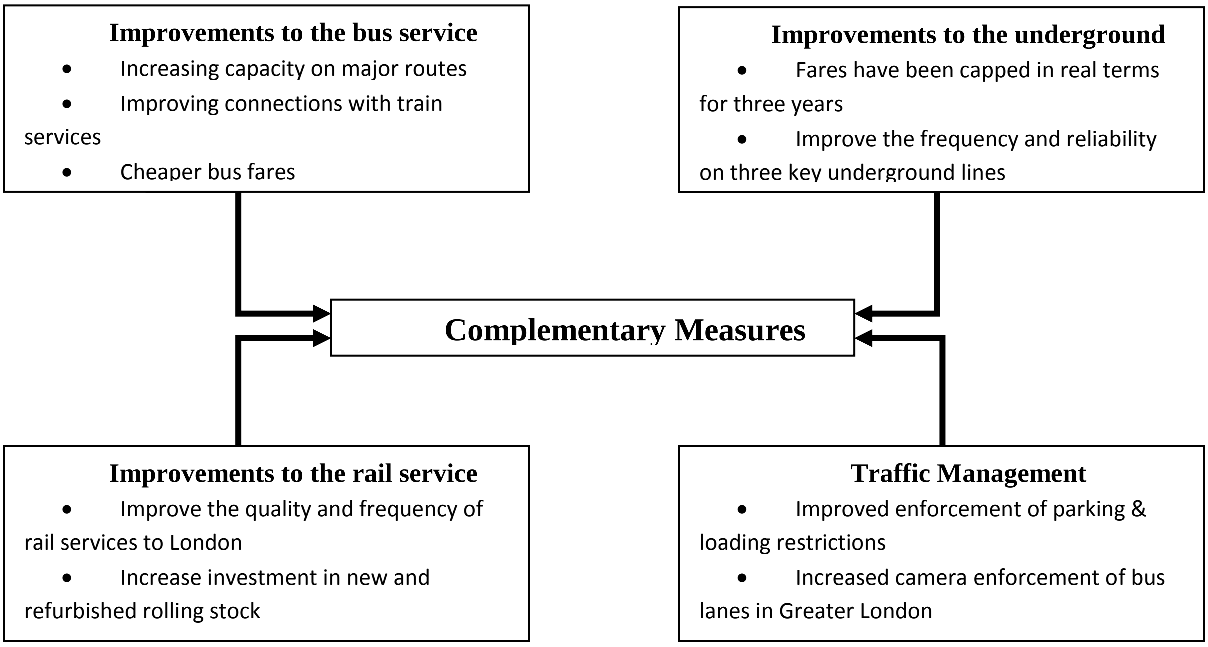
- Insufficient alternative transport modes into Central London.

The low level of awareness of public transport travel opportunities among people in Inner London (just outside the zone boundary) was surprising. This led to a TfL campaign to raise awareness, particularly of bus and London Overground services, in these areas of London.

4. COMPLEMENTARY MEASURES PROGRAMME

4.1 What are Complementary Measures?

Congestion charging is complemented by a range of measures designed to make public transport and other alternatives to car travel easier, cheaper, faster and more reliable. Revenue from congestion charging enables these initiatives to be developed and expanded. Particular emphasis was placed upon the improvements to the bus service because could be implemented quickly and help promote social inclusion. The following diagram shows some of the complementary measures that were implemented both before the scheme was in place and those made possible by the revenue stream it has subsequently generated:



The need to develop a deliverable Complementary Measures strategy that recognised the system of governance of London's roads was a primary issue in determining the manner in which the Traffic Management Complementary Measures programme was drawn up.

London Boroughs have a central role in the efficient operation of traffic, as they are highway authorities for 95% of roads in London, albeit that 33% of the traffic uses the other 5% of roads, the Transport for London Road Network, for which TfL is the highway authority.

It was important, therefore, to devise a strategy and subsequent programme that addressed issues on both TfL and borough roads. Following the results of number studies commissioned by TfL, aimed at clarifying the feasibility and scope of the measures that could be introduced within the necessary timescale – generally before the Congestion Charging go-live date in February 2003, it was decided to instigate a programme that focused on the following work areas;

i) Discouragement of existing rat running traffic through inappropriate areas near Congestion Charging boundary

ii) Eliminating the opportunity for motorists to park their vehicles in areas adjacent to Congestion Charging zone boundary and at on-street locations near stations in Outer London.

iii) Ensuring that TfL's programme of major capital works at or near the zone boundary was complete prior to go-live date.

iv) Rescheduling TfL's carriageway repair and maintenance programme to ensure that major routes would not be subject to planned road works for a reasonable period following the introduction of Congestion Charging.

v) Softer measures to promote usage of alternative modes of transport to the private car.

The first two work areas above involved working very closely with the boroughs, whilst areas iii) and iv) primarily required close liaison and co-operation from colleagues within TfL to achieve the objectives in question.

The table below itemises the Complementary Measures programme that was finally implemented;

COMPLEMENTARY MEASURES	**SCHEMES**	**COST (£MILLION)**
Environmental Traffic Management Schemes	51	7.1
Home Zones / 20 mph zones	49	13.3
CPZs (Inner Area)	34	6.9
CPZs (Outer Area)	53	3.3
Capital Works and Projects on TfL Roads	27	22.2
Traffic Signal Schemes	25	2.5
Soft Measures	22	2.9
TOTAL	**261**	**58.2**

Following the decision to site the CC zone boundary on the Inner Ring Road, it was necessary to devise a strategy which would manage the forecast change in traffic patterns as efficiently and effectively as possible.

4.2 Inner Ring Road - Boundary of CC Zone

It was quite an easy decision to take to designate the Inner Ring Road as the CC zone boundary. The route was well known to motorists and was sufficiently far away from the centre of the city to leave a large enough geographical area in what would become the CC zone (21 square kilometres).

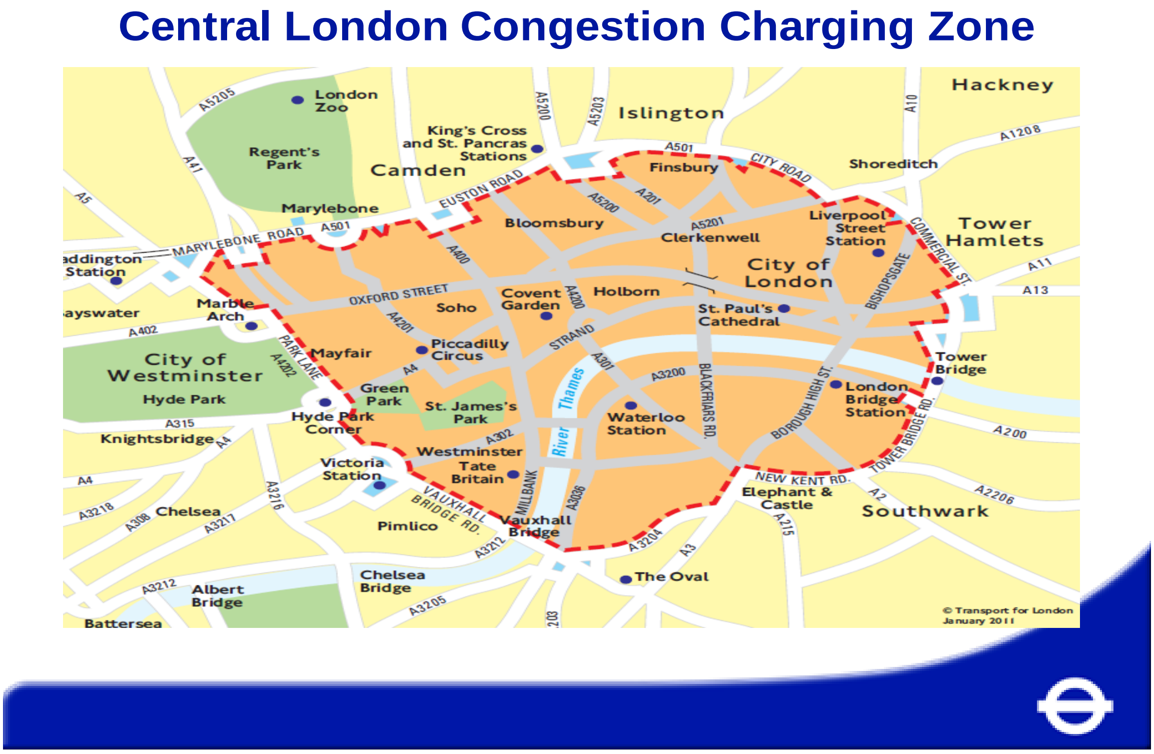


Fig 1 – Congestion Charging Boundary

The only significant debate was whether the River Thames could form the southern boundary of the zone. This would, however, have resulted in the creation of a number of problematic boundary points and accompanying escape routes adjacent to the river. Creation of the southern boundary at the river would also have meant that the area south of the river (the northern sections of the boroughs of Lambeth and Southwark, which are predominantly residential with low car ownership would have been excluded from the zone). TfL was keen that these areas should be in the zone as they were very different in demographic terms to those areas north of the river inside the zone, which were predominantly commercial, governmental and retail areas.

The decision was taken that the boundary should be a charge free route, i.e. vehicles would only have to pay the charge once they turned off the boundary route to enter the zone or crossed over the boundary route on one of the radial roads entering the central area.

Management of traffic on the boundary route was a particular challenge. It was essential to keep the traffic moving as efficiently as possible on the boundary route without significantly detrimentally affecting the level of service to traffic on radial routes approaching Central London. A programme of SCOOT implementation at signalled junctions on the boundary route and on major radial routes approaching the boundary was implemented as a priority. This allowed the Inner Ring Road (boundary route) to operate more efficiently without significant loss of capacity from the radial arms of the junctions.

The ability to closely monitor key junctions on the network was also a critical element of the scheme. The implementation of the Congestion Charging acted as a catalyst for the creation of a

London Traffic Control Centre. Prior to the introduction of Congestion Charging there had not been a central traffic control location in London. TfL now hosts a control centre staffed by police, bus operators and traffic signal engineers.

There is good real time visibility of key junctions with staff being able to intervene with revised traffic signal plans when traffic builds up to unacceptable level at any given location.

Fig 2 - Video Wall at London Traffic Control Centre

4.3 Bus Priority Measures

If traffic approaching the CC zone boundary were to expect greater queues due to reduction in green time at the signalled junctions, it would be necessary to ensure that those modes to which people were being encouraged to transfer to, particularly buses, would not also face significant congestion.

A programme of bus priority measures, primarily bus lanes, was created on radial routes approaching the zone boundary. TfL refocused its bus lane installation programme and examined in detail each radial route approaching the boundary to identify if there was scope to install bus lanes. Some roads proved unfeasible due to insufficient carriageway width but on a number bus lanes were successfully deployed. The bus lengths varied in length from about 200 metres to approximately 800 metres and some were designed to incorporate pedestrian crossings with signal priority for buses.

Fig 3 – Bus Lane approaching Congestion Charging boundary with typical red colour surfacing

4.4 Zone of Influence - Diversionary Effect of Congestion Charging

When undertaking traffic modelling for CC various scenarios were fed into the traffic model about the diversionary effect that CC would engender. The most significant unknown factor was how far away from the zone boundary would drivers make a diversion if they decided to do so – would they divert some distance from the boundary or would they wait until they reached the zone boundary or roads close to it?

No definitive answer was derived about where traffic would divert, so some intuitive assumptions were made and the Traffic Management team decided to focus on an area some 2-3 miles outside the zone boundary when devising the programme of complementary traffic management measures. The exact boundary of this 'Complementary Measures' area was determined by examining a series of major traffic junctions up to 3 miles from CC zone boundary – these are junctions where drivers make strategic decisions on routing when making radial journeys towards Central London and making sure that these strategic locations were included in the Zone of Influence.

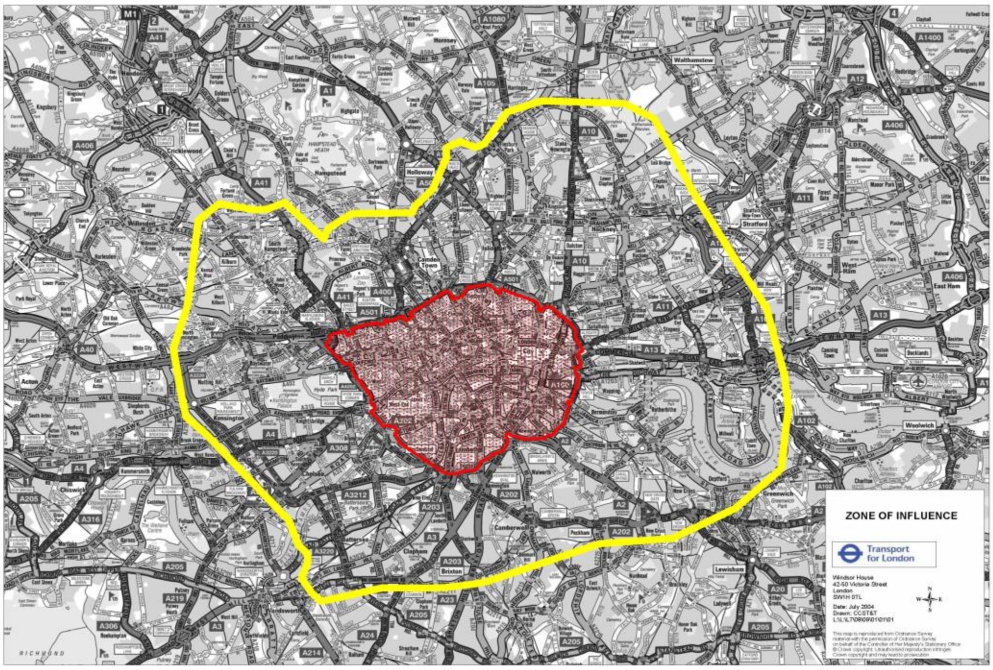


Fig 4 - Congestion Charging area zone (red) plus 'Zone of Influence' outside the Congestion Charging zone (marked by yellow ring)

4.5 Residential Areas outside the Zone Boundary

During the consultation programme it quickly became apparent that people living in the areas outside the zone were extremely concerned about the potential impact of the scheme.

Politically it was important to offer these people some inducements to alleviate their concerns about Congestion Charging.

Central to the package that was focused on residents (and businesses) in this area was a portfolio of measures designed to mitigate against the projected negative impacts following the scheme's introduction.

4.6 Controlled Parking Zones (CPZs)

TfL worked with local borough councils to ensure that the area immediately outside the Congestion Charging boundary was covered by CPZs where parking was permitted solely by local residents and businesses.

Within the zone of influence priority was given to introducing CPZs focused on underground and national rail stations and completing a comprehensive network of schemes in residential areas. A total of 34 new and extended CPZs were implemented. The Complementary Measures programme also resulted in on-street controlled parking provision being in place around virtually every underground station in Travelcard Zone 2 area.

CPZs funded outside the zone of influence were limited exclusively to those on-streets near underground and railway stations. Many outer London boroughs submitted bids for funding new and extended on-street CPZs around stations, fearing that car drivers from their area and the Home Counties, who had previously driven into Central London would, as a result of the introduction of Congestion Charging, park their cars at local stations and continue their journeys by rail. TfL modelling indicated that rail heading at stations in Outer London was unlikely to increase noticeably as a result of Congestion Charging and this has subsequently proved to be the case. A total of 53 new and extended CPZs in Outer London, which addressed boroughs' pre-Congestion Charging concerns were funded from the Complementary Measures programme.

The programme also included provision for reviews of operational hours of existing CPZs. This was particularly important for those CPZs near the Congestion Charging boundary where it was highly desirable that CPZs should operate at the same hours as the Congestion Charging scheme in order to eradicate the potential of motorists parking near the zone boundary, especially near the end of the Congestion Charging operational hours. Experience from other road pricing schemes, particularly Singapore, had shown that motorists had a tendency to 'lurk' near the zone boundary, particularly in last 10-15 minutes of the operational day in order to make a charge free journey into the zone once the charging period finished. The ring of CPZs at the zone boundary coupled with increased levels of enforcement by parking attendants ensured that this did not become an added unwelcome phenomenon in London.

A further issue which we had to manage related to those CPZs which traversed the Congestion Charge boundary. TfL made funding available to the boroughs in whose area these CPZs were located to reconfigure their CPZ boundaries to make them co-terminus with Congestion Charging boundary wherever possible.

4.7 Environmental Traffic Management Schemes /Home Zones/20mph zones

Environmental traffic management schemes consisted of a range of measures implemented at various locations within the zone of influence, aimed at discouraging traffic diverting away from the Congestion Charging area from using inappropriate roads near the zone boundary. These were largely aimed at areas with existing rat running problems.

The most common elements among these schemes were traffic management measures such as speed humps, speed tables, speed cushions, chicanes, width restrictions, lorry bans and selected road closures.

Often boroughs wanted to formalise the introduction of such measures and introduce them over relatively large areas by creating Home Zones and 20mph zones. The scale of the 20 mph zones / Home Zones programme was substantial. In total 49 were implemented, including one in the Barnsbury area of London Borough of Islington which is now believed to be the largest 20 mph zone in the country. The scale of 20 mph zone implementation in the south of Islington borough was significant with 5 schemes receiving funding of £5.2 million, of which £2.7 million was allocated to the Barnsbury scheme.

Monitoring results of the complementary measures introduced in Islington indicate that there have been some very positive outcomes that have exceeded the most optimistic expectations:

ISLINGTON 20 MPH ZONES	
Objectives	**Outcomes**
To reduce through traffic at peak times by 30%	Peak hour traffic cut by 20-50%
To protect sensitive residential streets from CC related traffic diversions	All day traffic cut by 30-40%
To reduce vehicle speeds	85th percentile speeds in low 20s mph
To reduce volume and severity of road traffic accidents	Vehicle speeds reduced by 10-25%
To improve amenity	HGVs cut by 75%

4.8 Capital Works and Projects on TfL Roads

The requirement was to ensure that any major capital projects being undertaken by TfL at locations at or near the Congestion Charging boundary should be completed prior to the go-live date posed particular problems.

Major schemes had been planned on the Inner Ring Road at Shoreditch and Vauxhall. Decisions had to be taken about whether they could be implemented before February 2003 and if this was to prove problematic, they would have to be postponed until the Congestion Charging scheme had been operational for a reasonable period of time.

Major contributions from the Congestion Charging Complementary Measures budget were given to these projects to allow them to be reprogrammed to include provision for longer working hours and more staff resources to ensure that they were completed in a timely fashion.

Similarly Congestion Charging was also able to influence the reprogramming of the carriageway repair and maintenance timetable through contributions from the Complementary Measures budget to ensure that the boundary route and major radial routes approaching it were repaired and resurfaced prior to go-live date.

There are 165 entry points into the Congestion Charging zone. The traffic at each of these locations needed to be managed as effectively as possible, not least to maximise the opportunity for the boundary cameras to capture the images of the Vehicle Registration Marks of each of the vehicles entering the zone. Attention was paid to remarking the carriageway lanes and at some locations creating kerb build-outs to channelize the traffic so that each vehicle is in the optimum position to be captured by the boundary cameras.

TfL also examined the potential of closing roads at the Congestion Charging zone boundary or converting them to one-way operation out of the zone. Studies were carried out and recommendations passed to the borough councils, as highway authorities for the roads in question. A total of 5 such modifications were completed. These schemes were desirable but not essential to the successful introduction of the charging scheme.

4.9 Soft Measures

In addition to the programme of traditional style traffic management measures introduced to complement Congestion Charging, the programme also supported a range of ‘soft’ measures. These were primarily targeted to encourage those people entering the Congestion Charging zone to transfer away from the private car towards more sustainable forms of transport. They were primarily designed to further the objectives of the Mayor's Transport Strategy by encouraging increase usage of sustainable modes of transport.

Examples of such schemes included Personal Security Project focused on Lambeth North station to enhance the quality of signage, street lighting and streetscape design between the station and St Thomas' Hospital (£420k); Minicab Scheduling Software project – funding a Community Transport scheme, which had Education and Social Services minicab contracts in three Inner London boroughs to reduce the number of single occupancy minicab journeys operating in the area near the Congestion Charging boundary, particularly at peak times (£130k); Platform lengthening at Tower Gateway DLR station to accommodate 3-car trains (contribution of £150k); Public Transport Information – Contribution towards printing and publishing of new style bus spider maps (£300k); Formulation of Green Travel plans at NHS facilities and NHS Personalised Journey Planning project within Congestion Charging zone (£490k); pump priming funding for a new City Car Club scheme operated by Royal Borough of Kensington & Chelsea on behalf of seven boroughs (£490k).

4.10 Case Study: Tower Bridge Speed and Weight Enforcement System

A particularly challenging Complementary Measure was the project undertaken to meet the concerns expressed by the Corporation of London in relation to Tower Bridge forming part of the Congestion Charging boundary route and the possible detrimental effect that an increased level of vehicles – particularly speeding and overweight vehicles – would have on the structural integrity of the bridge. Prior to Congestion Charging the bridge was subject to a speed restriction (20 mph) and weight restriction (17 tonnes), but these limits were often abused, primarily because the City of London police did not have sufficient resources to enforce the regulations on a regular basis.

The location of Tower Bridge on London's Inner Ring Road (A100) logically justified its inclusion as a section of the Congestion Charging boundary route. Naturally TfL was mindful of the potential disruption to traffic caused by bridge lifts, which are rising in number due to the Mayor's policy of encouraging increased usage of the River Thames and are currently number about 900 per year. Each lift halts traffic for about 5 minutes, which activates a traffic signal plan at either end of the bridge, aimed at minimising the operational disruption to traffic in the local area.

Relocating the Congestion Charging boundary to the west of Tower Bridge was not considered appropriate a relocated boundary on London Bridge or Southwark Bridge would have necessitated traffic travelling on a redefined boundary route through the heart of the City of London, one of the areas where TfL were particularly keen to promote a reduction in traffic levels. Relocating the boundary to the east of Tower Bridge to the next crossing – Rotherhithe Tunnel was not feasible as this tunnel and the crossing further to the east, Blackwall Tunnel, both have significant height restrictions and are subject to regulations prohibiting vehicles carrying certain materials. There would also be major difficulties in defining a boundary route from Rotherhithe or Blackwall Tunnel to the Inner Ring Road, as any such boundary would inevitably have to be routed along roads which are designated as local roads and consequently do not perform the same strategic function as the Inner Ring Road.

Given that the decision was taken that Tower Bridge should remain on the Congestion Charging boundary, it was vital to address the existing problem of speeding and overweight vehicles crossing the bridge. This situation could have been exacerbated by the introduction of Congestion Charging if not effectively addressed. After much analysis it was decided to introduce a combined speed and weight enforcement system using roadside cameras. Particular care had to be taken to incorporate cameras that were sympathetic to the environment of the bridge – itself a national monument, icon of London and Grade 1 listed structure, situated next to a world heritage site – Tower of London. Camera location and design were modified following lengthy discussions with English Heritage, City of London Police, Metropolitan Police, Corporation of London (as owners of the bridge structure) and the boroughs of Tower Hamlets and Southwark, whose geographical areas are spanned by the bridge.

Cameras are sited at the northern and southern ends of bridge, some 400 metres apart. These record the time taken by a vehicle to pass between them and hence the average speed of the vehicle. Images of vehicles exceeding the 20mph speed limit are recorded on WORM disks, located in a utility room beneath the bridge. These disks are collected on a weekly basis by a City of London police officer and are subsequently analysed and processed in a police station with Fixed Penalty Notices being issued to the owners of those vehicles contravening the speed limit.

Fig 5 – Southern approach to Tower Bridge showing combined speed and weight enforcement cameras in the foreground

Fig 6 – Northern approach to Tower Bridge with recently installed speed and weight cameras

The weight restriction on the bridge prohibits its usage by vehicles plated at 18 tonnes or above. The weight enforcement cameras are sited on the same columns as the speed cameras, but are angled to capture images of the number of axles of vehicles, as 18 tonnes is also the limit at which all vehicles must have three or more axles. The cameras are linked to piezo sensors in the carriageway which are programmed to record specific axle configurations. Once the sensors identify a vehicle with three or more axles, the weight cameras automatically take a picture of the vehicle in question, which captures the number of axles. These images are recorded onto a WORM disk, which is then processed in same way as the speed infringements by the City Police.

The bridge is the first location in Britain where these two systems have been combined in this manner. Results, particularly with respect to the decrease in the number of overweight vehicles, have been encouraging with a reduction of some 50% of such vehicles being recorded.

4.11 Management of Complementary Measures Programme

London's government, even following the creation of a directly elected Mayor, remains a highly complex interface between a number of local, sub-regional and regional bodies.

The most intricate transportation relationship is probably between the Mayor through his executive arm Transport for London and the borough councils. There are a total of 32 borough councils plus the City of London. The plan below indicates the diverse nature of political control of London boroughs at the time of Mayor Ken Livingstone's first electoral term 2000-2004.

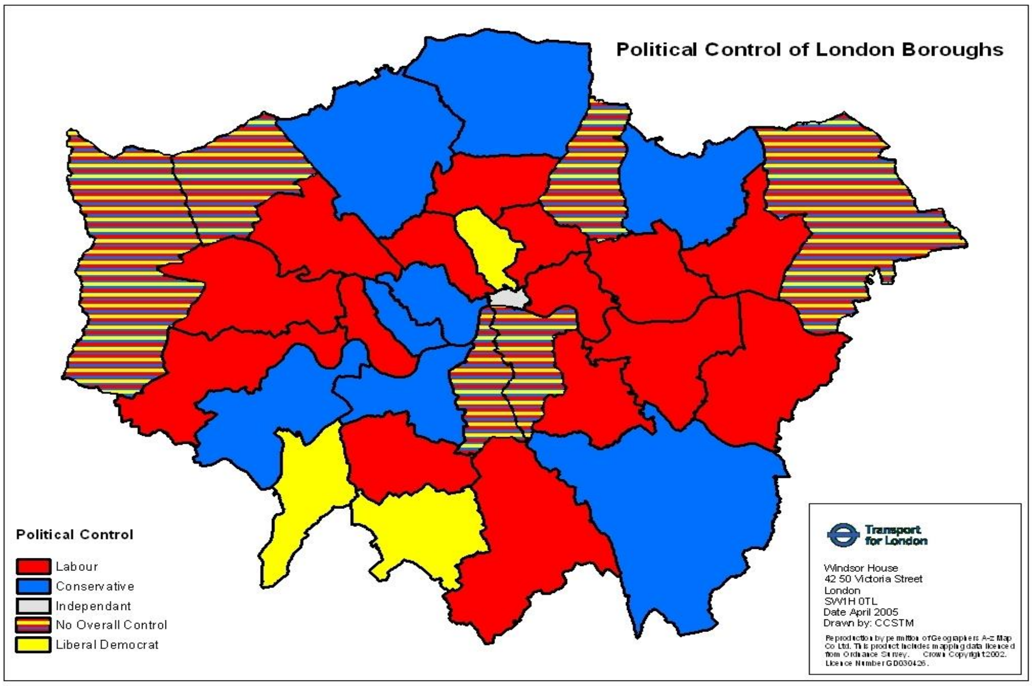


Fig 7 – Plan showing political control of London's 32 boroughs plus City of London 2002-2006.

As highway authorities for 95% of roads in London, boroughs have a central role in the efficient operation of traffic. The relationship between the boroughs and TfL was, therefore, crucial in delivering the Congestion Charging Complementary Measures programme.

The boroughs' attitudes towards Congestion Charging covered the complete spectrum from staunch support to active opposition. It was particularly important for the Complementary Measures team to construct productive working relationships with all boroughs, irrespective of their position on Congestion Charging.

Dealing with authorities with such a wide range of views towards the concept and implementation of the scheme involved considerable sensitivity. It was necessary to agree areas of common ground with boroughs and to encourage the implementation of particular elements of specific Complementary Measures, which were beneficial in their own right as well as ensuring that Congestion Charging would not have any further detrimental effects.

There was a need to dissuade boroughs promoting their favoured schemes for funding from the TfL Congestion Charging Complementary measures budget when such schemes were designed to address issues that already existed and would continue to exist even if the Congestion Charging had not been implemented. TfL used strategic and local modelling forecasts to determine whether individual schemes were eligible for funding from the Congestion Charging budget.

4.12 Conclusions

The Complementary Measures programme was important in that it delivered a wide range of the projects to time, to specification and within budget. The actual recorded level of traffic reduction following the introduction of Congestion Charging inside the zone and in areas outside was at the high end of TfL's forecast range. The level and pattern of traffic displacement outside the congestion charging zone did not emerge as an issue following the introduction of the scheme.

A feature of the Complementary Measures programme was the style of partnership working between TfL and the London boroughs that it engendered. It allowed the organisations to explore and develop areas of mutual interest and in doing so helped to raise the profile of Congestion Charging among major stakeholders.

Overall Complementary Measures have contributed significantly to the successful delivery of the Central London Congestion Charging Scheme. Their role being primarily justified by the contribution that they made to the resolution of pre-existing traffic related issues which could have been exacerbated through the introduction of the scheme.

5. THE WESTERN EXTENSION

When the original Congestion Charging zone was introduced into central London in February 2003, it covered some 21 square kilometres, with the Inner Ring Road forming its boundary. In February 2007, the Congestion Charging zone was extended westwards to cover a further 19 square kilometres, including most of Kensington & Chelsea and Westminster. The extended Congestion Charging scheme operated as one zone, with the same charges, discounts and exemptions applying no matter where you drive in the zone.

Congestion Charging- Western Extension

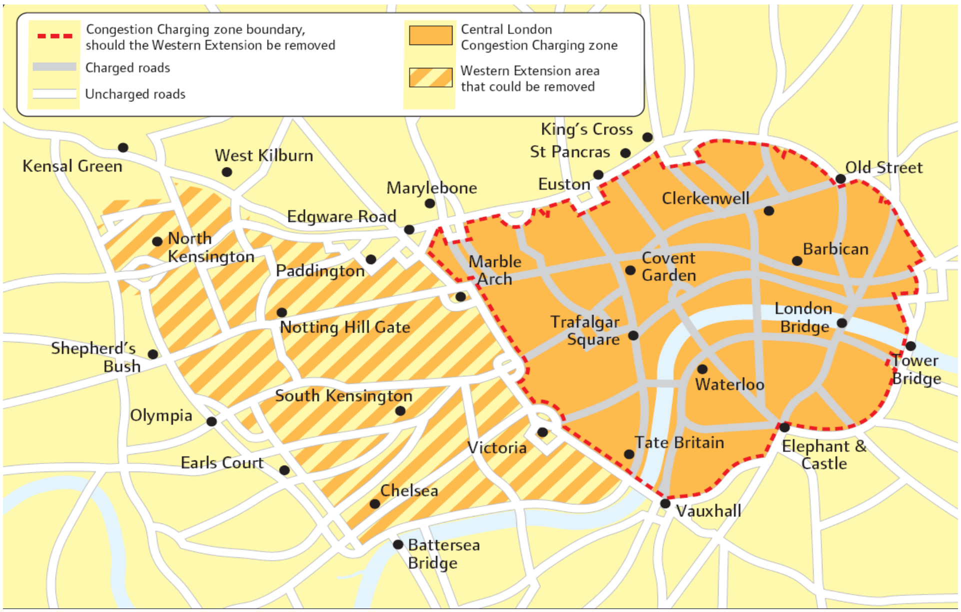


Fig 8 – Plan showing original Central London Congestion Charging Zone plus Western Extension, which was introduced in 2007.

The reason why it was decided to extend to the west was based on the demographics of the area, the presence of a clearly definable boundary route and a relatively low of average speed of traffic in this area compared to other areas bordering the original zone ;

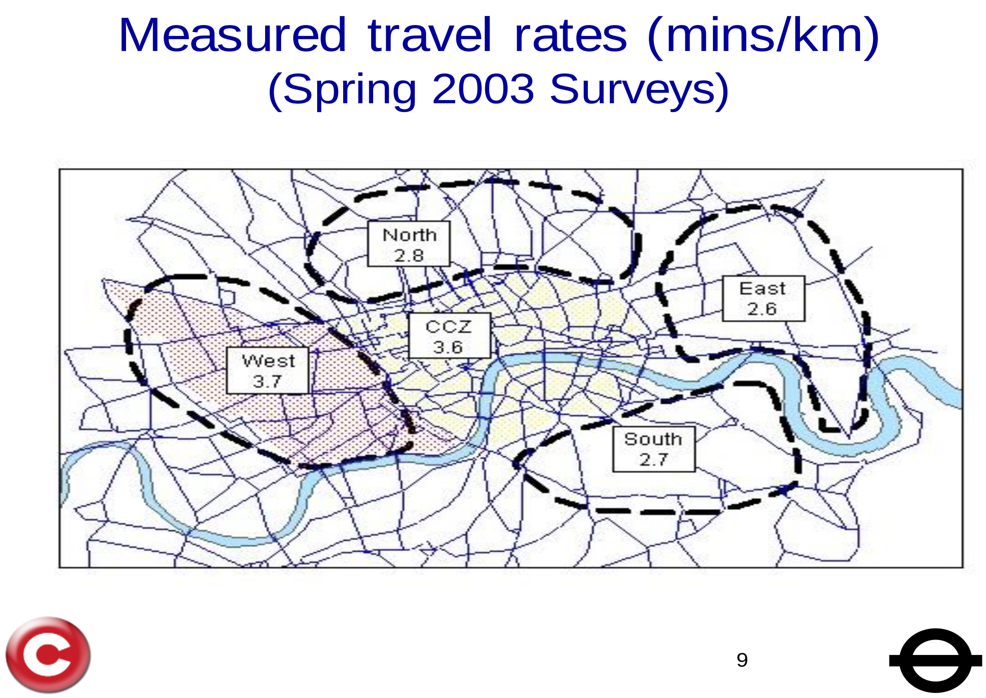


Fig 9 – Plan showing average time in minutes spent by motorists to travel 1 kilometre in areas adjacent to Congestion Charging Zone (Spring 2003).

5.1 Impacts of the Western Extension

As expected, traffic in the Western Extension decreased following its introduction, with around 30,000 fewer cars entering the area each day. Charging also helped to reduce vehicle emissions and encouraged people travelling in the area to use public transport, or to walk or cycle.

Initially there were significant congestion reductions in the Western Extension of around 20 percent. Traffic volumes in the Western Extension area also remained below those seen before Congestion Charging was introduced.

However, subsequent changes in the area, such as major development and utility works, and initiatives which have reduced effective road capacity, resulted in increased congestion. When the Western Extension was withdrawn in 2010, congestion levels were broadly the same as those experienced in 2006, prior to the introduction of charging.

However, without the Western Extension in place (whereby some deterred traffic returned to the constrained network), congestion would have been likely to have been significantly worse.

Information on the potential impacts of the options for changing the Western Extension – both on individuals and on London generally – is provided on the TfL website, and in a more detailed 32-page Supplementary Information document, which could be downloaded online.

Summary

Western extension has mirrored success of original zone		
• Traffic entering western extension	Down 13%	↓
• Traffic circulating in western extension	Down 9%	↓
• Traffic on boundary road	Up 3%	↑
• Traffic on Free Through Route	Broadly unchanged	↔
• Traffic outside western extension		
- West London Railway screen line	Down 7%	↓
- Thames Bridges	Down 8%	↓
• Traffic circulating within original zone	Broadly unchanged overall	↔

N.B. Generally at lower end of TfL expectations; but some disruption from road works

33

Fig 10 – Traffic Management Effects of Western Extension

Impacts – Western Extension

- Traffic on Free Passage Route (*between the original zone and western extension)* was effectively unchanged
- Traffic on western boundary showed small increases, as projected
- No evidence of traffic operational problems

Impacts – Central (Original) Zone

- Some evidence initially of increased traffic entering central zone
- Up 4% against 2006 at one time; then fell to 2% extra and falling to zero. Partly reflects increased extension residents trips but also partly reflects other factors
- No evidence of congestion response

5.2 Consultation about Removal of WEZ

During the Mayoral elections of 2008, the newly elected Mayor, Boris Johnson, stated that he would initiate plans to remove the Western Extension were he to be elected;

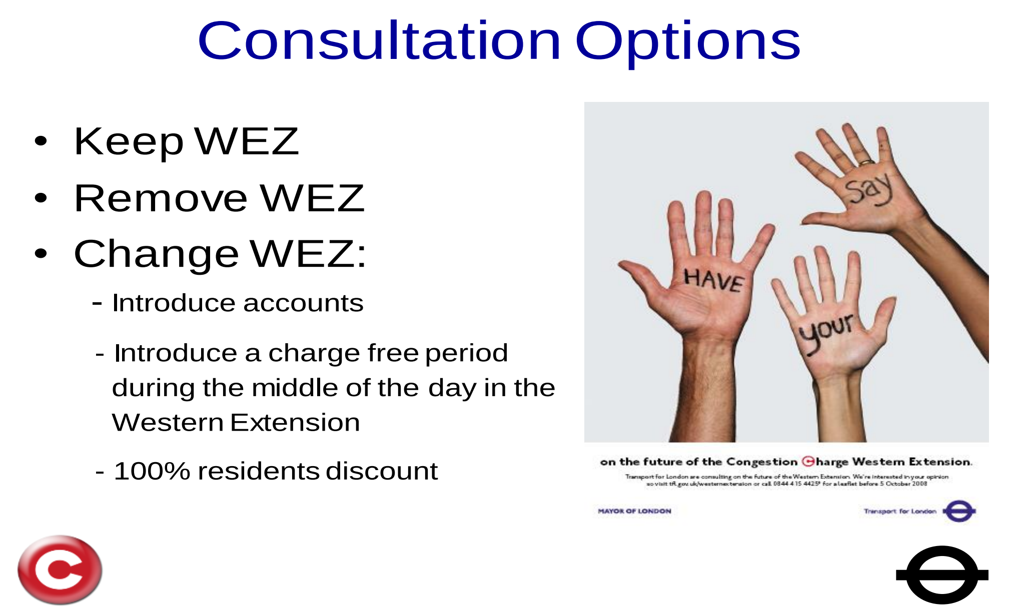


Fig 11 – Consultation Poster re Western extension (2008-09)

Responses to the consultation options

Option 1 Keep the Western Extension as it is

Overall, 19% of all respondents (individuals and businesses) to the consultation chose this option (21% of individual respondents and 6% of business respondents respectively). 19% of residents in the Western Extension and its designated buffer zones preferred keeping the Western Extension, compared to 46% of residents in the original charging zone and its buffer zones. In the attitudinal surveys, there was slightly stronger support for this option than in the consultation: 30% of Londoners and 23% of London businesses selected this option. Both businesses and the public in the original charging zone were more supportive of this option than the public and businesses in the Western Extension.

Option 2 Remove the Western Extension

Overall, this was the most preferred of the three ‘Keep, Remove, Change’ options, and was selected by the biggest proportion of respondents to both the consultation and the surveys. In the consultation responses, it was selected by 69% of the respondents overall, with 67% of individual respondents and 86% of business respondents preferring this option. 57% of those living in the Western Extension and its designated buffer zones selected the removal of the Western Extension, whilst 33% of residents in the original charging zone and its designated buffer zones also selected this option. Of business respondents operating in the Western Extension, 89% said they wanted it removed.

In the attitudinal surveys, support for this option was lower than in the consultation, however it was still the most preferred option, selected by 50% of businesses and 41% of the public. 59% of businesses in WEZ, and 48% of the public in WEZ, supported this option in the attitudinal survey.

Option 3 Change the way that the scheme operates

Overall, 12% of respondents to the consultation preferred this option (13% of individual responses and 7% of business responses). A quarter of individuals living in the Western Extension and its buffer zones preferred this option, and 5% of businesses operating in this area preferred this option.

In the attitudinal surveys, 15% of Londoners and 14% of London businesses preferred this option. There was a fairly similar level of support for this option from residents in both the Western Extension and its buffer zones (18%) and the original charging zone and its buffer zones (16%).

Respondents to the consultation and the surveys were also invited to describe other changes in the open text box. In most cases (57% in the consultation, 63% in the public survey and 54% in the business survey), no further comment was made. Where respondents did identify other changes, the most frequently-mentioned were changes to discounts and exemptions, and to the scheme boundary.

5.3 Impact of WEZ Removal

- The surveys carried out suggest that the removal of charging went smoothly with no significant adverse road network or environmental impacts that were attributable to the removal of charging in the former zone.
  - TfL's best estimate, based on a combination of continuous automatic and periodic manual traffic counts, was that traffic entering the former zone increased by around 8 per cent for vehicles with four or more wheels, as a direct result of the removal of charging. This compares to TfL's prior expectation of an attributable increase of between 8 and 15 per cent – and the observed change was therefore towards the lower end of this range.
  - TfL expected an increase of between 6 and 12 per cent in the volume of traffic circulating in the former zone. TfL's best estimate, based on the available data, was that there was an attributable 7 per cent increase in the volume of circulating traffic. This was again towards the lower end of TfL's range of prior expectation.
  - TfL expected a small net reduction, over the long term, of between 1 and 2 per cent in traffic entering the central London charging zone, which remained in operation. This would reflect both the impact of removing the extension, but also changes to the operation of the scheme in the central zone. The measured net aggregate reduction to traffic measured over the first seven months of the year following the removal of WEZ was 1 per cent. This was broadly in-line with TfL's expectations, although it should be seen in the context of ongoing background reductions to traffic volumes across London.
  - Surveys of traffic speeds and congestion following removal of charging show a variable picture – in part reflecting seasonal factors associated with the timing of the surveys over the first six months of the year. Comparing equivalent surveys over the first six months of 2011 with those during the same period in 2010, congestion, measured as excess delay, was 3 per cent higher in 2011, whereas average traffic speeds were 1 per cent lower.
  - There was no evidence of a significant differential impact on air quality in the former zone resulting from the removal of charging. Looking at air quality, in the first half of 2011, PM10 concentrations were notably higher in all parts of London, including the former extension zone, compared with the equivalent period in 2010. This reflected the recognised unusual weather patterns that prevailed across London in spring 2011. However, concentrations of NO_2 (Nitrogen Dioxide)

were generally lower across London and in the former extension in the first half of 2011 compared to 2010, although the reasons for this London-wide trend are not, as yet, fully understood. It is however clear that air quality trends in the former extension behaved in a very similar way to those elsewhere in London.

6. THE LOW EMISSION ZONE

The London Low Emission Zone (LEZ) was initiated in February 2008 to complement the Congestion Charging Zone and to address the issue of London's air quality by discouraging heavily polluting Heavy Goods Vehicles (HGVs) and other vehicles from entering London.

Despite significant improvements in recent years, London's air pollution is still a concern and contributes to:

- 4,000 premature deaths in London annually (GLA health report, 2008)
- 50,000 deaths in the UK annually (UK Environmental Audit Committee, 2009)

Heavier diesel vehicles are a major source of air pollution that affects people with asthma, chest and heart conditions: the poorest, the old, the very young and the sick suffering disproportionately.

The Mayor's Air Quality Strategy published in December 2010 sets out a range of measures to tackle air quality, including the LEZ:

- Cleaning up buses (Euro IV for NOx and PM by 2015)
- Age limits for taxis (15 years from 2012,10 years from 2015)
- Age limit for private hire vehicles (10 years from 2012)
- No idling zones
- Best Practice Scheme for construction equipment on site
- Street cleaning and Dust Suppressants
- Smoothing traffic flow
- Boiler replacements & energy efficiency

6.1 What is the London Low Emission Zone?

- Environmental zone covering the entire area of Greater London (1,580 square kilometres)
- Encourages the most individually polluting vehicles driving in London to become cleaner
- Operates 24 hours a day, every day of the year
- Introduced in 2008 following extensive consultation and has been very successful to date. In January 2012 more vehicles were included and standards were tightened. Standards are now Euro IV for HGVs, buses and coaches and Euro III for larger vans (between 1.2 and 3.5 tonnes) and minibuses.
- Vehicles need to meet specified emissions standards or pay a substantial daily charge to drive within Zone

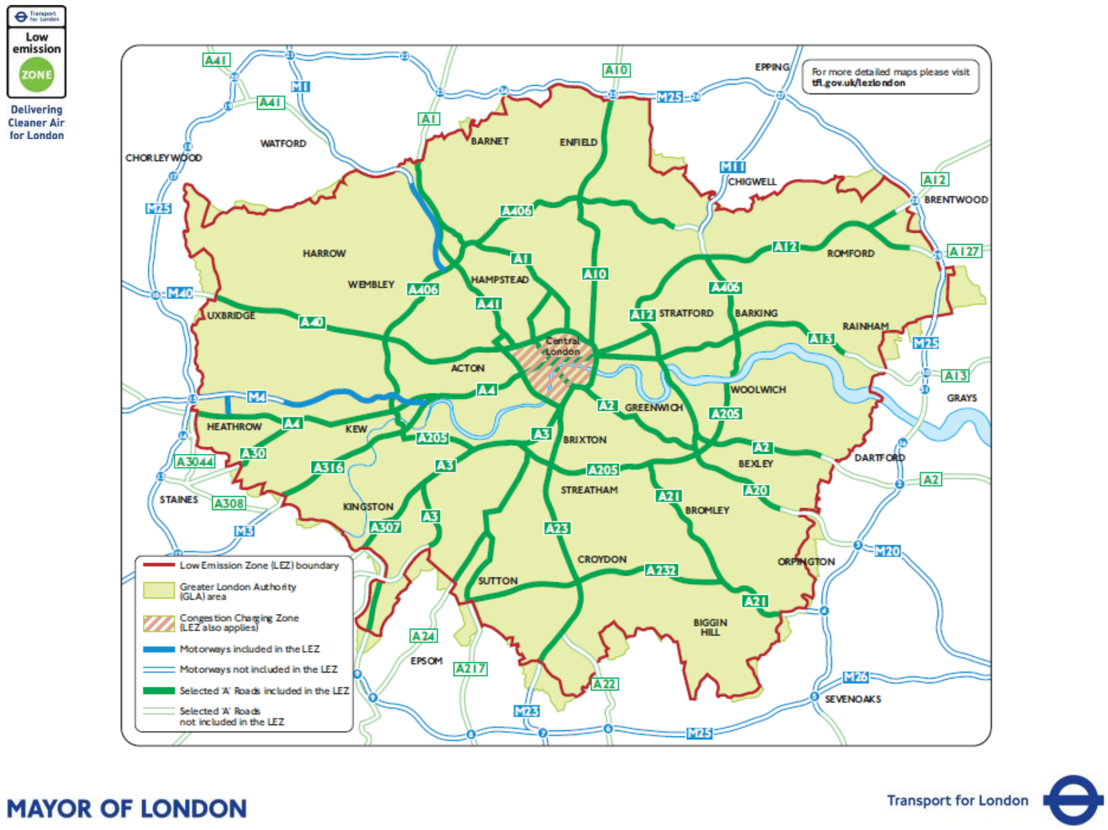


Fig 12 – Plan of London Low Emission Zone

6.2 Enforcement

- Lorries, Buses and Coaches
  - Daily Charges £200 per day
  - Penalty Charges £1,000 per day (£500 if paid within 14 days)
- Larger Vans and Minibuses
  - Daily Charges £100 per day
  - Penalty Charges £500 per day (£250 if paid within 14 days)
- TfL would prefer vehicle operators to meet the standards rather than pay a daily charge or risk a fine
- The first time a vehicle is seen in the Zone, the vehicle operator is issued a warning letter and no further action is taken for 28 days

6.3 Options to meet the Standards

Options available to operators include:

- Fitting and certifying an approved filter
- Buying a new or compliant second-hand vehicle
- Reorganising fleet so only compliant vehicles travel in zone
- Converting the engine to run on only gas with spark ignition
- Or paying the daily charge

6.4 100% Discounts / Exempt Vehicles

- There are very few exemptions so as to maintain the benefits of the scheme
- Some specially adapted Showman's Vehicles are eligible for 100% discount from LEZ
- The following vehicles are automatically exempt from LEZ:
  - UK and Foreign Military Vehicles
  - Historic Vehicles (registered pre 1973)
  - Non-Road Going Vehicles

6.5 Scheme Impacts

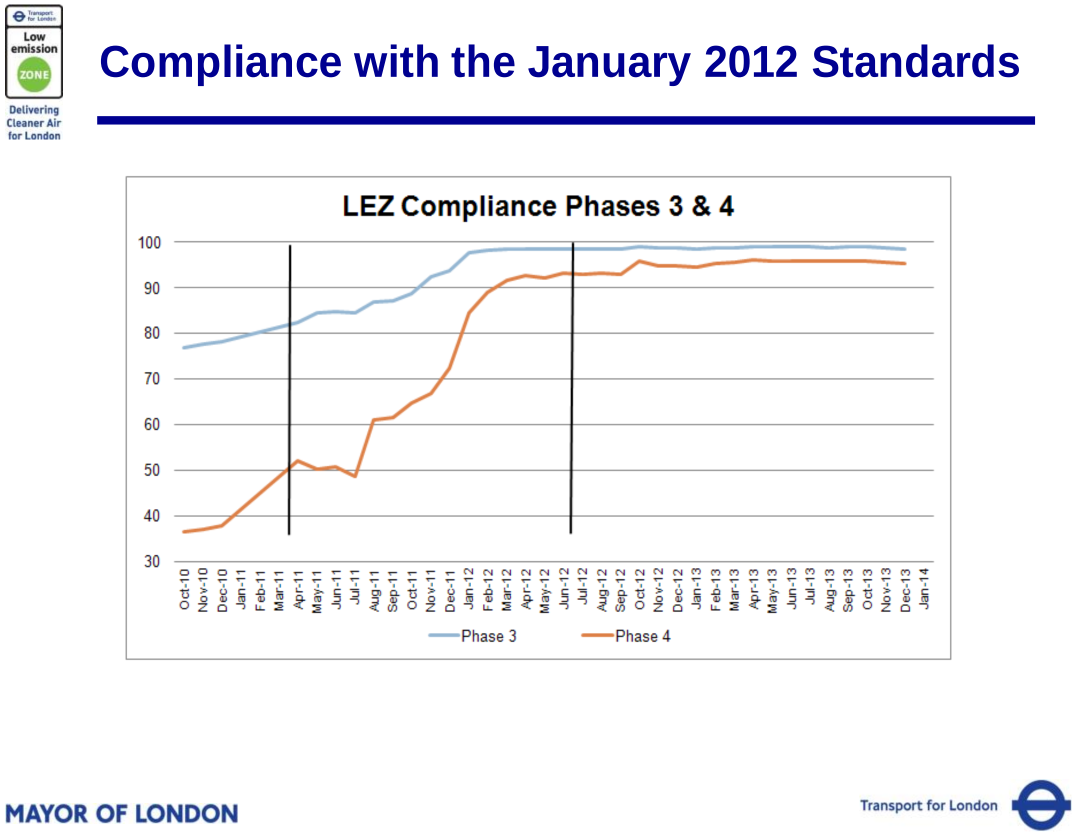


Fig 13 – Compliance Levels of Vehicles – London Low Emission Zone
(*Phase 3 – Euro IV Standards introduced for HGVs, buses and coaches*
Phase 4 – Euro III Standards introduced for larger vans and minibuses)

Since its introduction in 2008 LEZ has had a real impact on pollution saving 28 tonnes of Particulate Matter which is equal to saving:

127 million km driven by a Euro III articulated vehicle or 160 return trips to the moon or approximately 677,000 times around the M25

- LEZ reduces pollution at the road – where the pollution is concentrated and targets the kind of pollution – fine particles, which are most hazardous to health.
- The LEZ changes in 2012 are forecast to deliver around twice these reductions in air pollution – critical to London meeting legal air quality standards. Including vans and minibuses will give children with chest complaints over 12,000 days free from suffering symptoms and adults almost 18,000 days

6.6 Lessons from LEZ

- Integrated operator information and stakeholder engagement strategy key to ensuring high levels of compliance
- Public information for Operators affected by the scheme changes is key
- Early engagement with key external stakeholders to ensure compliance options / intentions are well understood
- Effective management of external suppliers (abatement industry and VOSA (certification and testing)
- Political backing essential
- Early establishment of required industry standards on abatement equipment and manufacturers

7. CONGESTION CHARGING IMPACTS

7.1 Traffic

The major point to emphasise is the reduction in traffic in the CC zone has been consistent since the introduction of the scheme and continues to the present time. (See figures below)

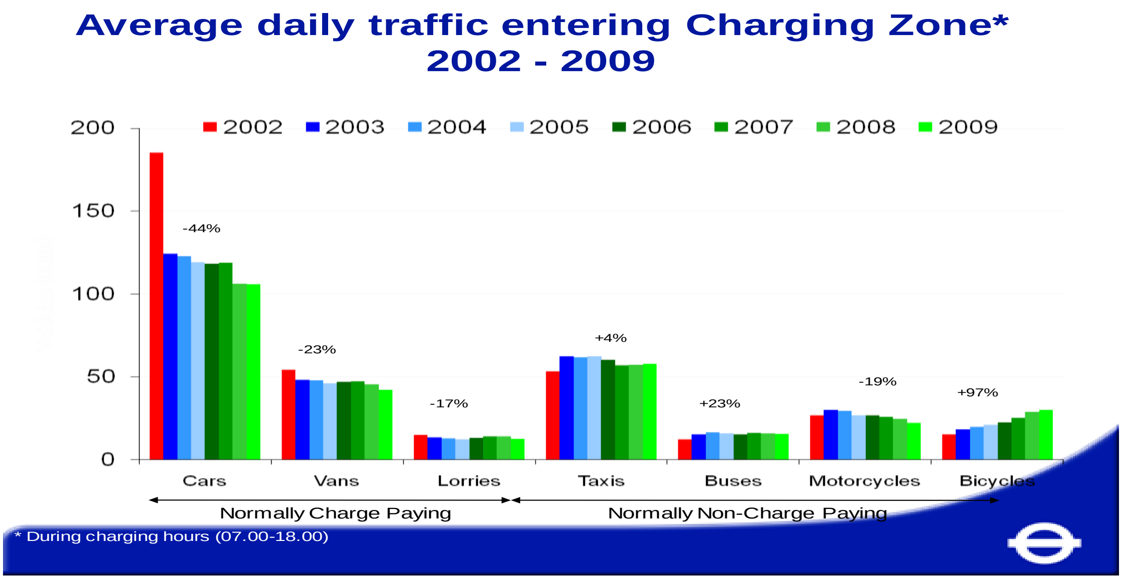


Fig 14 – Average Daily Traffic Entering Congestion Charging Zone 2002-2009

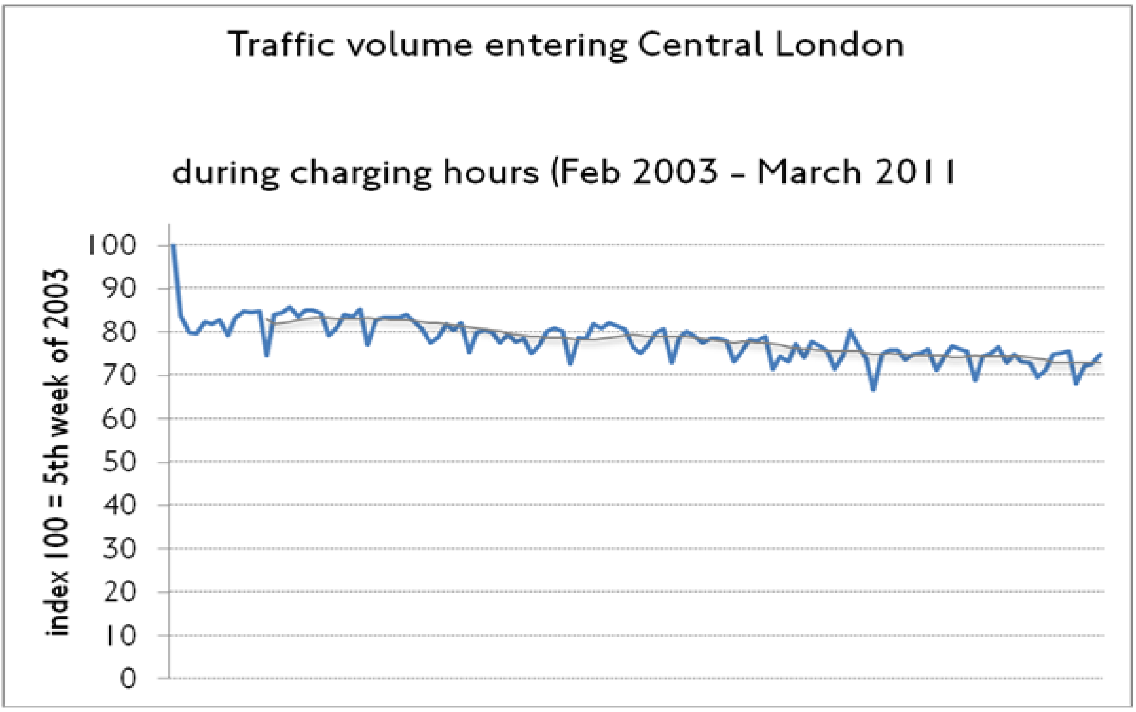


Fig 15 – Index of Traffic Volume entering Congestion Charging Zone 2003-2011

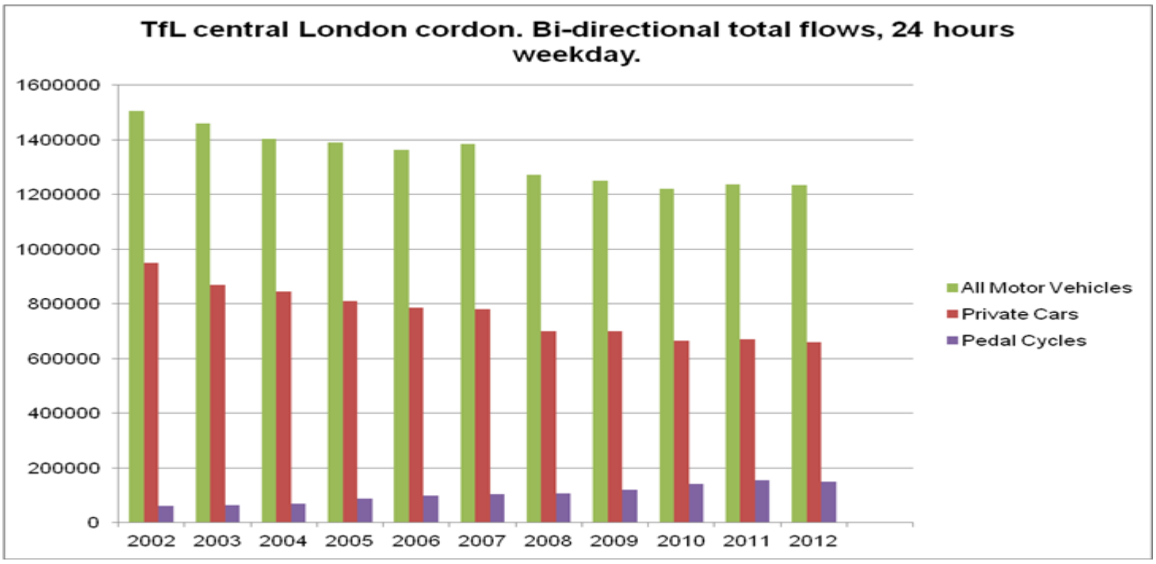


Fig 16 – Bi-Directional Traffic Flow at Central London Cordon (approximates to Congestion Charging boundary) 2002 -2012

Throughout the duration of the CC scheme there has been no indication of the volume of traffic starting to increase at any time following the sharp reduction that occurred on the introduction of the scheme in 2003.

7.2 Levels of Congestion

Although the decrease in traffic volume has been sustained throughout the scheme, the level of congestion recorded in the zone has increased;

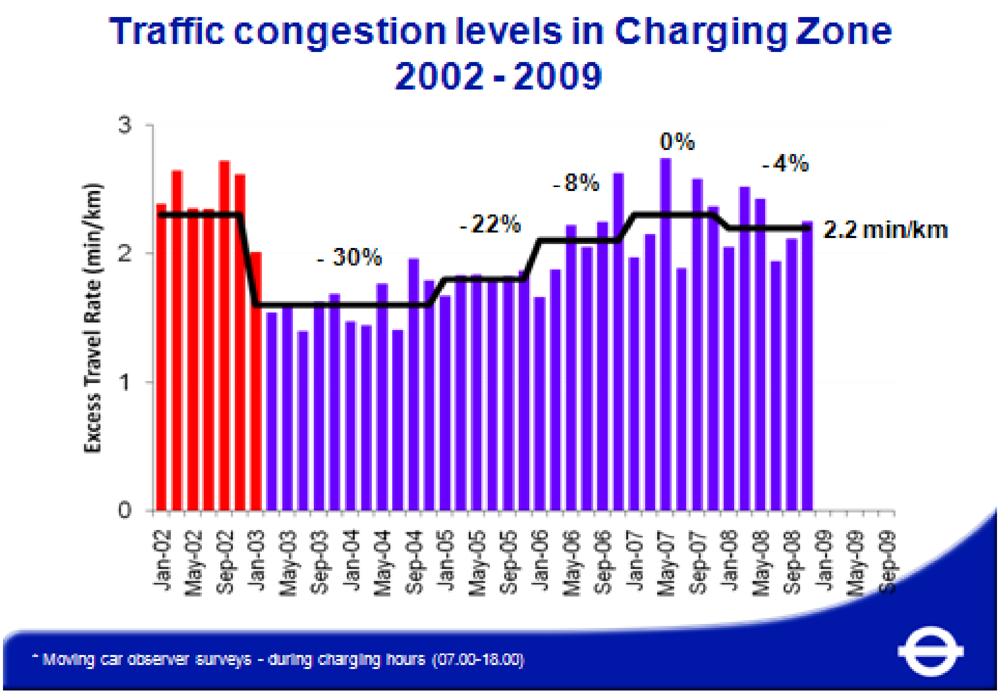


Fig 17 – Index of Traffic Congestion Levels in Central London Congestion Charging Area 2002-2008

Congestion is measured by comparing the time a vehicle takes to drive selected 1 kilometre sections of route in freeflow conditions compared to the time taken to drive those same sections of route during CC operating times.

Reasons for the increase in congestion have been identified as follows;

- Retiming of traffic signals inside the zone – removing ‘green’ time from vehicles and reallocating to pedestrians.
- Reducing highway capacity inside the zone through the implementation of projects aimed at encouraging modal shift to more sustainable modes of transport, eg creation of bus lanes, cycle lanes inside the zone.
- Large scale utility works by gas, electricity, water and telecommunications companies, especially the Thames Water Victorian Mains Renewal programme, which involves every street in London being opened between 2008 and 2015 and the old cast iron water distribution pipes being replaced by UPVC pipes.

7.3 Other Impacts

a) Economy

Monitoring programme carried out by TfL and other, independent bodies indicates that the effect of Congestion Charging on the economy has been largely neutral. The monitoring programme encompassed the effect of the scheme on a wide range of businesses including the financial sector, health and education facilities, hotels and restaurants, the retail sector and the property market.

There is no definitive evidence to suggest that the scheme has had a detrimental impact on the business performance despite widespread concerns prior to the introduction of the scheme.

b) Environment

The reduction in the volume of traffic in Central London engendered by the scheme has undoubtedly led to environmental benefits. It is difficult to disaggregate the direct effect of Congestion Charging on the environment, particularly as vehicles are continuing to become cleaner as engine technology advances.

However even if a rudimentary analysis is undertaken linking the reduction in traffic volumes in Central London to environmental indices, it can robustly and conservatively asserted that Congestion Charging has been directly responsible for reductions of traffic emissions inside the zone equating to 8% of NO_x , 7% of PM_{10} and 16% of CO_2.

c) Road Safety

There was concern prior to the introduction of the scheme that the increase in traffic speeds inside the zone would lead to a greater number and greater severity of road traffic accidents and personal injury accidents suffered by pedestrians and other road users.

The monitoring programme compared the area inside the zone with other areas outside the zone and identified a discernible reduction increase in traffic related accidents inside the zone.

Indeed the number of accidents inside the zone has continued to decrease at the same rate as for London as a whole.

d) Net Revenues

By law, revenues raised by Congestion Charging must be spent on improving transport in London. In 2012-13 a total of £181 million net revenue was generated and spent on the following initiatives; bus network improvements, roads and bridges, road safety, walking and cycling, funding borough transport plans.

Since the start of the Congestion Charging scheme over £1 billion has been raised to fund a range of transport improvements in London.

Much greater detail on all the above Impacts issues can be found in various monitoring publications on the TfL website. These include six Congestion Charging annual Impacts Monitoring Reports (June 2003 – July 2008) and annually produced Transport in London reports since 2009.

8. LESSONS LEARNT

8.1 Political Commitment

The fact that Congestion Charging scheme in London became a reality was primarily a result of the political stance taken by the incoming Mayor in 2000. Ken Livingstone, standing as an Independent candidate, clearly stated in his manifesto that he would introduce a road charging scheme in Central London, if elected. The fact that he made this commitment during his election campaign obviated the need for a subsequent referendum.

This political model gave the Mayor a democratic mandate and it was never seriously suggested that a referendum should be held during the period of the scheme design, preparation and consultation.

It cannot be overstated the courage that Ken Livingstone showed in adopting this model. It was a radical departure from all previous positions taken by senior politicians on the issue and proved to be the key element in the delivery of the scheme.

8.2 Extensive Public Consultation and Stakeholder Engagement

Given the radical nature of the scheme that was being proposed, it was imperative that the level of public consultation was as wide as could be feasibly achieved. This involved a structured approach involving major stakeholders such as borough councils, major businesses, trade representative groups etc. through to individual residents inside and, more particularly, outside the zone.

Use was made of a wide range of communications channels to reach as many stakeholders as possible. Individually targeted information proved especially effective. (This is now much more readily achievable with communication platforms such as twitter and Facebook).

It was necessary to be focused and have robust and defensible counter arguments to put to objectors. Pre-prepared factsheets and FAQs were critical in this respect.

It was generally agreed that it was preferable to engage objectors, ideally face to face, rather than be accused of being disingenuous and being reluctant to share information.

8.3 Good Public Transport Alternatives

Even in areas well served by public transport, there was a desire among consultees for enhanced public transport provision. This was particularly noticeable in areas just outside the zone boundary (Zone 2 of the Transport for London area). This was initially surprising but as the public consultation programme evolved, it became apparent that many people were not aware of the level of public transport services that were available to them. This was noticeable primarily among car users, but also, perhaps more surprisingly, among public transport users also. People who solely used the London Underground often had only limited knowledge of bus services.

It was far easier to provide additional bus services than new underground services, given the limited time period between the commencement of the public consultation and the scheme go-live date. This was achieved by creating seven new additional bus routes, creating more capacity on existing bus routes and implementing on-street bus priority measures.

London Underground was being upgraded during the time prior to Congestion Charging go-live and incremental additions to capacity such as addition of train cars where feasible and increasing train frequencies were implemented.

8.4 Effective Traffic Management – *especially just outside boundary*

This was a vital area to which Transport or London dedicated significant personnel and financial resources. We were concerned about a number of issues including diverted traffic running through inappropriate areas, protecting residential areas near the zone boundary, traffic ‘lurking’ outside the zone boundary to enter the zone when it became charge free.

Politically it was important to be seen to be taking account of the interests of residents and businesses (just) outside the zone boundary. This ultimately proved to have a doubly effective impact as it not only served to mitigate against a core traffic impact, it also helped to ameliorate the concerns of those people and businesses who were initially deeply hostile to the concept of the scheme.

8.5 Changes / Improvements

The introduction of the scheme on day one is not the end of the story – it is in many ways, the beginning!

As the scheme evolves, there will inevitably be a need to make changes – some minor but many major. Over the course of the 11 years that the Congestion Charging scheme has been operating in London, there have been a number of significant changes – both political and operational.

The introduction and subsequent removal of the Western Extension (WEZ) was a politically driven initiative. Many more changes have occurred to the scheme during the past 11years. Central to these have been;

i) The introduction of Pay Next Day in 2006 in response to research showing that many people were receiving Penalty Charge Notices for entering the Congestion Charging zone, simply because they forgot to pay. This initiative gave them a further 24 hours to pay the charge before incurring a fine.

ii) The introduction of Auto Pay in 2011, which has since become the preferred method of payment for 70% of users and significantly reduced the number of Penalty Charge Notices issued.

iii) Programme of revision of discounts for ‘clean’ vehicles to take into account evolving vehicle technology.

Probably as important as the actual changes themselves was the fact that channels of communication on CC have remained open since its introduction. It is important that people still feel that they can influence the manner in which the scheme develops. This was probably more for the scheme in London than others such as Stockholm, as there was no trial period in London. A trial period offers a natural and logical time for changes and modifications. This facility was not on offer in London and, therefore, it was even more important that those managing and operating the scheme are seen to be receptive to the views of users and other interested stakeholders.

Centre for Transport Studies
STOCKHOLM

THE STOCKHOLM CONGESTION CHARGES

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Abstract
Congestion charges were introduced in Stockholm in 2006 as a seven-month trial, followed by a referendum where a majority voted in favour of the charges. This led to the reintroduction of congestion charges in August 2007, and they have been operational since then. The system has attracted worldwide attention, both because it achieved substantial congestion reductions, and because the system overcame fierce initial hostility, surviving a heated and complicated political and legal process, and eventually gaining support by more than 2/3 of the population and all political parties. This report summarises the story of the Stockholm congestion charges, pointing out experiences and lessons learnt.
Note: Most of the material in this report has been published before in other papers and reports by the author and various coauthors. The intention of this report is merely to make the material accessible in one single, coherent source.

Keywords: Congestion charges, Stockholm, sustainable transport.

JEL Codes: H23, H54, R41, R48.

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目录

1 INTRODUCTION

Congestion charges[1] were introduced in Stockholm in 2006 as a seven-month trial, followed by a referendum where a majority voted in favour of the charges. This led to the reintroduction of congestion charges in August 2007, and they have been operational since then. The charging system consists of a cordon around the inner city, with a time-differentiated toll being charged in each direction. Traffic across the cordon was reduced by around 20%, leading to substantial congestion reductions in and around the city.

Congestion pricing has been advocated by transport economists and traffic planners for a long time as an efficient means to reduce road congestion. Despite growing problems with urban congestion and urban air quality, and despite a consensus that investments in roads or public transit will not be sufficient to tackle these problems, cities have been reluctant to introduce congestion pricing. In recent years, however, it seems that this is changing. London (2003), Stockholm (2006), Durham (2002), Milano (2008), Rome (2001), Gothenburg (2013) and Valletta (2007) have all introduced different forms of charging or permit systems to combat congestion and/or environmental problems, and many other cities are considering it. New York, Manchester, Copenhagen and Edinburgh have all recently tried to introduce congestion charges, and even if these attempts have been unsuccessful, it is a sign that congestion charges are being seriously considered to a greater extent than a decade ago. The soon ubiquitous “value pricing” roads in the US are also examples of how congestion problems are now being tackled through pricing measures.

The congestion charges in Stockholm have attracted enormous attention worldwide. Obviously, the opportunity to gauge the effects of congestion charges on traffic, congestion levels and travel behaviour has attracted great interest. But perhaps even more interesting is that the congestion charges overcame fierce initial hostility, survived a heated and complicated political and legal process, including a referendum initially forced through by opponents to the charges, and has eventually gained support by more than 2/3 of the population. The Stockholm charges went from “the most expensive way ever devised to commit political suicide” (to quote the then-secret feelings expressed by the Head of the Congestion Charging Office[2]) to something that the initially hostile media eventually declared to be a “success story” (e.g. Dagens Nyheter, June 22, 2006).

This report[3] tries to summarise the lessons that can be learnt from the Stockholm experiences.

1.1 Background: some basic insights about congestion pricing

It is well established, both theoretically and empirically, that infrastructure investments are not sufficient to eliminate road congestion in the cores of large cities. There are several reasons for this: two of the most important are the eventually inevitable scarcity of urban land and public resources.

Congestion charging will of course not solve everything. Introducing congestion charges will usually reduce the need for transport investments, but generally speaking not eliminate it. Normally, a growing urban region will need both congestion charging and transport investments, perhaps both roads and public transport. Obviously, cities are different as to what investments are the most cost-efficient and the most needed. Generally speaking again, a sustainable urban transport system must incorporate four strategies: attractive public transport, walkability, compact spatial planning, and restraints on car traffic. All these four will strengthen each other, and without one of them, the remaining three will lose effectiveness. The purpose of

[1] Legally, the congestion charge is a tax, according to Swedish law, and the official Swedish term is hence “congestion tax”. We have chosen to use the international standard term “congestion charge”.

[2] Quote Gunnar Söderholm, social-democratic head of the Congestion Charging Office during the trial, when (after the trial) describing the local Social Democrats’ feelings when the national Social Democratic government more or less forced the congestion charges onto the local Stockholm party district.

[3] The report draws heavily on previously published papers by the author and coauthors. Some parts are taken verbatim, in particular from (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012; Eliasson, 2008a, 2010, 2014). Further references are given in the report. The intention is not to present new material, but merely to collect previously published works in a single easily accessible place, in particular for translation into Chinese.

this paper is to present evidence and lessons about congestion charging – which is one way to restrain car traffic; parking pricing is another example – but the other three need to be included in a comprehensive sustainable urban transport strategy.

It is probably worth to point out that it is also well established that car drivers are in fact sensitive to costs. It is a common misconception among laymen, and sometimes among decision makers, that drivers “have to” drive, and do not react to changes in the driving costs. This notion has been refuted numerous times in many kinds of contexts. Increasing the cost to drive at certain places at certain times will decrease the number of drivers choosing to drive there and then. How large the decrease becomes depends on the ease of adaptation, among other things – in other words, how good alternatives there are. Alternatives may be other time periods, modes, routes, destinations etc. It is imperative to keep as many options open as possible to achieve good traffic reduction effects – but it is up to the drivers themselves to choose how to adapt.

2 THE STOCKHOLM STORY IN BRIEF

2.1 Basic facts about Stockholm

The City of Stockholm has around 0.9 million inhabitants, and is the central part of the Stockholm county, with a total of 2 million inhabitants. Around 2/3 of the City inhabitants live in the inner city – that is, within the toll cordon - and the rest outside. The area[4] of the toll zone is around 35 km^2. The zone has around 330 000 inhabitants, of which approximately 60 000 commute to workplaces outside of the zone. The zone has close to 23 000 workplaces, employing approximately 318 000 persons, of which more than two thirds are commuting from outside the zone.

The population of Stockholm has been growing rapidly for many years, and together with increasing trip lengths and car ownership, this has led to steadily increasing traffic volumes. Traffic volumes across the cordon used to increase at the same pace as the traffic in the county as a whole from the early 1970’s (when regular measurements started) up until the early 1990’s, when traffic across the cordon stopped growing. Traffic in the rest of the county, however, continued growing at the same pace, as did the number of transit trips across the cordon. The most likely explanation of this sudden end to traffic growth is simply a lack of road capacity. Traffic across the cordon then remained surprisingly stable for the next 15 years or so, despite significant changes in employment levels, fuel prices etc., with the only appreciable effect being a traffic decrease of around 5% when the Southern Bypass opened in 2004.

Because of its topology, with lots of water and well-preserved green wedges, road congestion levels in Stockholm are high compared to the city’s moderate size. Before the introduction of the congestion charges, the main roads arterials leading to, from and within the city centre had congestion indices typically averaging around 200%, i.e. three times the free-flow travel time. Partly because of this, and partly because of good public transport supply, the transit share is high: 60-65% of all motorized person trips to and from the city centre are made by transit. During rush hours, the share increases to 80%. The public transport system in the county of Stockholm consists of a subway network with 100 stations and over a million trips per day, a commuter rail network with 51 stations and nearly a quarter of a million trips per day, five light rail lines with 98 stations with a bit more than 100 000 trips per day, and an extensive bus network with nearly a million trips per day. Public transport fares are subsidized at a rate of around 50% of actual costs.

2.2 The story of the charges – an overview

Just like in many other cities, transport planners and economists had suggested that Stockholm should introduce congestion pricing for a long time, without getting either public or political support. In the early 1990’s, road tolls were proposed as a way to partially finance a large infrastructure package for Stockholm. This ignited the interest from environmentalists, who appreciated the traffic management potential of the tolls, even if they didn’t approve of that the revenues were planned to be partially used for new motorways. The

[4] As a comparison, the congestion charge scheme of London introduced in 2003 encompassed a 21 km^2 zone, this was almost doubled by the western extension in 2007.

infrastructure package agreement broke down in the late 1990's, and the tolls were never introduced – but the ball had been set rolling. Several stakeholders carried out analyses of congestion charging schemes, and perhaps more important, the issue had entered the agenda of the environmental movement, in particular the Green party.

In 2002, the social-democratic national government set up a commission to negotiate a new infrastructure agreement for Stockholm. The idea was floated to use road pricing as a funding source. When the Conservative party accused the social-democrats of having secret plans to introduce ”road tolls” after the election 2002, the social-democratic mayor in Stockholm promised very clearly and publicly that there would be no road tolls in Stockholm during the next election cycle (although she wanted to prepare a suggestion in time for the next election). The social-democrats went on to win both the national and the Stockholm election, provided that they could ensure support from the Green party. In return for support for a social-democratic national government, the Green party demanded that a ”several-year, full-scale congestion charging trial” should be carried out in Stockholm. The social-democrats obliged.

This led to an extremely heated debate. Congestion pricing was an unpopular measure from the outset, and the broken election promise made matters worse. The opposition raged, while silently celebrating what they anticipated to be a landslide victory in the next election. Both proponents and opponents of the charges used dramatic rhetoric to describe what would happen with or without congestion charges, respectively. Even many of those in favour of congestion charges were sceptical: the way the trial was introduced, and the short time available for preparation, made them fear that a failed attempt at introducing congestion charges would block the question for many years ahead. The media picture was overwhelmingly negative: 39% of all newspaper articles on the topic were negative, compared to 3% positive (the rest were neutral) (Winslott-Hiselius, Brundell-Freij, Vagland, & Byström, 2009). Opponents to the charges suggested a referendum about the charges, confident that they would win. The idea was silently welcomed by the social-democrats, who saw it as a way to put some distance between them and the charges: with a separate referendum, it would be possible to vote for the social-democrats and still vote no to the charges. However, it was decided that the referendum should not be held until after the trial, in conjunction with the next regular election in September 2006. This turned out to be of crucial importance.

The trial had the purpose to “test whether the efficiency of the traffic system could be enhanced by congestion charges”. The toll was expected to “reduce congestion, increase accessibility and improve the environment”, both in terms of emissions from car traffic and the perceived urban environment. The toll rate was set so as to reach the target of reducing car traffic across the cordon with 10-15 percent, a target loosely based on previously suggested road pricing schemes for Stockholm.

The congestion charging trial started in January 2006, when a time-differentiated cordon toll around the inner city was introduced. Traffic across the cordon dropped immediately, leading to dramatic congestion reductions all over the city. After a few weeks, the decrease in traffic volumes across the cordon during the charged period stabilized around 22% compared to 2005 levels, resulting in congestion reductions around 30-50% (Eliasson, Hultkrantz, Nerhagen, & Rosqvist, 2009; Eliasson, 2008b). Public attitudes gradually became more positive, while the media picture changed completely: the share of positive newspaper articles increased from 3% to 42% while the share of negative articles fell from 39% to 22% (Winslott-Hiselius et al., 2009). In the referendum in September, 53% of valid votes were in favour of keeping the charges[5].

Representatives for all political parties in Stockholm had promised to follow the outcome of the Stockholm referendum. The election ended up with liberal/conservative majorities both nationally and in Stockholm, and

[5] Some surrounding municipalities also arranged referenda, although they had no legal influence, since the congestion charges were entirely within the border of the city of Stockholm. (Around 2/3 of the city's population live inside the cordon. It should be noted, by the way, that residents within the cordon pay on average much more in charges than residents outside the cordon, while they get less of the travel time benefits, since congestion problems mainly exist into the city in the morning and out from the city in the afternoon). Counting the votes of all referenda that were held, there was a majority against the charges, but the selection was heavily skewed: referenda were only held in municipalities with liberal/conservative majorities and where opinion polls showed that there was a majority against the charges.

the new majority in Stockholm obligingly asked the new national majority to reintroduce the congestion charges, which had been turned off before the referendum. The crux was the negotiation about the revenues. Legally, the charge was a national tax that ended up in the national government's coffers, but the Stockholm region understandably argued that it was really their money. Eventually, the regional and national politicians brokered a huge, ten-year infrastructure package worth around 10 billion euros, where one part of the deal was that the charge revenues were earmarked for a new bypass around Stockholm.

The trial hence turned out to be a milestone in the development of urban road pricing. First, to the surprise of all but a few hard-headed road-toll enthusiasts, it finally tipped the balance of a forty-year political consideration of road-tolls in Stockholm by invoking more or less a land-slide change of the opinion of the general public in favour of tolls. Second, it was the third full-scale demonstration of an urban congestion charge, after Singapore and London, and the second to be based on a time-differentiated scheme, after Singapore.

As time went on, all political parties accepted and, eventually, even embraced the congestion charges. The reasons for this included the congestion reduction, the means to finance infrastructure, the possibility to get leveraged funds from the government, and the steadily increasing public support for the charges. The media interest for the charges faded, after having been in the headlines almost daily for four years. Rather than discussing the existence of the charges, the political parties and other stakeholders gradually moved on to discussing how the charges could be redesigned and how the revenues should be used. The traffic reduction has remained remarkably stable over time (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012). At the time of writing (February 2014), the liberal/conservative majorities in the national government, the city of Stockholm and the county of Stockholm – the former opponents of the charges – have agreed to substantially increase the level of the charges and introduce a new toll on the western bypass, with the dual purpose to finance a metro extension and reduce congestion even further. The only objection from the left/green opposition is that it is too little, too slow and too late.

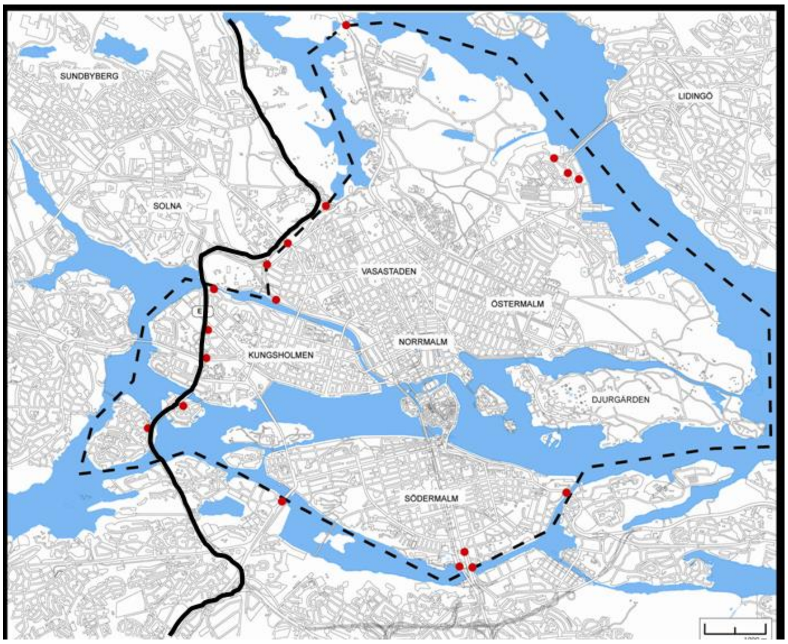
3 THE CHARGING SYSTEM AND ITS EFFECTS

The effects of the Stockholm system were studied in an extensive evaluation program. This evaluation program was particularly important since the fate of the charges would be decided by a popular referendum. The evaluation covered not only effects on traffic volumes and travel times, but also effects on emissions, perceived urban environment, traffic safety, delivery traffic, public transport, taxis etc., generating almost 30 different sub-reports.

3.1 Description of the system

The system consists of 18 charging points located at the main bottlenecks on the arterials leading into and out from the inner city. These 18 points form a cordon around the inner city. The cordon shape is just a consequence of the topology of the city, though, not a design constraint; it is a common misconception that congestion charging systems have to shaped as cordons (system design is discussed in section 5).

Vehicles are registered automatically by cameras that photograph the number plates; there is no opportunity to pay at the control points. The owner of the car is then sent a monthly invoice for the total charge incurred during a month. During the trial, the main means of identification was transponders ("tag-and-beacons" or DSRC, dedicated short-range communication). When the charges were reintroduced, the automatic camera identification, originally intended only as a secondary means of vehicle identification, worked so well that it was decided to abolish the transponders.



6:30-7:00	10 SEK
7:00-7:30	15 SEK
7:30-8:30	20 SEK
8:30-9:00	15 SEK
9:00-15:30	10 SEK
15:30-16:00	15 SEK
16:00-17:30	20 SEK
17:30-18:00	15 SEK
18:00-18:30	10 SEK

Figure 1. The charged area. The dashed line is the charging cordon, the dots are charging points and the solid line is the non-charged Essinge bypass. Right: Charges in different time intervals (weekdays only).

The cost for passing a control point in any direction is 1-2€ (using 10 SEK = 1€) depending on the time of day (see Figure 1), with a maximum amount per vehicle and day of 6€. The cost is the same in both directions, and each passage is charged. No congestion charge is levied during nights, weekends, holidays on in July. Various exemptions (e.g. buses, foreign cars and for traffic between the island of Lidingö and the rest of the county) mean that about 15% of the passages are free of charge.

Originally, there was an exemption for alternative-fuel cars, intended to stimulate the market introduction on such cars. This proved to be an effective measure: the share of alternative-fuel cars increased from 3% in 2006 to 15% in 2009. The sales of alternative-fuel cars was also stimulated in other ways, but several studies have concluded that the congestion charge exemption played an important role. The exemption was abolished for vehicles sold from 2009 and later, with the argument that it had filled its role as a facilitator for market introduction. In 2012, the exemption was abolished for all vehicles. The intention of the exemption was to stimulate more environmentally friendly vehicles, but the decision to equate “more environmentally friendly” with “alternative fuels” received criticism after a while, especially when the positive environmental effects of ethanol cars were questioned. The exemption applied to any car that could be propelled by other means than gasoline or diesel, such as ethanol, biogas or hybrids, regardless of which fuel was actually used (biogas and ethanol can alternatively be driven on ordinary gasoline) and regardless of how much emissions they generated. Subsequent Swedish policies intended to stimulate “green cars” have used other definitions, usually using constraints on fuel consumption per kilometer. The important policy conclusion from the “green car” exemption used in the congestion charging system is not the particular definition of what constituted a “green car” – many would argue that this definition in hindsight proved not well suited to the intention – but that it showed that this kind of exemptions can be a very effective stimulus on the vehicle market.

There is no congestion tax levied on vehicles driving on the Essinge bypass past Stockholm. This is the only free-of-charge passage between the north and south part of the county. The Essinge bypass was heavily congested even before the charges, so from a pure traffic perspective, there was a strong argument for also charging vehicles on the bypass. The opposition from the surrounding municipalities was so strong, however, that the politicians of the City of Stockholm decided that the bypass should be free of charge.

3.2 Traffic effects

Traffic across the Stockholm cordon had remained largely constant since the early 1990’s, despite growing population, and car ownership. Road traffic had grown in the rest of the region, so the most likely explanation for the lack of traffic growth in the inner city was simply lack of capacity. Figure 2 shows average daily traffic volumes across the cordon (weekdays 6:00-19:00) since 2000. A slight drop is seen in 2005 when the Southern Bypass was opened.

When the charges were introduced in January 2006, they had a substantial effect on car traffic from day one. After a few weeks with an even larger initial effect, the traffic reduction stabilized around 22% across the cordon during the charged period (comparing month-by-month to account for seasonal variation). Before the start of the trial, there was some doubt as to whether the traffic reduction would actually take place, especially since the trial was only seven months long, but effects turned out to be immediate and persistent.

When the trial ended July 31 2006 and the charges were abolished, traffic volumes immediately rebounded to almost the same level as before the charges – but not quite. A residual effect remained even after the charges had been abolished. From August 2006 to August 2007, i.e. between the end of the trial and the reintroduction of the charges, traffic volumes remained 5-10% lower than in 2005[6]. The most likely hypothesis is that some car users developed new travel habits during the trial that persisted even after the charges were abolished.

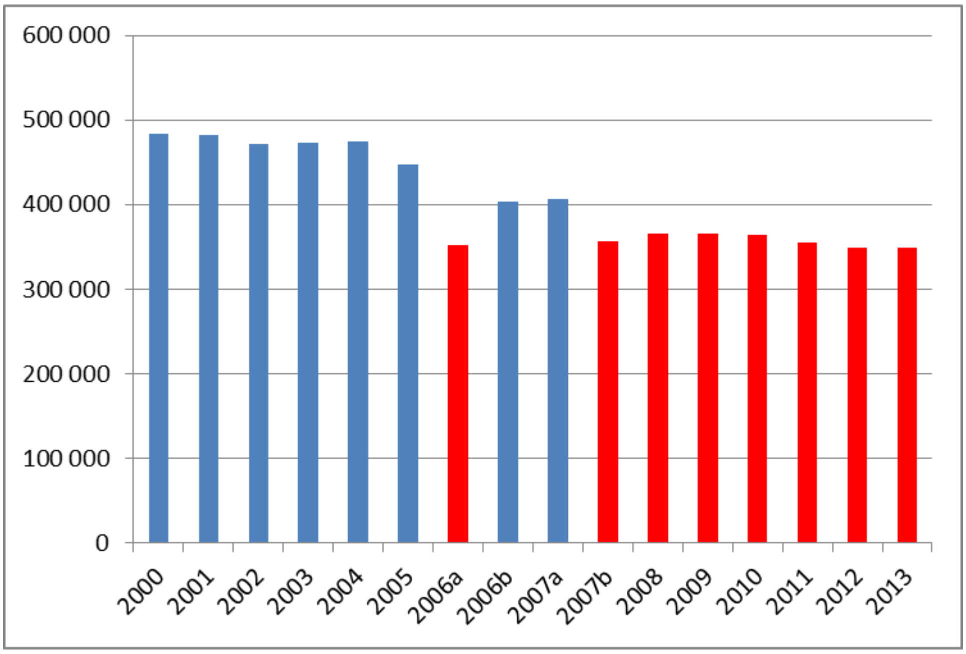


Figure 2. Average traffic volumes across the cordon, weekdays 6:00-19:00 excl. July. Blue: no charges. Red: charges. "2006a" is the trial period January-July 2006, and "2006b" is the remainder of 2006. "2007a" is the period January-August 15 2007, before charges were reintroduced, and "2007b" is the rest of 2007.

With the reintroduction in August 2007, traffic levels were again reduced to the same level as during the trial period in 2006. Since then, they have remained roughly constant, despite inflation, economic growth, growing population and an increasing car fleet. Rather than attenuating over time, the effect of the charges seems to have *grown* over time – otherwise, traffic would have been expected to increase due to various external factors (population growth, inflation etc.) – see Table 1. Controlling for such external factors, Börjesson et al (2012) show that traffic's elasticity[7] with respect to the charges has apparently increased from -0.70 in 2006 to -0.85 in 2009 and onwards. It may be too early to tell if this is a stable, long-term value, although it seems likely. But the most important conclusion is that there are no signs that the effect of the charges is wearing off, but instead increasing somewhat over time. This is consistent with the observation that there are more adaptation mechanisms available in the long term than in the short term. This result is in correspondence with

[6] The exact size of the residual effect is uncertain, since data from this period are less reliable due to roadworks and technical problems with the measurement equipment.

[7] Note that these elasticities are neither comparable with the usual cost elasticity of car traffic, nor with the fuel price elasticity of car traffic. Since fuel costs make up around half the marginal cost of driving, the cost elasticity of car traffic is around twice the fuel price elasticity. The elasticity of traffic across the cordon with respect to the charge is higher, since there are more adaptation mechanisms available, such as changing route, destination or time of travel.

that of Goodwin et al. (2004), who note that price impacts tend to increase over time as consumers have more options. In September 2012, the exemption for alternative-fuel vehicles was abolished. This led to a further reduction of traffic; before that, 6-8% of traffic across the cordon had been subject to that exemption. The observed reduction indicates that the exempted vehicles had the same price sensitivity as the rest of the traffic (a 20% reduction of these 6-8 percentage points translates to a 1.2-1.6% reduction of total traffic, which is very close to what is observed).

Table 1. Traffic reduction across cordon compared to 2005 traffic levels (charged weekdays 6:00-19:00). Second row: reduction compared to a theoretical counterfactual where external factors are kept constant. (no such calculations are available for 2012-2013).

	2006a	**2007b**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Traffic reduction from charges, compared to 2005	-21.0%	-18.7%	-18.1%	-18.2%	-18.7%	-20.5%	-21.4%	-22.1%
Traffic reduction adjusted for changes in external factors[8]	-21.4%	-20.9%	-20.7%	-21.9%	-21.7%	-22.3%	-	-

Detailed studies of the charges' effects get less and less meaningful over time, since the counterfactual becomes increasingly difficult to predict. Most of the detailed analyses of effects presented below are hence based on comparing 2005 with 2006, i.e. the last year without charges with the first year with the charges. Since traffic levels had been so stable for several years leading up to 2005, and have remained so stable from 2006 onwards (with a gap for the period August 2006-August 2007), the essential insights gained from these comparisons still seem relevant and applicable.

In relative terms, the decrease was largest in the afternoon peak period (-23 percent between 16:00-18:00), and somewhat lower in the morning peak period (-18 percent between 7:00-9:00). This indicates that a larger share of discretionary trips is made during the afternoon peak than in the morning and/or that departure times from work are less fixed than arrival times to work. Traffic declined in evenings as well. Hence, the reduction of outbound traffic during evening because of fewer incoming vehicles in the morning outnumbered the increase of evening traffic because of within-mode substitution from travel during day-time to free-of-charge evening. Despite the lower charge during mid-day (9:00-15:30), traffic decreased almost as much during this period (-22 percent). The seemingly high cost sensitivity during this time period is partially explained by the fact that many of the trips crossing the cordon during mid-day pay the higher charge when going in the other direction.

In addition, effects on traffic were seen further out from the toll zone than initially was expected. The number of vehicle kilometers driven in the inner city decreased by around 16 per cent. Outside the inner city, on the outlying approach roads and outlying streets, traffic volumes fell by just over 5 per cent. These effects have also remained roughly constant; traffic volumes have either remained constant in the following years, or followed their long-run trend. Queues were reduced also far from the cordon due to reduced spillback congestion. Hence, the charges do not seem to have generated any severe second-best problems neither in the short nor in the long term perspective.
Consequently, unwanted side effects that were anticipated outside the cordon, such as an increase of traffic on circumferential roads at the city's outskirts, were not found.

3.3 Travel times

Even more dramatic than the reduction in the number of vehicles was the reduced congestion. The newspaper headlines in Figure 3 provide an illustration. Improvements in travel times were tangible and easily perceived by the general public. Travel time improvements also occurred far from the inner city, when spillback queues were substantially reduced.

[8] Fuel price, total employment, car ownership, inflation, exempted share of traffic.

Figure 3. The front pages of Metro and Dagens Nyheter after the first day of congestion charging. (The headline in both newspapers reads: "Every fourth car disappeared".)

Figure 4 show average congestion indices for various types of roads, comparing May 2005 and May 2006. Congestion is measured by a congestion index where 0 percent corresponds to free-flow travel time, while 100 percent corresponds to twice the free-flow travel time. As can be seen, travel times for vehicle traffic declined substantially inside and close to the inner city. Particularly large declines were seen on arterials, on which delay times (time in excess of free-flow travel time) fell by one-third during the morning peak period and by one-half during the afternoon/evening peak period. This considerably improved reliability of travel times, i.e., travellers could be more certain about the duration of a car trip. The figure also shows the range of travel time variability, measured as the distance between the highest and lowest deciles of travel times (during a given 15-minute period). The highest decile of the travel-time distribution fell to a third or less compared to the pre-trial state for some categories of roads (such as arterials during PM peak).

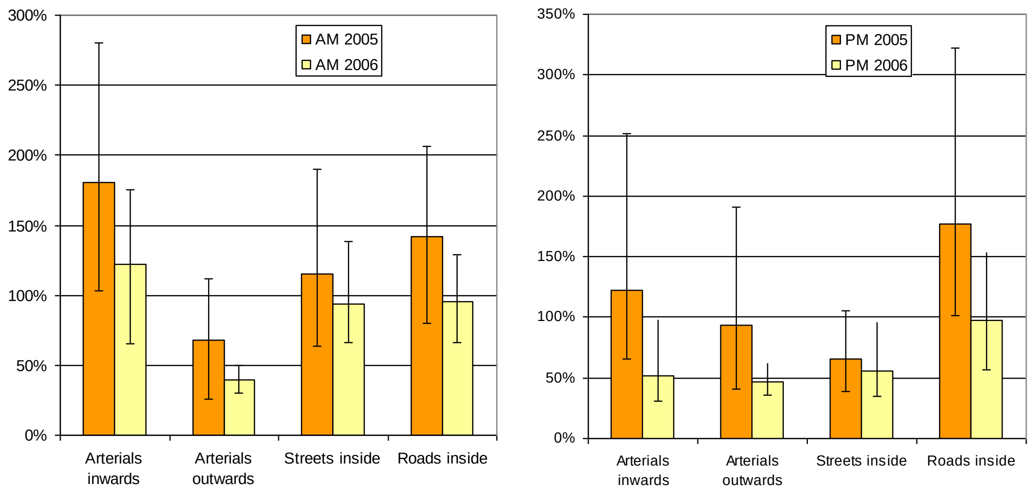


Figure 4. Relative increase of travel times for various categories of links. 0 percent corresponds to free-flow travel time. The coloured bars show average travel times while the "error bars" indicate the worst decile and the best decile of the travel time distribution. Measurements were taken from all weekdays for six weeks in April-May. "AM peak" refers to 7.30-9.00, "PM peak" refers to 16.00-18.00.

Figure 5 shows a similar picture, but showing more years and another categorization of streets and roads. The figure shows three periods without charges (April 2005, October 2005 and October 2006) and two periods with charges (April 2006 and October 2007). Generally, congestion is worse in April than in October, due to slightly larger traffic volumes and more pedestrians and bicyclists interacting with the traffic flow. It is apparent that the drop in traffic volumes across the cordon translated to congestion reduction in large area both inside and outside the cordon. In particular, the congestion reduction on the outer arterials should be noted, since these measurement points are situated rather far away from the actual cordon. Moreover, it can be seen that the general congestion level was around the same during the trial (April 2006) as after the reintroduction (Oct. 2007). Congestion levels during the non-charged October periods 2005 and 2006 were about equal, while the congestion level during the non-charged April 2005 was a bit higher.

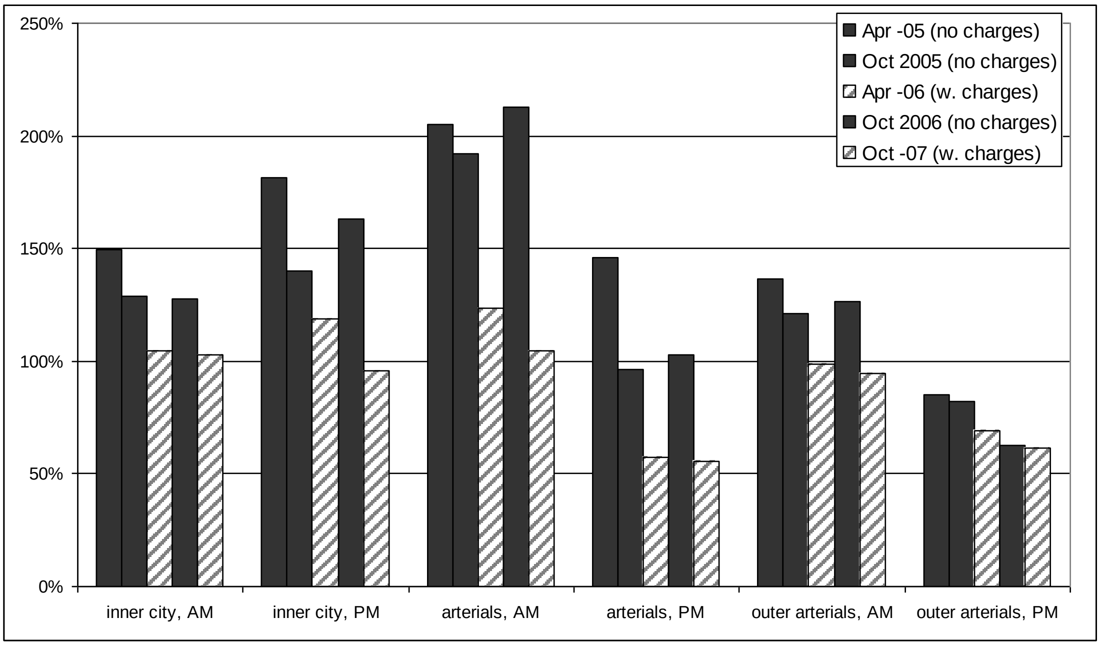
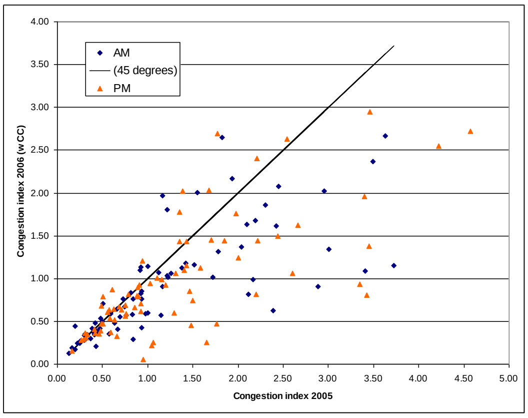


Figure 5. Average travel time increase over free-flow travel times for various categories of links, April and October 2005-2007.

The reduced congestion also meant that travel time reliability increased. For example, the worst travel time decile was reduced by a factor of 3 or more for arterials during the PM peak. The scattergram below (Figure 6) illustrates the increase in travel time reliability, showing standard deviation for link travel times for 2005 (on the x-axis) and 2006 (on the y-axis). Next to it is a similar scattergram showing the congestion indices for several links. Inspection of the diagrams reveals that most points lie below the 45 degree line, i.e. the situation has improved (if it has changed at all).



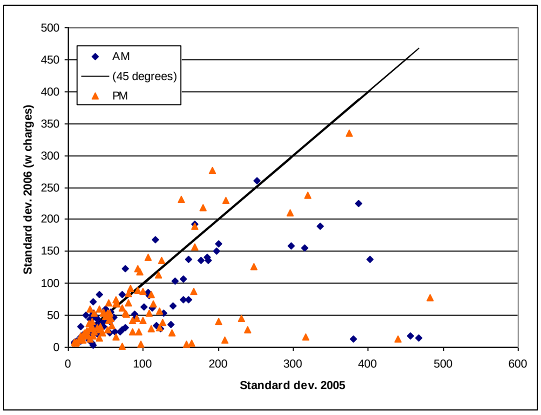


Figure 6. Scattergrams of link congestion indices (left) and standard deviation of link travel times (right), April 2005 and 2006.

3.4 Environmental effects

The reduction in vehicle kilometers travelled meant that emissions from traffic were reduced. The reduction was largest in the inner city, between 10 and 15 per cent (the reduction differed across different types of emissions). Since this is a most densely populated area, this is an important effect from a health point of view. In the inner city, of air-borne pollutants were reduced between 10 and 14 percent. For nitrogen oxides (NOx) the reduction was smaller (8.5 percent), since the extended bus traffic used older buses with higher emission factors. Overall, the results reveal that air quality was improved in many streets in the inner city. Carbon dioxide emissions from traffic in the whole metropolitan area (the county of Stockholm) decreased by 2-3 per cent.

The use of air pollution modelling allowed for a detailed assessment of the changes in population exposure due to the change in traffic. Since the main effects were seen inside the cordon where the daytime population density is high, this also results in important changes of average population exposure. The estimated reductions of NOx and exhaust particles emissions are refer to the change in concentration at rooftop level in the inner city (so-called urban background). This provides an indication of the average load of the population in this part of Stockholm. International research ascribes reduced mortality due to for example fewer cases of cardiovascular diseases and lung cancer as the most important health benefit. Forsberg et al. (2006) estimate that there will be 20-25 fewer premature deaths per year in Stockholm's inner city and a total of 25 - 30 less premature deaths annually in the Stockholm metropolitan area.[9] These are approximately three times larger effects than what would be found if a more general policy measure, such as a fuel tax increase, was used to obtain a decrease of emissions of an equal magnitude, since these reductions were concentrated to the most densely populated areas.

One of the goals for the trial was to “improve the perceived urban environment”. It is difficult to draw definitive conclusions about this, not least because of confounding with weather effects. However, studies indicate certain improvements for traffic-related indicators such as perceived traffic congestion, air quality and accessibility – not only for car drivers but also for cyclists and pedestrians. The result points to perceived improvements of exactly those factors for which measured changes can be demonstrated, i.e. those connected to traffic reductions. In the city environment study, citizens feel there is an improvement in traffic tempo, air quality and vehicle accessibility. The same tendency is seen in interviews with cyclists in the inner city and children living in the inner city. Inner-city children’s perception of the city environment has very clearly improved and many cyclists think there are fewer cars in the inner city and that the traffic environment has got better.

3.5 Retail

There had been fears that retail inside the cordon would be adversely affected, but studies of the retail markets were not able to show any effects of the congestion charges (Daunfeldt, Rudholm, & Rämme, 2009). For example, the durables survey in shopping centres, malls and department stores during the Stockholm Trial period showed that these developed at the same rate as the rest of the country. The same held for other retail sectors.

Fear for adverse impact on retail inside a cordon is common in many cities. Large efforts were made in Stockholm to track such effects, only to conclude that they were very small or non-existent. Similar conclusions have been reached in other cities with congestion charges. There may be effects on particular stores, especially if they lie close a cordon, but the average effect in an urban centre is usually small. This should be evident, especially in the long term: if the retail market inside the cordon gets less attractive, then floorspace rents will, in equilibrium, decrease to counteract this, making the effect on the number of stores even smaller.

[9] The standard cost-benefit model used for infrastructure planning in Sweden has a dose-response relationship based on older studies. This indicates that the reduction in traffic due to the trial saved about five life years on an annual basis. This is the number used in the cost-benefit analysis by Eliasson (this issue).

3.6 What did the disappearing drivers do instead?

Traffic measurements will only give changes in aggregate terms, and does not reveal *how* car drivers adapted – how many switch to other modes, departure times or destinations, for example. A panel travel survey with two waves was used by Franklin, Karlström and Eliasson (2010) to investigate how private trips were affected. Results (in 1000's car trips across the cordon during charged hours) are shown in Figure 7. These results should be treated with caution, since it is difficult to separate seasonal and trend effects from the effects of the charges.

Approximately 25% person trips across the cordon disappeared. Out of these, around 10 percentage points out were work trips switching to transit, while one percentage point was work trips switching to the Essinge Bypass (hence, route switching was only a minor adaptation strategy). Six percentage points were discretionary trips switching to other destinations or reducing trip frequency, possibly by trip chaining or combining trip purposes, and under one percentage point switching to the Essinge Bypass. The remaining five percentage points are disappearing professional traffic—deliveries, taxi, craftsmen etc. Since we do not have travel surveys for this type of traffic, we cannot decompose it further. That professional traffic is affected at all by the relatively low charges may come as a surprise, but there is significant evidence in the interview studies carried out with professional drivers that they in fact tried to plan their routes and trip chains in order not to cross the cordon unnecessarily often, and moreover to decrease the number of trips altogether.

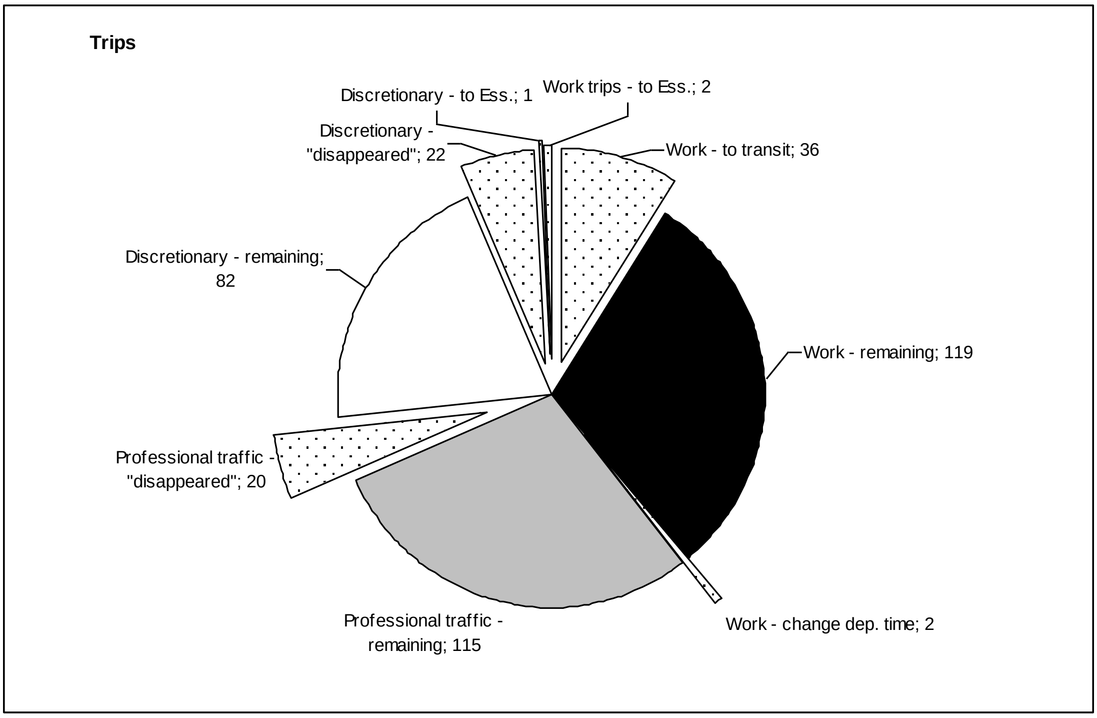


Figure 7. Estimated changes in car trips across the cordon during charged hours (1000's trips). (When comparing to measurements of vehicles across the cordon, note that "through" trips are counted as two cordon crossings.)

It is worth emphasizing that there are many ways to adapt. Route and mode changes are far from the only adaptation strategies. Trips, especially discretionary trips, are not "replaced" in a simple one-to-one fashion. Many people, traffic experts not least, seem to be unconsciously stuck with the assumption that there is a more or less fixed number of trips to be made, and that the effect of the charges should be possible to sort neatly into categories like "mode change", "destination change" and "departure time change". In reality, adaptations are much more multi-faceted. This means that commonly encountered statements such as "congestion charging won't work in our city because our transit system is too bad" or "…because we have no ring road" are miss an essential point: there are many more ways to adapt than changing mode or route. Which adaptation strategy will dominate depends on the characteristics of the city and the design of the system, and which travel alternatives it leaves open.

Another important insight is that traffic isn't just work trips. Work trips only make up a fraction of car traffic – a typical figure could be 30-40%, with the rest being discretionary trips and professional traffic (where a typical figure could be 15-25%). Discretionary trips are easier to affect, because there are more ways to adapt in the short run, and represent a significant fraction of traffic, especially during afternoon peak hours, when congestion is often just as severe as during the morning peak. Professional trips are very heterogeneous: some types are very difficult to change, while some are not. Typically, values of time are very high, which means that time savings for professional traffic will constitute a significant part of the travel time benefits. Despite all this, it's common that the discussion focuses exclusively on work trips, both among planners, policy makers and the general public. This is a mistake that surprisingly often confuses the discussion about what congestion charging can do and how they may work.

Over time, the question of how drivers adapted becomes increasingly pointless. This is because travel patterns are much less repetitive and stable than many people think. Many of the affected drivers are occasional car drivers, who drive on the charged road perhaps a couple of times each month. Around two thirds of the drivers crossing the Stockholm congestion charging cordon on any given day are "occasional" drivers, who drive across the cordon three days a week or less. Other days, they use other modes, times or routes. These drivers will change on the margin, and it will often be impossible to tell if and how they changed. In fact, many car drivers will not even know if or in what way they adapted. A study in the spring of 2006 showed most drivers were unaware that they had reduced their trips across the cordon. A comparison of drivers' stated change in behaviour and objective traffic measurements showed that around ¾ of the decrease in trips had apparently gone unnoticed by drivers.

Moreover, there are many other changing processes going on. People move and change jobs, for example: between any two years, 20-25% of the workforce will have changed jobs (or started working), and 15-20% of the population will have moved. After just a few years, it is pointless to ask how a given person has "adapted" – because the entire situation where travel choices are made has changed.

3.7 Public transport

The Stockholm trial consisted not only by congestion charges but also of an extension of public transit services. The extended services were motivated partly to meet increased demand for public transport, and partly by a political will to show "carrots" and not just "sticks".

Drivers switching from car to public transport meant that the number of passengers in the transit system increased by around 4-5%. Crowding in the public transport system, measured by the number of standing passengers, increased somewhat in the metro but decreased on the commuter trains, most likely thanks to expanded public transport capacity.

Reduced road congestion in and around the inner city led to increased speeds and punctuality for bus services. During the trial period in 2006, bus timetables were not adjusted so the improved accessibility did not significantly shorten travel times for inner-city buses, but there were signs of improved punctuality. Bus traffic across the charge cordon – which do not have fixed time tables once they have passed the cordon - experienced considerably shorter travel times. After the trial period, no dedicated studies of this are available, since the counterfactual becomes more and more hypothetical.

Travel surveys showed that few car drivers were enticed to switch to public transport by the service extension in itself, even if the data are inconclusive. The second purpose was to provide additional capacity in the transit system. The added capacity was relatively minor: the increase in passenger capacity by the buses meant that around 14 000 trips were made each day by the buses, compared to well over one million public transport trips across the cordon each day. But in the specific corridors served by the buses, they most likely contributed to keeping crowding on commuter trains from increasing. The third purpose of the transit extension was to increase the effect of the congestion charge by making the switch from car to public transport easier. However, onboard surveys on the new buses found very few former car drivers on the buses. Of the vehicle-traffic reduction of 22% over the charge cordon, at most 0.1% can be ascribed to the extended bus services (Eliasson et al., 2009).

4 PUBLIC AND POLITICAL ATTITUDES

The main obstacle for congestion charging is often the lack of public acceptability. Hence, the most remarkable and interesting development in Stockholm may be the change in attitudes, from fiercely hostile to overwhelmingly positive. This section presents some evidence about this development, and discusses what factors influenced it[10].

4.1 The change in attitude – "familiarity breeds acceptability"

When the decision was made to carry out a congestion charging trial in Stockholm, it was met with vocal resistance, although polls showed a more mixed picture. Figure 8 shows how the support for congestion charges has evolved over time. In the spring of 2004, 43% of Stockholm citizens stated that they would "probably" or "most likely" vote yes to permanent congestion charges. Support fell, however, once the start of the trial approached. Right before the start of the trial, support had fallen to 34%, with the "most likely yes" group falling the most. Once the trial started, however, support increased to 53%. The media image also changed once charges were in place, from intensely critical to, in many cases, very positive. The percentage of trial-related newspaper articles with a positive angle increased from 3 % in the autumn of 2005 to 42 % in the spring of 2006, while the share of negative newspaper articles was almost halved from 39 % to 22 % (Winslott-Hiselius et al., 2009). The trial ended on 31 July, 2006, and was followed by a referendum in September at the same time as general and local-government elections were held. Excluding blank votes, 53% of Stockholm citizens voted to keep the charges. After the election, the centre/right coalition gained power both at the national level and in the city of Stockholm. The centre/right coalition in Stockholm had opposed the congestion charges, but had promised to follow the outcome of the referendum, so they had to ask the national Government to reintroduce the charges permanently. After a few weeks of consideration, the new centre/right Government said it would do so, but as part of a broader package of transport investments in Stockholm, to be negotiated. The revenues from the congestion charges were earmarked for road investments. On the other hand, the investment package also contained major rail investments, but these were claimed to be financed by other sources of funding. After the decision to include the charges in an investment package, no political parties proposed abolishing them anymore. The charges were reintroduced permanently in August 2007, although the negotiation over revenue use was not settled until late 2007. A poll in December 2007 showed a 65% support for the charges, and several polls since then have shown similar or higher support. The most recent, in late 2013 (not shown in the diagram), showed a support of 72% (excluding "don't know").

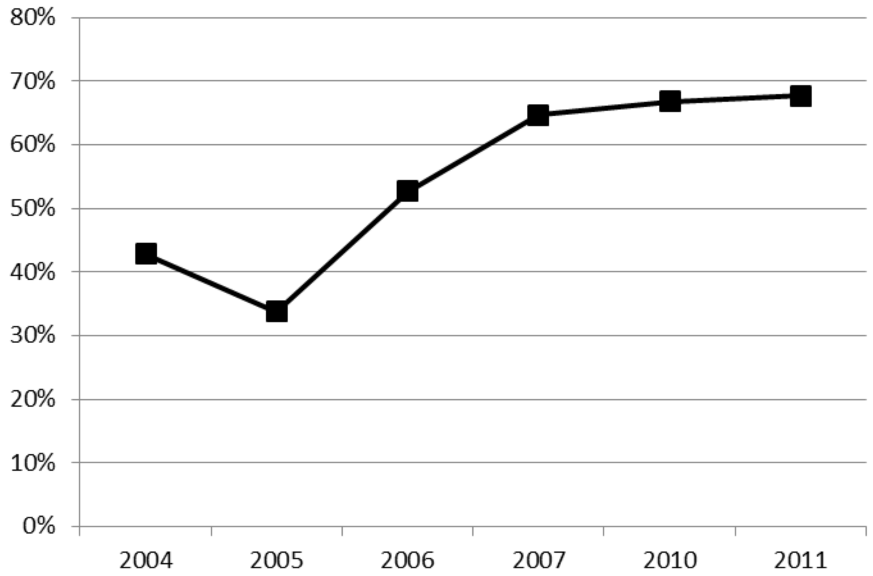


Figure 8. Would vote "yes" in referendum about congestion pricing (excl. "Don't know").

[10] This section draws heavily from Eliasson (2014).

Figure 9 shows support for the charges in four groups: people without car in the household, car owners who never or very seldom cross the charge cordon, car owners who sometimes pay the charge, and car owners who often pay the charge. (2007 and 2010 data are missing, since these surveys did not ask about driving across the cordon.) The support shows the same U-shape in each group. In fact, the dip from 2004 to 2005 is most pronounced for the *unaffected* groups, i.e. people not expecting to pay the charge.

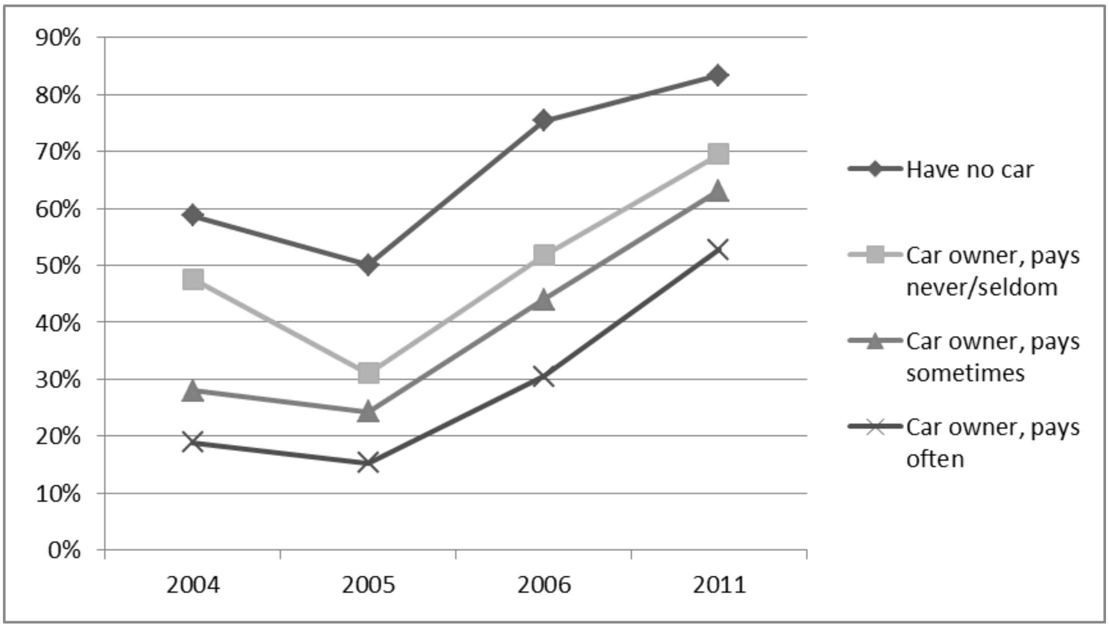


Figure 9. Support for congestion charges depending on car ownership and paid charges.

Evidently, the amount of tolls paid makes a large difference for the support, looking at each cross-section. But the figure also indicates that the *change* in attitudes is at least partly driven by other factors than self-interest variables such as tolls paid and time gains. The changes in attitude over time for each group look very similar, regardless of how much they are affected by the changes in travel costs and travel times. Even the group who do not own a car shows the same U-shaped attitude pattern. And even in the most affected group, support for the charges has more than tripled from a low point of 15% to 53%. In other words, there is a majority in favour of the charges in all groups by 2011.

Just as respondents seem to be unaware of their behavioural changes, they seem to be remarkably unable to remember their past attitudes. This is actually well known from voting research: people tend to forget that they have ever had another opinion than their current one, or have ever voted differently than they would vote now. Surveys in 2006 and 2007asked respondents whether they had changed their attitude to the charges. From 2005 and 2006, voters intending to vote ”yes” in the referendum increased by 19 percentage points from 30% to 49% (including undecided voters in the base). 29 percentage points of the 49% yes-voters stated that they had ”become more positive” during 2006 – that is, some of the positive voters must have become even more positive. But when the same question is repeated in 2007, only 13% of voters state that they had ”become more positive” during 2006. Not only is this less than half the 29% from 2006, it is lower than the 19 percentage points that became so much more positive that they changed from ”no” to ”yes”.

The development of attitudes is remarkably close to the general pattern described in Goodwin (2006), reproduced in Figure 10.

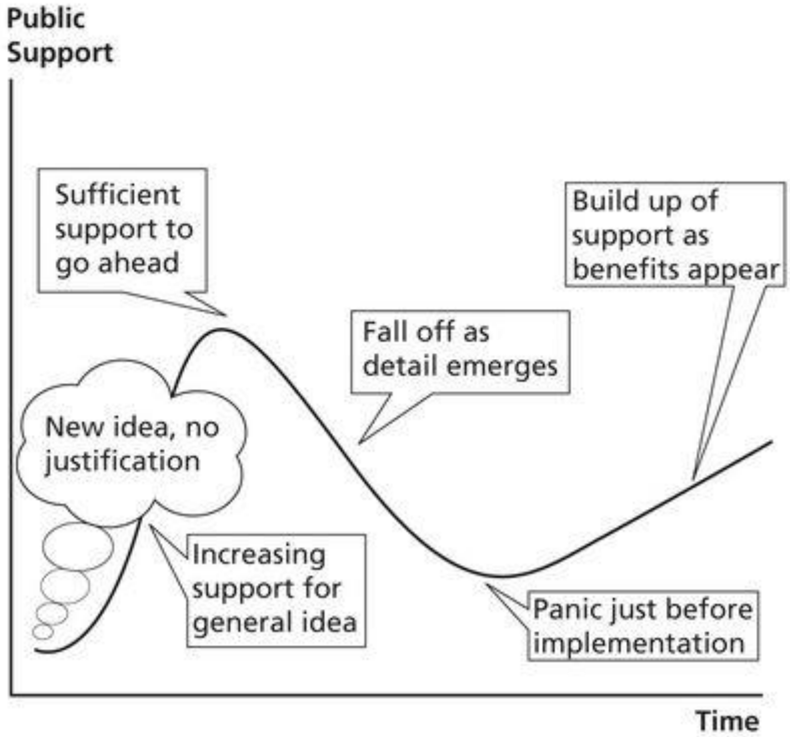


Figure 10. "The gestation process for road pricing schemes" – reproduced from (Goodwin, 2006).

Once the idea has been introduced and explained, a fairly large fraction of the population is generally willing to support the idea of congestion pricing. How large this fraction is depends on how the question is formulated and framed – for example, revenue use, the purpose of the charges and what policy alternatives it is contrasted against all matter. But once a detailed proposal is worked out, support generally decreases. There may be several reasons for this – for example, that the disadvantages suddenly become more evident than the potential advantages, or fears that the technical system will not work or become very expensive. This is sometimes summarised in the formula "acceptability decreases with detail". But once the system is in place, support will generally increase, which is often summarised as "familiarity breeds acceptability". There are probably several reasons for acceptability to increase once a system is in place.

1. "Better than you thought": the benefits may turn out to be larger than anticipated. A major reason for public resistance to congestion charges is a belief that they simply will not work (Bartley, 1995; Jones, 2003). In Stockholm, the positive effects on road congestion and urban environment were much larger than most people expected.
2. "Not as bad as you thought": the downsides of charges – increased travel costs and/or changes in travel behaviour – may prove to be not as bad as expected. Once the charges are in place, many people may discover that the charges do not in fact affect them negatively as much as they had feared. There is a lot of evidence in Stockholm evidence for this phenomenon (Henriksson, 2009). Transit crowding didn't increase significantly, congestion didn't appear in new places, the technical system worked smoothly, and it may have been easier to adapt to the charges than anticipated (for example, drivers have reduced their car trips across the cordon around four times more than they are aware of, according to a study which asked drivers how they had changed their behaviour and compared this to actual traffic measurements).
3. Familiarity with road user charging may reduce the general reluctance towards pricing a previously unpriced good. There is evidence that people in many cases do not like prices as an allocation mechanism (Frey, 2003; Jones, 2003). But once familiar with the concept that road space is in principle a scarce good that can be priced – much like parking space or telecommunication capacity – this reluctance may tend to decrease.
4. Finally, it is a general psychological phenomenon to resist change. In the psychological literature, different variants of this general phenomenon are referred to as status quo bas, loss aversion, endowment effect, or cognitive dissonance. This means that once people have adapted to the charges and the short

travel times, they value the time gains higher and the increased travel costs lower than they did before the change. Some people may react with "accept the unavoidable": once the charges are in place, it is less worthwhile to spend energy on opposing them.

Further analysis of Stockholm attitudes show that even if self-interest and belief in effects strongly affect attitudes, these are not the sole determining factor, especially when looking at how attitudes change over time. All groups, regardless of travel patterns, car ownership and belief in the charges' effectiveness (*ex ante* and *ex post*) show the same U-shaped change in attitudes – more negative attitudes before the introduction of the charges, and increasingly more positive attitudes after the introduction. In fact, this pattern is more pronounced for unaffected groups.

This can be interpreted using results from social psychology explaining how attitudes are formed. First of all, attitudes are more or less well developed. They tend to be more developed in issues where an individual for example has a lot of direct experience, has encountered the issue many times, know a lot about the issue and towards which they have strong emotions. When people are faced with a new issue where attitudes are not well developed, new attitudes are often formed by associating the new issue to some similar but familiar issue, where the individual already has a well-developed attitude.

There have been suggestions that the introduction of congestion pricing established a new social norm, where driving in rush hours was less socially accepted. There is scant evidence of this, however. In fact, it is easier to interpret the introduction, polarization and subsequent lack of controversy in the opposite way – that the charges could gain broad acceptance once it was shown that it could in fact be reconciled with existing social norms: in particular, that the charges were not an attack on mobility or car use as such. This interpretation simultaneously explains why it was politically rational to first ignore congestion charges, then to advocate them in spite of public resistance from large groups, and why this resistance then died down. It also illustrates the importance of legitimacy. The story has four phases.

1. For a long time, planners and economists in Stockholm had limited success in advocating congestion pricing. Their argument was that it would increases efficiency in the transport system. But very few people have a pre-existing attitude to this concept, and even fewer have an emotional engagement in it. Instead, when faced with the question, people associated to superficially similar issues such as mobility restrictions or taxation, where they have an existing attitude, most likely a negative one. For an issue to be politically interesting, it must generate enthusiasm among a sufficiently large group of voters. But since transport efficiency is simply not an issue that many people get enthusiastic about, the issue had virtually no political upside.
2. This changed when congestion pricing was reinterpreted as an environmental policy, which happened in Stockholm during the mid 1990's. While allocation efficiency in the transport sector could not arouse enthusiasm or engagement among the general public, environmental concerns definitely could. This was what was needed to get congestion pricing on the political agenda – a link to an area with where strong and emotional attitudes existed.
3. When the decision to carry out the congestion charging trial was made after the election in 2002, a fierce debate broke out. Consistent with what was said above about the necessity of emotions in politics, the arguments soon turned principal, moral and emotional, leaving little room for compromise. This might have been an inevitable development: if congestion pricing had not been elevated to a moral-emotional question, it hadn't entered the political stage in the first place. But just as inevitable, the morally supercharged arguments for congestion pricing implied (or could be perceived to imply) that all car traffic was evil and unnecessary, and should be banished. This might be one reason for the decreasing support also among car drivers that were actually unaffected: they might simply have been alienated by the anti-car rhetoric. There are also other reasons that may have caused non-affected groups to develop more negative attitudes: the charges were claimed to have adverse equity effects, be unfair, and a waste of taxpayers' money. The most recurring argument was the lack of democratic legitimacy. The social democrats had made a very clear promise not to introduce road pricing during the election period – and here they were doing it anyway.
4. When the referendum ended in a yes to the charges, the new government decided to earmark the revenues for a motorway tunnel west of Stockholm. From an attitude point of view, this was probably important

for several reasons. First, the charges now had democratic legitimacy. In addition to the referendum result, there was now a political agreement about the charges and the revenues – made by the liberal/conservative alliance no less, which meant that all political parties had now sanctioned the charges in some way. Second, the revenues were earmarked for roads. As it was really part of a multimodal package, the revenues could just as well have been earmarked for the railway investments that were also part of the package. But earmarking the revenues for roads not only spoke to motorists' self-interest. It sent a moral signal: it's OK to be a car driver. It indicated a reinterpretation or reassociation of the congestion pricing issue from a morally charged anti-car measure to a technical-rational measure that was effective – it "worked" in the sense that it generated revenues and reduced congestion. And technical measures arouse much less emotions: people usually do not love them, but they do not hate them either. The most important function of the earmarking may hence have been to discharge some of the sentiments around the charges, moving the debate from the moral domain to the technical-rational domain. Thirdly, it calmed the fears of Stockholm politicians (from all parties) that revenues would end up in the national coffers, either directly or indirectly, by subtracting the revenues from Stockholm's "fair share" of national infrastructure grants.

The introduction of a certain measure always has the potential of becoming politicized. Congestion pricing is an evident example: pricing as such may meet resistance even among people who agree in principle that road traffic should be reduced. In fact, regulation (bans on car driving in certain areas, odd/even number plate restrictions, slowing down traffic through physical measures) are often more popular than pricing measures, despite being inefficient in the standard economic sense. Much of the debate before the charges were introduced centred around whether pricing was, in principle, a fair, legitimate and democratic allocation mechanism. After the charges were in place, this debate faded into the background – pricing seemed to become a reasonable accepted way to allocate road space, just as with many other scarce goods (including transport-related things as train tickets, airport slots or car ownership).

One way to view the congestion charging debate is that the issue seems to have moved from the technical-rational domain to the moral domain and back again. When presented as a purely technical-rational suggestion, it failed to gain political interest because the type of benefits it could potentially bring (increased transport efficiency) could not generate sufficient enthusiasm. It seems that too few people had strong attitudes regarding this type of benefits, meaning that it could not generate the necessary emotion to gain political traction.

By reinterpreting it as an environmental measure, the issue moved gradually to the moral domain. This connected to strong attitudes regarding local and global environment, and maybe also general anti-car sentiments in some groups, and hence the necessary political engagement emerged. But the other side of the coin is that it made the issue divisive – even unaffected groups became more negative. These negative sentiments were probably bolstered by other moral arguments, e.g. about lack of democratic legitimacy, waste of public funds, over-taxation and freedom of mobility. These attitudes were also strong and well-developed, making the debate very heated.

But after the referendum, the infrastructure agreement and the establishment of democratic legitimacy moved the issue back into the technical-rational domain. This discharged some of the negative moral-based attitudes. Moreover, this connected the issue to concepts such as "rationality" and "efficiency", which in Sweden have very positive associations.

4.2 Other factors influencing public attitudes

Several factors influencing attitudes to congestion charges have already been mentioned above, but it is worth summarizing what kinds of factors have repeatedly been found to influence acceptability in several countries.

First, self-interest variables are obviously important. All else equal, individuals get more positive the less charges they pay (or expect to pay), the more time gains they get, the higher they value travel time savings, and the more satisfied they are with public transport. Individuals also become more positive if revenues are used in a way they appreciate, which can be viewed as a form of self-interest (Eliasson & Jonsson, 2011;

Hamilton & Eliasson, 2012; Hårsman & Quigley, 2010; Schade & Schlag, 2003a). Among other things, this means that the system has got to deliver benefits. In Stockholm, the perceived effect of the charges was the most important factor explaining attitudes to the charges. Even if one should not confuse "perceived" effects with "objective" effects – since attitudes influences what effects are actually perceived – it seems clear that achieving objective effects is necessary to reach acceptance. This underscores the importance of designing the system carefully, and only using congestion charges when congestion really is a problem. Moreover, it seems likely that measuring effects and communicating the results through, for example, the kind of scientific evaluation carried out in Stockholm will increase the awareness of positive effects – provided, of course, that there are in fact positive effects.

Second, positive attitudes to congestion charges are strongly influenced by concerns about and engagement in environmental issues (Eliasson & Jonsson, 2011; Hamilton & Eliasson, 2012). In Stockholm, the charges were to a certain extent marketed as "environmental" charges, and voters' environmental concern was an important factor explaining the acceptability of the charges. This is in line with findings in the literature that social norms of this type influence acceptability in general, and that support depends not only on the "objective" characteristics of the measure itself, but also on the defined objective of congestion charges. Moreover, several authors have found that it is not just perceived *individual* benefits that determine acceptability: perceived *social* or *collective* costs and benefits can also affect acceptability strongly. Hence, the "branding" of the charges matters – how they are marketed, explained and perceived. In Stockholm, re-labelling congestion charges to "environmental charges" and emphasizing their positive effects on air quality may very well have had an impact on acceptability. Other cities may employ different strategies, but the general conclusion remains: it is important how the charges are "branded". A condition for this to be possible is that the system design is well aligned with the stated purpose of the charges. A system marketed as "congestion charges" system should for example not levy charges where or when there is no congestion.

As was emphasized above, the most important factor seems to be own experience of congestion pricing. The same pattern has been observed in e.g. Oslo and London. One study (Hamilton & Eliasson, 2012) compared attitudes in Stockholm, Helsinki and Lyon, concluding that the only variable that could explain the much higher support for congestion charges in Stockholm was simply that the Stockholm population had experienced the introduction of congestion pricing, while the others had not.

Congestion is viewed as one of the most important urban problems (65-80% of the three populations agreed). But Hamilton et al. found no significant correlation between attitudes to congestion pricing and concerns about road congestion. On the other hand, they found a strong correlation between concerns about road congestion and being in favour of expanding road capacity. Apparently, it is not mainly concerns about congestion that is driving support for congestion pricing, despite the fact that such concerns are widespread[11]. This is consistent with earlier several studies finding that one of the most common arguments against congestion pricing is a distrust in congestion pricing's ability to reduce congestion (Jones, 2003; Schade & Schlag, 2003b). On the other hand, this distrust may partially be a reflection of self-interest: Schade and Baum (2007) find that respondents who expect congestion pricing to be disadvantageous to themselves not only have more negative attitudes to it, but also perceive them as less effective and more unfair than other respondents.

Congestion pricing attitudes are related to attitudes to public interventions in general. Hamilton et al. show that negative attitudes to congestion pricing are strongly correlated with negative attitudes to taxation in general, speed enforcement cameras, and belief in a public administration's ability to distribute a scarce resource fairly. This finding may partly explain the apparent paradox that left-wing parties are often more in favour of congestion pricing than liberal/conservative parties.

Equity effects are often cited as one of the main reasons for opposition to congestion pricing. Whether congestion pricing has progressive or regressive effects depend on the design of the system and on initial travel patterns. As to Stockholm, there are several studies (Eliasson & Levander,, 2006; Eliasson & Mattsson,

[11] Other studies have got mixed results on this issue. While Rienstra, Rietveld and Verhoef (1999) found that respondents with more concerns about congestion were more positive towards congestion charges, Hårsman et al. (2000) and Schade et al. (1999) found the opposite.

2006; Franklin et al., 2010; Karlström & Franklin, 2009). These find no regressive effects; some indicate progressive effects, while some indicate neutral effects. It should be noted that the equity argument may be used for other reasons than honest equity concerns: it may simply be perceived as a more legitimate argument than self-interest (Schade & Baum, 2007). This is supported by the finding that Hamilton et al. found weak or no correlation between the attitude to congestion pricing and agreeing with the statement “More should be done to reduce the difference between rich and poor in society”.

Equity and “fairness” can be interpreted in different ways. Initially, the dominating perspective is often “before-after” – how travel costs and travel times change for different groups, such as rich vs. poor, men vs. women, inner city vs. suburb residents. At least in cities with decent transit shares, it is often the case that “rich” will pay more than “poor”, with middle-income groups “suffering” the most, relatively speaking. But once the charges are in place, another perspective becomes more important – “fair” pricing. In other words, what price is “fair” to charge? From this perspective, it is “fair” that one pays more to drive on a congested road or to cause emissions in densely populated areas – irrespective of income or place of residence, for example.

4.3 Political acceptability

Political acceptability is different from public acceptability. Obviously, political acceptability is influenced by the level of public acceptability – but public acceptability is neither a necessary nor a sufficient condition for political acceptability. Crucial for the analysis and understanding of political acceptability are power issues: the power over the design of the charging scheme, the power over the revenues, and how the charges and their revenue stream will affect decisions and funding of transport investments in general. The fact that congestion charges are now politically accepted in Sweden is not only, or perhaps not even primarily, due to the higher public support. It is also because the charges have been integrated in the general transport investment planning process, and this has – at least partly – solved the power and negotiation issues above.

To understand the political and institutional drivers behind this development, one must start with the legal context. Swedish congestion charges are not “charges” but national “taxes” from a legal point of view. Existing infrastructure cannot be “charged”, only “taxed”, according to the constitution’s definition of a charge, and Swedish municipalities[12] cannot levy taxes on other than their own citizens. Hence, although it was the city of Stockholm that was responsible for designing the charging system and carrying out the congestion charging trial, the responsibility for actually levying and administering the charges had to be assumed by the national government through a parliamentary decision[13]. More important, this meant that it is the national government that has the formal power over both scheme design and revenues. Although the Government promised to refund the revenues to the Stockholm region, disagreements quickly emerged regarding how revenues should be calculated, how revenues should be used and which vehicles should be exempt. Further disagreements, such as whether and how charge levels should change along with inflation and economic growth, can be expected. Many politicians have stated that their main argument against introducing the congestion charge was the uncertainty about the political power over scheme design and revenues.

Adding to these uncertainties was the uncertainty about how the existence of the new revenue stream would affect the complicated negotiation between national and regional levels about national infrastructure grants. Most of the major transport investments in Sweden are paid for by the national government, whereas municipalities and regions are responsible for local streets and transit operation. As expected, there is often disagreement on where the border between different responsibilities should lie. The politicians in Stockholm, regardless of political colour, had long argued that they were not receiving their fair share of national infrastructure grants. Whether this claim was founded or not, it meant that the arrival of a new revenue stream in the form of congestion charges was not necessarily welcomed. Several politicians feared this would mean that Stockholm would have to pay an even larger share of transport investments with their own money. The

[12] A ”municipality” (”kommun” in Swedish) is the smallest geographical administrative unit in Sweden, roughly corresponding to a city. Most of the spatial planning responsibility, including infrastructure planning, lies at the municipal level.
[13] This task was given to the National Road Administration, and later moved to the National Transport Agency.

government, they argued, would point to the revenues from the congestion charges and claim that Stockholm obviously needed even less national infrastructure grants than before.

The solution to this dilemma was an agreement where the charge revenues were funding parts of a major transport investment package, where the national government also made a major funding commitment – much larger than had been the case for a long time. The charge revenues were earmarked for the road investments in the agreement, while the substantial rail investments were claimed to be paid for with money from other sources. With this, support for the charges had been secured from regional politicians of all parties.

From a political perspective, it is often a decisive question who has the power over revenues and charge levels. If it is the national level, then regions and cities will obviously be much more reluctant to introduce charges. But even if the region keeps the revenues, another issue is important: how the existence of this new revenue stream affects the complicated negotiation between national and regional levels about national infrastructure grants. In Norway, this problem is handled by a decision that the state "matches" income from regional charges with equal national funding. A recent trend in Sweden is that national funding is often leveraged with regional funding, sometimes from congestion pricing or toll schemes. This has made congestion charges more popular among politicians, which shows the importance of institutional context and incentives.

Giving regions the incentive and opportunity to introduce road user charges to obtain transport investments, where regional funds are leveraged by national funds, may fundamentally change the transport investment planning process. There are several advantages: regions are given an incentive to prioritize between transport investments and other responsibilities, as they are forced to "put their money where their mouth is". When there is congestion, regions are more likely to introduce congestion charges, which is obviously a potent and efficient policy measure. On the other hand, there are several disadvantages: since regional funding is leveraged, regions will be tempted to overinvest in transport infrastructure relative to other types of (non-leveraged) spending.

5 THE SYSTEM DESIGN PROCESS

5.1 Designing the charges

The goal of the system, as formulated by the politicians, was to "reduce congestion on the most congested roads and improve speed through the bottlenecks". This goal was then quantified, somewhat illogically, as a decrease in traffic volumes: the number of vehicles crossing the cordon should be reduced by 10-15%, a number loosely based on previous proposals for congestion charging systems.

Based on transport model simulations made before the trial a 10-15 percent reduction of the number of vehicles crossing the cordon was expected during charging hours. In fact, the traffic forecasts predicted a larger and, as it turned out, more correct predicted magnitude (Eliasson et al. 2003a, 2003b, 2004) – but such a large decrease seemed unreasonable at the time, even to the modellers themselves. No forecasts were made of the effects on accessibility, as the static network equilibrium models available for forecasting were considered as not being reliable for such purposes.

During the process of designing the charges using traffic models, it quickly became apparent that a target was needed that was directly related to travel speeds. The traffic volume reduction target, although easy to communicate and measure, simply revealed too little information about the effect on travel speeds. An obvious candidate for such an alternative target was to try to maximise social surplus. However, this was problematic because the travel times of the static network equilibrium model (which was the only available traffic model) were judged to be too unreliable at high congestion levels. Instead, the most important target used during the design process was the congestion levels at major bottlenecks.

Several variants of the charging scheme were tested, of which the most important variations were higher or lower charge levels and charges on the some of the bridges inside the cordon. There is a potential conflict between making congestion charging "efficient" in the theoretical sense, and making it easily understood

(Bonsall, Shires, Maule, Matthews, & Beale, 2007). In the design of the Stockholm system, ease of understanding was a major consideration. This explains the symmetries of the design: one single charging cordon with the same charge at all points of entry, the same charge in both directions, and the same for both the morning and afternoon/evening peak periods. The system could most likely have been made more efficient if these symmetries had been abandoned – but at the time, ease of understanding was judged to be more important than improving efficiency, and it is possible that this might have contributed both to acceptability and effectiveness.

A lesson from trying out different designs in the forecasting models was that it was easy to design a charging system that created more problems than it solved, by "moving around" congestion. Hence, spending a lot of effort on the design of the charging system is imperative for any city wanting to introduce congestion charges.

The Stockholm Trial provides interesting insights into what a road-toll system should look like – something which is also useful for other cities. Transport planners and economists have long discussed to what extent a charge-zone toll of the kind used in Stockholm is sufficient for controlling traffic in an entire city. Traffic relations change from street to street and from minute to minute. When the charge zone is as large as it is in Stockholm, there was concern that even if it had a big effect on travel over the charge cordon, streets inside the zone would soon be full of motorists already in the zone increasing travel as they realized the streets were less congested. Alternative solutions were discussed for several years prior to the Stockholm Trial, involving several sub-zones with varying rates of the congestion tax. None of the existing road-toll systems threw much light on this question. In London, it is a question of a small area in the city centre, in Singapore access to cars is also regulated and in Oslo and Bergen the system is designed to affect traffic as little as possible. The Stockholm Trial confirms that a simple charge-zone toll creates significant effects within a large area.

5.2 Can transport models be trusted?

Eliasson et al. (2013) provide a detailed comparison between forecast and outcome, concluding that the main predictions about behavioural responses were sufficiently accurate to draw correct conclusions. For example, traffic across the cordon was predicted to decrease 17% during peak hours and 16% during the entire charged period (6:30-18:30); the actual figures were 19% and 20%. The transport model predicted that around half of the disappearing trips would switch to public transport, which would lead to a 6% increase in passenger volumes; in reality, around half of the drivers did in fact switch to public transport, leading to an increase of passenger volumes of 4-5%.

In fact, the model seems to be much better at predicting changes in behaviour than the travellers themselves, both *ex ante* and *ex post*. Surveys in the fall of 2004, the fall of 2005 and the spring of 2006 asked respondents about changes in their travel patterns in response to the charges. Respondents gave reasonably consistent answers in the three surveys. The answers can be transformed to an equivalent aggregate traffic reduction, yielding an equivalent aggregate traffic reduction of 5-10%. This can be compared to an observed reduction of private trips[14] around 30%. In other words, around 3/4 of the reduction in car trips across the cordon seems to have gone unnoticed by the travellers themselves.

The one major shortcoming of the model system was the prediction of travel times. Some travel times were predicted fairly accurately, but some effects were wide of the mark. This was the case especially for links subject to spillback congestion (queues propagating back from a bottleneck, blocking other junctions and links). For links crossing the cordon, model-predicted travel time reductions were close to observations. For links within the cordon, model predictions were less accurate: delay reductions were underpredicted by 34 per cent, since the network does not model congestion at junctions, traffic lights etc. For links outside the cordon, predictions were completely off, since a static model does not capture spillback congestion. Hence, it was impossible for the network model to foresee that congestion outside the cordon will decrease when the queues propagating upstream from bottlenecks located at the cordon are reduced. This was a known issue during the design of the charging system. Rather than using travel time-based evaluation measures (such as consumer

[14] Total traffic reduction is less because professional traffic decreased much less than private traffic.

surplus or congestion indices), design targets were formulated in terms of volume/capacity ratios in the most important bottlenecks.

The results indicate that best-practice transport models seem to be reliable enough to be used as decision support and design tools even for substantial changes of the transport system – provided that the analysts are aware of inherent limitations of the model and interpret results accordingly. It should be stressed that the predicted effects of the charges were so large that several experts considered the forecasts unrealistic. As it turned out, however, the model gave much more accurate predictions than experts' judgments, in addition to providing more detail and consistency. The scepticism towards the predictions was understandable: the introduction of the congestion charges affected the whole Stockholm transport system in a completely unprecedented way. Traffic across the cordon decreased over 20%, meaning that traffic was down to levels not seen the 1970's, reducing queuing times by 30-50%. On some links and routes, the effects were even larger. Despite this, circumferential traffic did not increase, and public transport ridership increased by just a few per cent.

One way to judge whether the transport model was "good enough" is to consider whether the system had been designed differently, different preparatory measures had been undertaken, or the scheme been abolished altogether if the forecast had been perfect in all respects. Generally speaking, the answer is a qualified "no". The qualification is that the model's deficiencies, in particular the lack of dynamic congestion representation and departure time modelling, may have had become more of a problem if the system design had been more complex, with more charging points and more fine-tuned time/place differentiation. But given that the system design was constrained to be relatively simple, the model was good enough to answer the most important design questions: what traffic reduction was needed to reduce queues significantly, what charge levels were needed to accomplish this reduction, and what the secondary consequences in terms of possible traffic rerouting and transit crowding would be. One of the authors headed the design process, and can confirm the wide-spread observation that the effects of a significant change in a complex transport system are usually too complex and multi-dimensional to foresee without the help of a model. The most important advantage of using a transport model may not be that it gives exact answers, but that it gives *coherent* answers. During the design process, the model repeatedly gave results that were surprising at first, but were self-evident and easy to explain intuitively after some thinking. The point is that these "intuitive" explanations and conclusions had not been realized before the model results had been produced. In this sense, the model turned out to be an indispensable tool for system design and evaluation, and several design suggestions were discarded after model results had shown that they would not work satisfactorily.

5.3 General advice on designing congestion charges

The goals have to be explicit and relevant

First, the system needs a goal. The goal may be to reduce congestion reduction, improve air quality, yield revenues, or a combination of such goals. Whatever the goals are, they need to be explicit. Moreover, they should be quantified, at least to some extent. This quantification usually has to be done in cooperation between policymakers and traffic experts: setting up relevant goals and targets is harder than most policymakers realise. Goals must above all be relevant and consistent. Specifically, one should at this stage *not* specifically strive to make them easy to communicate to the public. Communication is important, but comes later. The goals set at this stage are the ones that will be used during the design process, and they need to be consistent and relevant, not necessarily easy to explain or sound good. An example of a consistent and relevant goal that happens to be rather difficult to communicate is "achieve maximal social benefit from congestion reduction" (perhaps given some restriction on charge levels). A common example of a goal popular among policymakers and communicators is "getting more people to choose public transit". This is *not* a relevant goal for congestion charges, which should be obvious. (The relevant goal is to make less people choose car during congested hours. If they instead choose transit, that's fine; if they prefer to adapt by cancelling trips or changing departure times or destinations, then this is just as fine.) Choosing ill-formulated goals and targets will very likely cause problems during the design process, at the very least causing confused discussions.

Designing the charges is a job for experts.

Designing a charging system is, as a rule, a very difficult task – how difficult depends on the topology of the city. (For example, Stockholm is reasonably easy, with the worst congestion problems located along a natural cordon, while Gothenburg is difficult, with congestion problems spreading out from a complicated multiple-arterial junction.) It is absolutely necessary to have sufficient time, and access to a reasonably good transport model. If one has access to design optimisation tools, this can come in very handy. Even given this, it will be difficult. In particular, intuition and prior knowledge will in general not be sufficient, even for experienced traffic planners: transport systems are simply too complex. There will almost certainly be surprises, and the first attempt at a charging system design will most likely not be optimal or even good – it may even make congestion *worse* overall by "moving congestion around". The system design is an iterative process, where involvement of politicians does not help. This is why it is so important that goals are stated clearly at the outset. Design and goal-formulating is, ideally, an iterative process as well: it is likely that some goals or (more likely) some design restrictions were forgotten at the outset. But this does not change the basic premise that while formulating goals and restrictions is a job for policymakers, designing the details of the system – locations and levels of the charges – is a job for experts. An ill-designed system may not only be suboptimal – it may likely cause *more* problems than before.

You need a good transport model.

Most transport models are constructed for other purposes than modelling the impact of congestion charging. Certain shortcomings of most current models become especially important in the context of congestion charges, and one needs to be aware of them. First, the value of time differs between vehicles, but this is often neglected in the assignment step. Technically, one must use multi-class assignment, i.e. divide traffic into several "classes", each with a value of time of their own. The value of time of each class will decide whether it is worth taking a detour to avoid a charge. Depending on the network topology, the value of time distribution over classes may affect results strongly. Often, there is little evidence on the value of time distribution, so sensitivity analyses will play an important role. Second, departure time choices and scheduling considerations are often sketchily implemented, if at all. Obviously, this will underestimate the impact of a time-differentiated charging system, since the opportunity to adapt by changing departure time is not reflected in the model. Less obvious, one may underestimate traffic decreases during non-charged hours – since those trips is partly made up of "return trips", i.e. the second leg of a trip whose first leg was during the charged time period. Third, static assignment models will in general underestimate travel times in the presence of severe congestion. They will, among other things, by definition neglect the effect of spillback congestion. This means that during the design process, it may be better to focus on traffic decreases in known bottlenecks, rather than to focus on actual travel times from a static traffic model (although travel times need to be used as well).

Try to get political and legal possibilities to adjust the system once it is in place.

Even with careful planning, surprises are likely to appear when the system starts. In the best case, surprises are positive (in Stockholm, travel time improvements were larger than anticipated, for example). But there may be negative surprises as well: unexpected "rat-running", for example. Because of this, it is good if one can get political and legal leeway to make minor adjustments to the system with a minimum of delay and hassle. Politically, this will be easier if goals are clearly formulated: if so, then it will be easier to see if they are met or not, and if not, the system can be changed. The legal problem may be harder to solve. In Sweden, for example, the charges (which are formally a state tax) have to be decided by parliamentary decisions, which requires a lot of time and political effort.

There is a conflict between "effective" and "easily communicated" design, but erring towards too simple seems more common.

Policymakers often stress that they want a design that is "simple to understand". While it is an important consideration that the system must be sufficiently simple for the presumptive users to understand, policymakers often seem to underestimate people's cognitive ability. The Singapore system and the US "value pricing" roads, for example, appear complex at first glance. The charge is finely differentiated by time and location, and on top of that may change several times each year. Despite its apparent complexity, it turns out that users are able to grasp and adapt to the system. Forcing the system to be too simple too early in the design process is likely to cause design restrictions that are difficult to solve. The reluctance of many politicians and planners to consider "too complicated systems" can lead to the point where the system becomes so simplified that it will not deliver the promised congestion reduction. This will not only be a waste of resources – it will also lead to low acceptability of the charges.

5.4 Information and technical design

In Stockholm, vehicles are registered automatically by cameras that photograph the number plates. During the trial, the main means of identification was transponders (“tag-and-beacons” or DSRC, dedicated short-range communication). When the charges were reintroduced, the automatic camera identification worked so well that it was decided to abolish the transponders. From the beginning, each daily charge was handled as one payment (one invoice per day), since it was believed that this was important to emphasize that each passage did in fact cause a payment. After some time, however, payments were aggregated to monthly invoices, without any consequences for traffic volumes. Obviously, this has reduced both operations costs and the hassle for users. In particular, the initial design with a very large number of invoices and very short time allowed for payment (initially five days) caused major problems for businesses.

Camera identification is used in London as well, although automatic identification rates are reported to be considerably lower in London. The main difference is that in London, it is the responsibility of the driver to pay the correct sum, and the system merely *checks* that vehicles passing through the charging zone have paid. In Stockholm, the system *automatically* issues the charge once it has registered a vehicle; if the vehicle is not identified, there is no need (or even possibility) to pay. The key argument in favour of “issuing/registration” rather than simply “checking” was that this made it easier to apply different charges according to the time of day.

The technical system was procured by the National Road Administration in a complicated tendering process eventually won by a consortium led by IBM. Information to the public was handled by the Road Administration. The system turned out to work very well from the start, both from a purely technical point of view and from an informational point of view; people knew what to do, how to pay, etc. Payment compliance was high, and the number of complaints was much lower than expected. On an average day in May 2006, 371,300 journeys took place over the charge cordon. 19 percent of passages were made with exempted vehicles (buses, taxis etc.), and an additional 9 percent were exempted due to the “Lidingö exception”. 267 500 passages were hence charged, resulting in 115 100 tax decisions (one tax decision was made per day and vehicle) and yielding toll revenues of SEK 3.2 million. Of the 115,100 daily tax decisions, only 100 were investigated by the Swedish Tax Agency and five were appealed. The Swedish Road Administration customer-service unit received on an average day in May 2,200 calls, in contrast to an expected number of 30,000 calls. Based on this, our assessment is that the system and the information generally worked well from a user’s perspective.

5.5 General advice on the technical system

Get the legal conditions clear early

Early in the technical design process, one must know the legal conditions. For example, what is an acceptable proof that a vehicle has passed a gantry? What possibilities to appeal must exist? The answers to such questions will have important repercussions on the technical design, for example whether transponders can be the sole means of identification or not.

In Stockholm, a problem occurred that hopefully should be rare: midway in the procurement process, the legal status of the congestion charge changed from a “municipal environmental charge” to a state tax (a legal investigation concluded that it was illegal for a city to charge moving vehicles on existing roads). This had many effects, including that the responsibility of the procurement had to be changed from the City of Stockholm to the national government. This increased the cost for establishing the system considerably.

Choose cost-efficient service level targets.

Consider what the cost-efficient targets of service levels are, given what the goals of the system are and how different service levels affect the intended function of the system. Going from, say, 95% to 99% or from 99% to 99.9% on any given service level may be a significant cost driver. In Stockholm, the “uptime” of the system (measured as the share of “lane-minutes” the system was actually registering passages) was required to exceed

99.9%. To meet this high requirement, the prime contractor designed a system where (almost) every component was duplicated, spare parts were obtained in large quantities, trained staff was made available to do on-site service with short notice, and technical IT support was initially on standby 24/7. Obviously, this increased investment and operations costs. Moreover, it should be obvious that lowering the uptime requirement to, say, 95%, would not affect the traffic-reducing effect of the charges. After all, the travellers are making their travel decisions based on the fact that they are highly likely to have to pay if they go by car across the charging cordon. From this perspective, uptime requirements could have been relaxed substantially without losing any of the ultimate effect on the traffic situation. This illustrates the principle of having cost-efficiency in mind when formulating technical system requirements.

Choose cost-efficient payment channels

Each payment transaction comes at a cost, both in terms of convenience for the user and as a fee from the financial service provider. Hence, allowing for aggregated monthly payments rather than paying each passage individually will reduce operating costs. Cash over counter (in shops, for example) might be necessary for user acceptance, but it is probably the most expensive form of payment.

Handling transponders is expensive

Transponder (or “tag-and-beacon”) technology is efficient in many ways, not least because it allows complex charging structures and makes it easy for the driver. The production of many transponders may be a significant cost driver, though, but less well known is that it is often a major cost to *administrate* transponders. New cars need new transponders, cars change owners, and transponders are lost, stolen, and broken. In Norway, where over 40 different road toll schemes are in operation, transponders are used in some, while others are managed by manned tollbooths. And even there, where the comparison technology is highly manual, there is a slight productivity advantage for those *not* using transponders (Odeck, 2008). With today’s technology, cameras and automatic number plate recognition (ANPR) can potentially reach a very high identification ratio, which offer ample competition for any transponder-based solution. The Stockholm system started out as a transponder-based system, with ANPR as an add-on for legal reasons, but has relied on ANPR exclusively since a few years.

When doing a functional procurement, make sure to align cost and risk responsibilities

In Stockholm, the congestion charging call centre was initially vastly oversized, which was a major cost driver initially. Part of the reason for this was that if the call centre would not meet its service quality targets (e.g. maximal answering times), then the prime contractor would be financially penalized, while it was buyer that carried the cost of call centre staff. Hence, risk and cost were borne by different parties[15], and the contractor had no incentive to increase its own risk by cutting down on resources. If procuring a system as a function, one should make sure that the party carrying the risk is also the one taking the cost for risk mitigation, in all areas of the operation.

High political risks will weaken the public negotiation position, and will increase costs by having the contractor require a risk premium

In Stockholm, the stakes were high for almost all actors involved. Individual careers as well as the prosperity of private firms and political coalitions was at risk, or at least perceived as being so. This dominated the context in which the project was carried out, and it was under the influence of this risk environment that decisions were made. There were many unknown factors that were thought to kill the project on their own. Above all, if the system did not work, or was perceived not to work, right from the start, it would almost certainly be abolished immediately. This is at least a partial explanation of cost drivers such as the oversized call centre, the excessive service level requirements etc. It all goes back to the intense political pressure and high political stakes: the outcome of the next election would depend on the outcome of the trial, perhaps not only in the city but also on the national level. This meant that the public negotiation position was weak – the system *had* to work, and it *had* to be finished on time. Obviously, such a situation creates opportunities for a contractor to charge more money. For the contractors, a failure – even if it was not due to mistakes of their own – could be potentially disastrous for future business. This means that contractors will require a risk premium to even engage in the work of constructing the system. Hence, the lesson is that a stable political environment and ample time to plan and implement the system will keep costs down. Conversely, the

[15] To be fair, it should be pointed out that this misalignment of costs and risks was an exception in the Stockholm procurement.

extremely tense and uncertain political situation in Stockholm at the time, and the legal uncertainties that required a large number of changes and redesigns during the development process, all contributed to a substantially higher investment cost than would otherwise have been necessary. The main contractor argues that a similar system could now be built for half the cost or less.

6 COST-BENEFIT ANALYSIS

Even if it is well established that congestion pricing will yield a social surplus, it is not evident either that it will be enough to cover investment and operational costs, or that a *real* congestion pricing system, with all its practical and political limitations, will be socially profitable.

6.1 Technology costs

The total cost for the charging system was approximately SEK 1.9 billion, including operations costs during the first year of operation. 1.05 billion was incurred prior to the start of operations. A significant part of this startup cost was costs for extensive testing. The system would only be operational for 7 months, making it absolutely necessary that everything worked right from the start. The startup cost also included, in addition to purely technical investments, system development in a wide sense, educating and training staff, testing, public information, etc., and certain other additional minor costs, such as those for traffic signals, and the services of the Swedish Enforcement Agency and the Swedish Tax Agency.

The rest of the costs (850 million SEK) were running costs and additional development costs during 2006. Far from all costs incurred during 2006 were pure running costs: the system was improved in several ways during the spring of 2006. Also included are the Swedish Road Administration's costs for closing down the system and evaluating the results during the second half of 2006. The investment and startup costs were considerably increased by the uncertain and heated political situation (as discussed above). The main contractor argues that a similar system could now be built for half the cost or less.

Actual running costs decreased significantly by each month of 2006, when it quickly became obvious that things in fact went better than planned: the number of complaints and legal actions were for example considerably lower than what had been anticipated, reducing costs for legal and tax administration. Further, the number of calls to the call center (the single biggest item in running costs) turned out to be around 1/20 than what had been anticipated – around 1500 calls per day instead of 30 000 per day. This meant that the call center was very much oversized, and during the spring, it was downsized – a considerable reduction of running costs. This means that investments costs could probably have been reduced quite substantially if the conditions (and not least the time constraints) had been different. This point may be especially important to note for other cities considering similar schemes. In 2006, the National Road Administration estimated future running costs to around 220 million SEK per year (around 25 million Euros). Since then, the responsibility for the system has been moved to the National Transport Agency system has been developed in various ways, in particular to incorporate the congestion charging system in Gothenburg which started in January 2013, and running costs have decreased further. At the time of writing (February 2014), the Transport Agency estimates yearly running costs to around 250 MSEK for *both* systems. The cost-benefit analysis presented here, however, uses the old estimate for running costs.

Yearly revenues for the first years of operation were a little more than 800 MSEK. Since a few exemptions have been abolished, revenues have increased somewhat to around 850 MSEK in 2013. Compared to the forecast before the start, revenues turned out to be around 14% less than predicted. 5% of this was due to the traffic reduction being larger than predicted. The major part of the revenue shortfall, though, was due to an underestimation of how many vehicles that would be exempted. This was purely due to a lack of data on the traffic composition, which should have been avoidable. Instead, neglecting to conduct reasonably simple traffic surveys beforehand meant that the exemptions became more costly than expected, and also created problems for the predicted cash flows.

6.2 Benefits

Most of the benefits are accessibility benefits, i.e. travel time savings and reduced travel time variability. From an economic point of view, it should be noted that it is these benefits that are translated into economic productivity and growth. For example, travel time savings are partly converted into more working hours (increasing economic production) and partly to better matching on the labour market. These effects fall partly outside standard cost-benefit analysis, since they usually do not account for tax wedges and agglomeration effects (Anderstig, Berglund, Eliasson, Andersson, & Pyddoke, 2012).

Secondary benefits include reduced emissions and accidents. In addition, the revenue itself may generate benefits if they are used to reduce distortionary taxes or investments with positive benefit-cost ratios.

The CBA in Table 2 (Eliasson, 2009) shows that the Stockholm system yields a large social surplus[16], well enough to cover both investment and operational costs. The annual social surplus is around 650 MSEK (after deducting operating costs). All major effects are primarily based on measurements, the most important sources being travel time and travel flow measurements.

		Loss/gain
Consumer surplus		
	Shorter travel times	536
	More reliable travel times	78
	Loss for evicted car drivers, gain for new car drivers	-74
	Paid congestion charges	-804
	Increased transit crowding	-15
	Consumer surplus, total	***-279***
Externalities		
	Reduced greenhouse gas emissions	64
	Health and environmental effects	22
	Increased traffic safety	125
	Externalities, total	***211***
Government costs and revenues		
	Paid congestion charges	804
	Increased public transit revenues	138
	Decreased revenues from fuel taxes	-53
	Increased public transport capacity	-64
	Operational costs for charging system (incl. reinvestment and maintenance)	-220
	Government costs and revenues, total	***606***
Tax effects etc.		
	Marginal cost of public funds	182
	Correction for indirect taxes	-65
Net social benefit, excl. investment costs		***654***

Table 2. Costs and benefits of the charges, MSEK per year.

[16] The value of travel time was assumed to be 122 SEK/h per vehicle (65 SEK/h per person for private trips, 1.26 persons per private car and 190 SEK/h per person for business trips and distribution traffic). The value of reliability was assumed to be 98 SEK per hour of standard deviation (i.e. 80% of the value of travel time). CO_2 emissions were valued at 1.50 SEK/kg. The Swedish value of a statistical life is 17.5 MSEK, the value of a severe injury 3.1 MSEK and a light injury 0.18 MSEK. The standard Swedish estimates of marginal cost of public funds and correction for indirect taxes are 1.3 and 1.23 respectively. The CBA is described in detail in Eliasson (2006, 2008).

The total start-up cost of the system was 1 900 MSEK, including information campaigns, extensive system tests and so on. Together with marginal cost of public funds and correction for indirect taxes, this gives a total social start-up cost of 2 900 MSEK. Hence, the start-up cost is “recouped” in terms of social benefits in about 4 years. The estimated yearly operational cost of the system (220 MSEK) includes not only running costs but also necessary reinvestments and maintenance such as replacement of cameras and other hardware.

Consumer surplus is negative, as expected, but the value of the time gains is high compared to the paid charges – time gains amount to almost 70% of the paid charges, which is very high compared to most theoretical or model-based studies. This is mainly due to ”network effects”, i.e. significant amounts of traffic that do not cross the cordon and hence do not pay any charge but still gain from the congestion reduction.

7 EQUITY EFFECTS

One of the major criticisms of congestion pricing is that it is regressive, since those with the least income have the hardest time affording to pay the toll. At the same time, there is a strong counter-argument to be made that congestion pricing can be regressive if the drivers are, by and large, those with the highest incomes, and those with lower incomes take transit. An advantage of the approach here is that we can examine the average effect either on income categories as a whole, or on income categories among drivers, transit riders, or even those who switch. There are a number of studies on the equity effects of the Stockholm charges (Eliasson & Levander,, 2006; Eliasson & Mattsson, 2006; Franklin et al., 2010; Karlström & Franklin, 2009), yielding similar conclusions. The analysis and results presented here is taken from Franklin et al. (2010).

The average effects for income and toll effect sub-groups are shown in Table 3. Asterisks mark the income categories whose effects are significantly different from the pooled income categories. The most notable result here is actually the absence of significant differences. The only significant trend here is among the un-tolled, where the income categories are significantly different from the pooled income categories. There is also a trend of increasing benefit with income, but an important note here is that all five income categories did indeed see an average benefit. In other words, for the only subgroup where income played a significant role, everyone was better off anyway.

Table 3. Average Welfare Effects by Refund Scenario

	Average Welfare Change, SEK/year/person		
	No	Refund Scenario	
Group	**Refunds**	**Lump Sum**	**Tax Reduction**
All	–78	+180	+173
	By Income Category:		
< 25 000	–50*	+244*	+124
25-40 000	–138	+110	+45
40-55 000	–39	+224	+192
55-70 000	–12	+234	+273
> 70 000	–152	+84	+322

Note: * = significantly different (>95%) from the average welfare change for pooled groups.

Also, although there are not significant differences between income levels, there are some differences in the average numbers, but these do not follow a clear trend from low to high incomes. The reason for this is likely that other factors, such as distance travelled and amount of toll paid (based on time of day), and number of times crossing the toll cordon, varied more widely *within* each income categories than *between* them. It appears that individual circumstances have a greater effect on welfare than income level.

The use of revenues can be extremely important to the equity effects of a toll system, as evidenced by prior studies (Eliasson & Mattsson, 2006). Therefore, while we cannot be definitive about the redistributive effects of toll revenue disbursements, we can at least identify some bounds, by testing two theoretical scenarios for refunding toll revenues. The first is deliberately progressive, a lump sum refund to all in our study population; the second, deliberately regressive, with an across-the-board reduction in the income tax rate.

Adding the effects of each of these refund schemes to the total welfare effects found above, we arrive at the average welfare effects shown in Table 3. Importantly, all of the effects are now positive, and this holds true for both a lump sum and a tax reduction. Thus, we see an affirmation of one of the core arguments for congestion pricing: that by reducing externalities, we can see a net positive effect. Moreover, the empirical evidence supports a theoretical result from Small (1983) suggesting that all income levels could see a benefit on average, as long as revenues were appropriately returned.

In comparing the two refund scenarios, we see the expected result that the lump sum scenario is progressive, with the lowest income categories receiving the greatest benefit, while the tax reduction scenario is regressive, with the highest income categories gaining the most. Certainly, the refunds themselves for the two scenarios should be progressive and regressive, respectively, but what this tells us is that these original tendencies are not overwhelmed by the pattern of costs due to the congestion charging system itself, as represented by the "No Refund" scenario. Treating the two refund scenarios as bounds, the conclusion we can reach is that a wide range of uses for the toll revenues could maintain a positive average effect for all income categories, even if some uses would be more progressive than others.

7.1 Equity, fairness and winners/losers

The equity analysis above concentrates on a short-run winner/loser perspective, just as most equity analyses do. This perspective lacks two considerations, however: the relationship between objective equity and the perception of fairness, and the relationship between objective (monetary) effects and support for the charges, which is not a simple linear relationship.

First, a problem with the “winners/losers” perspective concerns the way this translates to the question of “fairness”. Often, if a system affects high-income groups more than low-income groups, it is claimed to be a “fair” system. Hence, “fairness” considerations – which are known to affect acceptability – are interpreted as a question of identifying “winners and losers”. In Stockholm, the equity effects were generally speaking progressive: high-income groups paid more than low-income groups, men paid more than women, employed more than unemployed etc. But once the charges are in place, and the short-term winner/loser perspective fades, another perspective becomes more important: what price is actually “fair” to charge for a car trip? From this perspective, it is “fair” that one pays more to drive on a congested road or to cause emissions in densely populated areas – irrespective of income or place of residence, or what a hypothetical travel pattern would have been without the charges. This means that a system needs to be perceived as “fair” in this sense: it needs to be consistent with its stated objective. In Stockholm, one of the most common objections to the system nowadays is that traffic within the cordon is not charged. Although there are two good answers to this (the congestion is mainly located on the arterials along the cordon; most of the traffic inside the cordon crosses the cordon at some point on the trip), this shows how the debate has moved from “who wins/loses” to “what’s fair relative to the objectives”.

Second, according to standard transport-economic theory underlying classical equity analysis, most motorists would not think that the time saved was worth the charges they had to pay. Theoretically, the income from the charges is sufficient to compensate the losers, so the standard recommendation in the acceptance literature is that congestion charges must be part of a “package”, within which it is clear how the income is going to be spent for the advantage of the general public, if it is going to have any chance of being accepted. But the standard theory neglects three important considerations. First: network effects. Since queues propagate “upstream”, even those not going through the actual bottleneck will suffer from queues. Pricing traffic in the bottleneck to reduce queues, *all* upstream traffic will benefit – not only drivers actually paying the charge. Second: the effect on the urban environment. Typically, standard analysis of congestion charges takes no account of effects for pedestrians or cyclists, or the effect on the perceived urban environment. Third: the self-selection effect on trips and on the value of time. Congestion charges will tend to “sort” trips such that trips with high value will stay on the road (and enjoy time benefits), while low-valued ones will be priced off. Not taking this phenomenon into account will underestimate the value of the time benefits. From an acceptance perspective, the important point is that individuals can belong to different valuation "groups" on different days, or different journeys.

Another potentially important observation is that car drivers apparently changed behaviour without even noticing it. When motorists were asked if the congestion charging had made them change their travelling habits, there were too few answering "yes" to correspond with the actual reduction in measured traffic volumes.

One important reason is that travel patterns are much more variable than most people are aware of. It is simply *not* the same drivers paying the charge each day. On the contrary: a large majority of the drivers are "occasional" drivers, who pay the charge a one or a few times a week or even more seldom. Figure 11 shows the distribution of passage frequency groups during a two week period.

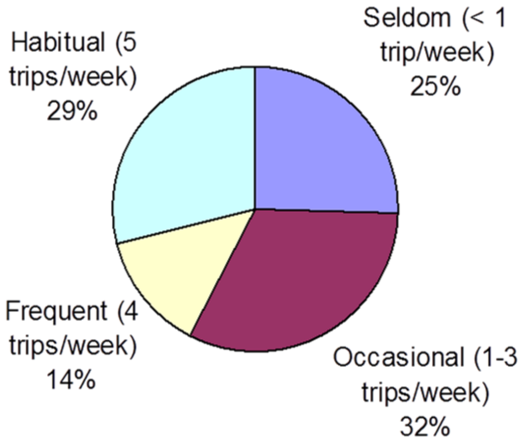


Figure 11. Drivers passing the cordon a given day, grouped by how often the pass cordon during a two-week period.

This means that most car owners are affected somewhat, but very few are affected a lot. Figure 12 illustrates this. Any given day, around 5% of private trips in the county are affected by the charges. Over two weeks[17], however, 43% of private cars in the county will pay at least once. However, over this two week period, only around 2% of car owners will pay an amount equivalent to the average return fare each day (270 SEK for 2 weeks), and only about 0.4% will pay an amount equivalent to rush-hour return fare each day (400 SEK per 2 weeks).

[17] Due to integrity legislation, statistics can only be aggregated over individuals over two-week periods, not longer.

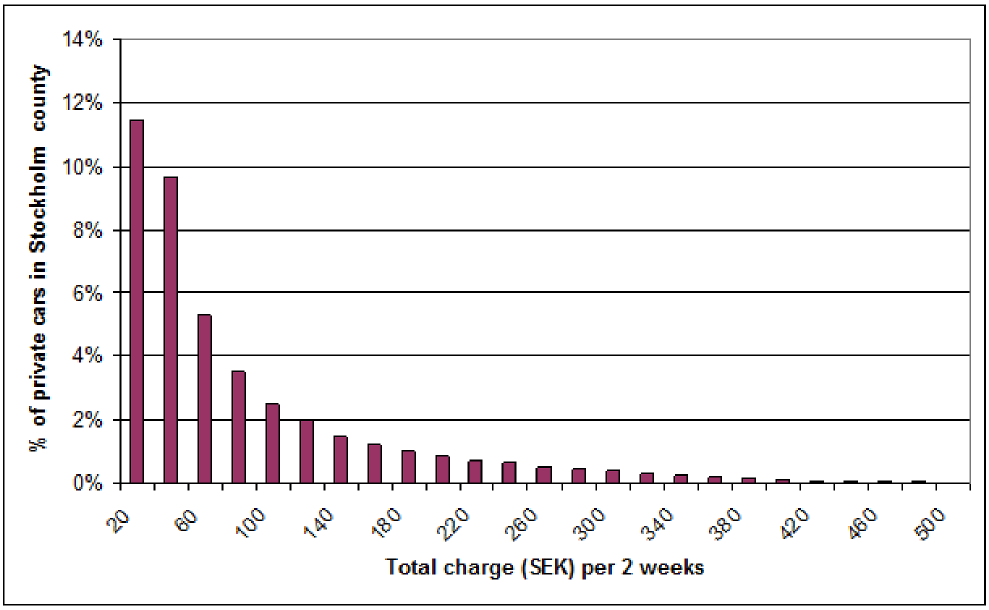


Figure 12. Share of private cars who pay various total charge amounts during a two-week period.

8 ARE THE RESULTS TRANSFERABLE?

In many respects, each city is unique. Introducing a charging scheme similar to the Stockholm system is by no means a guarantee for achieving the same congestion reductions as in Stockholm. But in a more fundamental way, it can be argued that the experiences are indeed transferable to other cities, in the sense that the charges actually affected car drivers in the way that had been predicted by transport models. During the design process, three independent transport models yielded very similar results regarding the anticipated effect of the charges. This was despite the fact the three models were estimated and calibrated on different data sets and used different methodologies (although all of them were nested logit models linked to a static equilibrium model). Despite this, the forecasts were deemed to be unrealistic – the charges could not possibly affect traffic that much, it was believed. The lesson here is twofold: a good transport model is an invaluable tool for designing an efficient charging scheme, and the result is likely to be correct (after accounting for known model limitations such as underestimating travel times in severe congestion and many models' inability to account for changes in departure times). The "transferable lesson" is hence that a well-designed charging scheme that seems to work in a traffic model is actually also likely to work in reality. A very common reaction from other cities is that "charges may have worked in Stockholm and London, but the particular situation in our city means that charges won't work here, despite our transport model saying otherwise". The same claim used to be common in Stockholm, in fact. The Stockholm experience is that transport models can actually be trusted.

The success of the Stockholm charges in reducing congestion and achieving public and political support has attracted great interest from cities around the world. A natural question is whether the positive results are transferable – if congestion charges would work just as well in other cities. Judging from the authors' experience as advisors to cities around the world, a common reaction is "it would not work in our city". Of course, all cities have their particular characteristics and local conditions, so a copy of the Stockholm system would not give exactly the same effect in another city.

But in a more fundamental way, it can be argued that the experiences are indeed transferable to other cities, in the sense that the charges actually affected car drivers in the way that had been predicted by transport models. The conclusion that a transport model was able to predict demand responses with good-enough accuracy leads to a more qualified answer to the question of transferability: if a congestion charging system is predicted to "work" in a given city – that is, reduce peak traffic in bottlenecks without unacceptably adverse side-effects or having to use unacceptably high charge levels – then that is likely to be true in reality as well, not just in the model. It should be noted, however, that the beneficial effects on congestion and travel times are likely to be underestimated by static network models. During the Stockholm design process, three independent transport models yielded very similar results regarding the anticipated effect of the charges. Despite this, the forecasts were deemed to be unrealistic – the charges could not possibly affect traffic that much, it was believed.

A related question is whether the effectiveness of congestion charges are highly dependent on the specific features of the land use and transport system, implying that the good experiences of the congestion charging systems implemented in Stockholm or London would not be transferable to cities with topological and demographical conditions, availability and attractiveness of non-charged routes and public transport provision or sizes.

This question is explored in detail in a study by Börjesson, Brundell-Freij and Eliasson (2014). The main conclusion is that although the social benefit of a given charging system (including the size of the charge) is considerably and non-linearly dependent on initial congestion levels, traffic effects and adaptations are surprisingly stable across different transport systems. Specifically, the level of public transport provision has only small effects on baseline congestion, and therefore on the total benefit of the charges. Interestingly, adaptation cost, traffic reduction across the cordon and the share of drivers priced off the road diverting to public transport are also surprisingly insensitive to the level of public transport provision, contrary to the common argument that public transport provision is crucial for effectiveness and efficiency. Drivers can adapt in many different ways except for switching to public transport, which explains the robustness of the results.

8.1 Why a “success”?

The newspaper quote in the introduction calling the trial a “success” was fairly typical. Even if certainly not everybody was in favour of the charges, the change in general opinion as reflected in polls and media seemed to justify such statements. But what were the key factors behind this? There is no conclusive answer to this question, but five main reasons were often mentioned by four key people involved in the trial – Gunnar Söderholm, head of the Congestion Charging Office responsible for (among other things) evaluation and information; Birger Höök, head of the Congestion Charging Unit at the Road Administration, responsible for the technical system and information regarding payment and technology; Gunnar Johansson, head of the IBM-led consortium that developed and operated the technical system; and the author, who was responsible for the early system design and chairman of the expert panel summarising and scrutinising the large evaluation package.

- *The technical system worked*. That the system worked from the start was of course a key factor. The number of misidentifications was extremely low, and from users’ perspectives, everything worked seamlessly. Further, the Road Administration made great efforts to develop a customer-friendly system.
- *The information campaign had worked*. Apparently, people knew what to do. Anticipated problems with people who did not know that they should pay, or did not know how to pay, did not materialise. Moreover, the anticipated problem of protests in the form of large number of court appeals or refusals to pay was never a problem. in spite of a lot of talk before the trial about “civil disobedience” in the form of refusal to pay or appealing to court.
- *Visible congestion reduction*. The improvements in travel times and the urban environment were visible right from the start. The astonishment of seeing almost empty streets during rush hours, in particular during the first months, cannot be stressed enough. After that, the potency of road pricing had been overwhelmingly proved, and the negative arguments shifted from “it won’t work” to other, often more constructive, arguments.
- *Extensive and scientific evaluation.* Even if effects were visible, one should stress the importance of being able to supply media with hard figures about the reduction of traffic volumes and congestion. Especially when the debate recovered somewhat from the initial shock caused by the enormous initial effects, it was extremely important to have professional, independent researchers and experts, coming from different backgrounds and organisations, being able to explain and evaluate what was happening. The size of the evaluation was itself an important factor: so many experts and researchers were involved in one way or another that it was impossible to wave it away.
- *Clear objectives*. The system had clear and measurable objectives – reducing congestion and improving the environment in the inner city – and the system was visibly designed with these objectives in mind. Moreover, the objectives were fulfilled.

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Singapore's Experience in Road Pricing

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Contents

1 Introduction

Singapore is a small city state with a land area of 716 square kilometres. It has a population of more than 5.3 million people, making it one of the most densely populated countries in the world. Singapore's transport needs are served by a road network of 3,425 kilometres used by a total of about 973,000 vehicles, of which about 607,000 of them are cars. In the field of transportation, road pricing has often been associated with Singapore. Besides the Vehicle Quota System (VQS) (or commonly known as the Certificate of Entitlement (COE) system), Singapore is also first in the world to introduce road pricing in June 1975. Initially, road pricing is a manual scheme based on paper permits and applicable during the morning peak period only. Many changes have been made to the road pricing scheme since then. It subsequently evolved over the past 30 years to an electronic scheme that presently operates almost throughout the day.

1.1 Public transport is key in Singapore's overall transportation strategy

Since Singapore's independence in 1965, the Government has focused on making Singapore's public transport system effective, cost-efficient, and attractive. This focus has not changed to date. Singapore has recently unveiled the Land Transport Plan 2013, which sets out the Government's transport strategy for the next 10 to 15 years. The Government will continue its focus of shifting more trips to public transport, especially rail-based transport. This will be achieved by building more rail lines and providing better rail and bus services. Nevertheless, given the convenience and comfort that private transport offers, a high quality public transport system may be insufficient to move people away from private transport. Furthermore, the rising affluence of Singaporeans has resulted in greater aspirations to own cars. Therefore, the Government needs to complement its public transport strategy with the management of road travel demand.

1.2 Singapore's management of road travel demand

Road pricing is an important component of Singapore's overall transportation strategy. While road capacity continues to be increased judiciously to meet rising travel demand, the strategy also calls for greater reliance on public transport usage and the management of road travel demand. Therefore, this is especially important in Singapore, given its limited land resource1. There are two aspects to the management of road travel demand. The first aspect is the restraint of vehicle ownership, which is achieved primarily through the COE system2, as well as the imposition of high upfront ownership costs. Ownership costs include the Additional Registration Fee (ARF)3, excise duties as well as road tax. The second aspect of the management of road travel demand is the restraint of vehicle usage, which is achieved primarily through the Electronic Road Pricing (ERP) system. An ERP charge is imposed on motorists based on the quantity, place or time during when they use their vehicles. The more one uses his car, the more he has to pay. Besides the ERP system, Singapore also sets policies on petrol tax and parking charges to manage vehicle usage.

[1] 12% of Singapore's land is already used for roads, compared to 15% used for housing
[2] Restricts the actual growth of the vehicle population to 0.5% per annum currently
[3] Currently 100% of the car's Open Market Value (OMV)

One of the goals set out in Singapore's strategy to manage road travel demand is to move away from relying predominantly on restraining vehicle ownership to one that balances between restraining vehicle ownership and usage. Although vehicle ownership measures are effective in controlling vehicle population growth, vehicle usage measures are needed to counter what behavioural economists termed "the sunk cost effect". With high ownership costs, car owners tend to maximise the value of their cars by driving whenever possible. Thus, relying on high ownership costs is not enough. Usage charges are equally important to manage the demand for road space. The resulting system would be a fairer and more equitable one.

2 Area Licensing Scheme (ALS) and Road Pricing Scheme (RPS)

In 1975, the Area Licensing Scheme (ALS) was introduced and was in place for 23 years before being replaced by the ERP system. This manual scheme was based on the need for paper licenses to be purchased prior to their passage through control points set up on the roads. It was a usage restraint measure to control traffic congestion in the Central Business District (CBD) during peak hours.

2.1 How the ALS worked

The ALS is a cordon-based pricing scheme and covered the more congested parts of the CBD, designated as the Restricted Zone (RZ). When the ALS first started, the RZ had an area of only 610 hectares; but over the next 14 years, it increased to 725 hectares eventually because of the inclusion of areas that had turned commercial in nature and the availability of reclaimed land at the sea-front. In 1995, road pricing was extended to expressways and was known as the Road Pricing Scheme (RPS). It was meant to be a pilot scheme to introduce the concept of road pricing at other congested points outside the RZ and served to familiarise motorists with point-based pricing as opposed to cordon-based pricing of the ALS. Prior to its demise in 1998, the RZ was demarcated by 31 overhead gantry signs at its control points. To gain access into the RZ during the restriction periods, non-exempt vehicles needed to purchase and display an ALS area licence (see Exhibit 1). The daily area licences could be purchased at roadside sales booths located at the approach roads to the RZ, petrol stations, post offices and convenience stores. Enforcement personnel were stationed at the control points during the restricted hours to observe whether vehicles displayed the valid licences on their windscreens, or on the handle-bars in the case of motorcycles and scooters. Violating vehicles were not stopped at the gantries, but their vehicle licence numbers were taken down and their owners would receive a summons for entering the RZ without a valid licence. The checks for licences were made only at the control points, and vehicles were free to move around or leave the RZ without having the licences.

Exhibit 1: ALS licence and gantry

2.2 Operating hours

The ALS started in 1975 with the restricted hours of 7.30 a.m. to 9.30 a.m. daily, except on Sundays and public holidays. Three weeks later, the restricted hours were extended to 10.15 a.m. in order to restrain the surge in vehicle entries immediately after the lifting of the ALS at 9.30 a.m. The ALS operated for two and three-quarters hours each weekday during the morning peak period until June

1989, when major fundamental changes were made. They were triggered by a rapid growth of vehicle population during that period. The restriction period was extended to cover the evening peak hours of 4.30p.m. to 7.00p.m. on weekdays. The evening period was later cut back by half an hour to 6.30p.m. in order to accommodate requests from residents who lived inside the RZ but worked outside, although this was subsequently extended back to 7.00p.m. because of increased traffic congestion. In 1994, more fundamental changes were made to the ALS scheme. The restricted hours were further extended to cover the inter-peak period of 10.15 a.m. to 4.30 p.m. on weekdays and the post-peak period of 10.15 a.m. to 3.00 p.m. on Saturdays. The Saturday restriction period was subsequently cut back to 2.00 p.m. due to improved traffic conditions within the RZ. When the ALS started in 1975, taxis, public transport buses, goods vehicles, motorcycles, and passenger cars carrying three or more passengers (excluding the driver) were exempted from the scheme.

Carpooling was allowed under the scheme to optimise vehicle usage and to counter the charge that the scheme favoured only the rich. The exemption on taxis was subsequently removed in 1975. In the review of June 1989, more vehicles were required to purchase licences prior to their entering the RZ during the restriction period. Motorcycles and goods vehicles, which together made up about two-thirds of the traffic entering the RZ, were no longer exempted. Furthermore, exemptions for car-pools were also abolished. This was because private cars were picking up bus commuters instead of forming genuine car-pools. This constituted a form of pinching of bus commuters by motorists and defeated the intent of the car-pool exemption.

2.3 ALS charges

The licence fees had been revised upwards over the years to cater for inflation and to check the gradual upward creep in the number of restricted vehicles entering the RZ. Starting at S$3 per day for a licence for cars in 1975, this had crept up to S$5 per day in 1980. However, with the major review in 1989, there was a reduction in rates – essentially because more vehicles were required to purchase licences. The daily licence fee for a car was reduced back to S$3. With the review in Jan 1994, there were two levels of fees for licences – the one that permits usage throughout the day, and the one that was applicable for use during the inter-peak period only. For cars, the daily licence fees were S$3 and S$2, respectively.

2.4 Impact of ALS on traffic

The initial drop in traffic entering the RZ was 44 percent, but it crept up to a 31 percent drop by 1988. However, this was despite the growth by a third in employment in the city and by 77 percent in vehicle population during the same period. The drop in traffic was caused by the decanting of motorists whose destinations were not the city itself but had merely been using the city roads as a bypass, as well as by those who changed their journey start time to avoid paying the ALS fees. There was little evidence to suggest that motorists had transferred to public transport in significant quantities, probably because the rail system only began operation in November 1987.

2.5 Limitations of ALS

Being a manual scheme, the ALS had limitations. It was labour intensive: about 60 enforcement officers were required at all the gantry points and another 60 officers at the dedicated licence sales booths. Extending the schemes to other points would have needed even more people to run them. The enforcement job was tiring as long hours were spent under the sun and rain. The environment these people worked in was at the roadside, and this was dusty and noisy. The work also required considerable concentration because of the varied vehicle heights and categories of licences. There were 16 types of licences for the two schemes, divided into daily/monthly, peak/inter-peak and the different vehicle classes. Human enforcement by visual means was prone to error leading occasionally to wrongful summonses being issued. Under the manual system, a licence offered a vehicle unlimited number of entries to the RZ or passage through the control points. Furthermore, as the licence was a flat fee for unlimited entries, the ALS was not equitable to motorists because the charges were not commensurate with the congestion caused (e.g. if a vehicle entered the RZ many times a day). As a result, it was tempting for motorists to transfer licences although it was not legally transferable between vehicles.

Moreover, there was always a rush to enter the RZ just before or after the restricted hours because of the sudden change of licence fee from nothing to S$3 or vice versa. This resulted in sharp and short peaks of entering traffic volume. "Shoulder-charging", or having intermediate rates, would have smoothened out the peaks, but it was difficult to implement in a manual system. Having more categories of licences would make enforcement more difficult and more prone to mistakes.

3 Electronic Road Pricing (ERP)

With the shortcomings of ALS, the search for a more efficient technology began in earnest before 1990. In July 89, the Government announced that it would implement ERP. Study missions were sent to USA and Europe where some form of electronic pricing had been implemented for road toll systems. Technology for an electronic road pricing system was emerging at that time, and after several years of discussions and prototype testing with potential suppliers, a contract for the installation of a Dedicated Short-Range Communication (DSRC) electronic road pricing system was awarded in 1995.

This led to the introduction of the ERP system in September 1998 to fully replace the manual road pricing scheme that had been in operation since 1975. The objective of the road pricing scheme is to charge vehicles for use of the road at places and at times where and when they cause congestion. The ERP system is one of the main tools which are keeping Singapore's traffic problems within manageable levels. Under the ERP scheme, vehicles pay an ERP charge when they pass a control point. The ERP is a point-based and cordon-based pricing scheme and ERP control points are made up of a cordon around the city (or the Restricted Zone) as well as along congested sections of expressways and ring/radial roads.

3.1 Components of ERP

The ERP system is a dedicated short-range radio communication system (DSRC) using a 2.54 GHz band. The three components are the: (a) In-vehicle Unit (IU) with the smart card called CashCard, (b) ERP gantries located at the control points across the road, (c) Control Centre.

3.1.1 In-vehicle Unit (IU)

The IU is a pocket dictionary sized device powered by the vehicle battery and fitted permanently to the lower right hand corner of vehicles’ windscreen or on handlebars of motorcycles and scooters. The IU has a slot for receiving a prepaid stored value contact smart card. The smart card, called the CashCard is issued and managed by a consortium of local banks. The CashCard is reusable and can be topped up with cash at petrol stations or automated teller machines. The IU has a backlit liquid crystal display. It displays the CashCard balance when the card is inserted into the IU and the remaining balance after the deduction of a charge after the vehicle goes under an ERP gantry. There are different IUs for different classes of vehicles, i.e. for cars, taxis, light goods vehicles, heavy goods vehicles, buses, motorcycles and emergency vehicles (fire engines, police cars and ambulances). This is necessary because the ERP charges are different for different classes of vehicles. The IUs are colour coded so that illegal switching of IUs between classes of vehicles can be discouraged.

Besides its role in ERP, the IU also serves another useful function in Electronic Parking System (EPS). EPS is an automatic system which allows the convenient payment of parking charges at numerous car parks in shopping centres, commercial buildings and housing estates in Singapore. Parking charges are deducted from the CashCard through the IU as vehicles exit the car park.

3.1.2 ERP gantries

The ERP gantries are a set of two overhead gantries mounted at each control point. They are at a height 6.1m above road level and placed about 12-15m apart (see Exhibit 2). The first gantry carries two radio antennae per lane, facing the incoming traffic. The antenna communicates with the IU of approaching vehicles. The first gantry also carries two enforcement cameras per lane, facing away from the traffic ready to take the digital images of the rear licence plate of violating vehicles. On the second gantry directly above narrow black and white bands painted on the road surface are optical sensors. The sensor camera holds the black and white band image when the road is empty. It detects a moving vehicle and measures its width by the interference in this image caused by a moving vehicle. The second gantry also carries a second set of radio antennae of two per lane, which again communicates with the IU of approaching vehicle. The logic for controlling all the gantry equipment is placed in a local controller in the vicinity. The local controller transfers data continuously with a central computer at a control centre by using leased telephone lines.

Exhibit 2: ERP gantry

3.1.3 Control centre

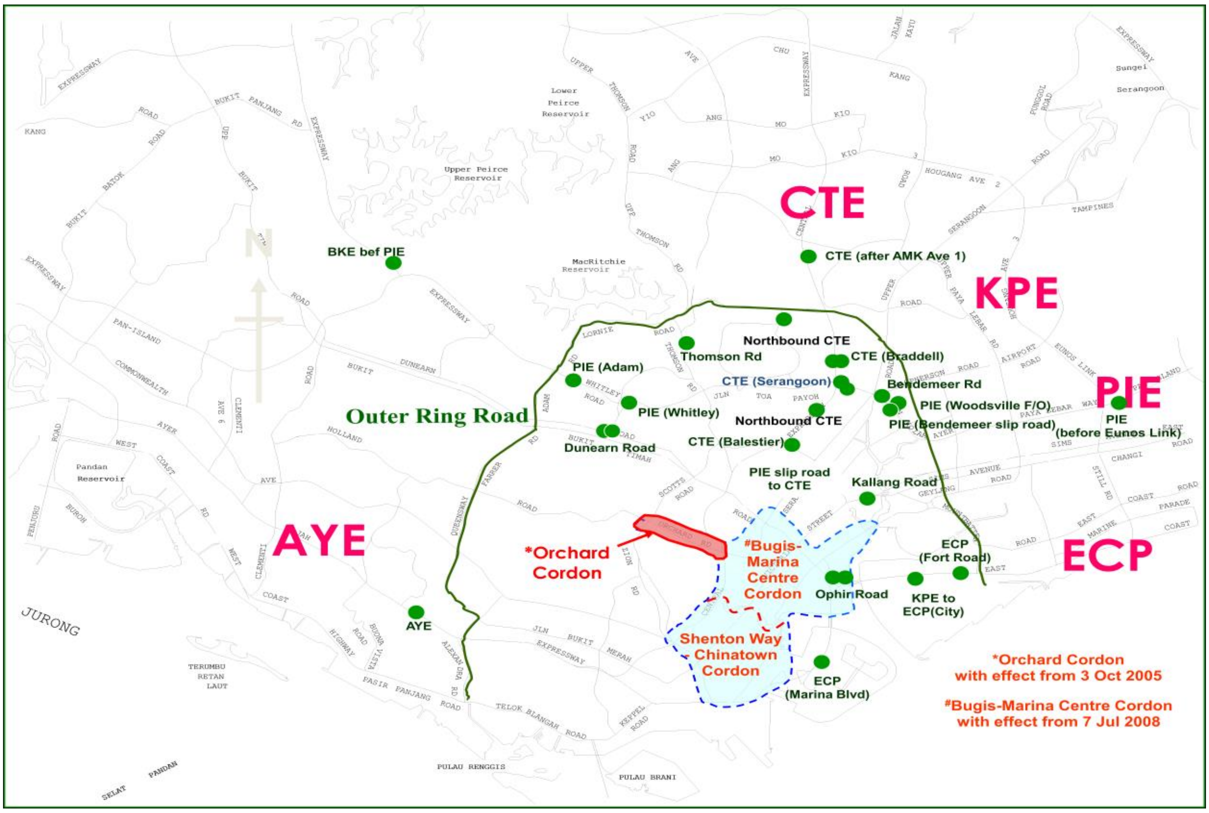
The control centre houses the central computers and peripherals. The centre receives the records of all ERP transactions, records of any faults in the equipment and digital images of violating vehicles (including those of vehicles which have experienced errors). The valid ERP transactions are stored for cash settlement at the end of the day with the CashCard operators. The digital images are sorted out and the registration numbers in these images picked up by an optical character recognition system for follow up on issuing summonses for violators or inspection notices for those vehicles experiencing errors. Given the critical importance for continuous operations, maintenance crews who are on standby are sent out to check and rectify faults by the Control Centre, as appropriate.

The ERP system, inclusive of the IUs installed, costs about S$200 million in 1998. The revenue from the ERP charges goes to the Government Consolidated Fund, and is not hypothecated for transport-related expenditure.

3.2 How the ERP works

The ERP system is both cordon-based and point-based. ERP gantries are located within 3 cordons, namely the Bugis-Marina Centre Cordon, the Shenton Way-Chinatown Cordon and the Orchard Cordon to reduce through traffic. Gantries are also located at specific points along expressways and arterial roads to reduce congestion (see Exhibit 3). There are a total of 71 ERP gantries in Singapore, with 32 gantries serving specific points along expressways and arterial roads, and 29 gantries serving the 3 cordons.

Exhibit 3: Map of ERP cordons and gantries



As the vehicle approaches within 10m of the first gantry, the antennae interrogates the IU, determines its validity, classifies the vehicle according to the IU and instructs it to deduct the appropriate ERP charge. Between the two gantries, the IU instructs the deduction of the appropriate charge from the CashCard, and confirms that this has been done to the second antenna. On the IU of the vehicle, the new balance in the CashCard after the deduction of the ERP charge is displayed for 10 seconds. At the same time, the optical sensor detects the passage of the vehicle. If there has been a valid ERP transaction, i.e. the correct ERP charge has been deducted, this information is stored in the local controller. If there has not been a valid transaction for some reason, the enforcement camera takes a digital image of the rear licence plate of the vehicle, recording the reason, i.e. no CashCard etc., and also stores this information at the local controller. The local controller sends back all the ERP transaction data and digital images to the control centre.

The records of valid ERP transactions are stored only for a day and are used to claim the total ERP charges from the CashCard operator. The violation/error images are kept for a period of six months, as they may need to be used if drivers challenge the summons issued for violations. Although exempted from paying ERP charges, fire engines, ambulances and police cars also have IUs, as otherwise they would have been photographed as violators. But they do not need to use a CashCard or if they use one, no cash deductions are made.

The ERP system is not intended to generate revenue for the Government. By pricing congested locations, the ERP system is intended to moderate vehicle usage during peak hours by encouraging motorists to consider alternatives. Motorists could use other routes to arrive at their destinations, travel during off-peak hours or switch to public transport or car-pooling.

3.3 ERP operating hours

The ERP operating hours for the 3 cordons generally start from 8am to 8pm on weekdays, and from 12.30pm to 8pm on Saturdays for 2 of the cordons. For expressways and arterial roads, the ERP operating hours start from 7am to 9.30am and from 5.30pm to 8pm for 2 of the expressways. When ERP was first introduced in 1998, there were no ERP charges during evening and Saturdays. ERP was only extended to the evening peak hours in August 2005 to reduce congestion for home-bound trips. The rationale behind the introduction of ERP during the evening is that congestion results in a negative impact to all motorists and road users, regardless of the time of the day. ERP was also extended to weekend Saturdays in October 2005 to reduce the through traffic in the Orchard corridor. This was because congestion had started to have a negative impact on shops in Singapore's busy Orchard shopping district.

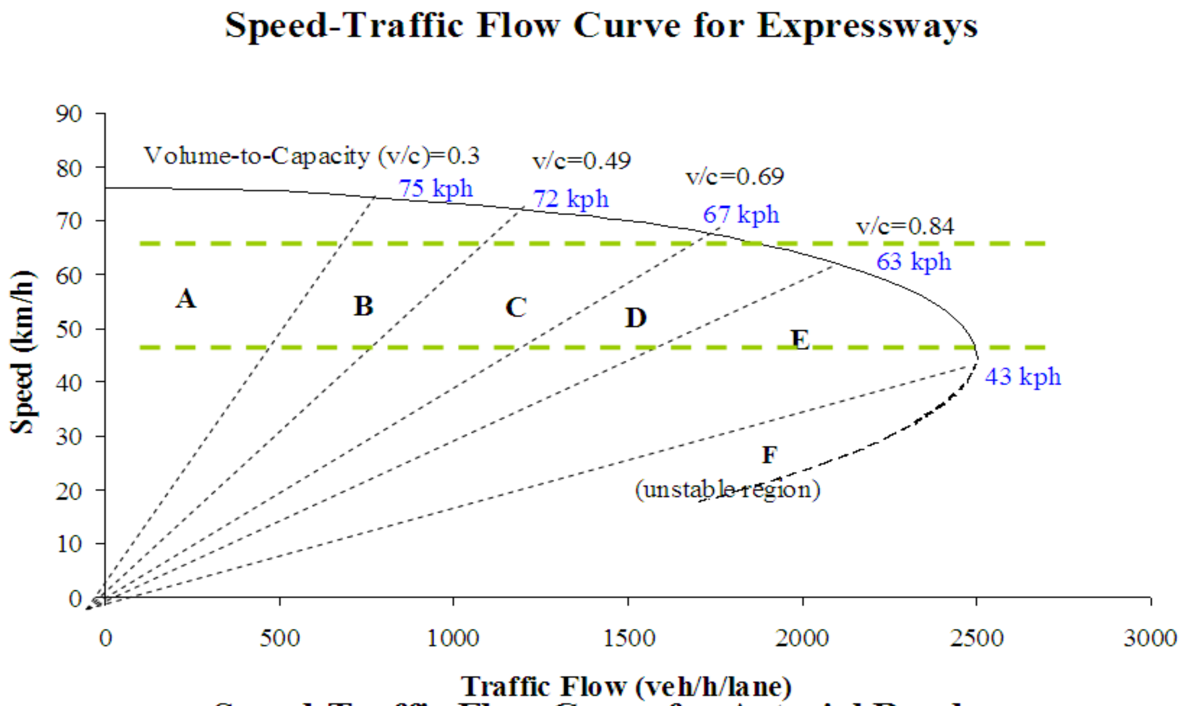
3.4 Passenger car unit (PCU) principle

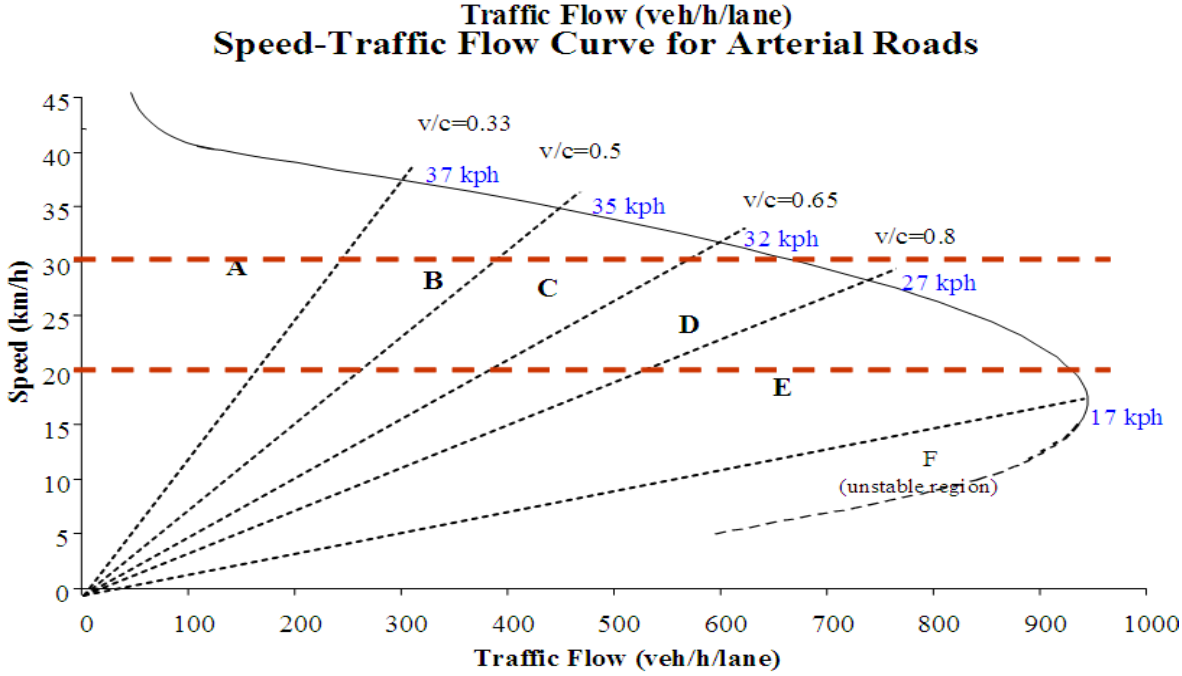
ERP charges are set based on the Passenger Car Unit principle. This means that cars have a passenger car unit of 1, motorcycles have a passenger car unit of 0.5 and commercial vehicles have a passenger car unit ranging from 1 to 2. The rationale behind this principle is that vehicles which take up more road space should pay more for congestion. Charges are pro-rated for different types of vehicles by taking reference to the charge for cars. For example, if the ERP charge for cars is four dollars, the charge for motorcycles will be two dollars, since the passenger car unit for motorcycles is 0.5.

3.5 Calibration of ERP charges

ERP charges are calibrated to maintain vehicle speeds within the optimal speed range on expressways and arterial roads. Charges are reduced when speeds exceed the optimal speed range and increased when speeds fall below the optimal speed range. For expressways, the optimal speed range is 45 to 65 km/h. For arterial roads, the optimal speed range is 20 to 30 km/h. Vehicle speeds are measured using the 85th percentile speed method, which is an international traffic engineering practice for assessing traffic conditions. This means that 85 per cent of motorists will experience speeds within the optimal speed range. There is a trade-off between vehicle speeds and the volume of traffic that can pass through a particular stretch of road, as shown in the following speed-flow curves for expressways and arterial roads. The greater the volume of traffic, the lower is the vehicle speed. ERP charges are adjusted to maintain the optimal speed range on expressways and arterial roads and keep the volume of traffic flow within Zone E on the speed-flow curves. This prevents traffic from reaching an unstable state where vehicle stop-start conditions become common. This unstable state is represented by Zone F on the speed-flow curves (see Exhibit 4).

Exhibit 4: Speed-traffic flow curve for expressways and arterial roads





ERP charges are reviewed at the start of every quarter of the year, as well as during the school holidays in June and December. If the speeds exceed the upper limit, the ERP charge for cars (1 PCU) is reduced by 50 cents for that half-hour and if the speeds are lower than the lower limit, the charge is increased by 50 cents. The current lowest rate charged for 1 PCU vehicle for a half-hour is 50 cents[4] and the highest is S$6. ERP charges are calibrated differently for different types of vehicles, locations and time of the day.

This concept of tying ERP rates to speeds is generally accepted and reinforces the fact that ERP rates to speeds is generally accepted and reinforces the fact that the ERP is a congestion relieving measure rather than a revenue raising measure. Such a philosophy has allowed ERP to be scrapped totally on Saturdays for the city after operating it for seven months. There are also half-hour slots within the ERP period where there are zero charges. Change of charges has not been an issue.

3.6 Method of change of charges at ERP gantries

During the peak hours, charges change every half hour to take into account the traffic volumes. This helps to spread the traffic flow to a longer period and thus ensure good traffic conditions. However, when the changes in charges between consequent half-hours are steep (say S$1), motorists either speed up or slow down or even wait at the approach to the ERP gantries to take advantage of the cheaper half-hour rates, leading to safety problems, The problem is acute when such vehicles wait along the expressway shoulders, which by itself is a traffic offence. To discourage such practice, signs have been put up to advise such waiting vehicles that they are under surveillance by the cameras which are used to monitor traffic conditions along the expressways. Furthermore, in February 2003, the software for charging was modified to introduce gradual stepping up/down of ERP charges from one half hour to the next when the difference was at least S$1 (per 1 PCU). The graduated charges are introduced in the first five minutes of the next half-hour period if it is an increase in the next half-hour (e.g. if the charge for the period 8am to 8.30am is S$1 and the charge for 8.30am to 9am is S$2, the charge will be increased to S$1.50 for five minutes from 8.30am and 8.35 am, before being increased to S$2 at 8.35am.) The graduated charges are introduced in the last five minutes of the current half-hour period if it is a decrease in the next half-hour (see Exhibit 5).

Exhibit 5: Example of ERP rates

Expressways															
Weekdays															
BKE between Dairy Farm Road and PIE	CTE after Braddell Road, Serangoon Road and Balestier slip road	CTE slip road to PIE (Changi) / Serangoon Road	CTE between Ang Mo Kio Ave 1 and Braddell Road	ECP after Tanjong Rhu Flyover	ECP from Ophir Road	KPE slip road into westbound ECP	PIE after Kallang Bahru exit, PIE Slip Road into Bendeemer Rd	PIE eastbound after Adam Road and Mount Pleasant slip road into the eastbound PIE	PIE slip road into CTE	PIE westbound before Eunos Link	CTE northbound between Jalan Bahagia and PIE	northbound between PIE and Braddell Road, PIE to CTE northbound before Braddell Road	ECP eastbound before exit to Rochor Road, entrance from Ophir Road	For Orchard Cordon and Rest of CBD, please view page 3	Time
54	31, 33, 34	68	35	30	29	80	32,45	37, 38	42	65	51	46, 67	52, 53		Gantry No.
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00					7.00am - 7.05am
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00					7.05am - 7.25am
$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00					7.25am - 7.30am
$1.00	$2.00	$0.50	$0.00	$1.50	$0.00	$1.50	$0.00	$0.50	$2.00	$0.00					7.30am - 7.35am
$2.00	$4.00	$1.00	$0.00	$3.00	$0.00	$3.00	$0.00	$1.00	$4.00	$0.00					7.35am - 7.55am
$2.00	$3.50	$1.00	$0.00	$2.50	$0.00	$2.50	$0.00	$1.00	$3.50	$0.00					7.55am - 8.00am
$2.00	$3.00	$2.00	$0.50	$2.00	$0.00	$2.00	$0.00	$1.50	$3.00	$0.00					8.00am - 8.05am
$2.00	$3.00	$3.00	$1.00	$2.00	$0.00	$2.00	$0.00	$2.00	$3.00	$0.00					8.05am - 8.25am
$2.00	$3.00	$3.00	$0.50	$2.00	$0.00	$2.00	$0.00	$2.00	$3.00	$0.00					8.25am - 8.30am
$2.00	$4.50	$3.50	$0.00	$4.00	$0.00	$4.00	$0.80	$2.00	$4.50	$0.50					8.30am - 8.35am
$2.00	$6.00	$4.00	$0.00	$6.00	$0.00	$6.00	$1.50	$2.00	$6.00	$1.00					8.35am - 8.55am
$1.00	$4.00	$2.50	$0.00	$3.00	$0.00	$3.00	$0.80	$1.00	$4.00	$0.50					8.55am - 9.00am
$0.00	$2.00	$1.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2.00	$0.00					9.00am - 9.05am
$0.00	$2.00	$1.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$2.00	$0.00					9.05am - 9.25am
$0.00	$1.00	$0.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1.00	$0.00					9.25am - 9.30am

[4] 1 USD = 1.265 SGD as at March 2014.

3.7 Methods of payment for ERP charges

There are 3 different modes of payment for ERP charges. Motorists can use either a NETS CashCard or a Contactless E-Purse Application Standard card, or CEPAS card in short. These are cards with stored cash value which can be credited again once the stored value is used up. The CEPAS card is the national standard for Contactless Smart Card and is also used on public transport in Singapore.

Alternatively, motorists can also choose to be billed the ERP charges that they incur through their credit cards automatically. This service comes with an administrative fee in exchange for the convenience that motorists enjoy.

3.8 Implementation issues

3.8.1 Mitigating the impact of ERP to businesses: Phasing in of ERP rates

As part of the package to introduce pay-as-you-use electronic road pricing (the former manual road pricing scheme charged a fixed amount per day, regardless of the number of times a vehicle went under the gantry), the ERP charges for commercial vehicles were phased in over a number of years. This was targeted at commercial vehicles, since these were the ones that made multiple trips into the city per day. For taxis, the ERP charge was phased in over a three-year period, i.e. they paid the full rate only in the third year (or from September 2000 onwards). For goods vehicles and buses, the ERP charge was phased in over a four-year period, with them paying the full charge from September 2001 onwards.

3.8.2 Technology issues

The motorists have no issues on the accuracy and reliability of the ERP system. Although there might have been some doubters in the initial period, when there was a tendency for motorists to slow down as they approached the ERP gantries, this is no longer the case.

3.8.3 Violation grouses by motorists

These are more of the nature that violations were inadvertent and not deliberate. The motorists are convinced that it is not possible to cheat the system. There have been no recorded cases of fraud detected. More than 80% of the violations are because there was no CashCard in the IU or there was insufficient cash balance. As mentioned before, violators blame the IU for not forewarning them that the CashCard was not inserted. To ameliorate this problem, this offence is now treated administratively and not as a summons. Violators are asked to pay an administrative fee of S$10 in addition to the ERP charge instead of a summons charge of S$70, which is charged for vehicles with no IU.

3.8.4 In-vehicle unit (IU)

There are grouses on the user-friendliness of the IU. Motorists have to slot in the CashCard before making the journey. Some drivers remove the CashCard when they leave their car, and forget to reinsert it before starting their journey and unwittingly commit an offence. They would like the IU to forewarn them that the CashCard is not inserted when they start the vehicle, or when they approach an ERP gantry. Motorcyclists do not have this problem because they have to remove the CashCard each time they leave the vehicle because otherwise it might be stolen. Thus removing and reinserting CashCards have become a habit with them.

CashCards that are left in the IU in a vehicle is visible to anyone, except that the cash balance is not shown. Nevertheless, there have been some thefts of CashCards in car parks at isolated locations. Some drivers would like to conceal the CashCard within the IU and reduce the temptation to would-be-thieves. Indeed, there are IU covers on sale marketed by some entrepreneurs for this purpose, although these are not widely used. In the first instance, IUs were given to owners of the existing fleet of vehicles. However, it is not a requirement for all vehicles to have an IU. Nevertheless, all new registered cars come with an IU and a new owner has to explicitly make a request, if he does not want an IU. To date, 99% of the vehicle population have fitted IUs. All IUs have a five-year warranty on them, which meant that faulty IUs were replaced free of charge. The number of faulty IUs is less than 100 per annum. When the five year warranty expires, replacements will be charged.

3.8.5 ERP gantries

Another grouse among motorists trying to plan their trips to coincide with the cheaper half-hour slots was that their watches and the ERP gantry time did not match. Originally, the ERP gantry showed the word "In Operation" when the gantry was charging. The newer ERP gantries are now showing the clock time with two amber traffic light aspects, which are lit up during the hours of operation.

3.9 Treatment of foreign vehicles

There are about 37,000 foreign-registered vehicles entering and leaving Singapore each day. Foreign vehicles can either elect to have a permanent IU fitted or rent a temporary IU at one of the commissioning centres near the borders, if they think that they would need to use the ERP priced roads. About 16,000 have fitted permanent IUs because they come to Singapore frequently. On an average, about 200 foreign vehicles rent temporary IUs monthly. These are the occasional visitors. As from September 2003, foreign vehicles using the ERP priced roads need no longer go through the hassle of renting a temporary IU. A daily rate of S$10 would be charged which allows them unlimited use of these roads. The violation images (caused by these vehicles having no IU) will be used as the basis for computing the number of days they use the ERP-priced roads. This will be charged when they leave Singapore at the checkpoint. The new scheme is finding favour with foreign motorists who need to use the ERP priced roads.

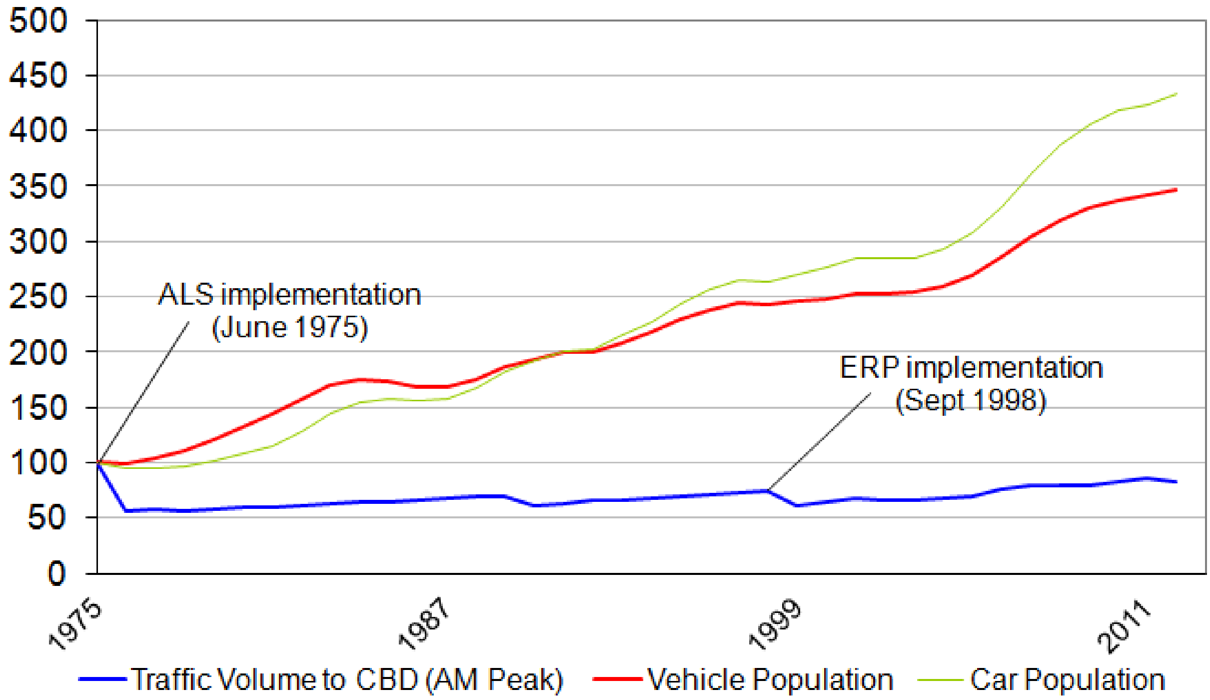
3.10 Impact of ERP

3.10.1 Impact on traffic

Traffic conditions along the city roads and the ERP priced expressways and major roads continue to be good because the ERP charges are adjusted to achieve reasonable speeds. There are short periods of congestion on the unpriced alternative routes, but the motorists have adjusted themselves to the routes they prefer. During the first five years that the ERP has been in operation, the city has grown by 5% in terms of development. No major roads have been constructed within the city. A new underground radial railway line has been constructed to serve the north-east sector.

The ERP system has reduced congestion in Singapore significantly. Since ERP is implemented in 1998, it has helped to reduce the volume of traffic to the CBD. Over the 14-year period from 1998 to 2012, the vehicle population in Singapore has increased by 3% per year, but the traffic volume to the CBD has only increased marginally by 0.8% per year (see Exhibit 6).

Exhibit 6: Impact of ERP on traffic



3.10.2 Impact on carbon emissions

From the data collected, the number of cars entering city area during the morning peak hours reduced from 74,014 to 52,824 when the ALS was implemented in 1975, and likewise, a drop in traffic volume during the morning peak hours from 55,268 to 51,384 was observed when the ERP came into effect in 1998. These two one-step reductions in traffic volumes in 1975-6 (for ALS) and 1998-9 (for ERP) resulted in CO2 emission reduction of about 0.14% and 0.02% of the total annual CO2 emissions respectively (or 56 ktonnes and 9 ktonnes respectively). The cumulative CO_2 emission reduction as a result of ALS from 1975 to 2008 is estimated to amount to about 1,907 ktonnes, while the cumulative CO_2 emission reduction as a result of ERP from 1998 to 2008 is estimated to amount to about 103 ktonnes.

It is reasonable to assume that the ERP system had also kept congestion in check beyond the city areas, preventing cars from travelling in slower moving traffic or getting trapped in gridlock, hence, contributing to CO_2 emission reduction. Fuel savings derived are based on the fact that cars travelling at slower speeds burn more fuel to travel the same distance. Thus, an estimated CO_2 emission reduction in 2008 amounted to about 0.85% of the total CO_2 emissions (or 340 ktonnes), while the estimated cumulative CO_2 emission reduction from 1998 to 2008 amounted to about 3,738 ktonnes.

3.10.3 Impact on motorists' behaviour

ERP gives motorists a few options:

- Pay ERP charge and enjoy good traffic conditions
- Change the time of the journey to pay a lesser charge or no charge at all
- Change to an unpriced or lower-priced alternative route
- Change to a public transport mode
- Change destination
- Abandon journey

It is expected that by now most drivers have already made the decisions and formed habits.

3.11 Measuring impact of ERP on motorists: Demand price elasticity

Demand price elasticity (E) is defined as:

E = percentage change in demand/percentage change in price

Economists use demand elasticities as an approximate measure of aggregate responses in the market. Elasticities for ERP should logically be negative, i.e. a reduction in price would see an increase in traffic volume and vice versa. For the city roads, elasticities are worked out only for the half-hour periods from 7.30 to 9am because vehicles would probably be making only one trip during this period. If we take the whole restriction period of 7.30am to 7pm, vehicles might make multiple trips into the city (RZ) and it would not be possible to work out the elasticity without knowing the number of vehicles which made the multiple trips.

Elasticity values for cars entering the city (RZ) for half-hour periods between 7.30am to 9.30am varied between -0.12 and -0.35 within the first year after ERP was introduced. It was expected that values would stabilise after some time. The current values vary between zero and -0.42. Elasticity values for cars were also worked out for the use of the expressways. During the period 7.30am to 9.30am (again assuming that only one trip is possible during this period), the elasticity values for half-hour periods vary between -0.16 and -0.44. The higher values feature when ERP charges are removed for a particular half-hour or when the charges for that half-hour reach the upper ranges of S$2.50 to S$3. On expressways, motorists seem to be more willing to changes their travel patterns and behaviour when ERP charges are removed or when they are confronted with paying the upper ranges charges.

4 Lessons learnt

Road pricing in Singapore has been effective in managing congestion on roads in the CBD since its inception in 1975, and in recent years on expressways and other major roads outside the CBD. In summary, the pricing strategy of the ERP system should continue to be flexible and relevant in order to cater to different traffic conditions.

Singapore will continue its focus of shifting more trips to public transport, especially rail-based transport. At the same time, the Government will manage the demand for road usage, by controlling vehicle ownership and vehicle usage.

While the ERP system is a key policy tool in controlling vehicle usage, it cannot operate on its own and has to work with other policy tools, such as vehicle ownership control measures and road building.

5 Conclusion

Technology has helped to make the expansion of the original road pricing scheme possible. As congestion becomes increasingly widespread in Singapore, it would not be practical to continue building ERP gantries to address the congestion problem. Moreover, the ERP charges imposed at specific locations may also lead to undesirable impact. For instance, the congestion may shift to other roads in residential areas.

In the longer term, Singapore is studying the next generation of ERP system that makes use of GPS technology, which can enable road pricing to be more effective. The use of GPS technology may provide more flexibility in road pricing, for example, by making distance-based road pricing possible along congested stretches of expressways and roads. Distance-based road pricing would be a more equitable and efficient system than the current point-based charging system, where motorists are charged based on the number of gantries that they pass through rather than the distance travelled on a congested road.

AN OVERVIEW OF CONGESTION CHARGING ON ROADWAYS IN THE UNITED STATES OF AMERICA

Congestion Pricing Theory and Select Case Studies

Prepared
For The
Energy Foundation
Beijing Office, China

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February 23, 2014
Revised March 20, 2014

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Abstract

Traffic congestion is one of the most significant challenges facing transportation agencies around the world today. Excessive congestion has the adverse effects of increasing travel times and greatly reducing highway capacity, sometimes called person and vehicle throughput, during congested periods. Broadly defined, *congestion charging* (also referred to as congestion pricing) is a system of surcharging users of public goods that are subject to congestion through excess demand. A key component of congestion pricing is the application *of variable rates* to the toll lane or facility. Variable rates send a price signal to users, give them some control over the price they pay and incentivizes them on when to travel.

In the United States there is a growing national momentum within transportation agencies to consider roadway congestion charges as one means to mitigate congestion problems by providing users with economic incentives to use a roadway more efficiently, to use roads at different times of the day, or to use alternative modes such as transit or carpooling.

Congestion pricing is an effective policy because is allows highway authorities to better manage demand and vehicle and person throughput on a given roadway section. Because the price (or toll) fluctuates with time of day, demand is moderated to help ensure optimum highway performance. This policy is effective because a price tends to discourage some users from entering the lane or lanes as the cost increases. The facility can be managed to ensure free-flow conditions are maintained at all times. Peak-period throughput on congestion priced facilities often exceeds the throughput performance of the adjacent general purpose lanes by more than double.

This report lays out the theoretical and policy foundation for congestion charges in the U.S. It examines three types of congestion charges in the U.S.; high-occupancy toll lanes, express toll lanes, and variable pricing on tolled facilities. Three projects are selected for evaluation including I-394 in Minneapolis, Minnesota; I-95 in Miami, Florida; and, State Route 570 Bridge in Seattle, Washington.

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GLOSSARY

Congestion charges: tolls that are levied on drivers during congested periods for the purpose of enhancing facility throughput; most often the charges are variable by time period or are dynamic, this is a term that also called congestion pricing in the U.S.

Congestion pricing: another term for congestion charges and includes the concept of variable rates in the pricing structure to incentivize a desired consumer behavior change; the pricing component is the market element that may encourage shifts in travel to off-peak periods or encourage travel in other priority modes

Demand management: refers to strategies for limiting use of a roadway facility through regulatory means or through time or price incentives; there are many components to demand management including congestion pricing

Dynamic pricing: refers to toll that vary based on road user demand for a facility; rates are automatically adjusted up or down depending upon toll lane volumes and speeds; the purpose of dynamic pricing is to keep a facility free-flowing through market based price incentives

Diamond lane: in the U.S. these are lanes designated for transit and carpools; the designation may be for only specified periods of the day or may be implemented at all times

Express toll lanes: Refers to a high-occupancy toll lane where are users including transit and carpools pay the toll

General purpose lane: a regular lane with no user restriction and no toll

High-occupancy toll (HOT) lanes: refers to a lane that charges toll, perhaps only during peak-periods, but transit vehicles and carpools get free passage

High-occupancy vehicle (HOV) lanes: refers to diamond lanes above; only transit and carpools are allowed to use these lanes either in the specified period or throughout the day; HOV 2+ refers to a policy that allow carpools of 2 or more people free access; HOV 3+ refers to a policy that allow carpools of three or more people free access; see also occupancy requirements

Managed lanes: refers to a range of strategies that help to manage demand on a facility or allow the performance (throughput) of the facility to be improved; managed lanes strategies can be as simple as adding law enforcement to encourage rule compliance or as complex as adding video or technology to collect tolls or enhance operations and enforcement; includes access control, vehicle occupancy, and vehicle class

Occupancy requirements: on HOT lanes or HOV lanes rules are sometimes employed that require cars or vanpools to have a minimum number of occupants, most often 2 or 3 people

Peak-period pricing: charging drivers a toll to use a roadway facility during the morning and/or afternoon peak-period commuting times

Road pricing: same as congestion pricing, may also refer to flat tolls that are employed on toll roads, bridges or tunnels

Toll lanes: a lane or lanes that are priced to manage demand on a roadway; most often involves a variable price to encourage or discourage use depending upon demand

Toll facilities: refers to toll lanes, toll roads, bridges or tunnels

Variable charges: refers to toll rates that are adjusted up or down to help manage demand for a facility, see variable rates

Variable rates: refers to tolls that vary up or down by time of day, demand for a facility or speed, see variable charges

I. CONGESTION CHARGES OVERVIEW

Introduction

Traffic congestion is one of the most significant challenges facing transportation agencies around the world today. If left unchecked, congestion and associated problems such as air pollution, lost time and wasted energy will likely become even worse as demand for highway facilities increases. This can be a problem in both developed as well as developing nations. Excessive congestion has the adverse effects of increasing travel times and greatly reducing highway capacity, sometimes called person and vehicle throughput, during congested periods. Air pollution problems are intensified when the vehicle fleet using the roadway system is comprised of older and/or highly polluting vehicles. When particularly severe, problems associated with congestion can negatively impact health as vehicle emissions increase air pollution levels.

Broadly defined, *congestion charging* (also referred to as congestion pricing) is a system of surcharging users of public goods that are subject to congestion through excess demand. A key component of congestion pricing is the application *of variable rates* to the toll lane or facility. Variable rates give users control over the price they pay. If the price is too high, the driver may choose to travel in the non-tolled lane or travel at a different time of day when rates are reduced. The incentive of shifting demand and behavior, through a variable price is at the core of why congestion pricing is good public policy. Ultimately, it is a policy that helps to conserve resources, reduce construction costs and the adverse environmental and social impacts of highways by encouraging more rational consumption of limited roadway space.

Congestion charging on roads in the United States is a relatively new strategy that was first implemented in 1995 on the State Route (SR) 91 Express Lanes in Orange County California. This project involved construction of four toll lanes (two in each direction) in the median of the freeway. That project was followed closely by the I-15 high-occupancy toll (HOT) lane project in San Diego in 1996. That project converted a single high-occupancy vehicle (HOV) lane that had unused capacity to a high-occupancy toll lane. The congestion pricing policy in the U.S. stems from the recognition that even the most congested roads are likely to have excess capacity for a significant portion of the day. Congestion pricing is a market based pricing strategy that seeks to spread out demand more evenly throughout the day. In addition, it is often coupled with policies that allow free or discounted travel to vehicles such as carpools, buses, motorcycles and in some cases low emissions vehicles such as hybrid or electric vehicles.

Congestion pricing has long been used in other public service industries around the world and is manifested by charging higher peak-period rates for the use of bus services, electricity, subways, railways, telephones. Congestion pricing is also used by the airlines and shipping companies by charging higher fees for landing and gate slots at airports and through canals at busy times. This pricing strategy regulates demand, making it possible to manage congestion without increasing supply, that is the number of roadway lanes.

In the United States there is a growing national momentum within transportation agencies to consider roadway congestion charges as one means to mitigate congestion problems by providing users with economic incentives to use a roadway more efficiently, to use roads at different times of the day, or to use alternative modes such as transit or carpooling (1). Congestion pricing has the ability to enhance air quality through better lane throughput and reduced emissions as engines run more efficiently at higher speeds and without slowdowns or stop and go conditions. Congestion pricing uses market forces to deliver appropriate price signals to users and may ultimately enhance the quality of life for users and non-users alike as less time and energy are wasted.

Pricing Theory

The basis for congestion pricing comes from market theory in the field of economics which suggests that users be required to pay for the negative *externalities* they create, making them conscious of the costs they impose upon each other when driving during the peak-period. Additionally, this price will make users more aware of their impact on the environment. Nobel Prize winning economist, Dr. William Vickery of Columbia University in New York City, is often credited with the development of supporting research around congestion pricing and has been given the title of the *Father of Congestion Pricing*. His work suggested that roads and other services be priced so that users see the costs that arise from the service being provided (or roadway space) and when that service is fully used and when there is excessive demand that cannot be accommodated without facility or service expansion. Congestion pricing gives users a signal to adjust their behavior or to investors to expand the service or facilities *(2).*

The Federal Highway Administration, a unit of the U.S. Department of Transportation, reports in a document titled, *Congestion Pricing, A Primer*, that congestion pricing works like this *(3):*

> *Congestion pricing is a way of harnessing the power of the market to reduce the waste associated with traffic congestion. Congestion pricing works by shifting purely discretionary rush-hour highway travel to other transportation modes or to off-peak periods, taking advantage of the fact that the majority of rush-hour drivers on a typical urban highway are not commuters. By removing a fraction (even as small as five percent) of the vehicles from a congested roadway, pricing enables the system to flow much more efficiently, allowing more cars to move through the same physical space. Similar variable charges have been successfully utilized in other industries; for example, airline tickets, cell phone rates, and electricity rates. There is a consensus among economists that congestion pricing represents the single most viable and sustainable approach to reducing traffic congestion.*

Purpose of This Report

The purpose of this report is to discuss road user charging as it applies in the U.S., road pricing theory, elements of winning champions and public support, and how congestion charges are used on a sample of selected roadways in the United States. Road authorities in the U.S. have only recently begun to use congestion pricing to manage demand on congested roadways during peak-periods of the day. Although still relatively new, the roadway congestion pricing policy has become an essential tool in the highway manager's tool-box. An important dimension to this discussion is the concept of road pricing as *optional tolling*, that is, charging a variable toll on one or two lanes of a roadway, but not the entire roadway. The notion of optional tolls is particularly effective means of gaining support because it still provides for a "free" alternative and also encourages carpooling and transit usage if these modes are given free or reduced fee options on the tolled lane or lanes. This model has been the typical means for implementation in the U.S., although there are now some fully tolled roads that are implementing variable charges across all lanes.

As previously mentioned, congestion pricing can be applied in many ways to help manage transportation demand. In the context of this discussion, however, the author will explore three applications of the tool currently in use in the United States:

1. Conversion of existing high-occupancy vehicle (HOV) lanes to high-occupancy toll (HOT) lanes;
2. Variable pricing of Express Toll Lanes (ETL) where all (or nearly all) users are charged; and,
3. Variable pricing of existing toll facilities.

Part II of this report will explore in more detail the types of charge as identified above, and Part III will describe specific project examples from three locations around the U.S.

Specifically excluded from this discussion is *zoned-based or cordon pricing* which has not yet been applied anywhere in the United States. A number of major metropolitan areas around the U.S. continue to explore this option to manage congestion in core center city areas. Cities in Europe such as London, England, Stockholm, Sweden, and Milan, Italy currently employ zone-based pricing as does Singapore. Also excluded from this discussion is another form of congestion pricing called variable rate *parking pricing*, which uses the same market principles of supply and demand to adjust parking rates and encourage rational consumer behavior. Although employed in several areas of the U.S. its applications are less widespread.

Using Market Forces to Manage Demand

Congestion pricing on a roadway system involves the use of *market forces* to manage demand or usage of the highway or a facility on a highway such as a toll bridge or toll tunnel. Demand, or traffic volume, is managed by adjusting the toll charges up or down to encourage or discourage use. These varying charges manage the volume of users through price incentives and can ensure free-flow conditions for users who are willing to pay the toll. In the end, toll paying customers of the congestion priced facilities benefit from reduced travel time and increased travel time reliability. In the U.S. travel time reliability has become an important benefit for users because it allows them to plan their trip departure time with assurance that they will arrive at their destination on time(4). This is discussed in greater detail in Part III of this report. Users like congestion pricing because it reduces stress and aggravations and overall enhances their quality of life.

Although the United States has employed toll roads since the founding of the nation, only in the last two decades have congestion charges been applied on select roadways. While still controversial in some regions, the public has come to accept that congestion pricing fundamentally allows a roadway to perform at higher level, that is allowing greater vehicle and person throughput in a given section of roadway, thus benefiting all travelers, not just those who are willing to pay.

On a typical congestion priced roadway, incentives are applied that adjust the price up or down depending upon the time of day. For example, fees typically will be the highest in the morning and afternoon peak periods, thus encouraging some users to shift their travel to off-peak or shoulder periods when the price is lower. Additionally, congestion pricing often includes incentives for transit, carpools, vanpools, motorcycles and sometimes low emission vehicles. Those incentives may include free or reduced rates depending upon occupancy or class of vehicle. Some road authorities have chosen to allow hybrid or all electric vehicles to travel free at any time to encourage emissions reductions and support the goal of reducing the nation's reliance on imported oil.

Winning Public Support

Because road charging schemes involve paying a fee or toll, these policies can be highly charged and emotional issues for the public(5). Public acceptance is difficult to win, at least initially. Communicating clearly the purpose of congestion charges can be difficult. There are likely to be widespread disputes over the perceived purpose of road charging…, is it to raise revenue or to manage demand or both? To the public, adding a road use charge to an existing free facility may feel like price gouging even if the facility previously had restrictions that limited use such as HOV lanes. In the U.S. this is a particular problem because there is not a widespread tradition of toll roads around the country. Public sentiment often focuses on the notion that all roads should be "free."

What is needed to make congestion pricing work? Road use charges are not likely to ever become a grass roots cause. Rather, winning public support will likely require winning the support of political champions. The public almost never supports a fee increase of any kind or the conversion of formerly free roads to toll roads, even if it is optional and effects only one or two lanes of a facility. For this reason winning political support is often essential. When politicians become fully informed on the benefits of congestion pricing, and understand the trade-offs that are made, support becomes easier. There are few road use policies that generate as much return-on-investment as congestion pricing(6). In many cases congestion pricing can be implemented for a relatively small investment and yield large dividends in terms of enhanced highway performance.

Education and Outreach Components

What are the components of a successful education and outreach strategy to gain support for congestion charges? There is no sure bet formula, but the following elements have proven successful in applications across the U.S.(7):

Market research is an essential element of an education and outreach effort around gaining support for congestion charges. Market research helps develop an understanding of who the customers are and what are the messages that will resonate with that market.

Education and outreach also involve providing the necessary information to help the public and decision-makers in their learning and discovery process. Through this learning activity opportunities for engagement and discussion serve to clarify and communicate objectives effectively.

A marketing plan is an important component of implementing congestion charges. Marketing is more than just selling…, marketing is the element that communicates the value of congestion charge and why the customer should want it and how they will benefit from it. Customers need to know what they are getting for their money and what the value of that product or service is.

Evaluation is the element which requires the congestion charging authority to monitor and/or confirm the performance of the facility. It compares the project objectives with outcomes and provides the data to make adjustments in operations or pricing strategies to more closely match expectations. Evaluation reports are important for customers to continue to support an operation and to win new customers.

II. CONGESTION PRICING IN THE U.S.

Goal

The goal of congestion pricing is to balance traffic flow and throughput while minimizing congestion within the priced lanes therefore providing a congestion free trip for all users of the lane. Additionally, certain classes of users such as transit and carpools may be given free or discounted access to the facility, thereby encouraging mode shift and energy and emissions reductions. Congestion charges may enable improved flow and performance of all lanes on a roadway through better lane management. Congestion pricing systems typically aspire to allow drivers to travel at free flow conditions, that is to travel at speeds of 45-55 miles per hour (mph) or above. Road authorities in the United States are held accountable for maintaining that high level of performance at least 90 percent of the time thus ensuring that users get superior service on the lanes and value for the price they pay in the toll.

Types of Congestion Charging

The case for congestion charges has evolved from U.S. experience with high-occupancy vehicle lanes (also known as a HOV lane, carpool lane, diamond lane, and transit lanes) which are restricted traffic lanes reserved at peak travel times or longer for exclusive use of vehicles with a driver and one or more passengers, including carpools, vanpools and transit buses. The normal minimum occupancy level is 2 or 3 occupants. Many jurisdictions exempt other vehicles, including motorcycles, buses, emergency and law enforcement vehicles, low emission and other green vehicles. HOV lanes are normally created to increase higher average vehicle occupancy and thus increasing person throughput on the roadway with the goal of reducing the total number of vehicles, reducing overall traffic congestion and reducing air pollution. Sometimes, entire roads are designated for the use of HOVs only for particular times of the day.

While HOV lanes do work, that is they provide for greater person throughput, there are also cases where HOV lanes have performed sub-optimally, or are perceived to be under performing. In some of those situations around the country those lanes have been converted to HOT lanes or Express Toll lanes to achieve a higher level of performance. That is done by selling (i.e., tolling) excess capacity that may exist on the facility in peak and even off-peak periods. In some cases, the occupancy requirements have been changed to receive free passage. Most frequently that involves a policy change from two persons to three or more persons in the vehicle. Additionally, it is often necessary to adjust lane widths and shoulder dimensions to provide more physical capacity on the roadway or accommodate barrier or buffer separation.

High occupancy/toll lane (or HOT lane) is a road pricing arrangement that gives motorists in single-occupant vehicles access to high-occupancy vehicle lanes (or "HOV lanes") for the price of an electronic toll. (See cross-section in Figure 2.) Tolls are typically collected automatically via automatic number plate recognition or with the use of transponder systems. In some cases tolls are set based on a rigid price structure that adjusts solely on time of day. In other cases tolls increase as traffic density increases and speeds decrease within the tolled lanes. This is known as *dynamic road pricing* (or dynamic pricing). The example that will be explored in this report is the I-394 MnPASS lane in the Minneapolis-St. Paul metropolitan area of Minnesota.

Express toll lanes (ETLs) are a similar concept to HOT lanes. The main difference between HOT and ETLs is that, in HOT lanes, HOVs are granted free access, whereas in ETLs all vehicles pay according to the same schedule. There are a number of variations of ETLs that allow a reduced toll for certain classes of vehicles including buses, vanpools, motorcycles, or electric or hybrid vehicles. The example that will be explored in this report is the I-95 Express Toll Lane in Miami, Florida, also called the 95 Express.

Variable pricing on tolled facilities manages demand on congested roadways, bridges or tunnels which are *already tolled* by providing motorists with financial incentives to use the available roadway in a more efficient manner. Variable pricing can be levied by time of day pricing or dynamically to adjust up or down to the amount of demand. In some cases, variable tolls are levied by time of day with a dynamic component that adjusts the price up or down in response to demand to ensure free-flow conditions. The example that will be explored in this report is the State Route 520 bridge over Lake Washington in the Seattle metropolitan area in Washington State.

Figure 1. Example of Barrier Separated Directional HOT Lane on I-394 MnPASS in Minneapolis, Minnesota

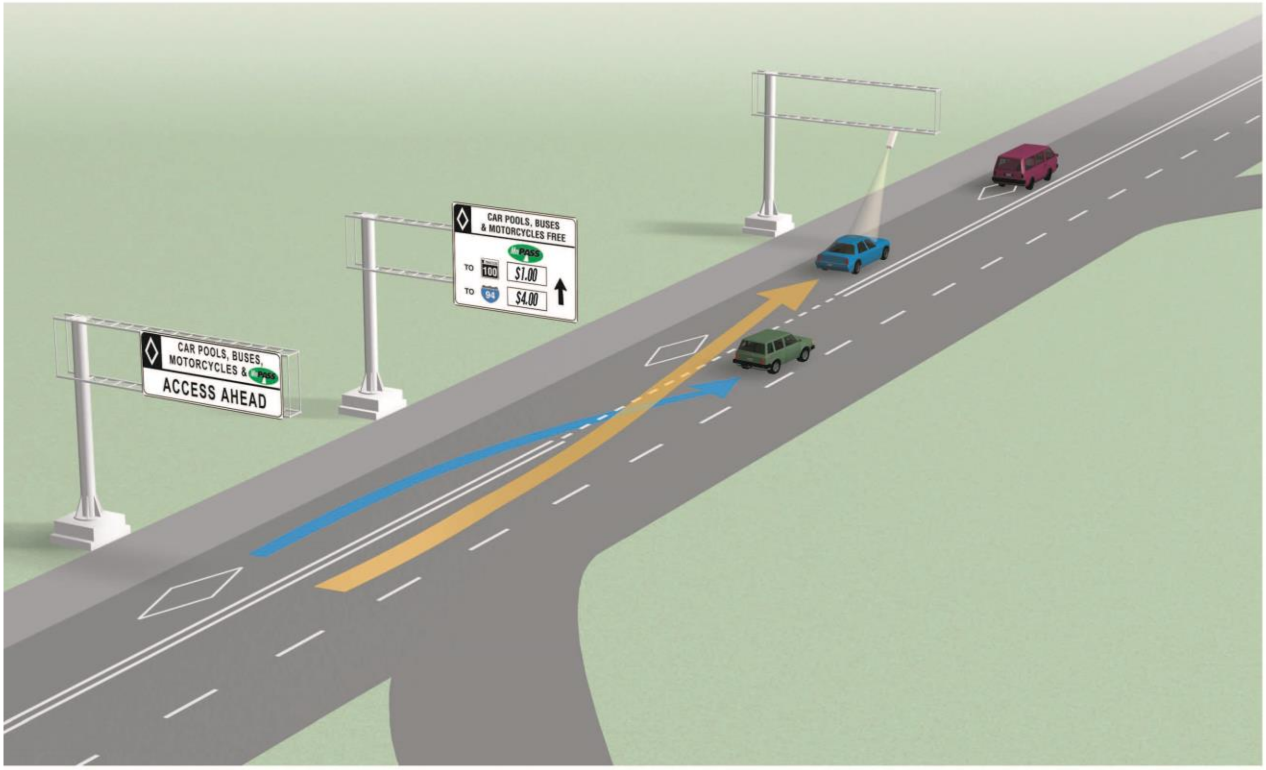


Figure 2-A. MnPASS: Depiction of Typical Section Showing MnPASS Lane, Entry/Exit Zone, Overhead Signage, and Transponder Antenna Reader

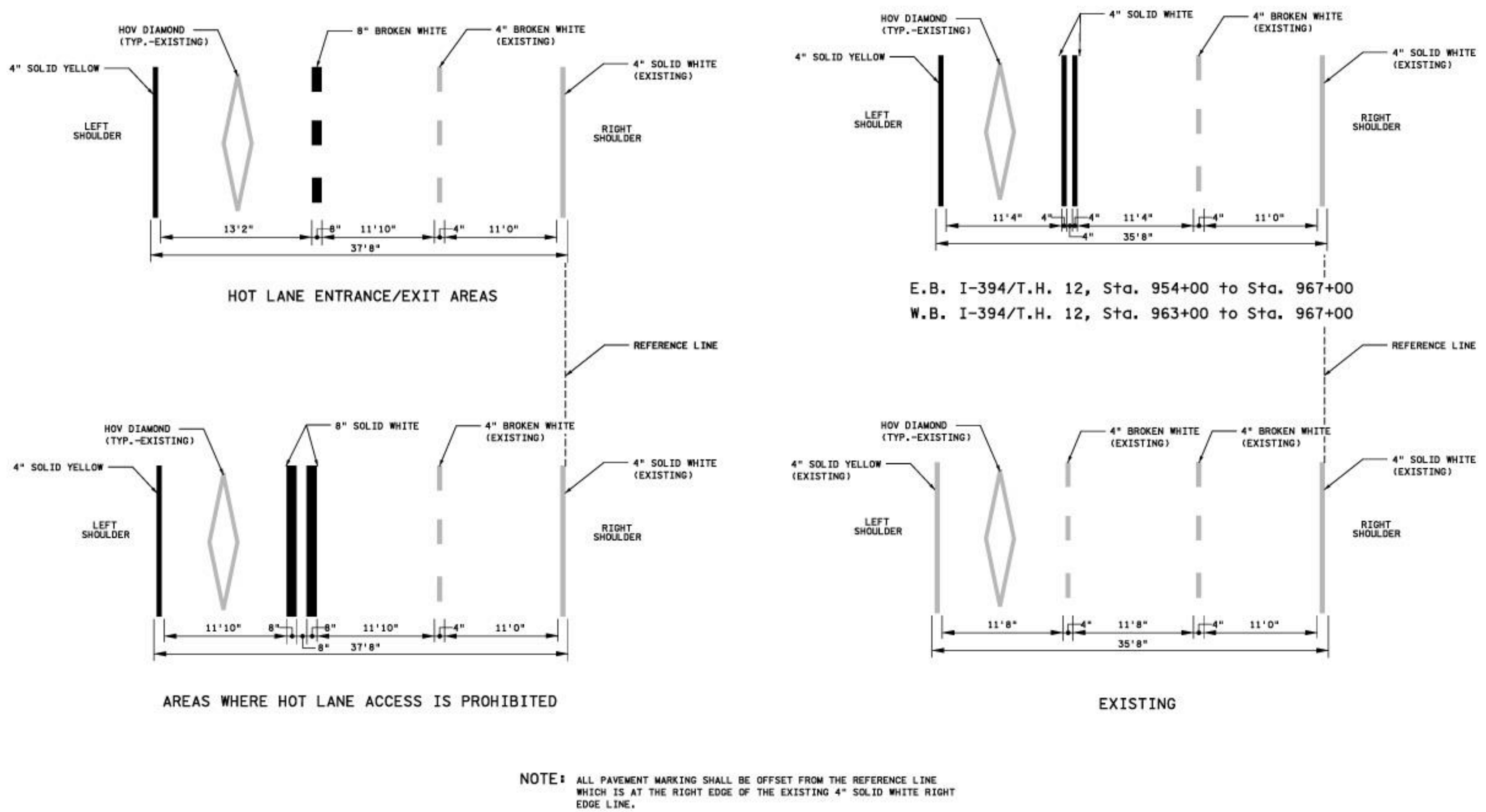


Figure 2-B. Typical HOT Lane Design and Striping Concept Plan; Without Barriers or Pylon Lane Separation

Congestion Charging System Components

Policy
It is imperative to have a cogent congestion pricing policy in place for users, operators and enforcement officials to understand the objectives and purpose of the system. Components of a toll policy may be corridor specific or they may be general, but will include the operations plan, pricing structure, and uses of the revenue in accordance with the tolling authority.

Technology
While there are many types and uses for technology that might be deployed on a congestion priced roadway, there are three essential technologies that must be deployed and these include in-vehicle transponders, roadside toll collection technology, and roadway monitoring or management technologies.

- Transponders
- Toll collection equipment
- Monitoring and management systems

Enforcement
Toll facility operators must be committed to enforcement and prosecution of violators. Without a strong and effective enforcement program the performance of a facility will quickly decline and operational objectives will be unattainable. Enforcement that law enforcement officials must conduct include lane violations entry and exist rules, occupancy rules, as well as other typical driving rules such as speed enforcement. Although it is assumed that tolls are collected electronically, toll violations could be part of the enforcement effort as users may try to avoid charges by removing or shielding transponders at the collection antennas.

Customer Service and Marketing
A particular important element of a toll collection system is the customer service center (CSC). The function of the CSC is setting up accounts, distribution of transponders, collecting fees, answering customer inquiries and marketing among other functions. The CSC becomes the face of the operation for the customer and therefore is vitally important to it success.

III. PROJECTS PROFILED

- Minneapolis-St. Paul, Minnesota
- Miami, Florida
- Seattle, Washington State

Figure 3. Congestion Pricing Projects Around The U.S.

MINNEAPOLIS, MINNESOTA: I-394 HOV TO HOT LANE CONVERSION

Project History

The I-394 corridor is an east-west oriented facility which links to I-94 on the east end near downtown Minneapolis, to I-494 and the Twin Cities western suburbs (Figure 4.). This 11 mile long corridor has three lanes in each direction, which includes eight miles of diamond lanes, and contains three miles of barrier-separated and reversible dedicated lanes on the east end from Highway 100 to I-94.

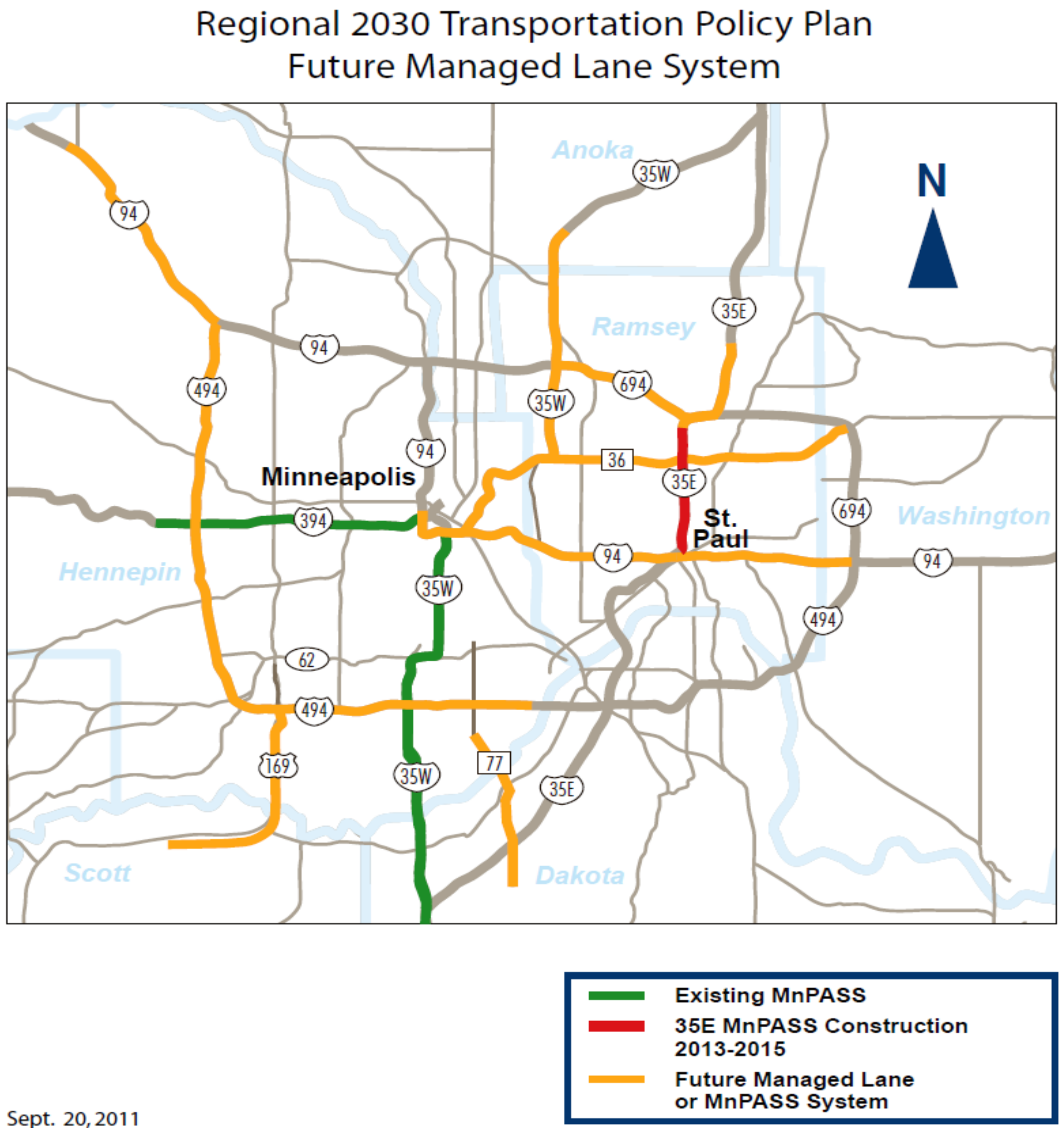


Figure 4. MnPASS System, Minneapolis St. Paul Metropolitan Area

The I-394 corridor accommodates approximately 150,000 vehicles per day of which less than 5% are heavy commercial vehicles (trucks). A combination of significant congestion in the general-purpose lanes plus a less-than-full HOV 2+ facility had created a perception that the existing HOV lanes were underutilized. A performance assessment indicated that in fact about 50% of the HOV lane capacity was unused in the peak-periods. This condition had persisted since the opening of this facility in 1992 and led to periodic requests that the HOV lanes be opened to solo drivers.

An alternatives assessment conducted by Mn/DOT and completed in 2001, concluded that converting the lanes to general purpose would not be cost effective and would result in a congested facility. The study also concluded that converting to a HOT lane operation would be the most cost-effective action.

I-394 HOT Lane Profile

- 150,000 average daily traffic
- 11 mile east-west corridor
  - 8 miles of single lane
  - 3 miles of two lane reversible
- 5 access points in each direction
- First facility to use double white stripe buffer lane separation
- Skip stripe delineates access points (25% open)
- 2+ carpools, transit and motorcycles are free
- No requirement for all users to have transponder
- 10% of users on the roadway are toll paying customers
- More than 18,000 transponders are registered in the corridor
- Maximum toll is $8.00, minimum toll is $0.25 ($1.30 avg. toll)

Figure 5. I-394 MnPASS HOT Lane Slip Ramp at Highway 100

Figure 6. I-394 MnPASS HOT Lane Showing Double White Stripe Buffer Separation and Pricing Signs

Figure 7. MnPASS Transpo eld Behind Rearview Mirror

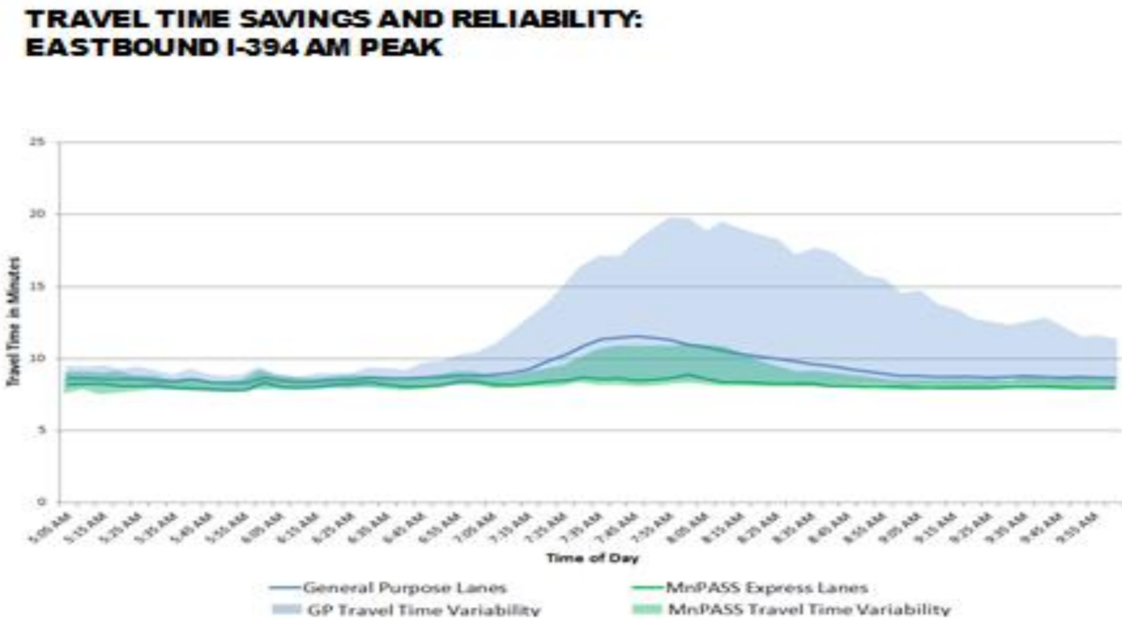


Figure 8. I-394 HOT Lane Travel Time Savings and Reliability

I-394 HOT Lane Performance

I-394 MnPASS HOT lanes have been operating since 2005 and provide an option for single occupant drivers to pay a toll to bypass congestion. To date more than 11,000 MnPASS accounts are opened on I-394 and more than 15,000 transponders are tied to those accounts. The MnPASS lanes carry 850 toll-paying vehicles in the morning and afternoon peak hour. The target speed of 55 mph has been maintained for all user including transit and carpools. Average daily use of the HOT lanes is in the range of 4000-5000 vehicles. On average, drivers of the MnPASS lanes save two to three minutes on their trip over the general purpose lanes (Figure 8). A wide variability of travel times between the MnPASS lanes and the general purpose lanes points to the reliability of the MnPASS lanes as a strong motivation for their use.

Overall, the efficiency of MnPASS HOT lanes has improved over the pre-MnPASS condition as vehicle throughput has increased by 48 percent and person throughput by 25 percent. By the measures of vehicle and person throughput performance of the lanes has been significantly enhanced.

Implementation Effort

Once authority was provided by the state legislature, an implementation task force was appointed by the Governor of Minnesota. This task force provided guidance and oversight on the project from initiation to completion. The task force deliberated on a variety of challenging design and operational issues that were either determined by the project management team to be of significance or determined by the task force itself to be an area of importance to be considered. The areas of discussion included:

1. Access Points/Traffic Operations
2. Hours of Operation
3. Enforcement
4. Dynamic Message Signs
5. Toll Rates
6. Type of Vehicles Allowed
7. Transponders
8. Expected Revenues
9. Public Outreach
10. Project Evaluation

Public Involvement and Outreach

The I-394 MnPASS project was a ground breaking project for HOT lane pricing in the U.S. As such, it was imperative that all issues be thoroughly considered and reviewed and ultimately, acceptable and realistic solutions developed. Public outreach meetings and presentations were planned carefully to provide ample opportunity to discuss topics in sufficient detail. The following principles were employed to facilitate the most meaningful input process possible:

- Developing as complete an understanding of the issues as possible
- Presenting technical and policy analysis
- Provide ample opportunity to thoroughly discuss topics
- Respecting all opinions including those of citizenry
- Considering concept changes or modified solutions based on technical or policy analysis
- Responding to all media inquiries
- Delivering project updates to local units of government
- Recognizing that the project may require technical and operational changes as experience is gained
- Leave no question unanswered

Project managers were diligent about answering questions and providing briefings. All information was provided to the media and the public and was made available on the project web-site.

MIAMI, FLORIDA: I-95 EXPRESS TOLL LANE

Figure 9. I-95 Express Lanes

Project History

The Miami, Florida I-95 Express Toll Lane (also called 95 Express) was implemented in a phased approach which to converted a single HOV lane in each direction into dual express lanes on 21 miles of Interstate 95 from Fort Lauderdale to downtown Miami. In developing the project, the Florida DOT worked with transit system operators to develop a plan to reduce congestion and provide more travel options in Miami-Dade and Broward Counties. The project was implemented under two construction contracts in three phases and was completed in 2012. Under the dynamic tolling scheme tolls can range from $0.25 during off-peak times when the facility is not subjected to high demand to $7.00 in cases of severe congestion, but in FY 2011 the average peak period toll was $1.70 in the southbound express lanes and $2.25 in the northbound express lanes. The I-95 Express project combines tolling, transit, technology, and telecommuting components together to effectively reduce congestion and improve the reliability of travel on I-95, particularly during the weekday rush-hour periods.

The scope of the 95 Express project extended beyond the conversion of HOV to express lanes. It also includes improved traffic monitoring and incident management capabilities, ramp metering, and bottleneck elimination. There is a significant transit component to the project as well: 23 new express buses have been added, and three new BRT routes were added in January 2010. Since opening in 2008, the average number of peak period transit riders has increased from 1,800 to 4,600, and is continuing to grow. Plans for a network of managed lanes in the southeast Florida urbanized area are nearing completion for 2014 opening, and two more links will get under way early in 2014.

Registered Carpools of 3+ Participants

While singe occupant vehicles and 2+ carpools all are eligible to use the I-95 for a toll, the conversion of the I-95 HOV lanes to Express lanes operation now requires all 3+ carpools to register for free passage and all users are required to have transponders. As of 2012, over 2,200 3+ carpools have registered. Registration allows authorities to periodically check with employers to determine that the carpool is still in operation. The intent of this policy, which is somewhat controversial in that it excludes family carpools from free usage and at the same time to encourage workers to form carpools thus removing one or more vehicles from the freeway during peak periods. Other metropolitan areas in the U. S. have now started to follow suit such as Atlanta and Los Angeles.

Additionally, registered hybrid vehicles are currently allowed free passage on the facility as well. Other free user of the system include:

- Miami-Dade and Broward County Transit
- Registered South Florida Vanpools
- Motorcycles
- Emergency Vehicles
- Registered Over-the-Road Motor Coach Vehicles

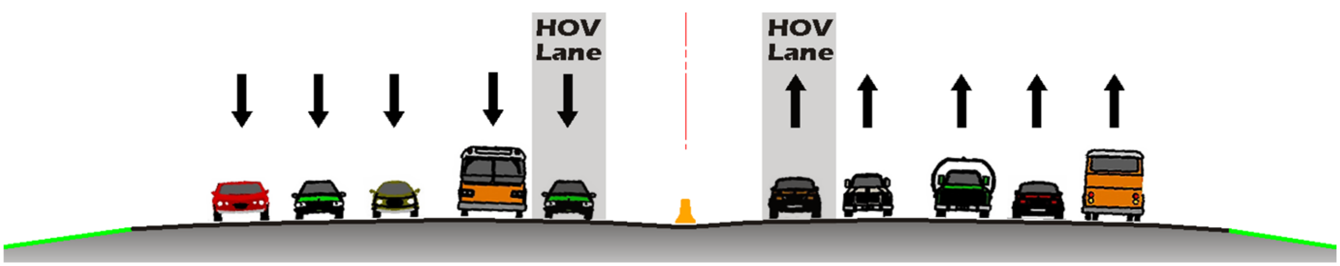


Figure 10. Before Condition On I-95; 5 Lanes With 4 General Purpose And 1 HOV Lane In Each Direction

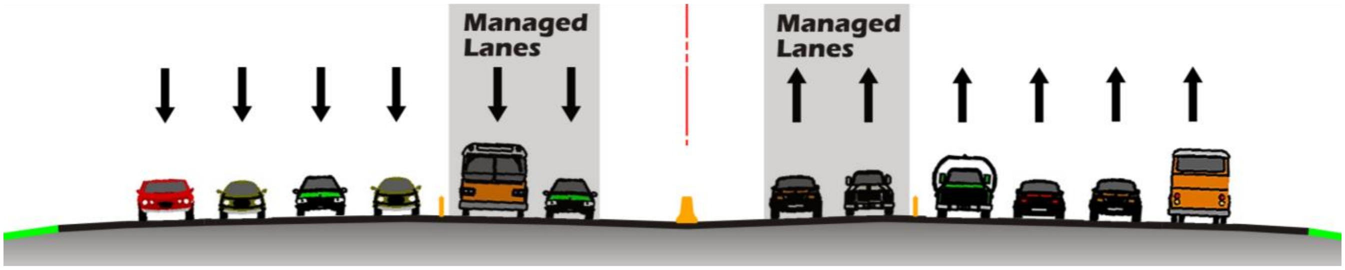


Figure 11. After Condition On I-95; 6 Lanes; 4 General Purpose And 2 HOT Lanes In Each Direction

I-95 HOV to HOT Conversion Features Profile

- Reduce lanes from 12' to 11'
- Reduce shoulder widths
- No new right-of-way
- No relocation of noise walls
- Limited major construction
- 3+ carpools and transit free
- All users are required to have transponder

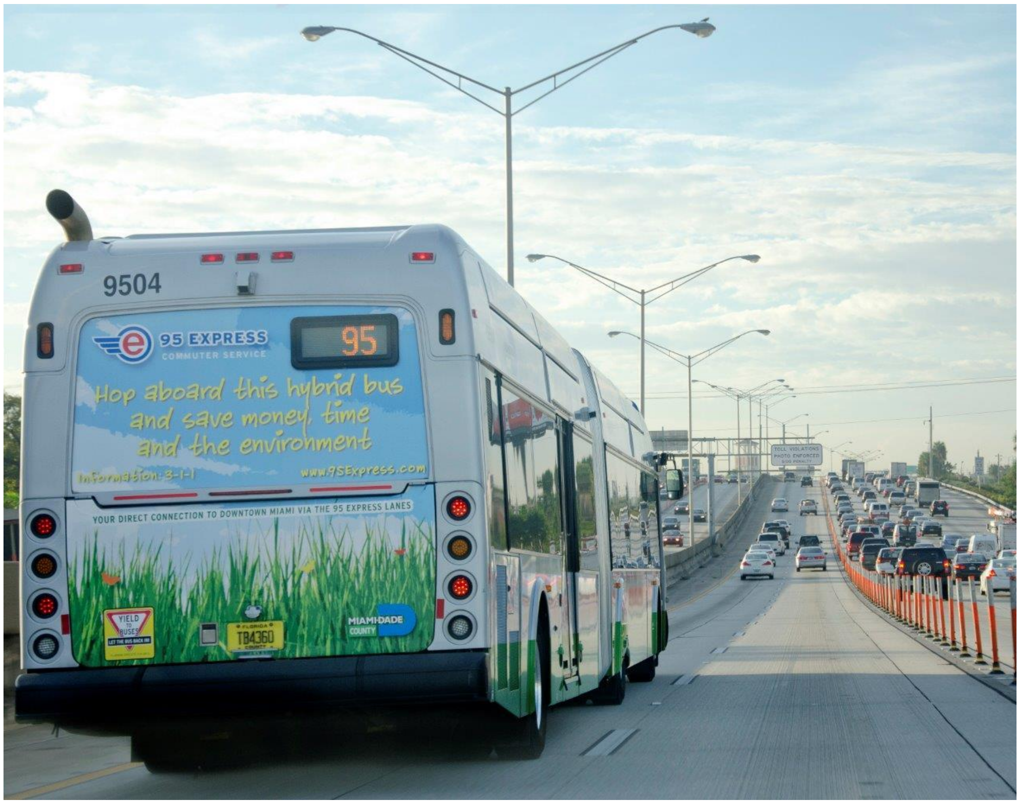
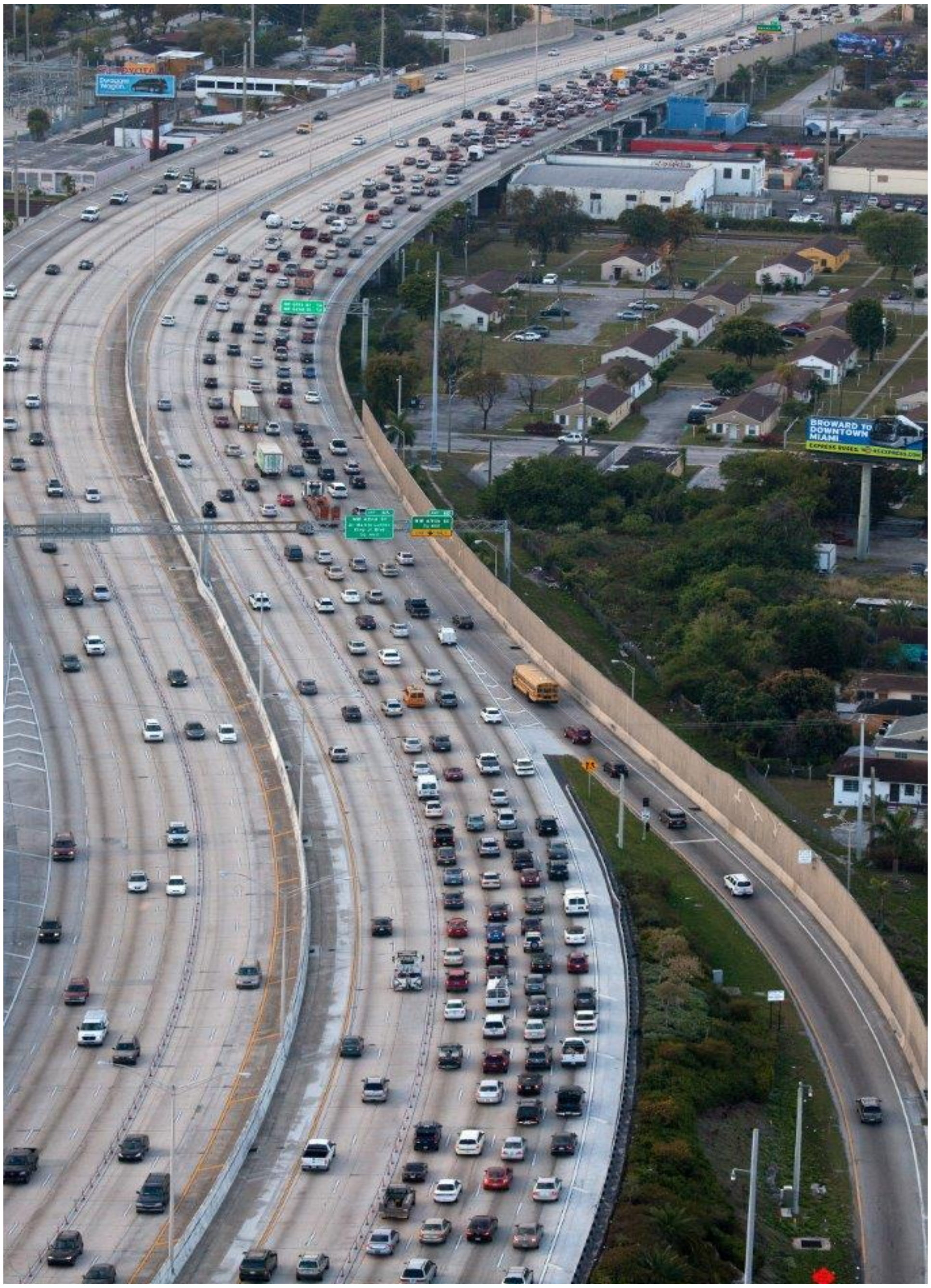


Figure 12. I-95 Express Lane With the 95 Express Bus (Note the Plastic Pylon Lane Dividers) (Source: Florida DOT)



TASK FORCE DISCUSSIONS

H

The task force deliberated on a variety of I-394 Express Lane issues that were either determined by the project management team to be of significance or determined by the task force itself to be an area of importance to be considered. The areas of discussion included:

1. Access Points/Traffic Operations
2. Hours of Operation
3. Enforcement
4. Dynamic Message Signs
5. Toll Rates
6. Type of Vehicles Allowed
7. Transponders
8. Expected Revenues
9. Public Outreach
10. Project Evaluation

Figure 13. I-95 Miami Showing HOT Lanes Free-Flowing in Peak Period Congestion

Current Performance of the I-95 Express Lanes

In 2013 the I-95 corridor generated 22 million trips and $19.6 million in revenue. The maximum toll is $7.00 and is frequently being reached. The system's "dynamic tolling" increases prices as the lanes get more congested. By driving up prices, traffic is driven back into the general-purpose lanes, easing congestion on the express lanes. Approximately 3% of the vehicles in the lane are exempted which means they may be HOV 3+ carpools, emergency vehicles or among the several other classes of exempted vehicles. The facility has a record of 90 percent reliability, meaning that target average speeds of 45 mph or greater are being maintained.

Since its opening, the 95 Express facility has had a dramatic, positive effect on travel in South Florida. During the morning peak period, average speed in the southbound express lanes has increased to 62 mph from 20 mph before the project opened, and during the evening peak, average speed in the northbound express lanes has increased to 56 mph from 18 mph before the project opened. In addition, the average peak period speed in the general purpose lanes has more than tripled southbound and more than doubled northbound. The reliability of the facility has increased as well; the speed is above 45 mph 100 percent of the time in the southbound express lanes and 92 percent of the time in the northbound express lanes. As of February 2012, the I-95 Express lanes were generating $1.3 million per month, which is 115 percent of the projected amount.

Lane Add Significantly Increased Capacity

One of the significant features of the I-95 Express Lanes is that this project included a relatively low-cost added lane in each direction. The lane-addition was accomplished by narrowing the Interstate highway standard lane width of 12 feet to 11 feet (as shown in Figure). This has been done on many freeways over the years without apparent negative effects. This priced lane capacity was provided without taking away or converting free general purpose lanes. Congestion on I-95 during peak periods was severe enough that demand for using the priced lanes was strong from opening and has continued to be after five years of operation and this success of the project is at least partially due to the performance enhancement of pricing and partly due to the added physical roadway capacity.

Transit Benefits

Transit ridership is growing significantly in the corridor because of the enhanced speed and performance. Prior to the managed lanes, the two transit agencies--Broward County Transit (in Ft. Lauderdale, about 25 miles north of Miami) and Miami-Dade Transit, operated what they called express bus service using the congested HOV lanes. Once the managed lanes opened on the most-congested stretch of I-95 just north of downtown Miami--the bus service was able to offer significantly faster travel times and reliable schedules. The two transit agencies also initiated no-transfer express service from Ft. Lauderdale to Miami.

Reliability

Research is showing that people are increasingly willing to pay not just for the time savings but also the reliability of the trip time. A recent analysis of customer opinions on the SR 91 lanes in Orange County estimated that about half the peak-period toll amount was for reliability, the other half for time savings. Feasibility assessments of proposed priced lanes should rely not only on estimated time-savings but on the trip travel time reliability as well.

STATE ROUTE 520 BRIDGE REPLACEMENT, SEATTLE WASHINGTON

Figure 14. State Route (SR) 520 Bridge; Toll Applied to Old Bridge in Preparation for New Replacement

Description

Seattle, Washington's SR 520 Bridge floating bridge over Lake Washington, formerly a free facility, has been converted to a toll bridge. This conversion is necessary in order to begin generating the funds necessary to construct a replacement facility which is estimated to cost over $2 billion. The conversion began in late 2011 while construction on the new adjacent facility got underway. An important aspect of this electronic tolling operation is the variable charge that was implemented to better manage demand on the existing facility. The charge is based on a set schedule that is highest in the peak-periods at $5.25 per trip. Tolls are collected in both directions and the purpose of the toll charge is to both manage demand and raise revenue for the new replacement structure. Tolling on SR 520 is expected to raise $1.1 billion overall toward the SR 520 Bridge Replacement and HOV Program.

The SR 520 bridge is an all-electronic tolling facility. There are no toll booths so drivers pay the toll through a *Good To Go!* account or Pay By Mail where a toll bill is sent in the mail to the vehicle's registered owner.

There were over 100,000 trips per day over the SR 520 bridge prior to tolling, and that number has been reduced by about 68,000 today due to diversions and trips that were eliminated. Photo enforcement is used to send invoices to those drivers who are not pre-registered. New transit service was also implemented on the bridge prior to the initiation of tolling on the facility.

Figure 15. SR 520 Bridge Location Over Lake Washington

When the corridor is complete, it will include six lanes, with two general-purpose lanes and one carpool lane in each direction, spanning Lake Washington from I-5 in Seattle to just west of I-405 in Bellevue. Designed to withstand earthquakes and windstorms the new SR 520 will have carpool lanes and increased transit service that will make bus trips more frequent and reliable. It also will have space for walking or riding a bike across the lake, shoulder lanes to keep traffic flowing when something goes wrong, and new interchanges to reduce traffic impacts and improve communities near the corridor.

IV. CONCLUSIONS AND LESSONS LEARNED

Congestion pricing serves to help optimize performance of highways. By putting market forces to work with congestion pricing, road authorities are able to more effectively and efficiently manage demand for highway facilities. Congestion pricing harnesses market forces and drivers respond rationally when given a rational price signal.

Use of congestion charging with dynamic pricing offers an effective way to provide sustainable operational performance on a highway or a system. Congestion pricing moves more people more reliably. It increases the capacity of existing facilities within current rights of way. Transit and carpool usage is enhanced with greater speed and reliability.

Congestion pricing works because, time-savings is important to users, but reliability and predictability are becoming more and more important to travelers. The proximity to priced and reliable facilities encourages communities to make compatible lane use decisions that are transit friendly and provide a means to preserve long-term corridor viability.

In the United States, it is clear that continued expansion of the highway system to accommodate all demand is an untenable solution. Freeways have an enormous footprint in urban areas and greatly impact quality of life for residents.

Winning public and political support can be is an enormous challenge because people don't like to pay for something that was formerly free. Communicating clearly the prupose of congestion pricing can be challenging. There are likely to be widespread disputes over the perceived purpose of road charging. Crafting and communicating the objectives of road pricing projects must be managed carefully. Once implemented, however, customers and non-customers realize that congestion pricing options offer choice and people like choice.

The key to winning public acceptance lies in the realization that congestion charges may make more efficient use of HOV lanes, enhance both travel time savings and reliability and may make the general purpose lanes also work better. The promotion of congestion pricing as an option or a choice is a particularly effective means of gaining support. Congestion charges on HOT or ETL still provide for a "free" alternative that also encourages carpooling and transit usage if these modes are given free or reduced fee options on the tolled lane or lanes. Congestion charges can help to reduce emissions from polluting vehicles by allowing them to run and operate more efficiently. Successful congestion pricing projects around the U.S. have an ongoing program to monitor performance and make operations adjustments as may be required for customer satisfaction and to enhance facility performance.

V. CONGESTION MITIGATION AND AIR QUALITY (CMAQ) IMPROVEMENT PROGRAM of the U.S. DOT

Introduction

Jointly administered by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA), the Congestion Mitigation and Air Quality Improvement (CMAQ) Program provides a flexible funding source for transportation projects and programs that help improve air quality and reduce congestion. State and local governments can use CMAQ funds to support efforts to meet National Ambient Air Quality Standards (NAAQS) under the Clean Air Act in both nonattainment and maintenance areas for carbon monoxide, ozone, and particulate matter(8).

The CMAQ program of the U.S. DOT is funded at an average annual funding level of $3.3 billion nationwide. The program is design to used as a flexible funding source to State and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act of 1991. Funding is available to reduce congestion and improve air quality for areas that do not meet the National Ambient Air Quality Standards for ozone, carbon monoxide, or particulate matter (nonattainment areas) as well as former nonattainment areas that are now in compliance (maintenance areas).

Under the program, a State with PM 2.5 (fine particulate matter) areas must use a portion of its funds to address PM 2.5 emissions in such areas. Projects eligible for funding to mitigate PM 2.5 include diesel retrofits. Eligibilities also include transit operating assistance and facilities serving electric or natural gas-fueled.

The CMAQ program also has performance-based features that the Secretary of Transportation uses to establish measures for States to assess traffic congestion and on-road mobile source emissions. Each Metropolitan Planning Organization (MPO) with a transportation management area of more than one million in population representing a nonattainment or maintenance area is required to develop and update biennially a performance plan to achieve air quality and congestion reduction targets. A CMAQ outcomes assessment study for the program is also required.

Under the latest provisions of the law greater focus is placed on projects and programs that address fine particulate matter PM 2.5 .The law requires that a portion of CMAQ funds provided to PM 2.5 nonattainment areas be used for projects that reduce this pollutant.

A State without nonattainment or maintenance areas may use its CMAQ funds for any projects that are eligible under CMAQ or the Surface Transportation Program (STP). States with nonattainment or maintenance areas that received a minimum apportionment in FY 2009 may use part of the current CMAQ funds for any STP-eligible projects.

Transfer of Funding

As under previous laws that authorized Federal surface transportation programs, States continue to have the ability to transfer CMAQ funds to FTA for award as grants.

MAP-21 also changed the approach to the transfer of CMAQ funds to other elements of the Federal-aid program. Transfers of up to 50 percent of CMAQ funds are allowed under MAP-21. States that exercise this transfer authority-cutting available CMAQ funds-could affect traffic congestion and emissions reduction efforts. Progress on those fronts will need to be reported once performance measures that are required under MAP-21 are established.

CMAQ-Eligible Activities

Under MAP-21, CMAQ funds continue to be available for a wide range of transportation projects, but new language in the act emphasizes select project types, including electric and natural gas vehicle infrastructure and diesel retrofits. Eligible activities include (but are not confined to) the following:

- Advanced Truck Stop Electrification Systems
- Alternative Fuel Projects
- Bicycle and Pedestrian Improvements
- Diesel Retrofits
- Idle Reduction Technology
- Intelligent Transportation Systems
- Intermodal Freight Transportation
- Public Education and Outreach
- Public Transportation Improvements
- Traffic Flow Improvements
- Travel Demand Management
- Vehicle Inspection and Maintenance Programs

MPO Performance Plans

The law requires each metropolitan planning organization (MPO) meeting the following two criteria to develop a performance plan to achieve targets for emissions and congestion reduction: (1) serving a Transportation Management Area with a population greater than 1 million; and (2) representing a nonattainment or maintenance area. The MPO performance plans must be updated biennially, and each update must include a retrospective assessment of the progress made toward the performance targets for air quality and traffic congestion. The Secretary of Transportation will establish performance measures for States to use to assess traffic congestion relief and reductions in mobile source emissions.

Evaluation of Projects

The Secretary of Transportation must maintain and disseminate a cumulative database describing the impacts of CMAQ projects in terms of reducing congestion and emissions. Data collected must include project name, location, sponsor, cost, and cost-effectiveness (based on reduction in congestion and emissions) to the extent already measured. The Secretary, in consultation with the U.S. Environmental Protection Agency (EPA), must also evaluate the cost-effectiveness of projects periodically and share the results with States and MPOs so that they can use them in selecting future projects.

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Congestion Pricing for New York City: Past Failure, Future Success?

Charles Komanoff

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February, 2014

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Photo at right depicts the author presenting at the International Forum on Economic Policies for Traffic Congestion and Tailpipe Emissions in Hangzhou, China, on Dec. 12, 2013.

Photo at right depicts the author in Guangzhou in March 2010, during a break from the International Symposium on Analysis and Countermeasures of Traffic Congestion in Urban Centers in that city, sponsored by South China University of Technology.

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1. Introduction

Of all the world's cities, New York would seem to be the best suited for congestion pricing. Consider these powerful "drivers" for tolling vehicle entry to the Manhattan Central Business District (CBD):

- Both the CBD and the roads and bridges leading to it are notoriously congested, costing businesses and commuters billions of dollars in time and uncertainty year in and year out.[1]
- The CBD is clearly demarcated by natural and man-made boundaries, making tolling of entrances a straightforward proposition technically and conceptually. (See New York City map on next page.)
- The "radial" configuration of commuter-rail and subway routes ensures that most trips by car to the CBD have viable transit alternatives. Indeed, in the 24-hour course of an average weekday, four out of every five people entering the CBD already do so on a subway, commuter train or bus rather than in a car, truck or taxi.[2]
- Nevertheless, the city and regional public transportation network is chronically under-financed, ensuring that any potential new revenue source is given serious consideration.
- People's attraction to the CBD, whether for commerce, entertainment or sheer human contact, is so great, and many drivers' attachment to their cars is so strong, that most vehicle trips to the CBD will likely continue even in the face of a new toll, thus guaranteeing that congestion charging will generate significant revenue.

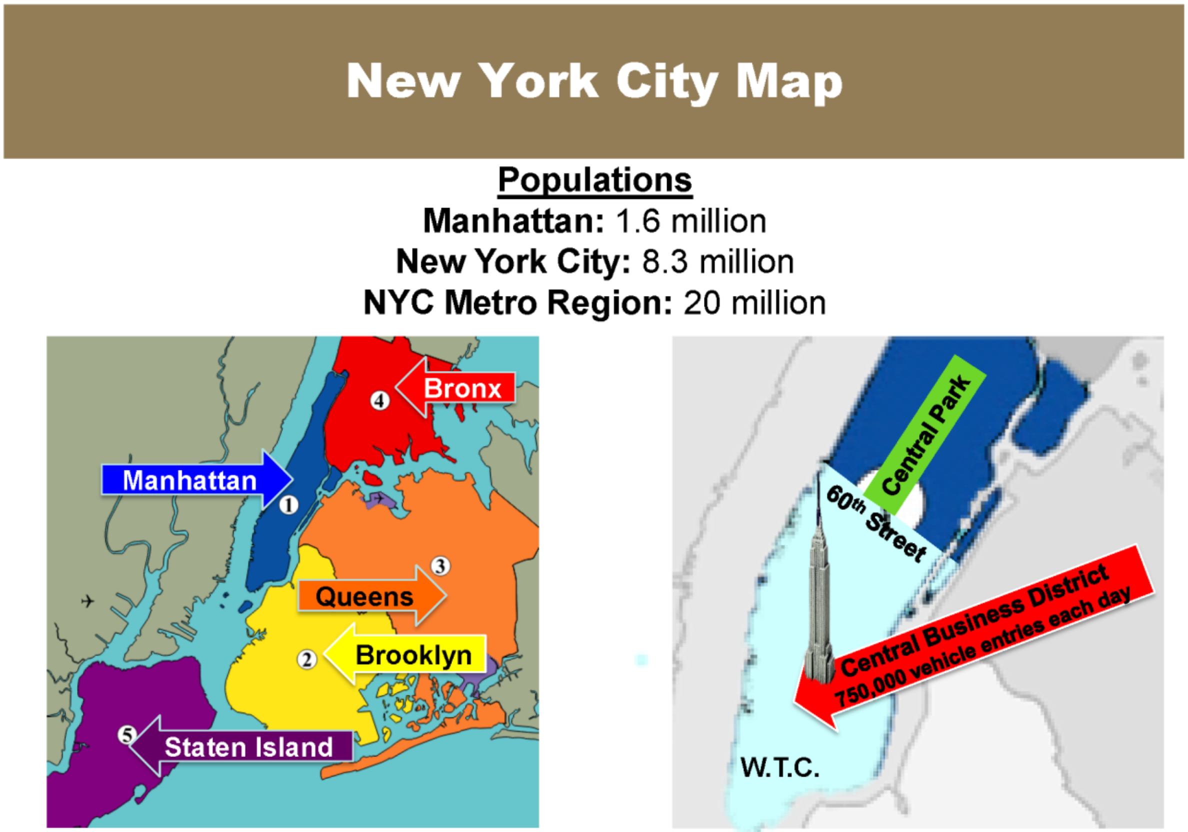
These factors would appear to make congestion-charging of the Manhattan CBD a classic "win-win" proposition. With a congestion toll, drivers save valuable highway time, first as some car trips are "priced off" the roads, and again as investment of toll revenues to improve public transportation draws off more trips. Transit users gain directly as their daily rail, subway and bus trips are made faster and more reliable. Businesses benefit as New York solidifies its status as a "world city" and gains increased economic activity.

2. The Bloomberg Congestion Pricing Attempt (2007-08)

These considerations motivated then-mayor Michael Bloomberg in 2007, when he unveiled a plan to charge an $8.00 fee for each car trip into the heart of Manhattan made between 6 am and 6 pm on weekdays. The proposal, which was patterned after London's congestion charging scheme begun four years earlier, would have applied to vehicles entering Manhattan's central area via any of the four free bridges that cross the East River from Brooklyn and Queens, or by crossing 86th Street from northern Manhattan or the Bronx. Trips into the CBD via the two tunnels under the Hudson River from New Jersey and one tunnel each from Brooklyn and Queens, all of which are already tolled, wouldn't be charged beyond their current toll. Trips *within* the charging zone would be tolled at $4.00, half the full rate, to ensure that Manhattan residents who drove on the district's jam-packed streets paid for adding to congestion.

[1] The city's premier business association, Partnership for New York City, placed the cost of traffic congestion in the New York City region at $13 billion/yr in a 2006 report, "Growth or Gridlock? The Economic Case for Traffic Relief and Transit Improvement for a Greater New York." <www.pfnyc.org/reports/Growth%20or%20Gridlock.pdf>.

[2] See BTA spreadsheet, "Travel" tab. The BTA is summarized, and a Web link is provided for it, in the Appendix.



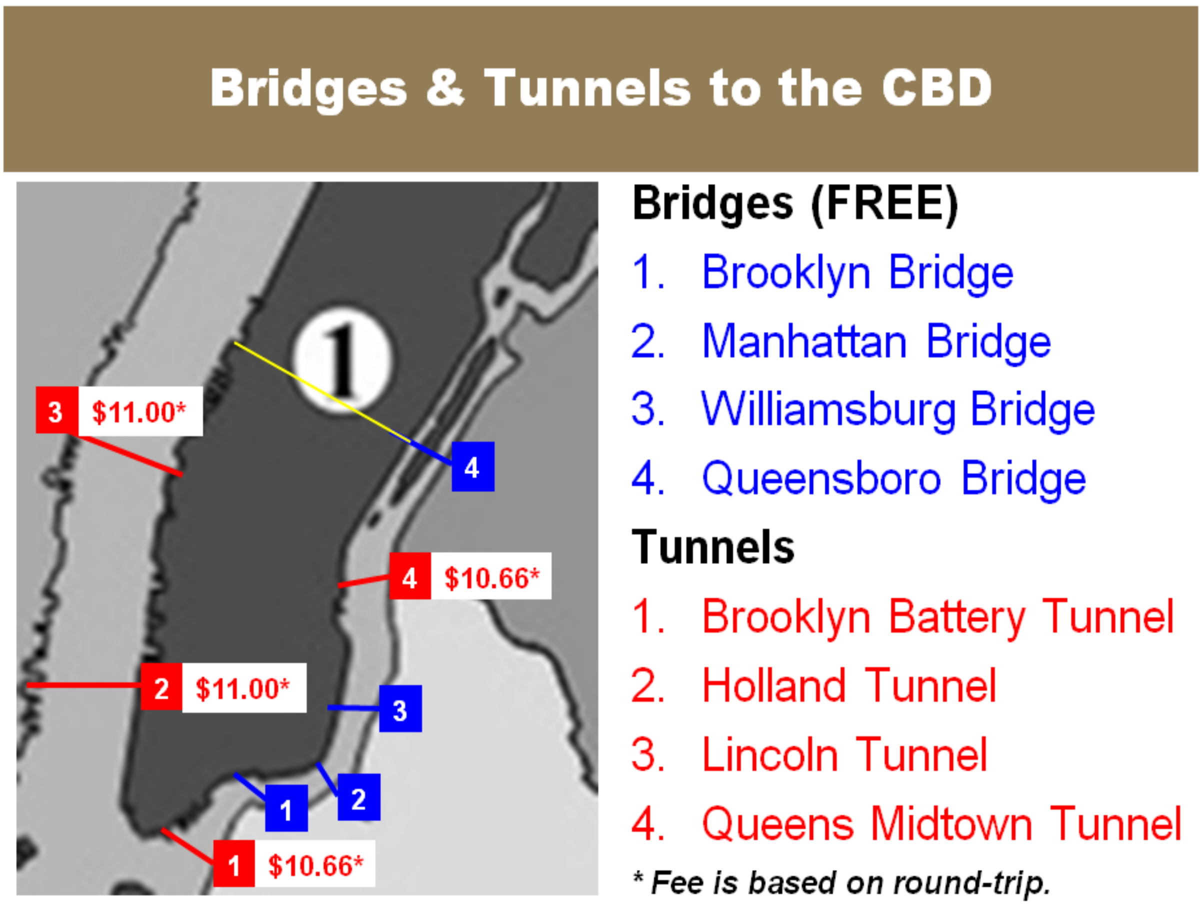
The Bloomberg plan was intended as a departure from past proposals in prior decades to toll the East River bridges , all of which had failed to win political approval. First, the Bloomberg plan would toll vehicles entering the CBD from the north as well as via the East River bridges, thus mitigating the sense of drivers from Brooklyn and Queens that they were being singled out to solve what was actually a multi-directional congestion problem.[3] Second, the plan would transact tolling largely via digital means, thus obviating the need for toll plazas and dispelling the idea that tolling would *add* to congestion and pollution by causing idling vehicles to queue at toll plazas.

Rather, Mayor Bloomberg insisted, his toll plan would make New York City "greener" by curbing vehicular traffic and, thus, improving air quality and reducing carbon emissions. Indeed, the mayor made his congestion pricing plan the centerpiece of an ambitious set of environmental initiatives grouped under the rubric "PlaNYC" which he rolled out during Earth Day observances, in April 2007, at a time of heightened environmental awareness and concern. The title of the mayor's PlaNYC report, "A Greener, Greater New York," embodied his philosophy that the city had to become green in order for it to prosper

[3] Motor vehicles enter the Manhattan CBD via three "portals," with the East River bridges and tunnels accounting for 39 percent, the two Hudson River tunnels accounting for 13 percent, and the remaining 48 percent entering from the north. These figures are available in the BTA spreadsheet, "Hub-Bound" tab.

and grow.[4] Moreover, Bloomberg was riding a tide of popularity and good feeling as a visionary yet business-minded mayor who was looking out for the city's – and the world's – long-term interests.

Yet the plan did not pass, and today, seven years later, New York City still has no congestion pricing. Instead it is saddled with what it has had almost as far back as the end of World War II: a toll patchwork in which most routes to the CBD are un-tolled while drivers pay ever-increasing tolls to use bridges in outlying parts of the city; a chronically underfunded public transportation system that must scratch for funds to pay for "state-of-good-repair" maintenance and sorely-needed upgrades; and endemic traffic congestion.[5]



Of late, these conditions have inspired advocates outside of government to develop a new proposal to embed congestion pricing within a more holistic "rebalancing" of the city's byzantine toll system — an approach that, they hope, might win over many of the naysayers who derailed the 2007 plan. I'm a

[4] The full PlaNYC report, "A Greener, Greater New York," is available at http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/full_report_2007.pdf.

[5] Compounding congestion in several neighborhoods within or en route to the Central Business District is a phenomenon known as "toll shopping," in which drivers detour around tolled entrances and gravitate instead toward free ones. This practice is pronounced among drivers of heavy-goods vehicles — the very traffic that should be minimized in the CBD — since their toll rates are especially high.

participant in that initiative and will describe it in Section 3, below. To set the table, let's summarize the factors that contributed to the defeat of Mayor Bloomberg's congestion pricing plan in 2007-08:

- To begin, New York City's municipal authority to impose congestion tolls is not settled in law. The Bloomberg administration was therefore forced to seek approval for its plan from the New York State Legislature, a more conservative, suburban-rural and automobile-oriented body than the relatively liberal, urban and transit-oriented New York City Council.
- Included in the mayor's initial plan was a network of nearly 400 tolling cameras within the CBD to charge car trips that remained within the charging zone. The intent was laudable, but the scheme's complexity undercut the elegance of tolling just the entrances to the CBD. Moreover, the cameras seemed invasive to some New Yorkers and contributed to a sense that congestion pricing was an alien intruder into the cityscape.
- The Bloomberg plan was further complicated by a host of exemptions: rebates for tolls paid "upstream" en route to the CBD, free passage for chauffeured "radio cars" used primarily by the affluent elites, and steep discounts for trucks that met low-emission standards, among others. Though each exception was meant to assuage a particular (and in some cases powerful) political constituency, the combination made the tolling scheme more convoluted and conveyed a whiff of favoritism.
- Over the years, the intended recipient of the Bloomberg plan's net revenues, the Metropolitan Transportation Authority (MTA), had continually been derided as inefficient and incompetent by elements of the media and certain politicians, often the very officials whose budgetary decisions starved the authority of needed funds. This negative aura persisted even in the face of steady gains in ridership and reliability for the MTA's subways, buses and commuter rail lines — so much so that much of the public never trusted that the plan's prospective transit benefits would actually materialize.
- The very idea of tolling vehicular access to the Manhattan CBD fed a gnawing sense that the interests of the 80 percent of New Yorkers from the "outer boroughs" were being subverted to a scheme that would largely benefit "gilded" Manhattan. This was felt especially by residents of Brooklyn and Queens, the city's two most populous boroughs, whose "right" to drive into the CBD on any of the four East River bridges without paying a toll was jealously guarded by local politicians.
- Closely connected to "borough resentment" was the notion that congestion pricing ran counter to New York's democratic grain by rationing car access to the CBD on the basis of ability to pay. The idea that rich drivers would now have the public roads and bridges all to themselves quickly took hold and was never fully dispelled.
- In retrospect, it was probably unwise to unveil the congestion pricing proposal at an Earth Day celebration. That the Bloomberg proposal would shift the city's transportation balance incrementally away from cars and toward transit was good enough for most environmental-minded New Yorkers, without explicit green branding. But some car-dependent "outer-borough" and suburban residents with less-attuned environmental sensibilities reacted negatively to what appeared to be the mayor's green messaging. Moreover, the administration never quantified the prospective gains in air quality, undercutting not only its messaging but its overall credibility in selling the plan.

- Also working against congestion pricing was its novelty. The idea of modulating vehicular access to a city through tolling had never been attempted in a U.S. city. Efforts to cite its success in Singapore, London and, most recently, Stockholm, fell flat among New Yorkers who regarded their city as unique. Instead of picturing quieter and less-congested "upstream" streets and tolls collected electronically "at speed," many residents envisaged traffic-jams at "toll booths" and around transit stops in outlying neighborhoods (the latter as CBD-bound drivers seeking to avoid the new toll cruised for parking instead). Machiavelli's dictum that the inherent difficulty of imagining innovation's fruits makes it hard to muster supporters applied dearly to this first-ever U.S. effort to enact congestion pricing.
- The city's media culture, always eager for controversy, handed a megaphone, as it were, to detractors who played their moment in the limelight to the hilt. Incidental flaws were cast as fatal ones, and an innovative proposal intended to enable New York to grow and prosper became caricaturized as a cynical ploy by the billionaire mayor to crush hardworking drivers and squeeze the soul from the city.
- City officials blundered by failing to consult beforehand with the myriad "stakeholders" — civic leaders, labor unions, local business groups, motorist and trucker associations, and lesser elected officials — who shape public opinion and hold sway over state legislators who would vote on the plan. Especially for a novel idea such as congestion pricing, the lack of preparatory groundwork guaranteed that the initial reaction would be puzzlement rather than enthusiasm.

In July 2007, three months after the Bloomberg plan was made public, the state governor appointed a blue-ribbon study commission which in January 2008 recommended a half-dozen important changes. One was to move the charging zone's northern boundary some 2 km south to the generally accepted northern boundary of the CBD, at 60th Street. Another change eliminated the intra-CBD toll and thus dispensed with the 400 cameras, but at a cost of reducing the toll "incidence" of Manhattan residents who were already seen as bearing too little of the costs.

As the debate wore on, the plan never gained the necessary traction. The confluence of the problems summarized above came to have greater political weight than support from business, environmental and "good-government" constituencies. Moreover, the reduced impact on traffic was viewed skeptically, with the single-digit gains in travel speeds forecast within the CBD (and far lesser reductions outside it) dismissed as marginal. And in a classic instance of "aspiration" trumping direct self-interest, many among the city's non-car-owning majority (55 percent of households) appeared to resent the *idea* of paying a toll to drive to the CBD more than they welcomed the promised dip in traffic and boost in transit service.

The Bloomberg proposal passed the City Council in March 2008, though not decisively and only after considerable arm-twisting by the mayor. In the same month, the plan lost its biggest backer in the state capital when the governor resigned in a sex scandal that pushed congestion pricing into the shadows. In April, the powerful and cagy leader of the lower legislative house, claiming the bill lacked a majority, declined to bring the measure to a vote. Congestion pricing for New York City, and the mayor who championed it, had suffered a stinging defeat.[6]

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[6] For an excellent and detailed account of the genesis and demise of the Bloomberg pricing plan, see "New York City's Congestion Pricing Experience and Implications for Road Pricing Acceptance in the United States," *Transport Policy* 17 (2010) 266-273, http://www.nyc.gov/html/dot/downloads/pdf/schaller_paper_2010trb.pdf. Its author,

3. A New Traffic-Pricing Proposal: "Move NY"

That was six years ago. In the interim, a confederation of transportation planners, transit proponents and what have come to be called "livable streets" advocates have fashioned an alternative proposal. The new plan is variously known as the "Move NY" plan, for the coalition that is gathering support for it; the "Sam Schwartz" plan, for its progenitor, a former high-ranking city traffic engineer who is held in broad esteem in New York City; and the "fair plan" or "toll rebalancing plan," because its most striking element is a wholesale reconfiguration of the city's bridge and road tolling system to make it more equitable and efficient.

The plan's proponents, of whom I am one, set as their fundamental precept that vehicles should be tolled most heavily on travel corridors that are badly congested and that also offer robust transit alternatives to driving; and that tolls should be lighter where congestion is less severe and where non-driving options aren't so readily available. From the standpoint of political acceptability, it would also be essential that tolling's costs and benefits be shared among the city's five boroughs, between the city and its suburbs, and between transit riders and drivers.

Moreover, to make congestion charging appear less arbitrary and more a logical extension of policies already in place, the tolls and other plan features should use "default" values that duplicate current practice. The Move NY plan does precisely this by setting its proposed level for the CBD fee to match the $5.33 toll (charged in both directions, i.e., $10.66 round-trip) that drivers currently pay to enter the CBD on the MTA's two tunnels under the East River from Brooklyn and Queens.

Moreover, since the MTA collects tolls on its bridges and tunnels 24 hours a day and on weekends as well as weekdays, the new congestion charge to enter (and exit) the CBD should also apply round-the-clock and every day of the week. Both features — the price, which, even adjusted for inflation, exceeds somewhat the $8.00 round-trip toll in the Bloomberg plan, and, more importantly, "24-7" collection (rather than just 12 hours for 5 days) — have the important corollary benefit of maximizing toll revenue, which, as we shall see, is another linchpin of the Move NY plan.

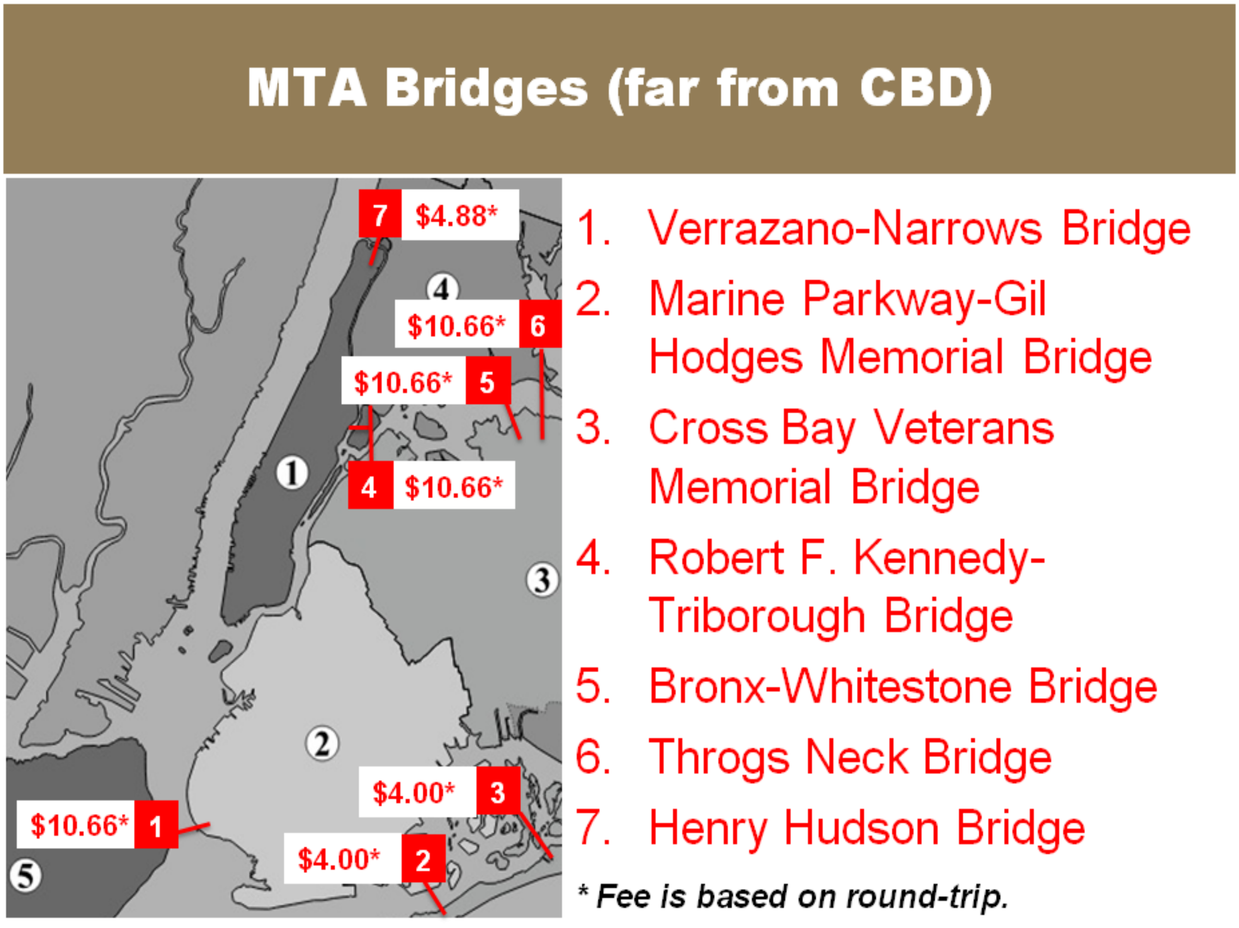
Here are the main elements of the Move NY plan (all results are derived from the BTA spreadsheet, which is discussed at length in the Appendix):

- *CBD toll* — All passenger vehicles will pay the same toll to enter and to exit the Manhattan Central Business District, $5.33 in each direction, that is now charged on the MTA's two tunnels under the East River between the CBD and Brooklyn and Queens.[7] Commercial vehicles will pay more (according to the number of axles), but their toll will be limited to one round-trip per day in a concession to service vehicles making multiple daily trips. The toll will be charged every hour

Bruce Schaller, a NYC Dept. of Transportation Deputy Commissioner since 2007, actively participated in designing and advocating for the plan.

[7] The $5.33 amount, and all toll figures in the text, pertains to trips by vehicles equipped with the regional digital toll-paying transponder known as E-ZPass. Non-equipped vehicles, which currently account for a little less than 20 percent of tolled trips in and around New York City, pay either with cash at toll booths or via mail, and are surcharged $2.17 per each one-way trip.

of the year. Accounting for toll attrition, which we estimate will remove from the roads one in every seven vehicle trips to the CBD, the new toll is expected to raise $1,700 million per year.[8]



- *Toll swap* — The MTA currently charges $5.33 for travel in either direction on its four "major" bridges serving outlying parts of the city (one connecting Staten Island and Brooklyn, the other three connecting Queens and the Bronx, with one also having a spur to northern Manhattan, 5 km from the CBD).[9] This toll will be reduced by $2.50, under the Move NY plan. Analogous discounts will be applied to the lesser tolls on the MTA's three "minor" bridges which also serve outlying precincts. These reductions will *reduce* current MTA toll collections by $605 million a

[8] See BTA "Results" tab, Part 5, for estimate that vehicular trips to and through the CBD will fall by just under 15 percent; this figure is the result of an iterative calculation that incorporates the "rebound effect" by which the improved vehicle speeds resulting from the initial drop in traffic re-attract some trips despite the toll. See pie chart directly below for a breakout of the revenue components of the Move NY Plan; the same figures may be found in the BTA "Revenues" tab, though they are derived in two other tabs, "Motor Vs" and "Motor Vs Weekends," each of which is more than 1,000 rows long, on account of the many "rebound" iterations required to reach equilibrium.

[9] Actually, the Staten Island – Brooklyn span, known as the Verrazano-Narrows Bridge, departs from this pattern, charging the entire round-trip toll of $10.66 westbound while eastbound passage is free. This anomaly contributes to the suboptimal "toll shopping" phenomenon mentioned earlier.

year, although $75 million of that lost revenue is expected to return as the toll reduction stimulates an increase in use of the MTA bridges.[10]

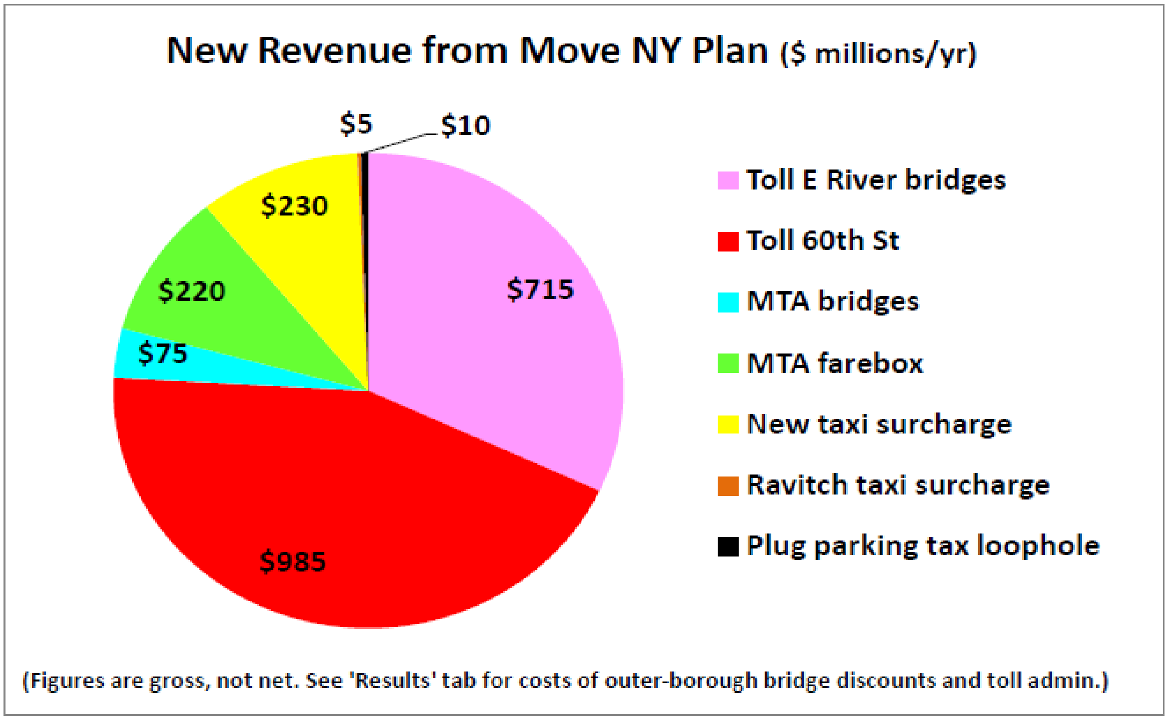
- *No change to tunnel tolls* **—** There are four vehicular tunnels to the CBD — two from Brooklyn and Queens, operated by the MTA, and two from New Jersey to Manhattan under the Hudson River, operated by the bi-state Port Authority. Current tolls on those tunnels will remain in place.
- *Yellow cabs* **—** The new CBD toll will *not* apply to the City's fleet of some 13,000 yellow taxicabs, which, though relatively few in number, nevertheless account for 40 percent of vehicle kilometers traveled in the CBD. Although most yellow cab trips begin and end within the CBD, charging a $5.33 toll for trips that enter or leave would lead to both "gaming" and a mismatch between the tolls and congestion causation. Instead, the Move NY plan envisions surcharging all three elements of the taxi fare structure, with the greatest percentage increase, 20 percent, applied to the "wait time" charge (since it is a close proxy for traffic congestion), with lesser increases of 15 percent on the fare "drop" and the distance charge. A typical cab trip, with an average distance of 4.5 km, will be surcharged $1.47, a rise of 14 percent, but slightly less, $1.22, on weekends, when the surcharge rates will be lower in recognition of less frequent transit availability and also lesser traffic congestion.[11] The resulting revenue, estimated at $235 million a year, will contribute to the revenue stream from the congestion charge.[12] As we point out below, the taxi surcharge is essential for ensuring that residents of Manhattan, who account for a large majority of taxi use, shoulder a fair share of the new tolls and charges.
- *Farebox windfall* **—** A further $220 million is projected to be generated from a projected 7 percent increase in subway trips stemming from the combined "stick" of the congestion charge (as some priced-off car trips are converted to transit) and "carrot" of improved transit service brought about from investing toll revenues in transit maintenance, upgrades and expansions.
- *A garage fee* **—** Finally, an estimated $10 million is raised by eliminating a decades-old entitlement by which Manhattan residents receive rebates of a citywide supplemental excise tax charged on garage storage of private autos. Though the amount is small, this step is symbolically important in signifying the intent of the Move NY plan proponents to charge Manhattan residents their fair share of the new charges.

Total revenues are estimated at $2,240 million a year, though this reduces to a net of $1,465 million after accounting for the "toll swap" (bridge toll discounts) as well as the estimated $170 million annual cost to administer the tolling system. Even with the swap, which will cost on the order of $600 million a year, the $1,465 million annual net revenue is nearly triple the $500 million per year that was anticipated to be raised through the Bloomberg plan. The primary reasons for the difference are, first, the Move NY toll is charged all 168 hours a week instead of just 60; second, the toll level, $10.66 round-trip, is higher than Mayor Bloomberg's $8.00; third, the Move NY plan does not rebate upstream tolls; fourth, the Move NY taxi surcharge is several times larger than that in the Bloomberg plan.

[10] The revenue cost of discounting current tolls on the MTA bridges is estimated in the BTA tab, "MTA Crossings."

[11] The overall taxi fare hike from the surcharges is less in percentage terms than the rises in the three fare components because the improvement in travel speeds reduces the wait-time charge.

[12] Included in the $235 million figure is an anticipated $5 million rise in a prior taxi surcharge fund. Note also that the proposed Move NY taxi surcharges on distance driven and wait time will not apply to travel outside the portion of Manhattan Island south of 96th Street.



4. Investing the Move NY Toll Revenues

How the nearly $1.5 billion in available annual revenue is to be spent will obviously be a matter of intense interest to the public and policy-makers. Under the Bloomberg plan, all of the net revenue was to be allocated to transit service improvements and enhancements. Move NY is proposing a somewhat different approach, with roughly one-fourth of the revenues to be made available to maintain and upgrade area roads and bridges, and the remaining three-fourths applied to transit. Even with this split allocation, the expected amount available for transit, roughly $1.1 billion a year, is easily double what would have been available under the Bloomberg plan — demonstrating the importance of maximizing the total revenue realized under the Move NY plan.

The intent is to win over motorist interest groups that have become inured to the idea that toll hikes benefit them by enabling transit upgrades that lure "other drivers" to public transportation. To the extent that this idea ever caught on with NY-area drivers, it has been overtaken by resentment against ever-rising toll increases on bridges used largely by drivers who are not journeying to the CBD and thus see little if any benefit from improving the primarily radial transit network. Instead, the Move NY plan can be said to benefit drivers in two ways that are new to congestion pricing in New York City, and perhaps elsewhere as well: by financing improvements in roads and bridges, and by cutting tolls on the outlying bridges nearly in half.

Assuming that net toll revenues are split 75/25 between transit and roads, the Move NY plan is expected to change travel in and around New York City in the following ways:[13]

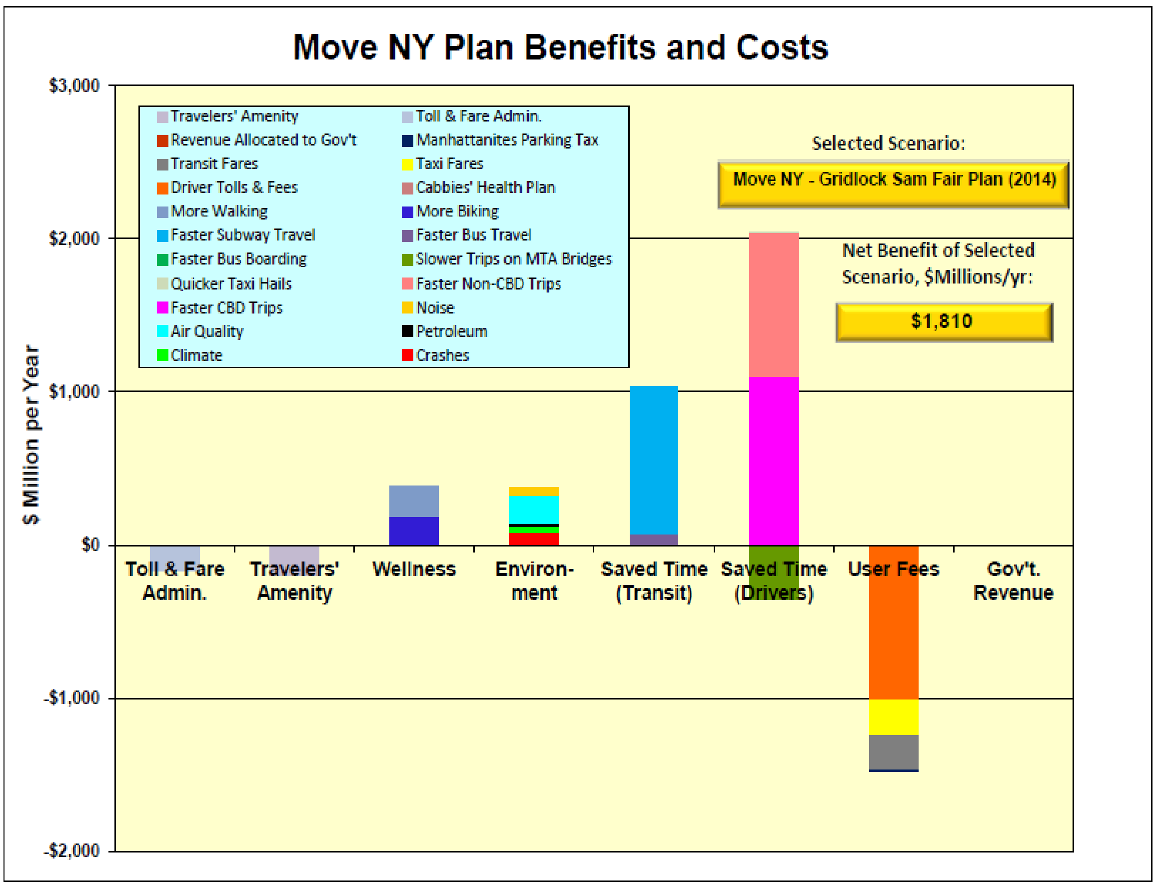
[13] All modeling results are shown in the BTA's "Results" tab.

- The number of daily motor vehicle trips into the Manhattan CBD will decline by around 15 percent.
- Vehicle speeds within the CBD will increase by 18 to 20 percent, on average. Speeds on roads and bridges leading to and from the CBD will increase by an average of 5 to 6 percent.
- Total driving within the CBD will decline, of course, but only by 7 to 8 percent. This modest decline reflects the prevalence of taxis in CBD traffic (around 40 percent). It nevertheless triggers a double-digit improvement in average travel speeds because under current hyper-congested conditions, even a small pullback in traffic levels evokes a sizeable reduction in paralyzing gridlock.
- Subway use is expected to increase by 7 percent, though bus usage rises much less, just 1 percent. (Subway trips already outnumber bus trips by two-and-a-half to one, making the gain in subway usage more significant.) The number of taxi trips is expected to grow by 4 percent, since time-sensitive taxi users are expected to be more attracted by the improved CBD travel speeds than they will be repelled by the fare surcharge. The average number of fares per a taxi driver's 10-hour shift rises by 16 percent, raising incomes for drivers and fleet owners alike — an important selling point to this influential (and iconic) sector of the city's transportation network.
- Dividing up the total net revenue according to the borough or county of residence of drivers and taxi takers who will pay the new tolls and surcharges (some of whom will also pocket the savings from the discounts on the outlying bridges), the largest cost share, 23 percent, will be borne by residents of Manhattan. Residents of the city's four other boroughs will contribute 43 percent, and the remaining 34 percent will be paid by residents of the surrounding suburbs along with travelers and tourists (many of whom use taxicabs) from more distant areas. This is a sharp reversal of the incidence under the Bloomberg plan, in which Manhattan residents would have contributed just 13 percent of total revenues.[14]

[14] The various borough or county shares of the new tolls are shown in the BTA's "Incidence" tab. The alternative shares under the Bloomberg congestion pricing plan may be seen by substituting that plan's parameters for those of the Move NY plan, which may be done with a single keystroke in the BTA's "Results" tab.

5. Cost-Benefit Analysis of the Move NY Plan

A cost-benefit analysis of the Move NY plan, in which the various benefits are monetized so they can be fairly compared, reveals a number of important findings. First, traveler time savings (a proxy for transportation efficiency) dominate the anticipated benefits, far outweighing the environmental benefits. This underscores the importance of representing traffic pricing for New York City as an efficiency plan rather than a green program. (Of course, any measure that improves New York's economic viability can fairly be said to be "green" insofar as it allows the city to retain or attract residents and businesses that might otherwise locate in the neighboring or distant suburbs, where the relative absence of mass transit, the prevalence of single-family homes, and the general substitution of sprawl for proximity all cause per capita energy use to be several times greater than in denser cities.)



Second, the societal benefit from the expected increase in "wellness" via active transportation (cycling and walking) is comparable to the aggregate environmental benefits from lower air and carbon emissions, fewer traffic crashes, less traffic noise, and reduced petroleum requirements. This would not have been the case forty or even twenty years ago, when per-km car and truck tailpipe emissions were perhaps 10 or 5 times as great, respectively, as they are today.[15] In countries that have

[15] These ratios are the author's rough estimates and are meant to capture the extraordinary progress in reducing emissions from on-road vehicles in the United States since circa 1970.

not yet reduced vehicle emission rates to the same extent, the relative environmental benefits from congestion pricing, due to both the reduction in vehicle use and the improved combustion efficiencies for the cars that continue to be driven, would be far greater than shown here.[16]

Third, a significant portion of the anticipated travel time savings from the Move NY plan accrues to trips that do not cross into the Manhattan CBD and, thus, will not face the new toll, but will nevertheless be made faster because traffic streams on the same roads have been thinned somewhat. Harnessing these "free riders" to support the Move NY plan presents an important political opportunity, though a challenging one because they are somewhat geographically dispersed and because of the inherent difficulty of framing avoidance of a cost as a benefit.

6. Potential Political Advantages of the Move NY Plan

Will the Move NY plan be more attractive politically than the Bloomberg plan that was unable to be enacted in 2007-08? Here are some potential advantages:

- The toll swap (reducing tolls on the "outer" MTA bridges while instituting them on the "inner" East River bridges and at 60th Street) could appeal powerfully to car-dependent New Yorkers, who are heavily represented in large parts of the outer boroughs and the neighboring inner suburbs, and whose elected representatives lined up against the Bloomberg plan. The persistent increase in tolls on the MTA bridges has reached a flash point, and toll relief would be both an economic boon and an important gesture for many area residents who bristle at having their toll dollars support a transit system they regard as benefiting others at their expense.
- The taxi surcharge will ensure that residents of Manhattan, who account for 70 percent of yellow-cab trips, collectively contribute the most to the new tolls and fees, helping neutralize the resentment of the Bloomberg congestion pricing plan as a giveaway to wealthy Manhattanites.
- Move NY is building support for the plan in hundreds of individual and small-group conversations with leading stakeholders, a process that emphasizes inclusion rather than reliance on expert authority or government fiat.
- The plan is being branded as an efficiency plan rather than an environmental one, thus keeping the focus on infrastructure and economy and making it possible for organizations and office-holders to support it without having to identify as greens.
- Sam Schwartz, the public face of the Move NY plan, is a well-known and respected traffic engineer with genuine New York "street cred." This is a marked difference from having congestion pricing fronted by a fabulously wealthy mayor who in theory could pay one CBD toll every second in perpetuity without blinking an eye.

[16] The dual impacts of congestion pricing on total tailpipe emissions — at the individual vehicle level and the "system" level — point to a dilemma for proposals to exempt electric or other clean-fuel vehicles from congestion charges. The concern is that while a zero-emission vehicle will not directly add exhaust to the local airshed, its incremental contribution to traffic congestion will cause a reduction in combustion efficiency, with a corresponding increase in emissions, among other fuel-burning vehicles in its vicinity. The author speculates that where traffic congestion is prevalent, which is precisely where congestion pricing is most recommended, this system-level increase in emissions could be considerable — an hypothesis that is ripe for modeling.

A Comparison

Bloomberg 2007-08: Summary	Move NY 2014-15: Summary
Vision	**Vision**
• Environmental	• Transport/Economy
Main Proponent	**Main Proponents**
• Billionaire Mayor	• Business + Labor + Community
Features	**Features**
• $8.00 round-trip, 12 x 5	• $10.66 round-trip, 24 x 7
• Small taxi surcharge	• Large taxi surcharge
• MTA bridges unchanged	• MTA bridges $5.00 less
Results	**Results**
• CBD Speed gain: 8%	• CBD Speed gain: 18-20%
• Net revenue: $520M/year	• Net revenue: $1,465M/year
• Manhattan pays: 13% of total	• Manhattan pays: 23% of total
• MV share to CBD: 17% (now 19%)	• MV share to CBD: 16% (now 19%)

- The nearly billion-and-a-half dollars that the new revenues will make available each year for transit and other transportation improvements is a large enough sum to attract support from contractors, construction unions, transportation officials and other stakeholders who customarily resist major changes from the status quo.
- The Move NY plan is simpler and more straightforward than the Bloomberg plan: no night-time or weekend exemptions, no rebates for upstream tolls, no exceptions for various classes of vehicles or drivers. The toll corresponds to the current toll paid on MTA bridges and tunnels rather than being pegged to an arbitrary level. The only intellectually complicating factor is the toll swap, which furnishes the “honey” that is turning many opponents into adherents.

7. Problems the Move NY Plan Must Overcome

On the other side of the ledger is the provision in the Move NY plan to toll off-peak trips to the CBD, even those made during the “graveyard” shift or on weekends, at the same rate as daytime peak trips. While this has a clear precedent in the unvarying 24-hour nature of the MTA’s bridge and tunnel tolls, it does impose the new toll on trips that would have avoided the Bloomberg toll. On the other hand, the adage “in for a penny, in for a pound” could be said to apply to congestion pricing: if New York is going to toll car trips to the Manhattan CBD, it may as well go all the way and raise truly large sums that can produce transformative gains in the region’s transportation network. (At a later date, once the CBD toll has been established, all city bridge and tunnel tolls could be switched to a time-varied regime.)

A further problem for Move NY is that traffic levels have declined somewhat since 2007-2008 — not by much, but enough to remove the specter of ever-worsening gridlock and weaken the motivation to toll to alleviate congestion. This is dictating a broadened emphasis to the Move NY effort, with equal weight given to easing congestion, correcting toll imbalances and inequities, and creating a robust new revenue source to pay for better transportation infrastructure. That is in contrast to the Bloomberg focus on congestion relief and environmental improvement.

Most problematic, perhaps, is the persistence of the MTA’s reputation for inefficiency. Hearteningly, the Metropolitan Transportation Authority has elevated its public image of late, with its widely praised rebound from the hurricane that inundated the subways and much of the city in 2012, with service innovations such as real-time train-arrival information via “countdown clocks” on subway platforms, and with more open and responsive management. Yet the Authority continues to be defined more by perennial delays and escalating costs for its two “mega-projects” — a new Manhattan subway line and a new tunnel to expand commuter-rail access to the heart of the CBD. Start dates for both projects have been pushed back numerous times, feeding the popular notion that new funding for the MTA is money poured down a rat-hole.

Move NY Campaign: Strategy + Schedule

- Emphasize:
  - Revenue (40%)
  - Efficiency (30%)
  - Toll Equity (20%)
  - Environment (10%)
- Quietly build public and political support.
- Late 2014-Early 2015 “window”:
  - After New York State elections (Nov. 2014)
  - Plug hole in MTA Capital Plan (starts 2015)

In response, the Move NY strategy must be to ensure that funds made available to transit from the toll revenues don’t directly feed the mega-projects but are directed instead to smaller capital projects that directly benefit service delivery and reliability and whose impacts will be felt across the system, rather than only in selected corridors. This is no easy task, insofar as Move NY does not control MTA capital budgeting, and given the public’s limited understanding that massive investments are required just to keep the region’s extensive transit network in a state of good repair. Conveying the value of transit investments is thus a key piece of the hundreds of small-group meetings that the Move NY team has been holding with stakeholders across the region.

The fate of the Move NY plan may be determined in the next 12 months. As shown in the graphic, the political “window” to enact the necessary state legislation opens in late 2014, immediately after the gubernatorial election, and extends to April 2015, when the legislature adopts the state budget for the next fiscal year. Also in that interval, the MTA must have a funding plan in place for its next 5-year capital plan, and the alternatives — raising gasoline taxes, hiking sales taxes, increasing the unpopular regional payroll tax, or more borrowing which will lock in fare hikes in future years — appear less appetizing than a new toll plan that would correct tolling imbalances that have dogged New York City for decades.

The Move NY campaigners intend to use the coming months winning enough support among a wide variety of stakeholders, even (especially) including some opponents of the prior congestion pricing proposal, to demonstrate to the next governor that there is a broad political consensus in favor of the Move NY plan. In this scenario, the governor’s endorsement caps a process that will have begun outside of government and that, patiently and collegially, marshaled the necessary support from the bottom up.

Appendix: The Balanced Transportation Analyzer (BTA) Spreadsheet Model

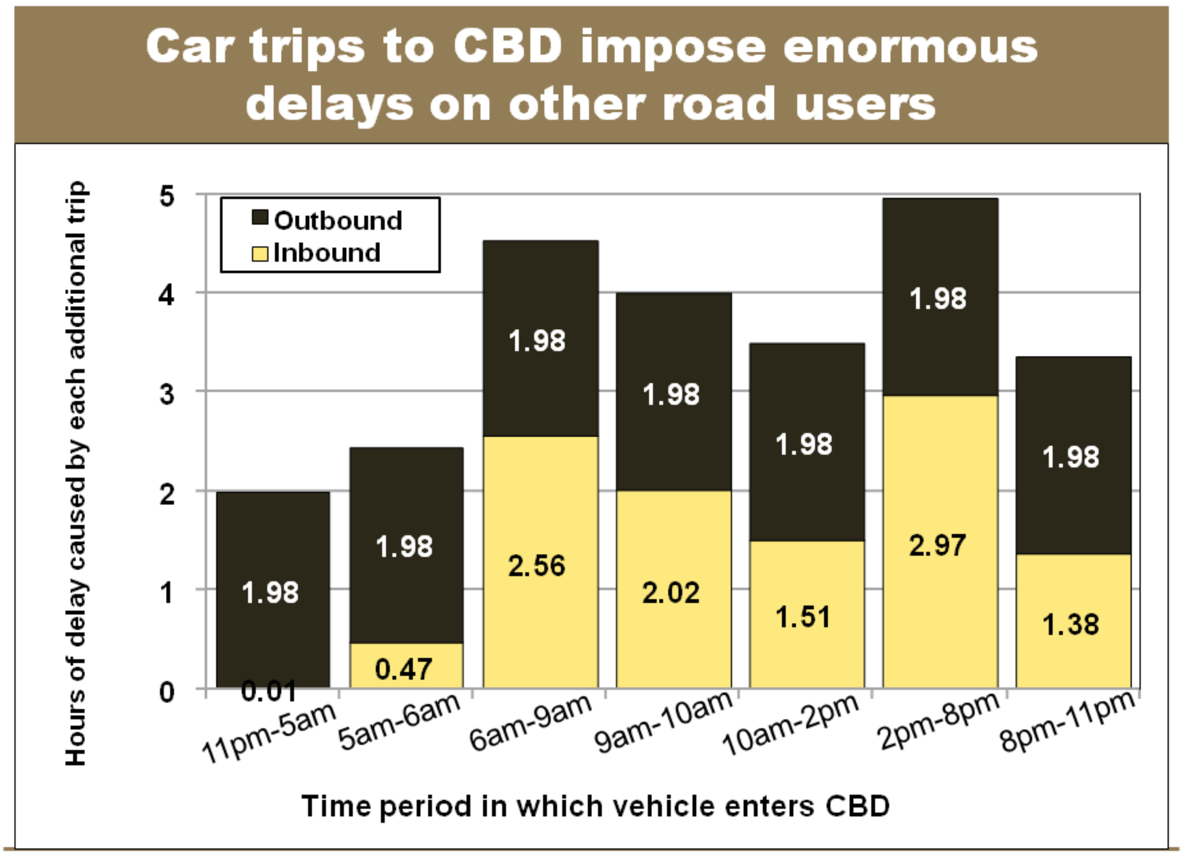
The analytical and quantitative foundation for the Move NY campaign is an Excel spreadsheet known as the “Balanced Transportation Analyzer,” or BTA. The BTA is a PC- or Mac-capable integrated spreadsheet model that estimates traffic speed improvements, revenue gains and other benefits from a wide range of congestion pricing proposals as well as from allied transportation measures such as transit investment of the toll revenues. The BTA incorporates current conditions of New York City traffic volumes, transit service and usage, taxi pricing and availability, and current toll rates on bridges and tunnels. I am the developer and programmer.

Development of the BTA began in 2007. The model now (February 2014) contains 63 interlocking worksheet “tabs” which are stocked with baseline travel data and connected by thousands of equations and algorithms. These tabs “communicate” with each other not only in the standard fashion of multi-tab spreadsheets, but interactively in that outputs from some tabs and cells are fed back as inputs to other tabs and cells whose changed values then change those outputs, in a recurring (recursive) process. Key data inputs have been gathered in one tab (“User Inputs”) so that changes to scenarios — e.g., higher (or lower) tolls, different types of taxi surcharges, alternative allocations of the revenues among, say, commuter rail investment, subway investment or roads and bridges upgrades — can be implemented within seconds.

The BTA model has also been programmed to allow the user to toggle among half-a-dozen “packaged” scenarios, including the Move NY proposal, the 2007-08 Bloomberg plan, a “baseline” plan reflecting current conditions (which acts as a programming check, since it is expected to return values of zero for all results) and a version of the Move NY proposal with time-varying tolls that has been tailored to yield the same revenue as the constant-toll plan discussed here. The user can quickly switch among these scenarios using a pull-down menu provided in the “Results” tab.

Model outputs include predicted gross and net revenues from new tolls, changes in the number of trips via transit and the associated revenues, changes in vehicle volumes and travel speeds by time of day and between weekdays and weekends, traveler time savings (in hours and “monetized” as dollars), geographical incidence of toll payments (i.e., among the five boroughs of New York City and for the seven surrounding counties), and the monetized value of the estimated improvements in air quality, reductions in vehicle crashes, increases in active transportation (walking and cycling), etc.

A key attribute of the BTA is its ability to estimate the aggregate delays to all other vehicles caused by a single ("incremental") vehicle trip to the CBD, as shown in the accompanying bar chart. The "delay cost" due to a single inbound trip ranges from a minuscule 0.01 hours for a trip made during the overnight period to nearly 3 hours for a trip made during the long afternoon-evening peak. (Note that the aggregate delay cost shown for the trip's outbound leg, a constant 1.98 hours, is an average value reflecting the modeling assumption that the return trip could be made at any time period.)



The time values shown in the chart are particular to New York City, of course. Nonetheless, they underscore a critical phenomenon that forms the essential rationale for congestion pricing: when traffic is heavy, the time that any traveler takes from all other road users by slowing them down far surpasses the time he or she might have hoped to save by driving rather than using a different travel mode. Yet in the absence of congestion pricing, the traveler has no reason to factor this "social time cost" into his or her travel choice. A congestion charge eliminates (or, at least, shrinks) this "time externality" so that the individual's choice is more closely aligned with the social outcome.

Notwithstanding its many capabilities, the BTA spreadsheet consumes only 4 megabytes (MB). It is continually updated to reflect changes in baseline data and new policy "wrinkles," and the most current version is always available on the Internet via this link: http://www.nnyn.org/kheelplan/BTA_1.1.xls.

(Alternatively, you can find the same link by Googling: BTA1.1. Note that the figures in the text of this paper reflect model parameters, assumptions and equations as of February 26, 2014.

The work to modify the BTA's inputs and relationships to reflect a city other than New York would be considerable, but manageable. The author would welcome the opportunity to participate in such an endeavor with researchers and officials in China, in order to provide an analytical tool to determine the merits of implementing congestion pricing in the People's Republic.

Eco-Zone in Milan:
Policy design, Enforcement
and Impacts on Traffic
and the Environment

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elaborato:	RELAZIONE	*codifica:*	140540010_01
doc collegati:	*140540009_00*	*revisione:*	01
data: 21/03/2014	*redatto:* Silvia Moroni (AMAT) Ario Ruprecht (SIMG)	*verificato:* Silvia Moroni	*approvato:* Bruno Villavecchia

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CONTENTS

1 ABSTRACT

Milan is located in one of the most polluted area in the world and it is historically affected by traffic congestion problems due to its central economic and cultural role in the Northern part of Italy and to one of the highest motorization rate in Europe.

Air quality is mostly affected by road traffic, therefore Local Administration is working to reduce exposure to traffic-related air pollution both by mean of short time interventions during winter season - when persistent episodes of high stability lead to the longest period of EU Limit Values non-attainment episodes - and by mean of structural measures in the context of the Sustainable Mobility Urban Plan.

In Milan traffic emissions, noise, accidents and congestion give external costs for more than 5 billion euros/year, for related health and life quality problems, material damages for buildings and artistic patrimony, global climate change and time losses in transport.

Milan launched several measures to face air pollution and traffic congestion including two innovative road price schemes applied to the historical center, the first, started in 2008 and called 'Ecopass', based on the 'polluter pays principle', and the second and definitive scheme, launched in January 2012, called 'Area C', which combine a Congestion Charge scheme with the banning of the most polluting vehicles.

The 'Area C' LTZ (Limited Traffic Zone) was introduced in observance to the results of a public referendum indicating that the vast majority (79%) of the Milan voting citizens wanted to potentiate public transports and to limit traffic-related pollution.

Thus the Area C was conceived as a congestion charge measure aiming to improve environmental conditions in the city of Milan and consequently to enhance the life quality and health both of citizens and city users.

The successful results of the Area C measure are the following: Less Traffic - 30,2% (reduction of daily entrance - 39.864 vehicles, compared with 2011 Ecopass, the previous pollution charge scheme); Less Road accidents - 23.8%; Less occupation of on-street parking -10% (with a gain in public space availability); Increase of public transport speed (during peak hours: +9,3% for buses and +5,4% for tram); Less pollutant vehicles: - 49% (-2.400 pollutant vehicles entering every day the Area C); More cleaner vehicles + 6,1 % (from 9,6% to 16,6% of the total vehicles); Less polluting vehicular emissions: Total PM10 -18% ; Exhaust PM10 -10%; Ammonia -42%; Nitrogen Oxides -18%; Carbon Dioxide -35%; Less Airborne Black Carbon (BC) concentrations: -52% (Summer, at kerbside) and - 28% (Winter, residential site).

Briefly, almost one out of three cars was left at home, the number of clean vehicles has almost doubled thus road traffic emissions had important reductions (in particular for CO_2) and inside the 'Area C' LTZ traffic-related toxic compounds, traced by airborne Black Carbon measurements, were found lower from 1 to 3 epidemiological change units (Janssen *et al.*, 2011), attesting an important benefit in public health.

In the framework of the Urban Traffic Plan (PGTU), as part of the Environmental Report required by the Strategic Environmental Assessment (SEA) procedure, it was assessed that 'congestion

charge' scenario at 2015 leads to a decrease of exposure to the highest Black Carbon traffic emission levels (>50 grams/day) for about 9,000 residents with respect to the 'Loop' circulation scheme (an alternative option for the same area), with an important improvement on public health. This result supported, together with other evaluations, the adoption by the Municipal Board, in March 2013, of the 'Area C' Congestion Charge scheme as a permanent and strategic measure, after one year trial period.

All the Area C LTZ incomes have been reinvested in projects for Sustainable Mobility such as the strengthening of public transport and the development of the bike-sharing system.

A survey carried out in April 2013 analyzing the perception of the citizens of Milan stated that 58% of residents expressed favorable views of 'Area C' measure.

Possible perspectives of road pricing schemes are going to be discussed in the Sustainable Urban Mobility Plan (SUMP) process, just started.

The Environment Mobility and Transport Department of the Municipality of Milan is responsible for the implementation of the Area C measure. AMAT, the local Agency, provides monitoring and assessment technical services.

'Area C' LTZ description and monitoring results can be accessed at the websites:

http://www.areac.it;
http://www.comune.milano.it;
http://www.amat-mi.it;
http://amat-mi.it/it/ambiente/qualita-aria/il-progetto-di-monitoraggio-del-black-carbon/.

2 INTRODUCTION: TRAFFIC AND AIR QUALITY ISSUES IN MILAN

2.1 GENERAL INFORMATION

The city of Milan is located in the centre of the Po Valley (Northern Italy) and represents the Lombardy Region capital city and the financial and cultural center (Figure 1). Milan is the second largest city in Italy, with a population of approximately 1.3 million inhabitants with a density population of 7,500 inhabitants/km^2, but including the neighbour municipalities it forms one of Europe's largest urbanized area with approximately 3.3 million inhabitants (Table 1). Most of tertiary and commercial activities of the region are located in Milan city, while numerous industrial activities take place mainly in the neighbour municipalities. The city is situated in the midpoint of a wide Regional urban system, formed not only by the city and the neighbour towns, but also by other crown cities located in Lombardy and other Regions, which have historically built up a strong relationship network with Milan. All this factors lead to high volumes of private and commercial vehicular traffic on the roads inside and surrounding the city.

Figure 1 - Milan is located in the Lombardy Region, in the North part of Italy

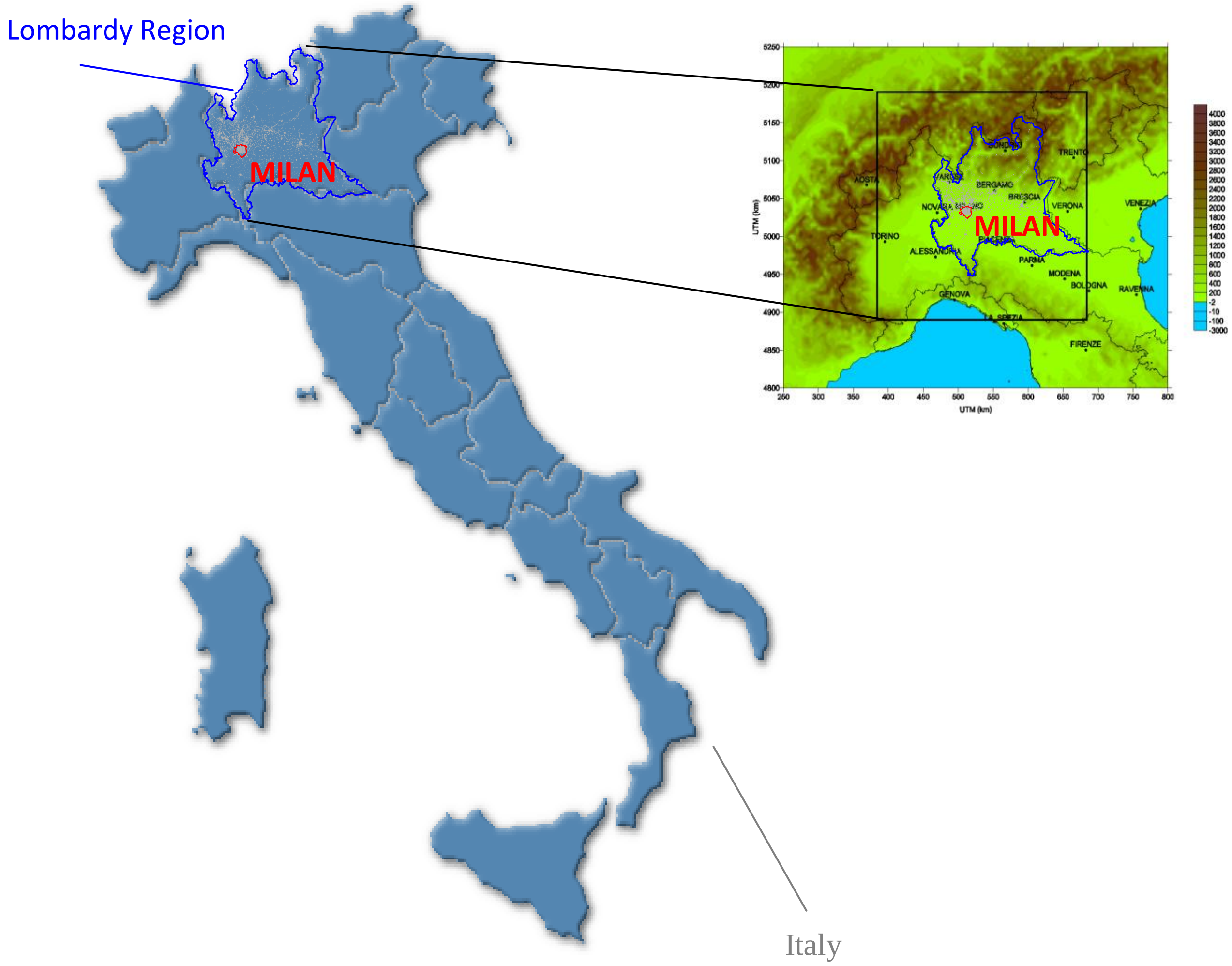


Table 1 - Milan general data

Area	**181.76 km^2 (70.18 sq mi)**
Milan city inhabitants	**1.3 millions**
Milan Daily city Users	**1 million**
Metropolitan area inhabitants	**3.3 millions**
Lombardy Region inhabitants	**9.6 millions**

2.2 AIR QUALITY ISSUES

Air quality is the most serious environmental and health problem for Milan, located in center of the Po Valley, one of the main polluted worldwide and EU areas (Figure 2, Figure 3).

The challenge of Milan's local government to control air pollution is particularly difficult, taking into consideration the very unfavorable meteorological conditions of the area in which the city is located. In fact, the orographic configuration of the Po Valley, surrounded by mountain chains on three sides that block low pressure fronts, cause pollutants accumulation sometimes for long periods. Especially in winter season - the most critical season for air quality - Milan weather is characterized by high frequency and persistent stable atmosphere episodes, with very low mixing layer due to temperature inversions, banks of fog and calm winds (Figure 4). In summer intense solar radiation and high humidity produce particularly muggy days during which photochemical activity is important.

This situation, together with the concentration of the human activities in the urban area, leads to a high number of exceedances of air quality EU Limit Values for PM10, PM2.5 and NO_2 specially in winter season and for O_3 in summer.

This happens despite a significative reduction of main pollutant emissions occurred over the last twenty years due to:

- ✓ the renewal of the vehicular fleet with lower emission vehicles,
- ✓ the improvement of fuels quality both in mobile and in fixed sources.

As a result of those pollutant emissions reduction a clear and progressive improving of CO, SO_2, NO_2, TSP and Benzene concentrations occurred over the past decades in the atmosphere of the city (Figure 5 - Figure 8; Source: ARPA Lombardia; AMAT processing ARPA Lombardia hourly data for 2013). It is interesting to observe that, starting from year 2005, stable NO_2 concentrations have been measured; this is linked to the raise of diesel cars fleet and the increase of NO_2/NO ratio in gaseous exhausts of new generation vehicles.

As far as particulate matter concentration, control measures on the sources lead to a slower and contained reduction in concentrations of this pollutant, affected also by an important secondary origin, due to precursors gases and their photochemical reactions in atmosphere. Even if in 2013 Milan accomplished for the first time the PM10 annual mean Limit Value - thanks also to favorable meteorological conditions - problems still remain in particular for a very high number of exceedance episodes occurring for PM10 24-hours EU Limit Value (50 g/m^3 not to be exceeded more than 35 times/year) and for PM2.5 annual mean still exceeding the EU Limit Value (Figure 9 -

Figure 11) implying important health effects for population (see Section 2.3).

Figure 2 - Worldwide NO_2 concentration map (*Source: ESA, European Space Agency, October 2004*)

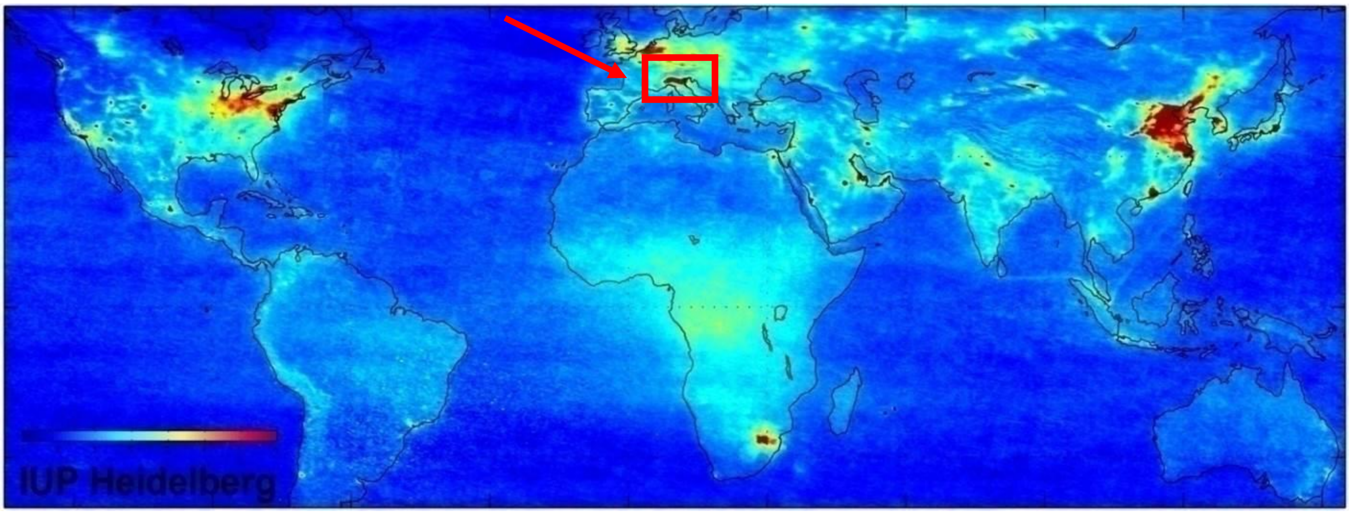


Figure 3 - PM10 concentration map over Europe (*Source: EEA, 2013*)

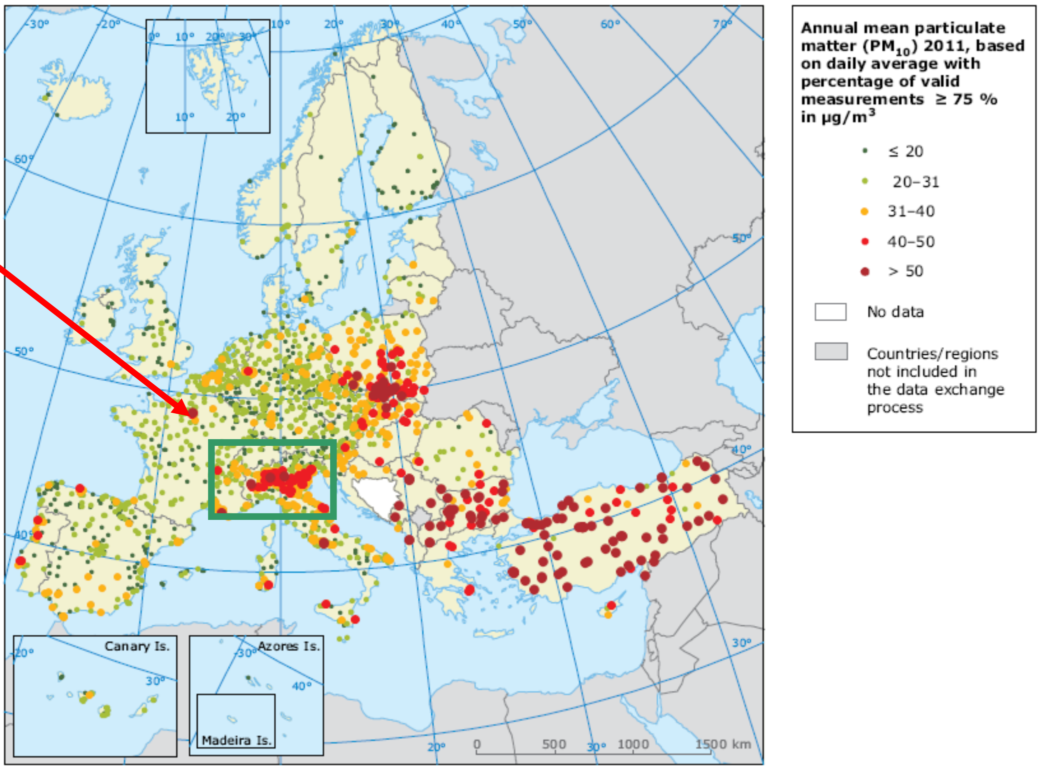


Figure 4 - Smog over the Po Valley during an high stable atmosphere episode, with very low mixing layer due to high pressure front and temperature inversion

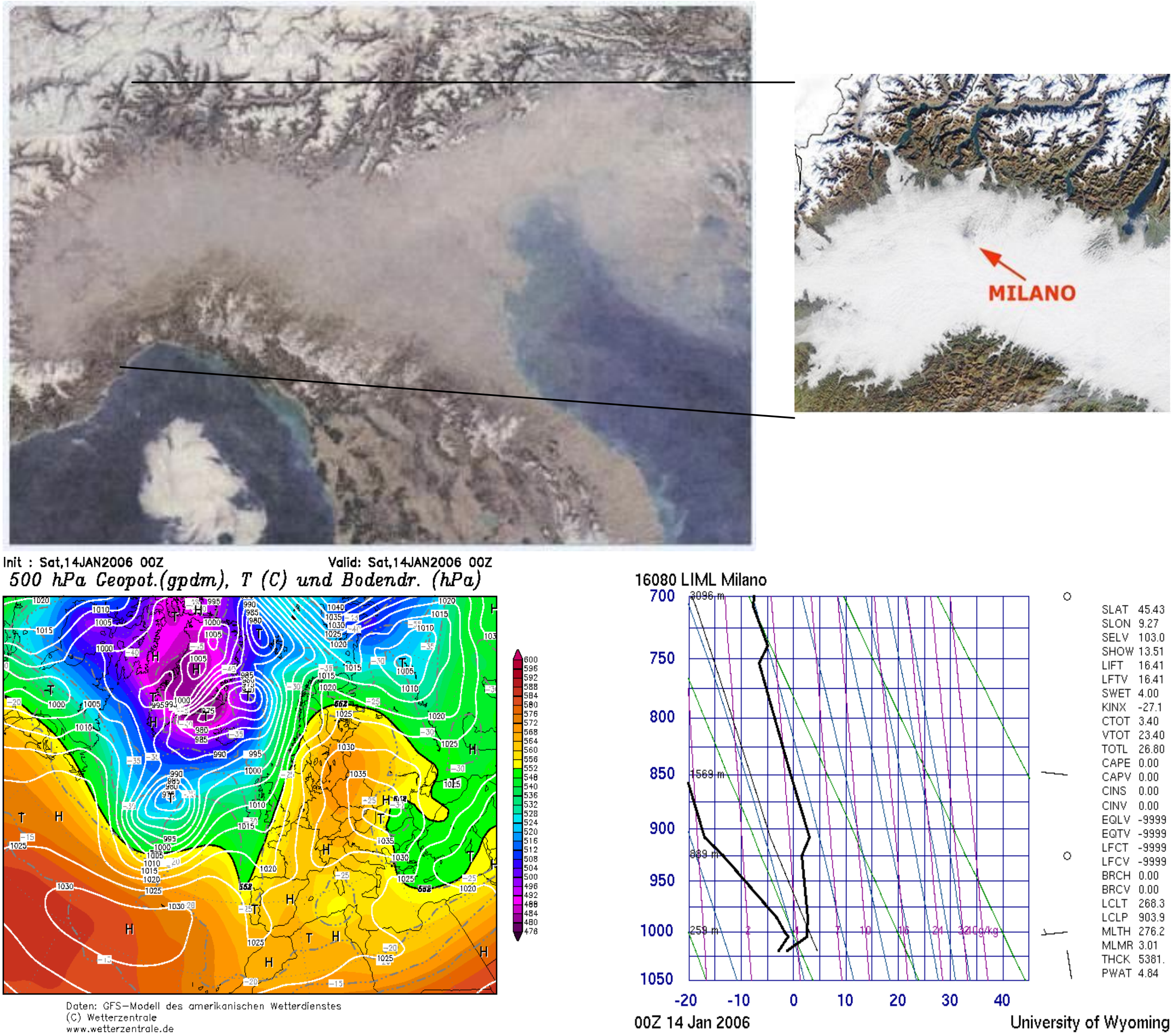


Figure 5 - Sulphur dioxide concentrations trend in Milan

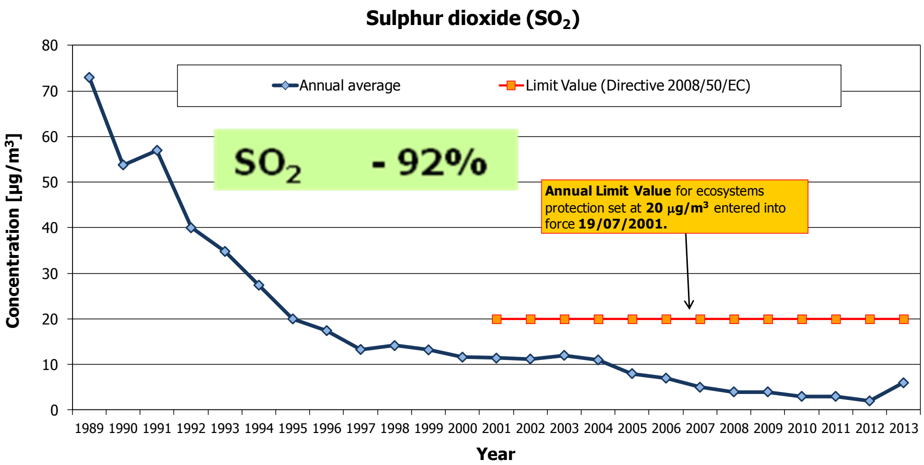


Figure 6 - Carbon monoxide concentrations trend in Milan

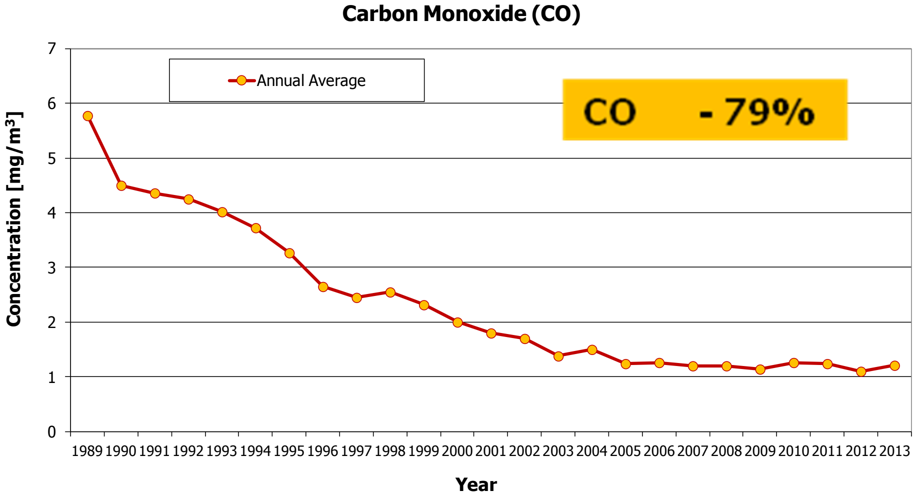


Figure 7 - Benzene concentrations trend in Milan

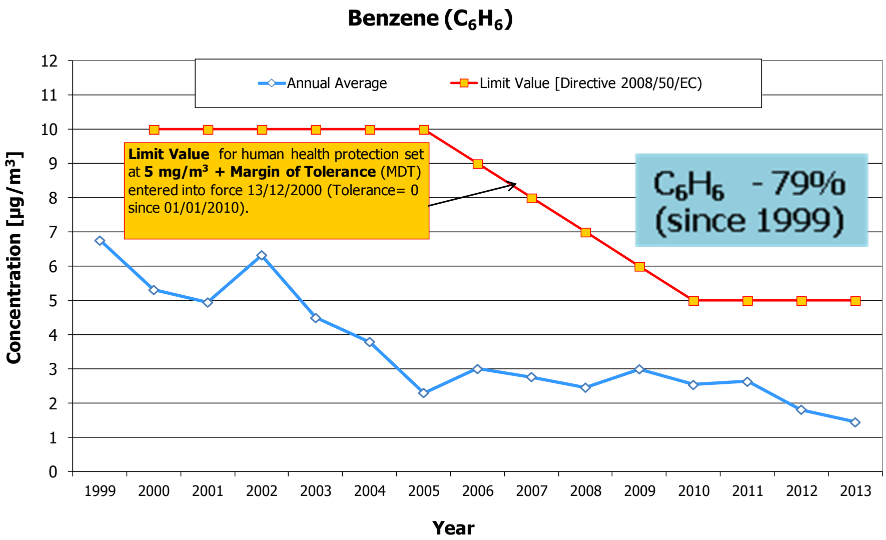


Figure 8 - Nitrogen dioxide concentrations trend in Milan

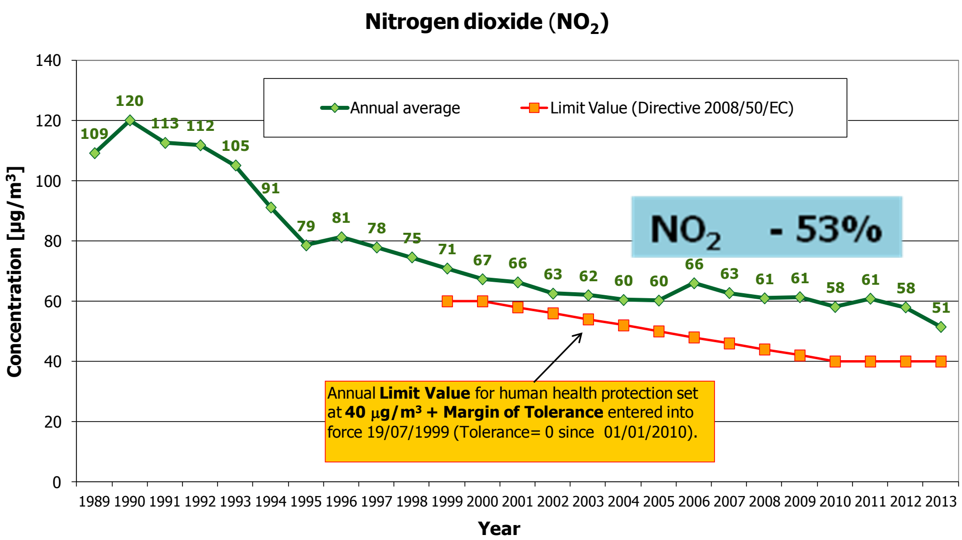


Figure 9 - PM10 concentrations trend in Milan

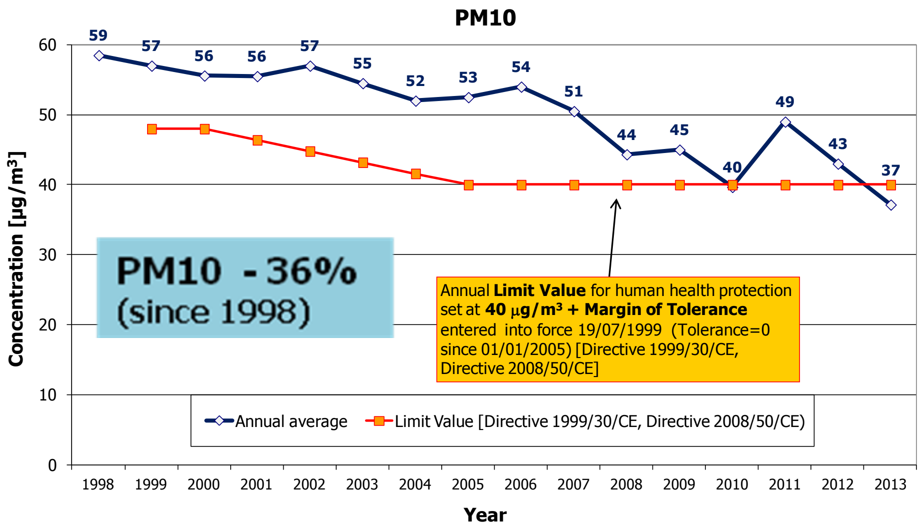


Figure 10 - PM10 24-hours mean Limit Value non-attainment episodes trend in Milan

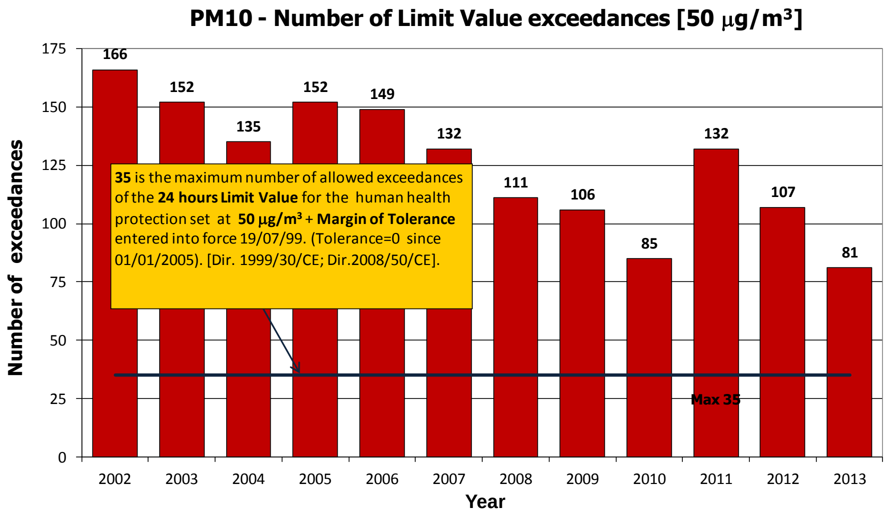
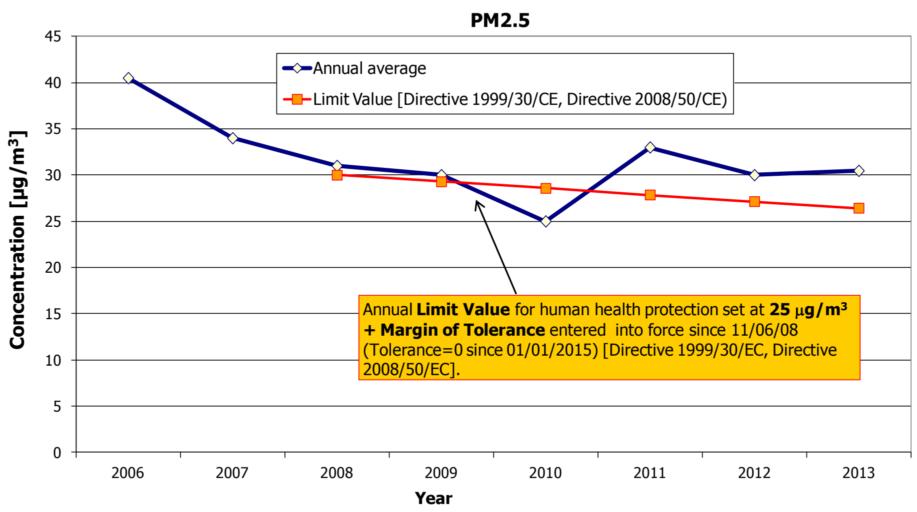


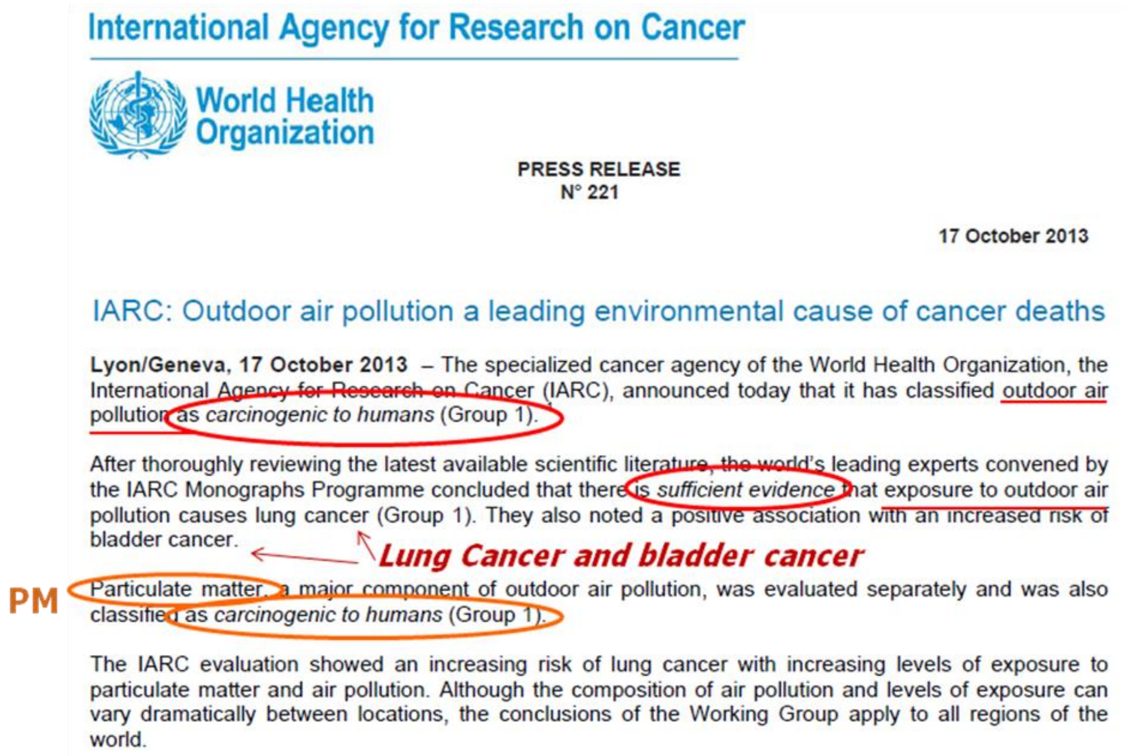
Figure 11 - PM2.5 concentrations trend in Milan



2.3 HEALTH EFFECTS OF AIR POLLUTION

Air pollution is an important risk factor for human health. Its effects are documented by such a number of clinical, toxicological and epidemiological studies that on October 17, 2013 IARC (*International Agency for Research of Cancer*), a specialized agency of the *World Health Organization* (WHO), has classified the *'outdoor air pollution'*, and separately '*particulate matter'*- one of its main component between the agents *'carcinogenic to humans'* (Group 1) (Figure 12).

Figure 12 - IARC/WHO Press release n. 221 extract: 'outdoor air pollution' and 'particulate matter' have been classifies 'as carcinogenic to humans' (Group 1)


International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 221

17 October 2013

IARC: Outdoor air pollution a leading environmental cause of cancer deaths

Lyon/Geneva, 17 October 2013 – The specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), announced today that it has classified outdoor air pollution as *carcinogenic to humans* (Group 1).

After thoroughly reviewing the latest available scientific literature, the world's leading experts convened by the IARC Monographs Programme concluded that there is *sufficient evidence* that exposure to outdoor air pollution causes lung cancer (Group 1). They also noted a positive association with an increased risk of bladder cancer.

Particulate matter, a major component of outdoor air pollution, was evaluated separately and was also classified as *carcinogenic to humans* (Group 1).

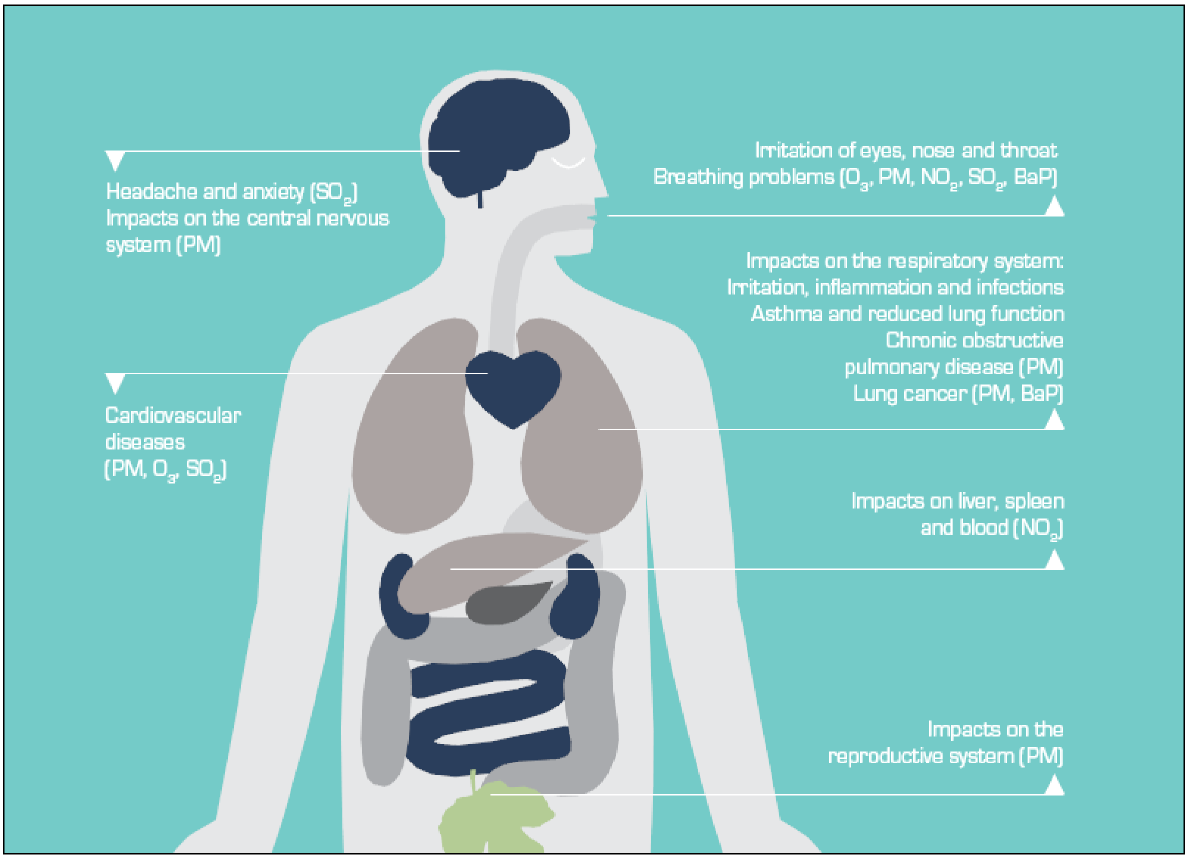
The IARC evaluation showed an increasing risk of lung cancer with increasing levels of exposure to particulate matter and air pollution. Although the composition of air pollution and levels of exposure can vary dramatically between locations, the conclusions of the Working Group apply to all regions of the world.

Scientific literature reports incontrovertible data on a wide range of health effects due to exposure to air pollution (Figure 13) that could affect population both on **long term** exposure (carcinogenic effects; increased morbidity and mortality due to respiratory and cardiovascular diseases, etc) and

on **short term**, for which there is onset an increase on mortality and exacerbation of temporary - but disabling - diseases (i.e. recurrent asthma; difficulty in breathing; eyes, nose and throat irritation, etc.). Particularly this diseases affect the most sensitive population, such as children, pregnant women and their future child, elderly and sick people.
Most recent researches are focusing on health effects related to the finer fraction of particulate matter (i.e. UFP - Ultrafine Particles or NP - Nanoparticles) that, being able to penetrate deeper into the human body, can constitute a ‘carrier’ of toxic compounds up to all body organs (nervous system, brain, etc.).
It is important to underline that both short and long-term studies have found these associations with adverse effects even ‘at’ or ‘below’ the current EU concentration Limit Values (WHO, 2013).
These results were recently confirmed and strengthened by the ESCAPE Project, a wide prospective analysis in 22 European cohorts (Beelen *et al*., 2013, Raaschou-Nielsen *et al*., 2013).
Available epidemiological data linked to air pollution for the City of Milan are reported in the following:

- According with MISA-2 study (*Meta-analysis on air pollution and health diseases*) 700-800 death/year were due to air pollution in the City of Milan over the 1996-2002 period (Biggeri *et al*., 2004);
- The most recent national study (EpiAir2 Project), referred to the period 2006-2010, indicates 134 death/year due to short term effects of air pollution in Milan (Alessandrini *et al*., 2013);
- A specific study conducted for the City of Milan reports 422 death/year due NO_2 concentration exceeding EU Limit Value (Bisanti L., 2012).

Figure 13 - Health impacts of air pollution *(Source: EEA, 2013*)



Therefore, enhancing air quality is one of the main and hardest challenge to effort for the Local Administration, taking into consideration that **a better air quality means a more healthy population**. The unfavorable meteorological conditions of Milan and the whole Po Valley, that force to adopt **shared and coordinated interventions at 'large' scale** (even supraregional) to achieve the objectives set by the European Community for the most problematic pollutants exceeding the EU standard limits (PM10, PM2.5, NO_2 and O_3), **does not exclude the opportunity and need** for **actions even at the 'local' scale,** where with targeted interventions is possible to obtain a **reduction of population exposure to 'primary' pollutant emissions** and consequent benefits in terms of public health both for residential population and the numerous 'city users' (workers, students, tourists, etc). **In the urban context of Milan the most important source of pollutant emissions is road traffic** to which a wide range of chemical compounds and specific-related health effects are linked (see Section 2.4). Given this, Local Administration is working to reduce exposure to traffic-related air pollution both by mean of **short time interventions** during winter season, when persistent episodes of high stability lead to longer non-attainment episodes, and by mean of **structural measures** in the context of the **Sustainable Mobility Urban Plan**. One of this measure is the Congestion Charge combined whit the banning of the most polluting vehicles, called 'Area C', subject of this report.

2.4 URBAN TRAFFIC AND HEALTH EFFECTS

In scientific literature there is sufficient evidence to support a causal relationship between exposure to **traffic-related air pollution** and exacerbation of asthma, and suggestive evidence of a causal relationship with onset of childhood asthma, non-asthma respiratory symptoms, impaired lung function, total and cardiovascular mortality, cardiovascular morbidity and lung cancer (Health Effects Institute, 2010 - Figure 14; Raaschou-Nielsen *et al*., 2013; Perez *et al*., 2013; Brandt *et al*., 2012).

It refers to the part of human air pollution exposure called by '*traffic-proximity'* or to '*TRP-Traffic Related Pollutants'*) (i.e. related to the presence in the immediate vicinity of 'primary pollutant' directly emitted by vehicular traffic) whose citizen health risks added to those deriving by 'regional pollutants', or more homogeneously distributed in space, characterized by an important 'secondary' fraction linked to the atmosphere reactive conditions - such as PM10, PM2.5, NO_2, O_3 - which constitute the 'background' exposure.

Figure 14 - HEI Report, 2010: Literature review (700 studies) collecting main scientific evidences of health effects of Traffic-Related Air Pollution exposure

The pollutants mix emitted by road traffic is characterized by finest particles (UFP - Ultrafine Particles or NP- Nanoparticles) and the presence of toxic and carcinogenic compounds such as PAHs (Polycyclic Aromatic Hydrocarbons), Black Carbon[1], benzene and heavy metals. This mix may

[1] *Black Carbon: for definition and description see Section 9.1.*


HEI

HEALTH EFFECTS INSTITUTE

January 2010

SPECIAL REPORT 17

Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects

HEI Panel on the Health Effects of Traffic-Related Air Pollution

cause chronic diseases in population or aggravate already existing, because of the exposure that occurs during residency, work or school activities and commuting. In particular, higher risks are found for most sensitive population, such as children, pregnant women and their future child, elderly and sick people (see also Section 10.2).

Exposure to traffic-proximity pollutant - reducing life-expectancy - generates high external costs that should be evaluated in a complete ‘**cost-benefit analysis’ during the planning stages** of the Mobility system and of the other development elements (e.g. Land use Plans) of a city. In **Milan traffic** emissions, noise, accidents and congestion give **external costs for more than 5 billion euros/year**, for related health and life quality problems, material damages for buildings and artistic patrimony, global climate change and time loose in transport.

2.5 TRAFFIC FEATURES

The overall mobility in Milan counts about 5.279.000 trips per day, of which 2.235.000 (42%) for interchange mobility and 3.044.000 (58%) for internal mobility (Figure 15). Interchange mobility is characterized by a prevalent use of private car (59%), while Public Transport covers a fraction of about 34%. Inside the city boundaries public Transport constitutes the main way to move (41%), followed by car use (30%), pedestrian movements (17%) and two wheelers trips (6% motorcycle, 6% bicycle).

Public Transport in Milan has the more extensive network in Italy (Figure 16) In particular the extension of Milan subway (Figure 17) equals the sum of those of other main cities in Italy such as Rome, Naples, Turin, Brescia, Genoa, and Catania.

Despite the large development of the public transport network, Milan has one of the highest European rates of car ownership (Figure 18), as more than half of Milan’s citizens use private cars and motorcycles.

Road transport sector is the most important source for the main pollutants in the City (Figure 19), according to the City of Milan’s emission inventory, drowned up for the city with Bottom-up approach (City of Milan-AMAT, 2007; Moroni *et al.*, 2007).

Figure 15 - Travel between Milan and the metropolitan area - Modal Split

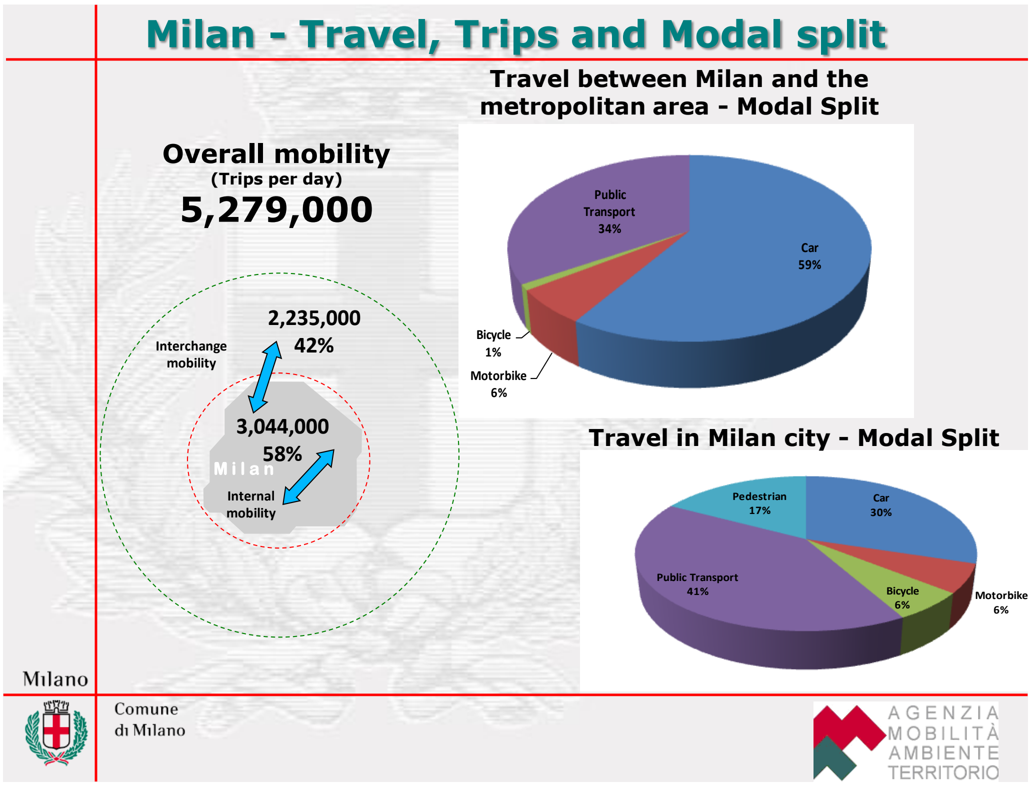


Figure 16 - Local Public Transport Network

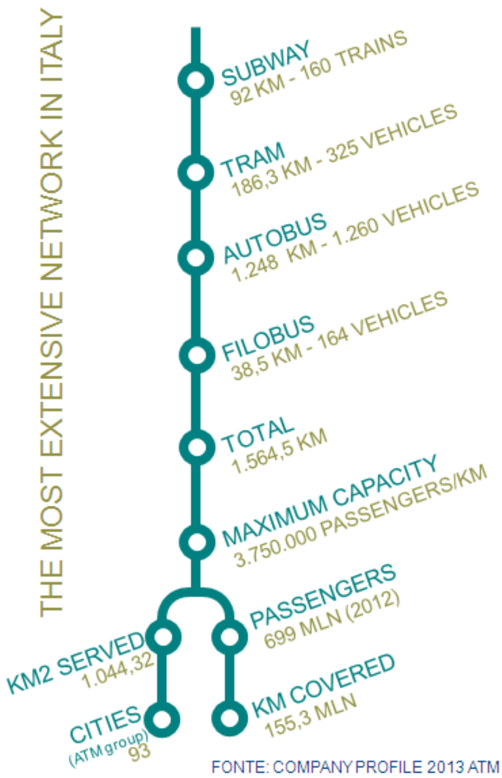


Figure 17 - Underground network and urban railway system

Figure 18 - Motorization rate (*Source: Eurostat, Urban Audit 2012*)

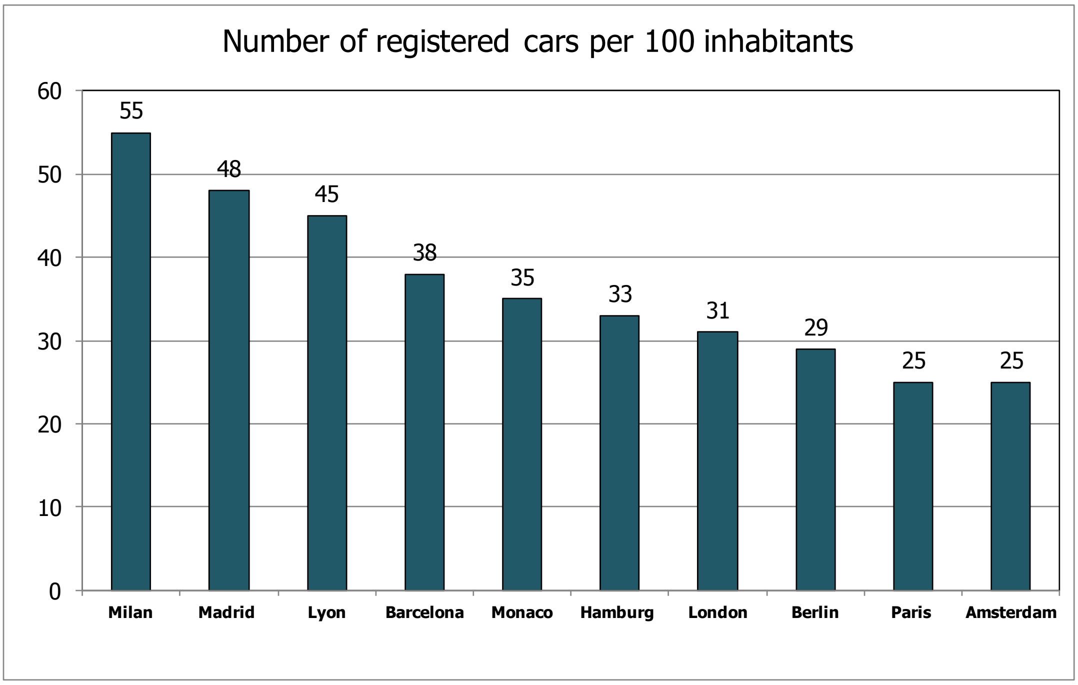
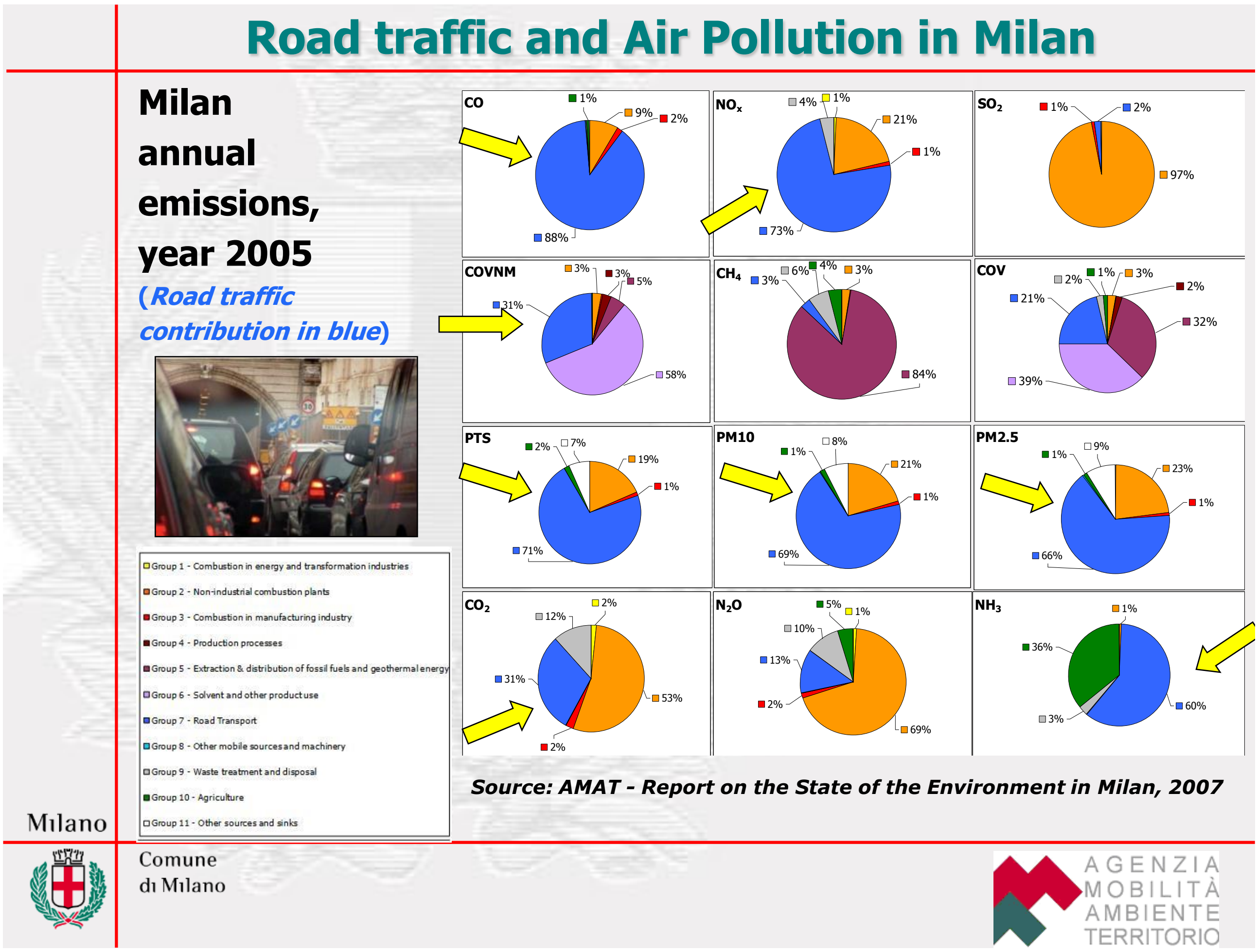


Figure 19 - City of Milan Annual Emissions, year 2005 - Road traffic contribution in blue (*Source: City of Milan- AMAT, Report on the State of the Environment in Milan, 2007*)



3 ‘AREA C’: THE CONGESTION CHARGE ZONE IN MILAN

By January 16th 2012 Milan Municipality implemented a new private traffic restriction scheme called *'Area C'* (‘C’ stands for ‘Congestion Charge’), which combine a Road Pricing Scheme with the banning of most polluting vehicles in the central part of the city.

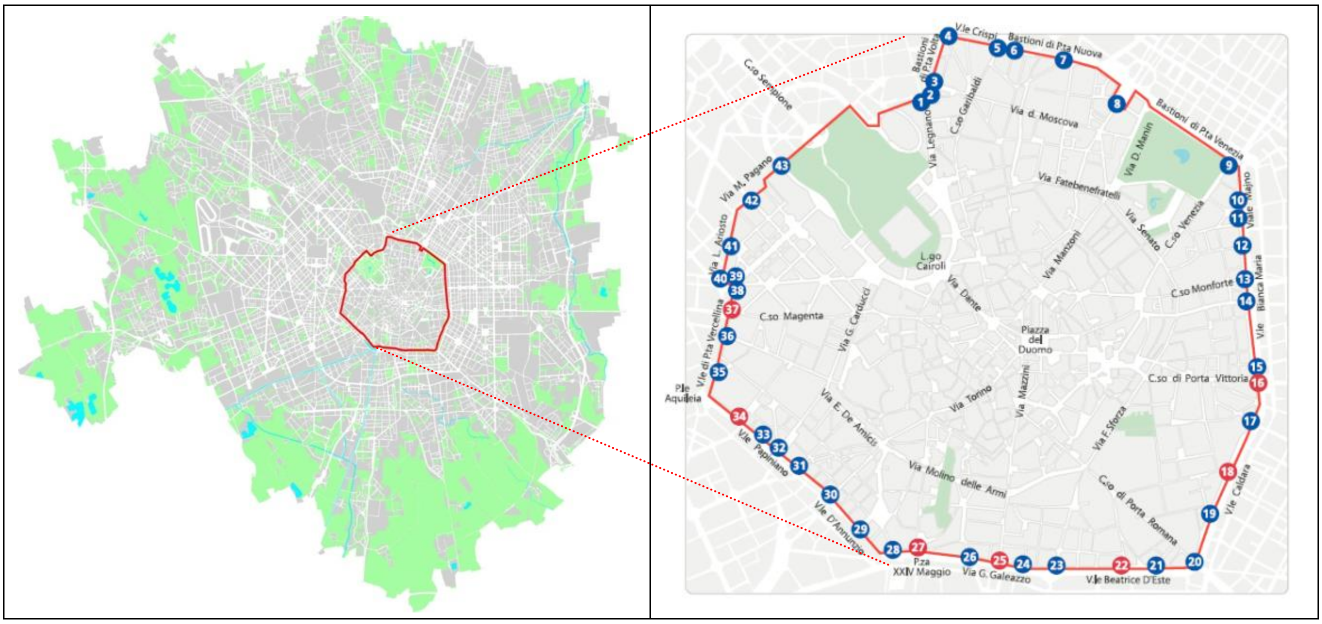
The area subject to the congestion charge is bounded by the ring road called ‘Cerchia dei Bastioni’ (Bastioni ring) and corresponds to an area of 8.2 km^2, approximately 4.5% of the whole territory of the Municipality of Milan (Figure 20).

Some data related to this central area of the city are reported in the following:

- 77,950 residents (6%) - 42,300 families
- almost 25% of businesses in Milan

- 39,000 persons/km^2 (daylight hours - in average)
- 140,000 persons/km^2 (daylight hours - picks within the historical center).

Figure 20 - City of Milan's Congestion Charge Zone, called 'Area C'



4 AIMS

In most recent years Milan adopted several measures to face air pollution and traffic congestion. The 'Area C' Limited Traffic Zone (LTZ) is a road pricing measure launched by the Municipality of Milan in 2012 to improve life conditions of those who live, work, study and visit the city center. The 'Area C' LTZ was introduced in observance to the results of a public referendum indicating that the vast majority (79%) of Milan voting citizens wanted to potentiate public transports and to limit traffic-related pollution.

Previously City Administration adopted (from 2008 to 2011) on the same area ('Cerchia dei Bastioni' o 'Bastioni ring') an innovative 'Pollution Charge' Scheme called '*Ecopass*', based on the 'polluter pays' principle, with fares based on pollution class of the vehicles. The results of this preceding measure - that indeed initially obtained relevant vehicular traffic emissions reductions - progressively decreased in term of traffic congestion, due to the renewal of the fleet with more environmental friendly vehicles, paying lower fees (Figure 21). The decrease of the effectiveness in term of congestion of the Pollution Charge brought to the necessity to implement a different traffic limitation scheme to face both traffic congestion and air pollution issues (Table 2).

Figure 21 - Vehicles entering the 'Cerchia dei Bastioni' area during the 'Pollution Charge' scheme adopted over the period 2008-2011

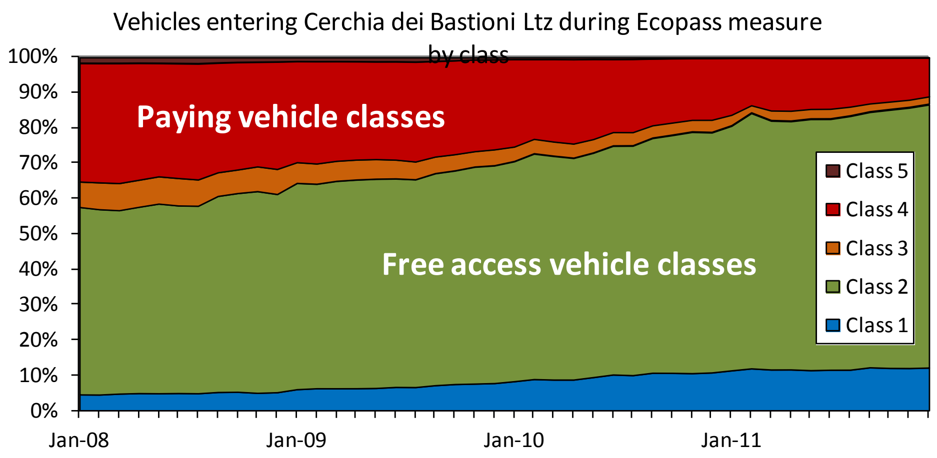


Table 2 - ‘Area C’ LTZ main goals

Traffic targets	Environmental targets
- Decreasing vehicular access to the Area C; Decreasing traffic congestion; - Reducing travelling time of private transport; Improving public transport networks; Decreasing the demand for public space occupation for on-street parking; - Reducing road accidents - Raising funds for the development of soft mobility infrastructures: cycle lanes, pedestrian zones, 30kph zones.	- Reducing pollutant emissions caused by traffic; - Reducing the health risks due to traffic related air pollution and noise; - Increasing the share of sustainable modes of travel; - Improving urban center life quality and attractiveness.

5 POLICY DESIGN

To enter the 'Area C' LTZ a ticket is required for Euro 4-6 diesel cars and for Euro 1-6 gasoline powered cars.

Inside the ‘Area C’ LTZ the circulation is forbidden to Euro 0 gasoline vehicles, Euro 0-3 diesel vehicles; after December 31, 2016 the access will be forbidden also to Euro 4 diesel vehicles. Furthermore inside Area C LTZ heavy duty vehicles longer than 7.5 meters can’t access.

Only electric, hybrid, LPG and natural gas, bi-fuel powered vehicles are allowed to enter Area C without charge in the first years of the measure (until December 31, 2016). Motorcycles and mopeds are exempted from payment. Exemption is also provided for those vehicles transporting people with disabilities, subjected to life-saving treatments or for those who must go the first aid. Vehicles for public transport services, vehicles for public utility services, tour buses, taxi, 'Euro 3' diesel vehicles belonging to residents and vehicles for the transportation of goods for public utilities and for the residences can access free.

‘Area C’ LTZ is operating on workdays from 07:30 am to 07:30 pm; on Thursday the operating time is 7:30 am - 6:00 pm.

To enter the ‘Area C' LTZ an entrance ticket must be purchased and activated. The ticket costs 5 euro and can be purchased at the parking meters, newsagents, tobacconists, ATM points (Milan Transport Company), at the ATMs of Intesa Sanpaolo, online on this site (www.areac.it) in 'Servizi Online' (online services), or calling the call center and in conventioned garages.

The ticket must be activated no later than midnight of the next day access, by sending an SMS message, calling the Call center, by visiting the website www.areac.it or in the municipal offices. There is an exception for the coupon purchased in garages that must be activated by midnight of the same day in which you made the access.

Each ticket to enter 'Area C' has daily time. The payment of an entrance covers all accesses made by the same vehicle during that day. There are six types of entrance tickets:

- Daily: 5 euro
- Daily ‘resident vehicle’: 2 euro (after registration)
- Daily ‘resident vehicle’: 3 euro (after registration)
- Daily ‘service vehicle’: 5 euro (only after registration and it can be bought only at the parking meters)
- Multiple daily: 30 and 60 euro, with the credit decreasing automatically (for even non-consecutive days)
- In the garages of the center participating to the initiative: 13 euro for the coupon ‘Area C’ + 4 hours of parking (not divisible). After the fourth hour, the cost does not exceed 2 euro per hour (even for cars exempted from payment of Area C).

6 ENFORCEMENT

The Control System of the 'Area C' LTZ is composed by 43 access points electronically monitored by surveillance cameras; 7 out of these 43 access points are limited to public transport vehicles (Figure 22). The surveillance cameras detect the entering vehicles and transmit the data collected to a computer which recognizes, by matching licenses database, their classification (residents, duty vehicles, free access ones) and the related due charge.

Figure 22 - Area C LTZ: the Control System

7 IMPACT ON TRAFFIC ISSUES

The main results in term of traffic issues are summarized in the following:

- ✓ Decreasing vehicular access to the Area C (Figure 23):
  -39,864 vehicles daily entering Area C

therefore

- ✓ Decreasing traffic congestion: - 30,2% (Figure 23)
- ✓ Improving public transport speed (Figure 24):
  +9,3% buses, +5,4% tram
  (during peak hours)
- ✓ Reducing road accidents: - 23.8% road accidents
  (-26.3% with injured; Out of Area C: -11%)
- ✓ Decreasing the occupation of on-street parking:
  (more public space available) -10%

Figure 23 - Area C LTZ: Traffic volume reduction during a typical working day

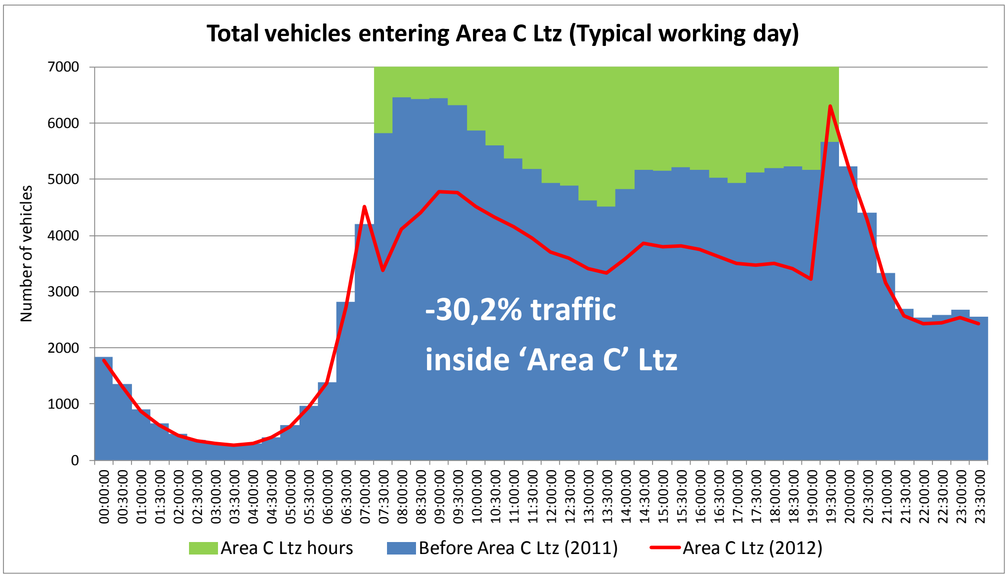
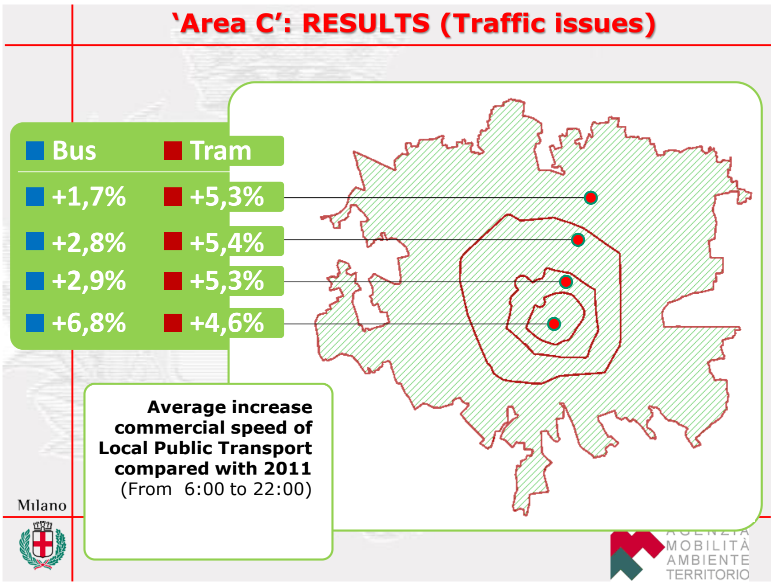


Figure 24 - Area C LTZ: Public transport speed improvement



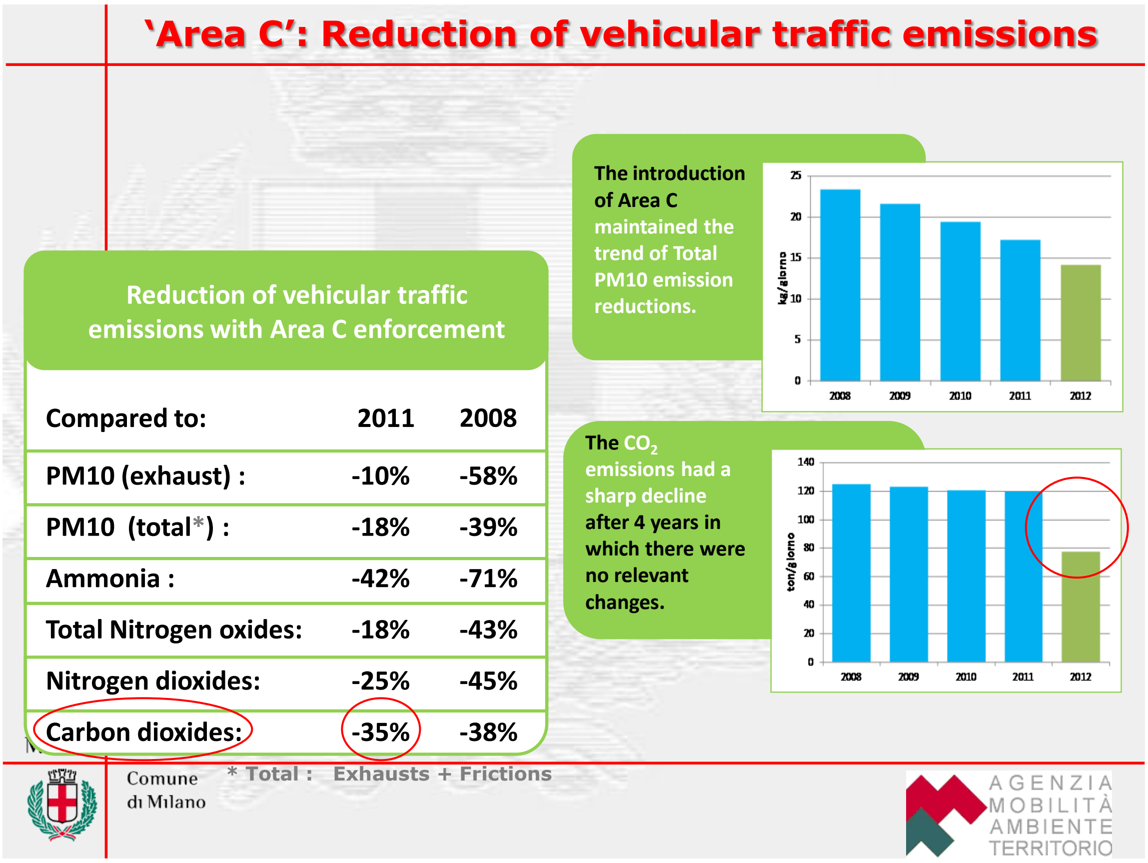
8 IMPACT ON VEHICULAR TRAFFIC EMISSIONS

The main results in term of vehicular traffic-related emissions are summarized in the following:

- ✓ Less Pollutant Vehicles entering Area C: - 49%
  (-2.400 pollutant vehicles entering every day the Area C)
- ✓ More Cleaner Vehicles: + 6,1 %
  (from 9,6% to 16,6% of the total vehicles)
- ✓ Less Vehicular Traffic Emissions:
  Total PM10 -18% ; Tailpipe exhaust PM10 -10%; Ammonia -42%; Nitrogen Oxides -18%; Carbon Dioxide -35%

Looking at vehicular traffic emissions trends (Figure 25) the main results are the maintenance of the PM10 total emissions reductions slope and the huge reduction - compared to those of the four previous years - of the carbon dioxide emissions, due to the large decrease of the total number of kilometers driven by vehicles consequent to this kind of measure.

Figure 25 - Area C LTZ: Reduction of vehicular traffic emissions



9 IMPACT ON AIR QUALITY: THE AIRBORNE BLACK CARBON MONITORING PROJECT

Road traffic within the city of Milan is the main contributor to the emission of several airborne health hazardous compounds. As a result, different traffic limitation interventions have been implemented in the recent years to improve air quality in the city center. However, the evidence of PM and other pollutants reduction has been as yet scanty.

In the context of the monitoring projects linked to the experimental phase of the Area C Ltz (year 2012) the Milan Municipality has carried out an air quality monitoring project based on Black Carbon (BC) measurements, following the example of other European cities such as Berlin, London and Barcelona where this pollutant have been measured for several year, proving the environmental effect of traffic measures.

This pollutant is being proposed at European and worldwide level as a new metric of particulate pollution health effects more suitable than PM10 and PM2.5 in the assessment of **traffic sources local interventions** (WHO, 2013; UNECE-CLRTAP/WHO, 2012; Janssen *et al.*, 2011; Health Effects Institute, 2010). In fact, several international studies have shown that even if interventions limiting vehicular traffic does not always mean a reduction in PM10 and PM2.5 concentrations measured in terms of mass, it is associated with them an **improvement in the 'quality' of particulate matter that becomes less toxic** (Reche *et al.*, 2011; Westerdahl *et al.*, 2009; Wang *et al.*, 2009; Bruckmann and Lutz, 2011; Kuenzli *et al.*, 2006).

The project has been developed by AMAT (City of Milan Mobility Environment and Land Agency) in collaboration with LARS, Environmental Research Laboratory of SIMG (Italian College GPs).

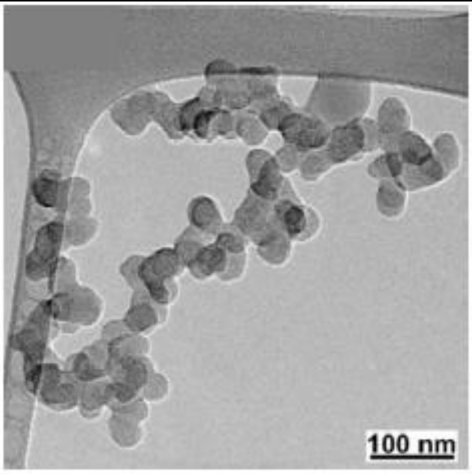
In the monitoring Protocol and the validation of final results are involved the experts Prof. Constantinos Sioutas (University of Southern California, Los Angeles) and Prof. Dane Westerdahl (Cornell University, Ithaca, NY; City University of Hong Kong).
The Black Carbon monitoring project included air quality measurements in four different seasons campaigns with two couples of fixed monitoring sites inside/outside Area C LTZ at urban residential locations (kerbside, 3rd floor level residential). In addition, a study of personal exposure to traffic proximity in the Area C LTZ and in pedestrian areas was also performed.

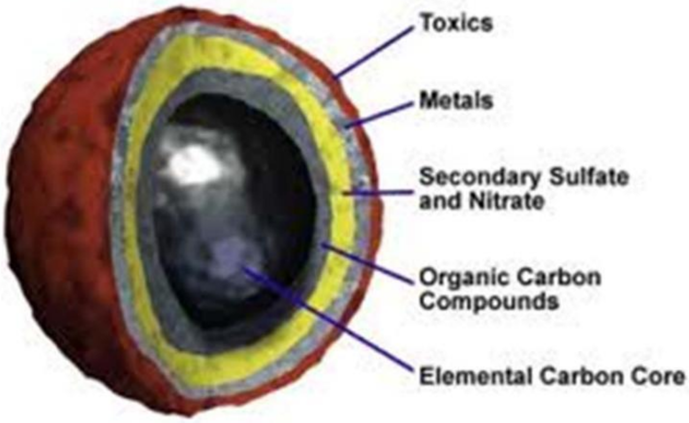
9.1 BLACK CARBON - A NEW METRIC FOR AIR QUALITY, HEALTH EFFECTS AND CLIMATE CHANGE

"*Black carbon particles are a* ***valuable additional air quality metric*** *to evaluate the* ***health risks of primary combustion particles from traffic including organics****, not fully taken into account with PM2.5 mass*"
'REVIHAAP. Technical Report' [World Health Organization, 2013]

The Black Carbon (BC) - expression of the PM2.5 and PM10 fraction consisting mainly of elemental carbon - which is a primary pollutant emitted during the incomplete combustion of fossil fuels (oil and coal), biofuels and biomass, and in urban areas can be taken as a tracer of emissions from internal combustion engines and the wide range of chemical species of varying toxicity present in them - as evidenced by the Environmental Protection Agency (US-EPA, 2012).
Black Carbon is particularly a good marker of diesel engines exhaust, which have been recently re-classified by IARC (*International Agency for Research on Cancer*, a WHO organism) increasing the *1988 health risk Group from 2A, "probably carcinogenic to humans*" to risk Group 1 "*carcinogenic to humans*" concluding that there is "*sufficient evidence*" that the exposure to the diesel engines exhaust without particulate filter is associated to an increased lung cancer risk. IARC highlighted the necessity of further studies and scientific researches to evaluate the health risk of exposure to diesel engine exhaust with particulate filters.
As reported by the recent WHO reports (WHO, 2013; WHO 2012), the review of the toxicological studies suggested that BC is harmful to the health both for its physical nature of nanoparticle and for the fact that thanks to its high specific surface it "*may operate as a universal 'carrier' of a wide variety of chemicals of varying toxicity to the human body*" (Figure 26). In particular BC, is associated with toxic and carcinogenic substances, such as polycyclic aromatic hydrocarbons (PAH) or metals. Thus the airborne Black Carbon concentration itself and the fraction in particulate matter (reported usually as BC/PM2.5 or BC/PM10) are a good indicator of PM toxicity and related health risk.

Figure 26 - Black Carbon dimension and structure (*Source: US-EPA, 2012; Williams M., 2013*)



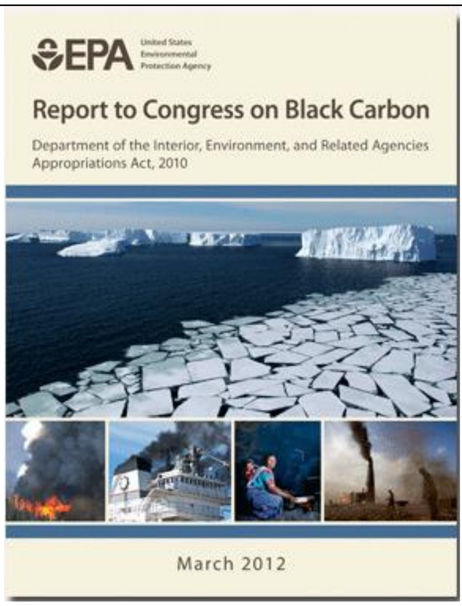


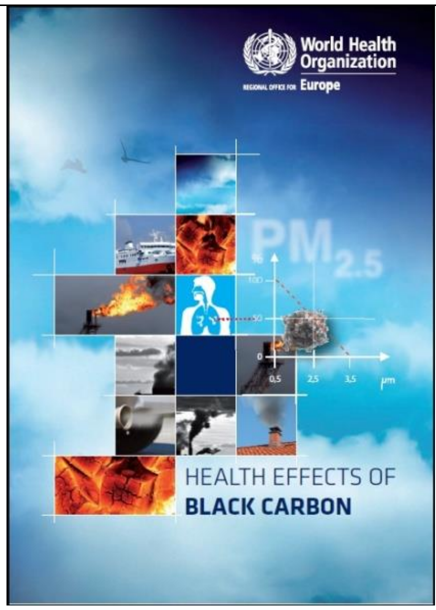
Latest WHO publication, containing the results of the REVIRHAAP project (WHO, 2013) reports as conclusion:

"A reduction in exposure to PM2.5 containing BC and other combustion-related particulate material for which BC is an indirect indicator should lead to a reduction in the health effects associated with PM and simultaneously contribute to the mitigation of climate change."

In fact epidemiological studies provide sufficient evidence of the association of cardiopulmonary morbidity and mortality with Black Carbon exposure and this pollutant was recently recognized as one of the short-lived climate-forcers. In Figure 27 most important and recent publications dealing with airborne Black Carbon are reported.

Figure 27 - Main Reports on Black Carbon (*Source: http://www.epa.gov/blackcarbon/; http://www.who.int*)



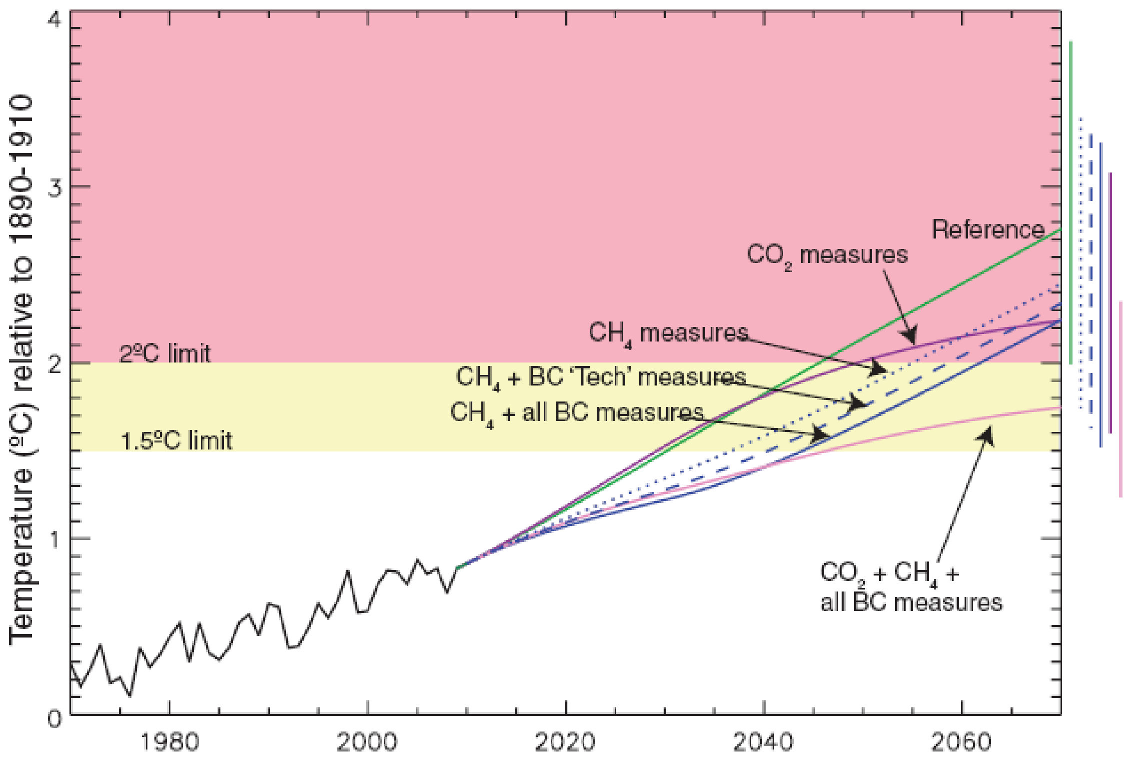


As part of the epidemiological studies, in particular, the meta-analysis reported in Janssen *et al.* , 2011, suggests that Black Carbon is found to be an indicator of more robust and more effective than

PM10 and PM2.5 in terms of relative valuations the health effects : for example, **the increase in life expectancy caused by a hypothetical intervention to reduce vehicular traffic expressed in terms of Black Carbon can be four to nine times higher than that assessed on the basis of an equivalent variation of the concentrations PM2.5 mass.**
In fact, airborne Black Carbon concentrations, deriving by a '**primary' pollutant**, have an **important gradient related to the distance from the emission source**, not showed by PM mass concentrations, characterized by a 'secondary' fraction (of great importance, for instance, in the Po Valley) and more homogeneously distributed in space. This fact makes Black Carbon an excellent tracer of 'traffic proximity' exposure and of the numerous health effects associated with it.
The measurement of Black Carbon concentrations in a city like Milan (where traffic contribute is about 70% for PM) allows to discern the environmental and health impacts of traffic emissions in different exposure situations, placed at a greater or a lesser distance from the traffic source. This applies, in particular, at street level (kerbside sites) and during the season when other sources do not affect Black Carbon emissions (e.g. residential heating in winter).
From the regulatory point of view it should be noted that the international scientific community is discussing[2] on the basis of the latest scientific research the new air quality standards in relation to the finer fractions of particulate matter (i.e. nanoparticles), not currently regulated. Nanoparticles show most important health effects with respect to the particulate mass (PM10 and PM2.5), to which the EU Limit Values are currently referred.
For the characterization of nanoparticles are available different parameters and Black Carbon is one of the main candidates in the definition of a future air quality standards, taking into consideration that measurement techniques of this parameter are at present more harmonized than those of other parameters, both for the fact that the measurement of Black Carbon in the atmosphere has been recently introduced by the European Union (30^{th} session of the Convention LRTAP - Long -range Transboundary Air Pollution - Geneva , April 30 - May 4, 2012), under the *Gothenburg Protocol* - the agreement regulating the emission limits for transboundary air pollution - both for its already known characteristics of climate forcer, and for the health effects associated with it.
Policies to reduce Black Carbon emissions are considered by the scientific community a *'win-win strategy*', since recent studies demonstrated (Shindell *et al*., 2012; Anenberg *et al*., 2012) that in the face of measures designed to control Black Carbon and methane emissions, in addition to those aimed at the limitation of CO_2, significant benefits are obtained as well as a slowing of climate change processes (Figure 28) and in terms of air quality and health effects associated with it, which are measurable in millions of premature deaths avoided by 2030 worldwide.
Adopting Black Carbon monitoring, a primary pollutant, excellent tracer of traffic proximity exposure in a city as Milan, could offer the possibility to assess both the health effects and the climate change of a traffic measure, respectively at 'local' and at 'global' level.

Figure 28 - Observed temperatures through 2009 and projected temperatures thereafter under various scenarios, all relative to the 1890–1910 mean. (*Source: Shindell et al., 2012*)

[2] *'How to regulate Ambient Nanoparticles'* , Focus Event at the 17^{th} ETH - *Conference on Combustion Generated Nanoparticles*, June 23 - 26^{th}, 2013



9.2 AIMS OF THE STUDY

The main two aims of the Area C Black Carbon monitoring project were the following:

1) To evaluate **Black Carbon** (BC), **PM10** and **PM2.5** concentrations **inside and outside 'Area C' Limited Traffic Zone (Ltz)** in **different traffic-proximity exposure conditions** (kerbside, residential, pedestrian);
2) To assess **effectiveness of Black Carbon** as a **new indicator** for **environmental** and **health effects** of traffic generated nanoparticles in **local traffic restriction interventions for Milan**, where the vehicular fleet is characterized by 48% of diesel cars.

9.3 SITES DESCRIPTION

Black carbon, PM10 and PM2.5 real-time measurements were performed contemporaneously inside and outside Area C LTZ, in four different seasons for several weeks, both at residential and kerbside couples of 'fixed sites', in order to represent different kind of traffic-proximity exposure for living population and city users.
In addition, a study of 'personal exposure' to traffic proximity in the Area C LTZ and in pedestrian areas was performed.

9.3.1 Urban residential exposure (fixed sites)

The first couple of sites, at kerbside, represents a '**direct proximity ground level residential exposure'** in the city. Both sites (Figure 29) were situated on the main ring road of each zone considered: one in the city center inside Area C LTZ (Site A: **Sforza Street**, Figure 30, along

'Navigli Ring road'), the other outside the traffic restriction zone (Site B: **Maciachini Square,** Figure 31, along 'External Ring road'), 5 km away. The monitors were placed at the street level, at a distance of less than 10 m from the center of the roadway. Sforza Street site, located on the Area C inner only one ring road, represents exposure on the busiest street inside the Area C LTZ. It is located in a wide garden relatively closed, at about 10 m from the center of a typical urban canyon street.

Maciachini Square site, located in front of a large and busy square, is very close to a traffic light but exposed to the winds approaching the city from North, so it benefits more of pollutants dispersion by wind than the Sforza site.

The second couple of sites represents a **'roadside third floor level residential exposure'** in the city. Two urban residential sites were chosen (Figure 32), one in the city center inside Area C LTZ (Site A: **Beccaria Street**, Figure 33, the other, outside the traffic restriction zone (Site B: **Porpora Street**, Figure 34), 3 km away. The monitors were placed on the terrace of two third floor offices. Both the sites are situated in a large square on which different important streets meet and are open to pollutants dispersion by wind. Measurements of air quality using BC for this type of site are rather sporadic in the literature, this study therefore represents an important contribution in this field of research.

Figure 29 - Location maps of the two sites representing a '<u>direct proximity ground level residential exposure</u>'

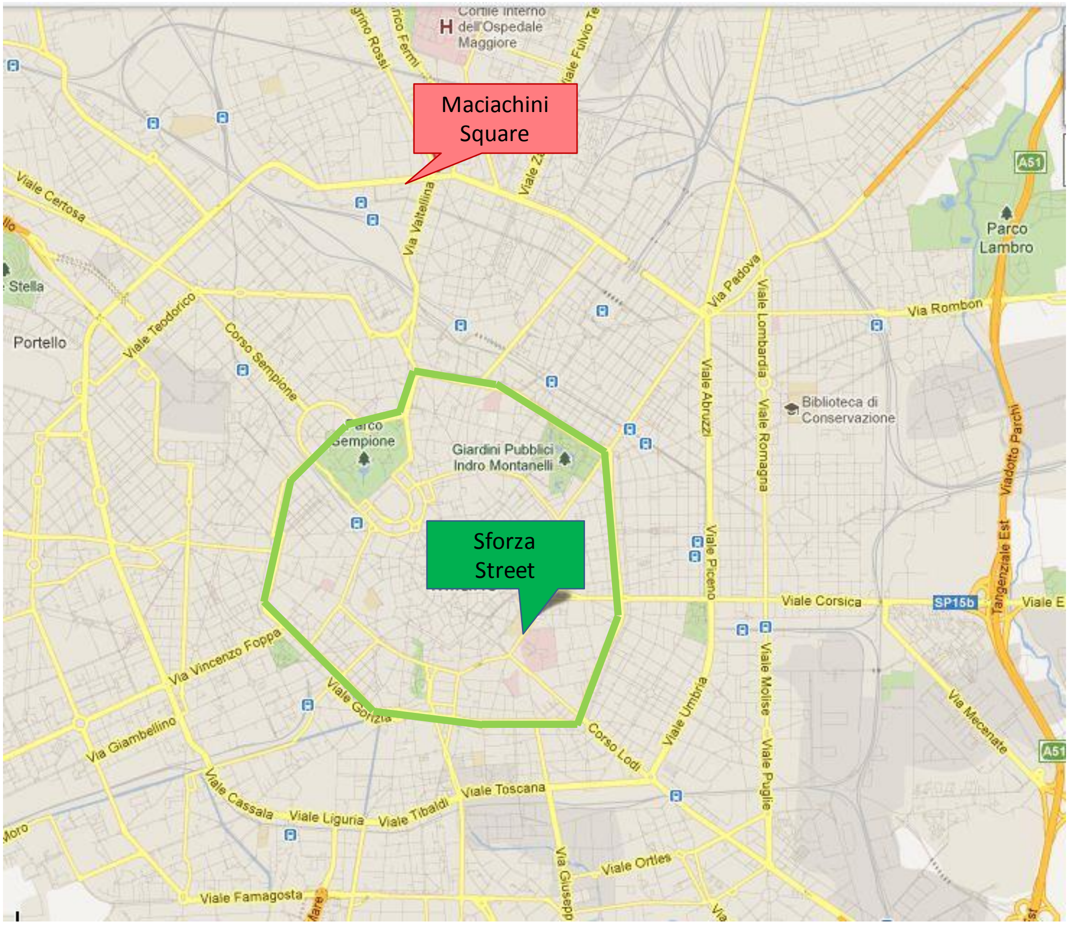


Figure 30 - Sforza Street site, Sormani Library

Figure 31 - Maciachini Square site,

garden, <u>inside Area C LTZ</u> ('<u>direct proximity ground level residential exposure</u>')	**Municipal Water Plant yard, <u>outside Area C LTZ</u> ('<u>direct proximity ground level residential exposure</u>')**

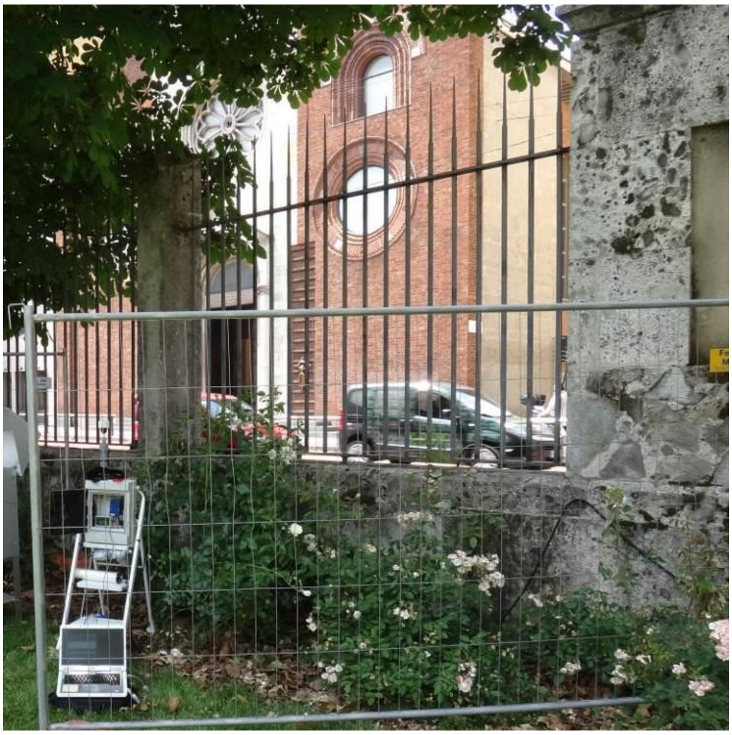


Figure 32 - Location maps of the two sites representing a <u>'roadside third floor level residential exposure'</u>

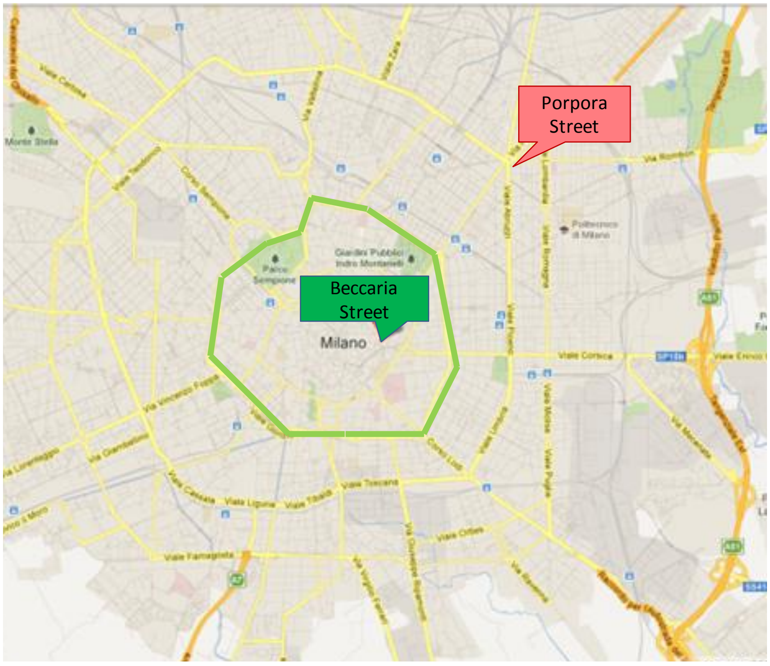


Figure 33 - Satellite view of the Beccaria Street site, Palazzo del Capitano's third floor terrace, <u>inside Area C LTZ ('roadside third floor level residential exposure')</u> in front of Verziere Square

Figure 34 - Porpora Street site, City of Milan building's third floor terrace, <u>outside Area C LTZ ('roadside third floor level residential exposure')</u> in front of Loreto Square

9.3.2 Pedes

In the framework of this study several mobile sampling campaigns, using 'portable' samplers, have been realized in order to evaluate Black Carbon 'pedestrian personal exposure' along one of the main access axis to the city center. For more details see Section 9.6.2.

9.4 SAMPLING PROGRAM

In the '**<u>direct proximity ground level residential exposure</u>**' sites two different sampling campaigns were scheduled, in **Spring** (from May 20th to May 29th, 2012) and at the end of **Summer** (from Sept 15th to Sept 25th, 2012), both without residential heating. In the **'<u>roadside third floor level residential exposure</u>'** sites the sampling campaigns were scheduled in **Winter** (from Febr 1st to Febr 26th, 2012), with residential heating on and in **Autumn** (from Oct 1st to Oct 28th, 2012), before and during the start of residential heating (Oct 15th is the data admitted by law), with merely the traffic source as anthropogenic contribution to PM an BC concentrations in the first two weeks of this last sampling period.

All the sampling campaigns were realized taking into account working days (with the Area C LTZ in force). In order to evaluate, as additional result, the effect of some 'Pedestrian Sunday' initiatives, that take place during the year, also some week-end days in the proximity of the scheduled sampling period have been monitored.

The sampling campaigns to measure Pedestrian personal exposure were performed in different seasons, at different hours of the day and lasted for several hours and in different traffic densities conditions (no campaign was scheduled in summer).

9.5 INSTRUMENTS AND METHODS

BC concentrations were measured at 5-minute time resolution with MicroAethalometer^{TM} (mod. AE51, Magee Scientific, USA) while PM10 and PM2.5 with Optical Particle Counters (mod. Aerocet 531 - MetOne Instruments Inc., USA; mod. DustMonitor - Contec Engeneering, Italy) programmed at a 15-minute sampling time (Figure 35-Figure 37). In the two sites, pairs of identical instruments have been used, each aligned and calibrated with a reference instrument: Aethalometer^{TM} mod. AE31, Magee Scientific, USA in the case of Black Carbon (Figure 38-Figure 39); BAM-1020, MetOne, USA with US-EPA equivalence certificate EQPM-0798 and T.Ü.V. 936/21205333/A in the case of PM. All instruments have been enclosed inside a weatherproof box for long outdoor operations and the sampling inlet of the Aerocet model has been heated at about 10-12 °C above the ambient temperature to avoid relative humidity interference and without excess heat to avoid re-evaporation of semi-volatile compounds.

At the end of the measurements a data processing system was adopted for the compensation and validation of the measured data.

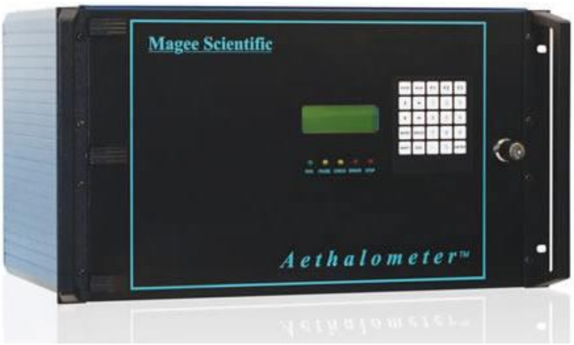
Figure 35 - MicroAethalometer™ (mod. AE51, Magee Scientific, USA) used to measure airborne Black Carbon

Figure 37 - Optical Particle Counter (Mod. Aerocet 531 - MetOne Instruments Inc., USA) used to measure airborne PM10 and PM2.5

Figure 36 - Optical Particle Counter (Mod. DustMonitor - Contec Engeneering, Italy) used to measure airborne PM10 and PM2.5

Figure 38 - Aethalometer™ (mod. AE31, Magee Scientific, USA) used to calibrate airborne Black Carbon monitoring instruments

Figure 39 - Beta Attenuation Monitor with PM2.5 and PM10 inlets (mod. BAM-1020, MetOne, USA with US-EPA equivalence certificate EQPM-0798 and T.Ü.V. 936/21205333/A) used to calibrate airborne PM10 and PM2.5 monitoring instruments



Meteorological data and traffic related pollutants concentrations (e.g. NO_2, NO, CO) considered in the data analysis have been processed using the Regional Air quality and Meteorological network dataset, selecting the nearest monitor station for any sampling site.

Boundary layer mixing height values have been estimated using: a) measured data by Sodar wind profiler, in the historical center of the city, as for nocturnal mixing height values; b) Batchvarova-Gryning model (Batchvarova and Gryning, 1994) applied to conventional meteorological ground parameters measured near the Sodar wind profiler, as for diurnal mixing height values.

For the pedestrian exposure campaigns the same precalibrated and aligned instruments were used: MicroAethalometer^{TM} (mod. AE51, Magee Scientific, USA) for BC and Optical Particle Counter (mod. Aerocet 531 - MetOne Instruments Inc., USA) for PM10 and PM2.5.
During pedestrian exposure campaigns the programmed sampling times were set at 1-minute for BC and 2-minutes for PM10 and PM2.5.

9.6 RESULTS AND DISCUSSION

9.6.1 Urban residential exposure

<u>At kerbside sites</u> in May, during working days with Area C LTZ in force, the 24h mean (SD) BC concentrations were 2.4 (0.5) g/m^3 and 4.0 (2.3) g/m^3 inside and outside Area C respectively ($p<0.0001$), indicating a difference in absolute values of 1.6 (2.0) g/m^3 or -40% inside LTZ as compared to the outside area. BC/PM10 and BC/PM2.5 ratios were 50% and 59% lower inside LTZ.

In September (Figure 40), at the same sites, during working days with LTZ in force, the 24h mean (SD) **BC concentrations** were 3.2 (0.8) g/m^3 and 6.7 (1.0) g/m^3 inside and outside Area C respectively ($p<0.0001$), indicating a difference in absolute values of 3.5 (1.4) g/m^3 or **-52%**

inside LTZ as compared to the outside area. BC/PM10 and BC/PM2.5 ratios were 50% and 60% lower inside LTZ.

At **third floor residential sites**, in February, the 24h mean BC concentrations reached a value of 5.6 (1.9) g/m^3 inside and 7.8 (2.5) g/m^3 outside Area C ($p<0.0001$), indicating a difference in absolute values of 2.2 (1.3) g/m^3 or **-28% in the LTZ**. BC/PM10 and BC/PM2.5 ratios were 32% and 25% lower inside LTZ.

At the same sites, in October, one-month sampling campaign has been realized before and after the residential heating start (Figure 41). Referring to the first week, characterized by more stable meteorological conditions and the heating plants off the 24h mean BC concentrations reached a value of 2.8 (1.4) g/m^3 inside and 4.1 (1.6) g/m^3 outside Area C ($p<0.0001$), indicating a difference in absolute values of 1.3 (1.1) g/m^3 or -32% in the LTZ. The BC percentage difference between in and outside LTZ decreased by about 50% with domestic heating on (-12% *vs*. -33% on average or -24% *vs*. -52% on single days).

No statistically significant changes were found in PM10 and PM2.5 concentrations between the inside and the outside site for any sampling campaign performed.

The results obtained in this study (Figure 42) are in agreement with literature for similar sites in other cities: **Berlin** (Brukmann and Lutz, 2012), **London** (TfL, 2010), **Barcelona** (Reche *et al*., 2011), **Munich** (Quadir *et al*., 2013) and a previous kerbside summer study on the same area (Invernizzi *et al*., 2011).

In Figure 40 e in Figure 41 Black Carbon concentrations together with PM10, PM2.5 and some meteorological data (wind speed, rainfall) are reported. It is possible to note the influence of atmospheric dispersive conditions on the concentrations.

Figure 43 shows the correlations between Black Carbon concentrations, traffic patterns, boundary layer mixing height and heating power consumption profile in a typical ‘Working Day’ during winter campaign at residential roadside sites. It is possible to observe how Black Carbon concentrations change as a function of the diurnal development of the boundary layer mixing height, following however the traffic rush hours and partially the switching on/off of the residential heating.

Figure 40 - BC concentrations inside and outside Area C LTZ during September monitoring campaign at kerbside sites

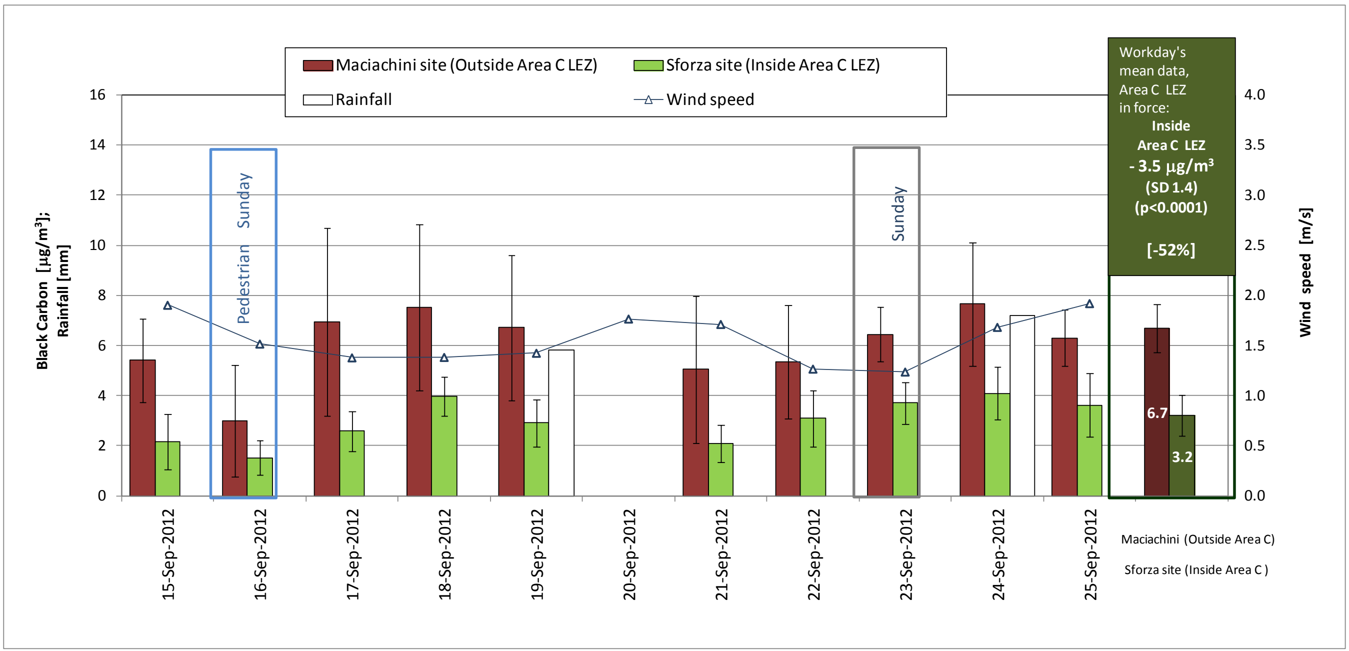


Figure 41 - BC concentrations inside and outside Area C LTZ during October monitoring campaign at residential sites

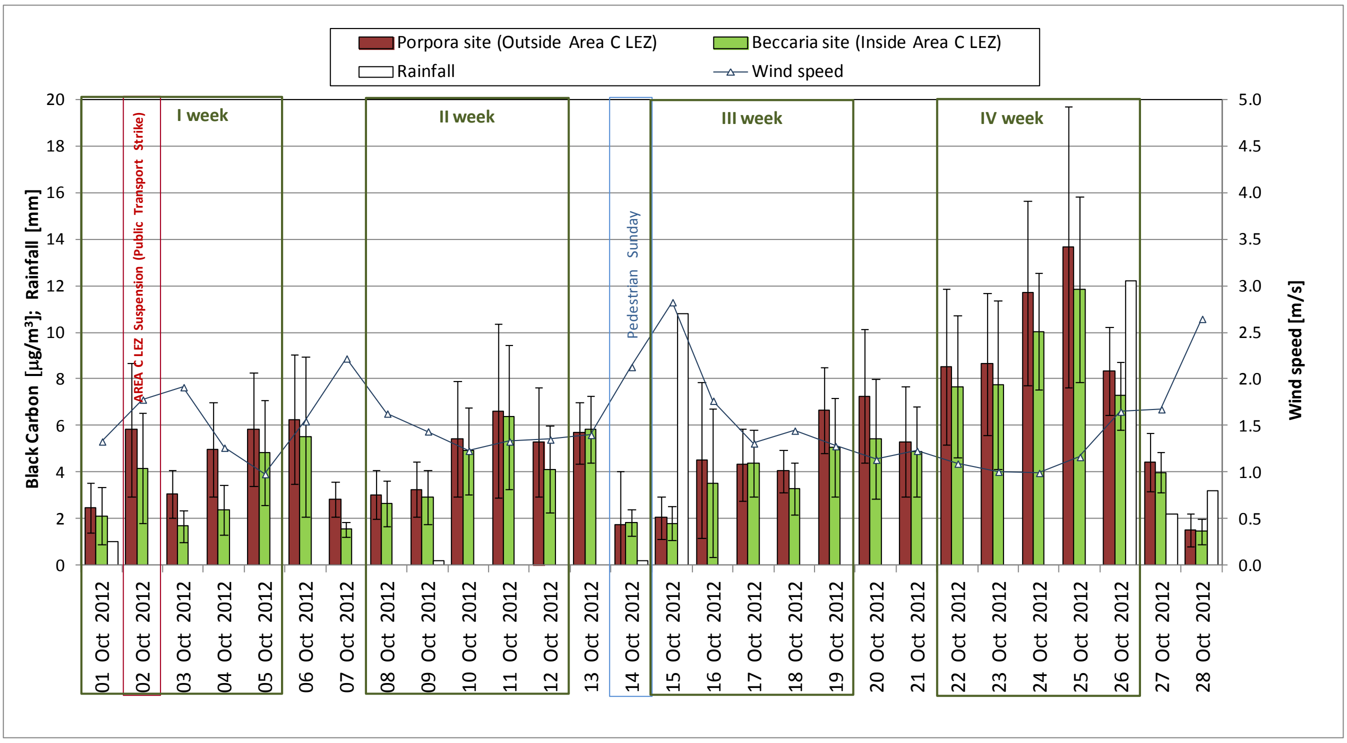


Figure 42 - Overview of Black Carbon monitoring results during the first year of Area C Ltz

Kerbside sites	3rd floor level residential sites

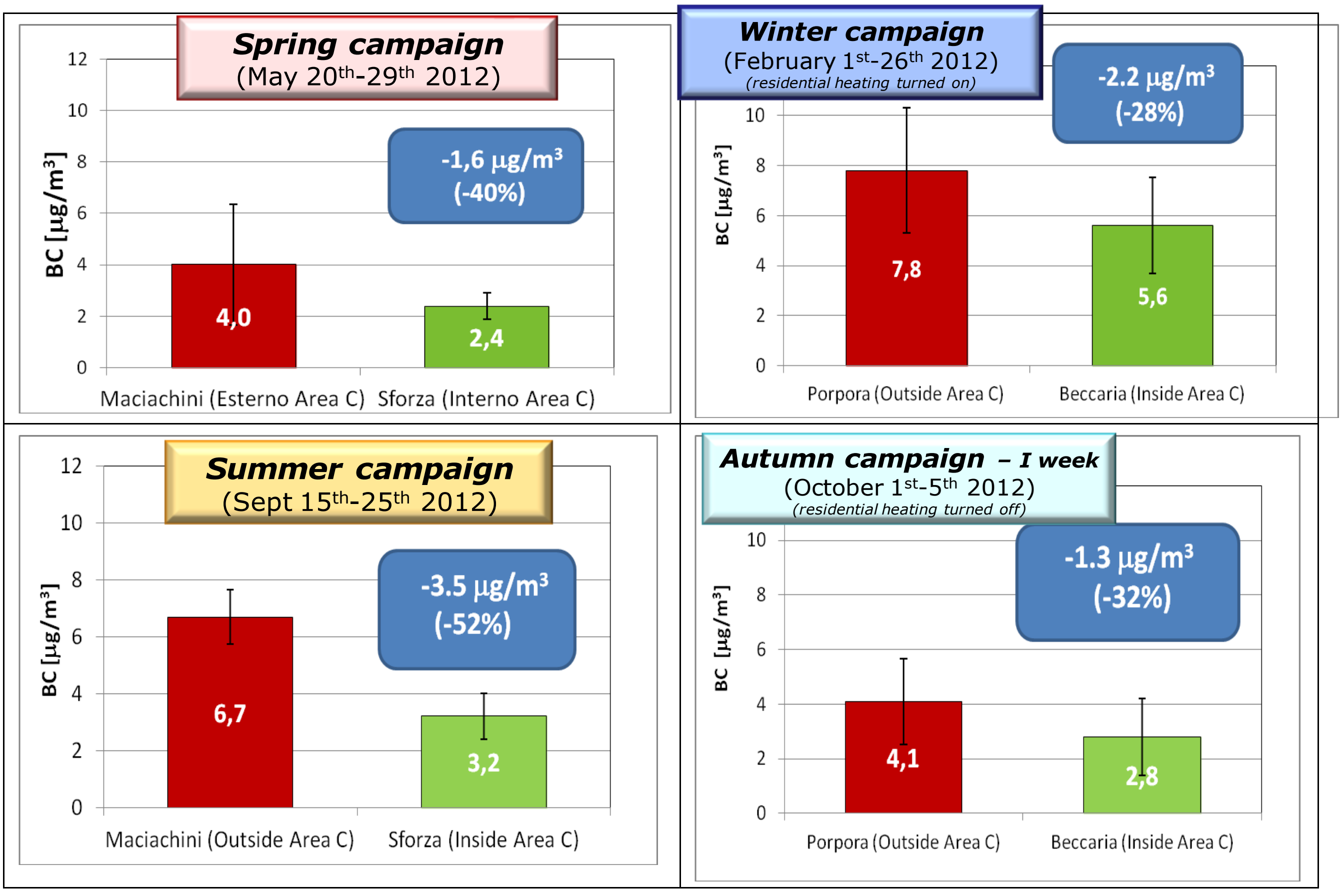
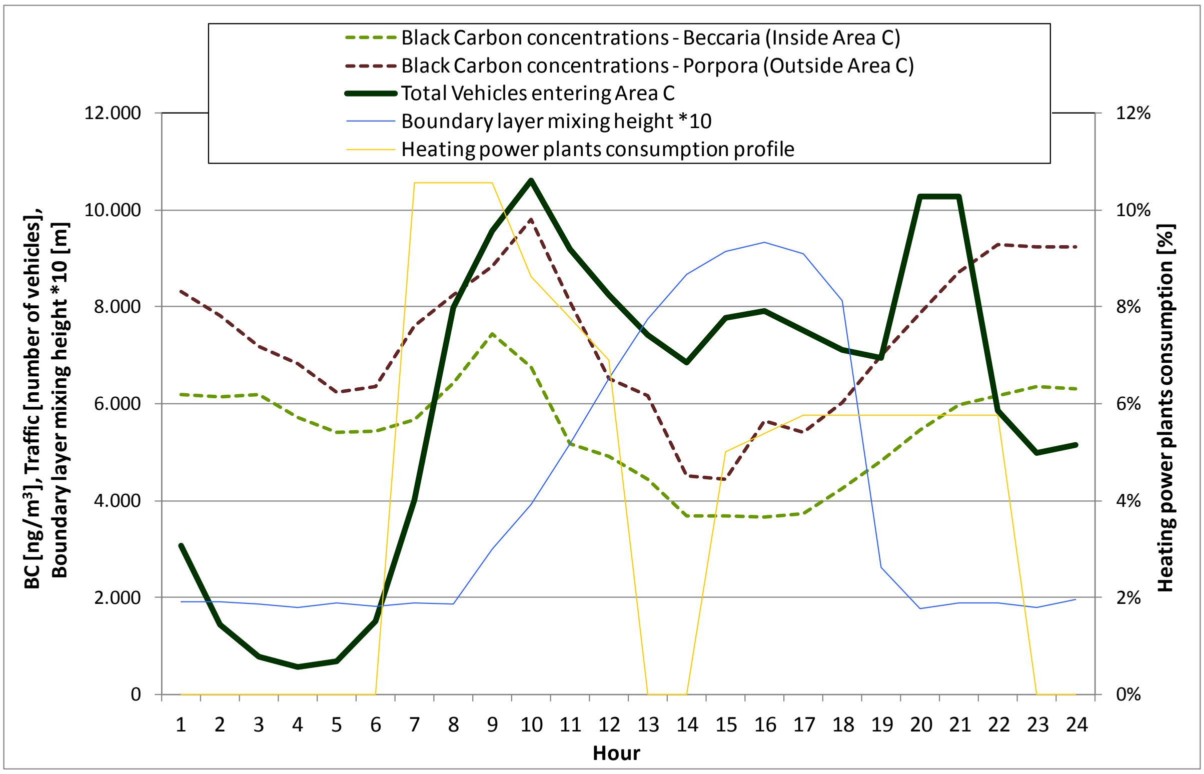


Figure 43 - Correlations between Black Carbon concentration in/outside Area C Ltz, traffic patterns, mixing height and heating power consumption profile. Hourly profiles of a typical 'Working Day', Winter campaign, Residential roadside sites

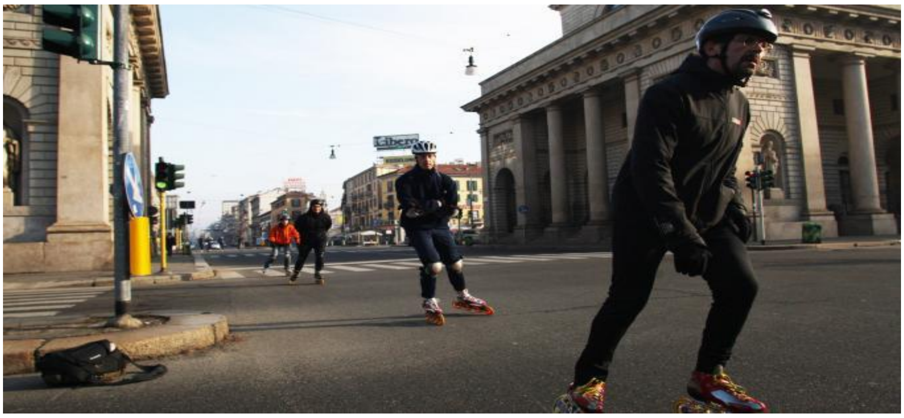


9.6.1.1 Pedestrian Sundays (o Car-free Days)

At kerbside, during the ‘Pedestrian Sunday' (Figure 44-Figure 45) initiative Black Carbon mean concentrations of the two sites were measured 78% lower (May 27th, 2012) or 75% lower (September 16th, 2012) compared to the nearest Sundays without traffic restrictions, also despite less dispersive meteorological conditions. These results are in a perfect agreement with traffic measurements which reports a 72% reduction in relation to a typical Sunday circulation. In October these results couldn't be confirmed due to perturbed meteorological conditions during most of the Sundays.

Figure 44 - Pedestrian Sunday Milan’s bunner

Figure 45 - A street view during a Pedestrian Sunday in Milan (Venezia Gate)



9.6.1.2 Area C LTZ Suspension during a Public Transport Strike

At residential sites during the autumn campaign, in correspondence to a temporary suspension of the Area C LTZ measure due to a public transport strike (October 2nd, 2012), an increase in Black Carbon concentrations has been registered, ranging from 1.9 to 2.4 times in Porpora site (outside Area C LTZ) and from 2 to 2.5 times in Beccaria site (inside Area C LTZ), compared to measurements on the previous and following days. Considering the toxicity associated with this indicator (Janssen *et al*., 2011) a possible increase in health risk could be expected during those days. This event allowed us to verify the extreme sensitivity of the Black Carbon indicator with increasing urban traffic congestion, not found in any other pollutant currently measured by the institutional Regional Environmental Agency monitoring network (PM10, PM2.5, NO_2, CO), that in the same days vary in a lower extent.

9.6.2 Pedestrian Personal Exposure

Pedestrian personal exposure has been measured by persons carrying **portable samplers** and strolling outside/inside the Area C along the itinerary reported in Figure 46. Contemporaneously one other set of instruments installed on a fixed site measured the BC and PM concentrations in order to take into consideration pollution temporal variations. The itinerary was repeated in three different days. The pedestrian routes covered a street that represents one of the most important access axis for the city center, **starting from Loreto square and arriving in S. Babila square** (first trip) **or up to the Pedestrian Area of Duomo square** (second and third trip). An example of the Black Carbon concentrations monitored during the pedestrian trip is given in Figure 47.

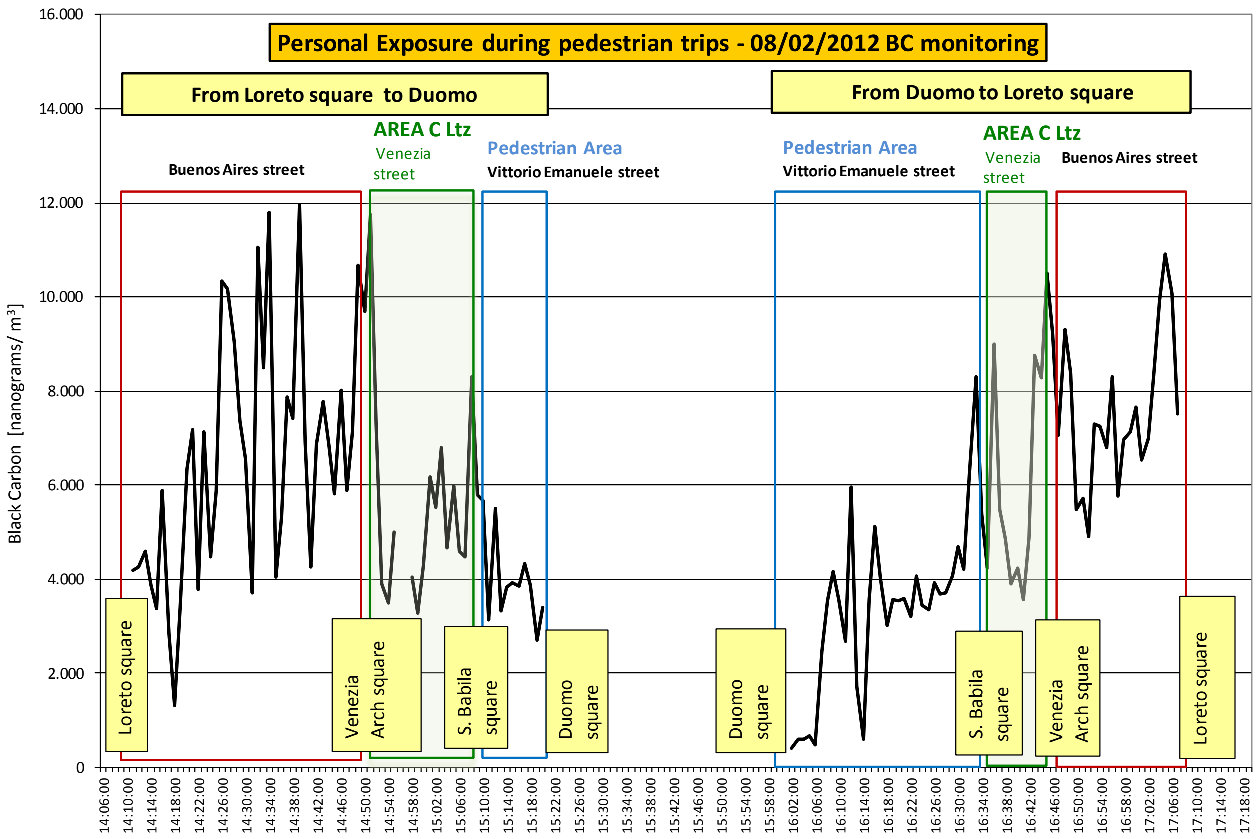
In comparison to the outside Area, measurements of the pedestrian exposure inside Area C LTZ showed, on average over the three repetitions of the same route, the following values:

Black Carbon up to -43% inside Area C Ltz, up to -59% in Pedestrian Area
BC/PM10 up to -46% in Area C Ltz, up to -63% in Pedestrian Area

These results may underestimate the exposure because itineraries hours not always were corresponding to the traffic rush hours.

Figure 46 - Pedestrian route (from Loreto Square to Duomo Square and vice versa)

Figure 47 - Personal Exposure during pedestrian trips from Loreto Square to Duomo and vice versa (Febr 8th, 2012)



10 'AREA C' FROM THE EXPERIMENTAL PHASE TO A STABLE MEASURE: ADOPTING BLACK CARBON AS A TOOL IN MOBILITY PLANNING

10.1 INTRODUCTION AND AIMS

In 2012 the Milan Municipality, with AMAT support, developed the Urban Traffic Plan (PGTU) updating. 'Area C' Ltz has been assessed as a structural measure with positive impact on main environmental aspects and coherent with the aim to reduce traffic congestion.
In March 2013 the Local Council, taking into consideration the PGTU SEA results, approved PGTU updating. On Mars 27th, 2013, after one year of 'Area C' trial phase, the Municipal Board confirmed 'Area C' as a permanent and strategic measure, complementary to others (as 30 km/h Zones, Cycle network, etc.).

In the framework of **Strategic Environmental Assessment (SEA)** procedure of the **Urban Traffic Plan (UTP), the Municipality** of Milan introduced Elemental Carbon (pollutant closely related to Black Carbon) among **quantitative indicators**, basing on the experience with the airborne Black Carbon measurement Project [described at Section 9].
The aim of the adoption of this traffic exposure tracer in the framework of the Urban Traffic Plan Assessment is to obtain a 'particulate toxicity indicator', easy-to-use within the normal planning activities of the local Public Authority and **related to the environmental and health potential effects of different policy scenarios**.

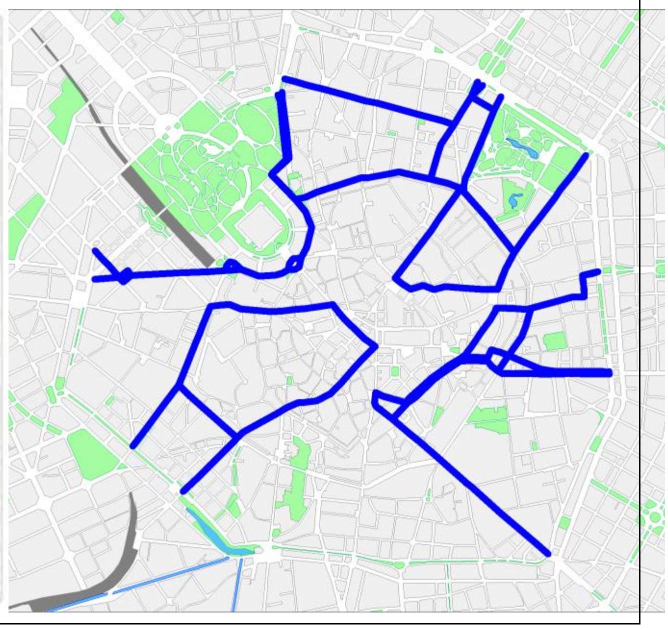
10.2 BACKGROUND AND METHODS

As reported in the Section 2.3, in scientific literature there is sufficient evidence to support a causal relationship between exposure to traffic-related air pollution and exacerbation of asthma, and suggestive evidence of a causal relationship with onset of childhood asthma, non-asthma respiratory symptoms, impaired lung function, total and cardiovascular mortality, cardiovascular morbidity and lung cancer (Health Effects Institute, 2010; Raaschou-Nielsen *et al*., 2013).
Being the carbonaceous nanoparticles such as Black Carbon (BC), a sensitive indicator of the spatial variation of road traffic emissions (‘traffic proximity’ indicator) and of their health-related effects (WHO, 2013), the emissions of Elemental Carbon (EC), pollutant closely related to BC, have been adopted as tracers of the population exposure (Keuken *et al*., 2012, Lefebvre *et al*., 2011).
According to the literature, a critical distance from the vehicular traffic source has been identified to which refer evaluations of some health effects that have 'sufficient evidence' (i.e. childhood asthma) on population. Children living closely than 75 meters to major roads have an increased probability by about 30% of receiving a diagnosis of asthma and by about 40%-50% to be on medication for asthma or have had recent acute episodes (McConnell *et al*., 2006; Perez L., 2012; Brugge *et al*., 2007).
In order to obtain an exposure indicator for the different mobility planning scenarios considered within the Urban Traffic Plan [Table 3, Figure 48-Figure 49] the **daily mean vehicular EC emissions** released **at a distance less than 75 meters from places of residence** have been calculated [Table 4-Table 5] using COPERT IV model emission factors (Katsis *et al*., 2012) and the **population exposed to different levels of EC traffic emissions** [Figure 50-Figure 51] has been evaluated.

Table 3 - Mobility Planning scenarios at 2015, evaluated for the SEA of the Urban Traffic Plan (UTP)

Reference	UTP Base	UTP Base + Road pricing	UTP Base + Loop
business as usual scenario, with traffic emissions variation due to the merely renewal of the car fleet	implementation of the 'Base' measures included in the Urban Traffic Plan (i.e. 30 km/h Zones, Pedestrian Areas, reserved lanes for public transport and bikes) without considering any specific vehicular circulation control scheme within the Bastioni Ring Area	Base scenario together with the adoption of the 'Road pricing' scheme to access the Bastioni Ring Area	Base scenario together with the adoption of the 'Loop' scheme for vehicle circulation inside the Bastioni Ring Area

Figure 48 - ‘Road pricing’ scheme to access	Figure 49 - ‘Loop’ circulation scheme within

Bastioni Ring Area	**Bastioni Ring Area**
	

10.3 RESULTS AND DISCUSSION

10.3.1 Urban Traffic Plan (UTP) 'Base' measures scenario compared with 'Reference' scenario at 2015

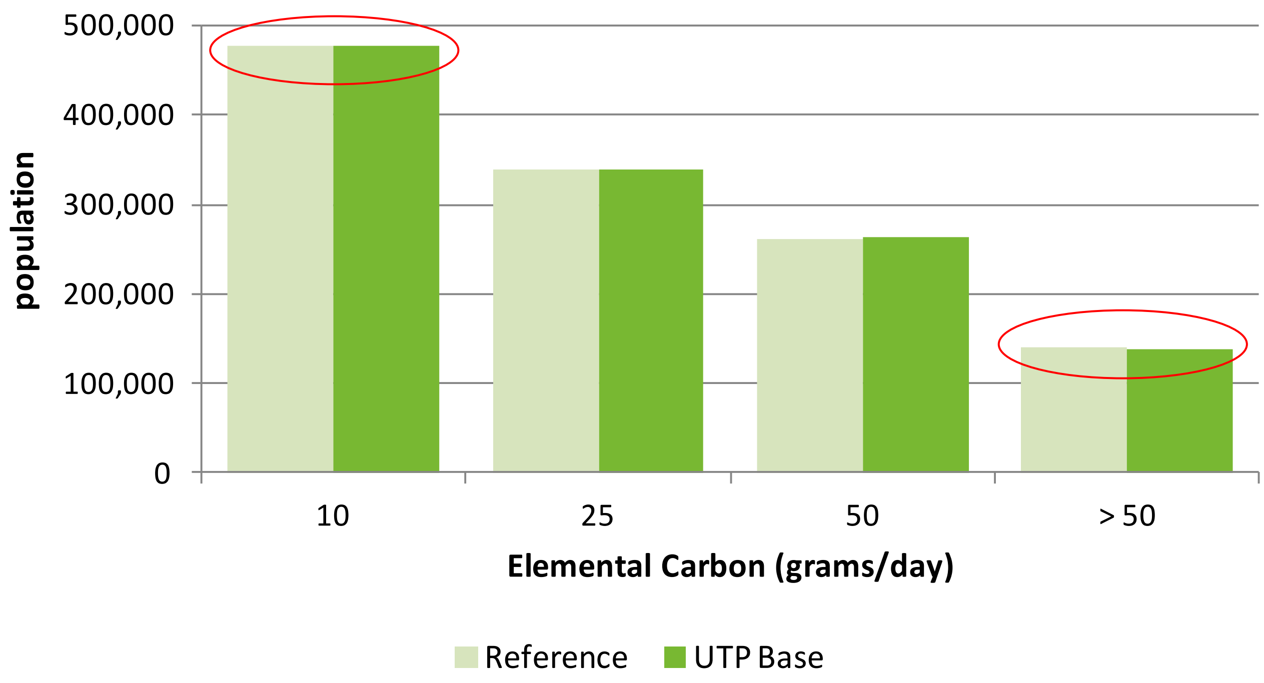
Most important findings of that assessment are (see Table 4):

- ✓ Slight increase of EC traffic emissions (+2%) and related population exposure inside Bastioni ring;
- ✓ Reduction of EC traffic emissions (-5%) and related population exposure in the area between Bastioni ring and Filoviaria ring;
- ✓ Decrease (-2.2%) of population exposure in the whole city (Figure 50) to higher emissions level (>50 grams/day), corresponding to about 3,000 inhabitants and slight increase of population exposure to lower EC level (<10 grams/day).

Table 4 - Averaged on population Working day mean Vehicular exhaust Emissions of Elemental Carbon [grams/day] released within 75 meters from residences: Urban Traffic Plan (UTP) 'Base' measures scenario *vs* 'Reference' scenario at 2015

Elemental Carbon traffic emissions [grams/day] released within 75 meters from residences	Reference	UTP Base	%
Milan (whole city)	22.0	21.8	-1%
Inside Bastioni ring	20.4	20.8	+2%
Between Bastioni ring and Filoviaria ring	30.9	29.5	-5%
Between Filoviaria ring and city boundaries	19.2	19.2	0%

Figure 50 - Population exposed to different traffic EC emissions levels released within 75 meters from residences: Urban Traffic Plan (UTP) 'Base' measures scenario *vs* 'Reference' scenario at 2015



10.3.2 Different mobility planning scenarios ('UTP Base +Road pricing' or 'UTP Base +Loop') compared with Urban Traffic Plan (UTP) 'Base' measures scenario at 2015

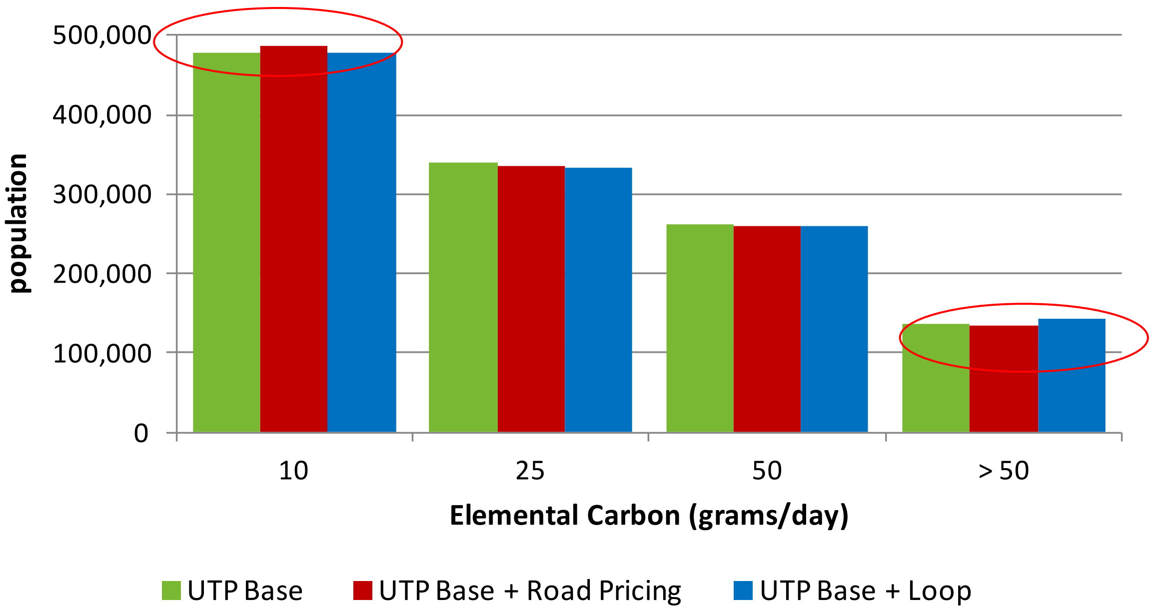
Main results of this assessment are(see Table 5):

- ✓ 'UTP Base+Road pricing' scenario: most important EC traffic emissions reduction (-12%) inside Bastioni ring and a small variation in the same direction (-1%) in the whole city
- ✓ 'UTP Base+Loop' scenario: EC traffic emissions reduction (-8%) inside Bastioni ring, but increase (+4%) outside it
- ✓ 'UTP Base+Road pricing' scenario: decrease of population exposure (Figure 51) to higher emission levels and increase for lower emission levels, corresponding in a shift of about 9,000 inhabitants, respect to the 'Loop' scenario

Table 5 - Averaged on population Working day mean Vehicular exhaust Emissions of Elemental Carbon [grams/day] released within 75 meters from residences: 'UTP Base+ Road pricing' and 'UTP Base + Loop' scenarios *vs* Urban Traffic Plan (UTP) 'Base' measures scenario at 2015

Elemental Carbon traffic emissions [grams/day] released within 75 meters from residences	UTP Base	UTP Base + Road Pricing	%	UTP Base + Loop	%
Milan (whole city)	21.8	21.5	-1%	22.1	+1%
Inside Bastioni ring	20.8	18.3	-12%	19.2	-8%
Between Bastioni ring and Filoviaria ring	29.5	29.3	-1%	30.6	+4%
Between Filoviaria ring and city boundaries	19.2	19.1	-1%	19.5	+2%

Figure 51 - Population exposed to different traffic EC emissions levels released within 75 meters from residences: 'Base+ Road pricing' and 'Base + Loop' scenarios *vs* 'Base' measures of Urban Traffic Plan (UTP) scenario at 2015



Concluding, it is possible to assert that BC/EC, excellent tracer of 'traffic proximity' exposure, offers the possibility to verify the effectiveness of different policies in mobility planning.
In the city of Milan, **'road pricing' scenario** at 2015 leads to a **decrease of about 9,000 inhabitants exposed to highest EC traffic emission levels** (>50 grams/day) respect to the 'Loop' circulation scheme, with an important benefit for public health.
This assessment has supported the **confirmation of the 'Area C' Congestion Charge** scheme adopted as a pilot measure in 2012.

11 KEY LESSONS LEARNT FROM 'AREA C' LTZ EXPERIENCE

11.1 TRAFFIC CONCERNS

Traffic congestion is a persistent and growing problem in metropolitan regions worldwide and local governments requires innovative solutions to face it.

The road pricing measure can be considered an efficient lever to find resources for improving life quality of citizens. In Milan, all the 'Area C' Ltz incomes have been reinvested in projects for sustainable mobility, such as the strengthening of public transport and the development of bike-sharing system.

Results at a glance:

- **One out of three cars was left at home, traffic congestion and accidents have dropped, public transport has increased its speed;**
- After a year, there have been **significant changes in citizen's travel behaviours**: they seem to have fully understood the objectives of the Area C measure, **shifting towards cleaner modes of transport.**

Even if the Area C Ltz was introduced in observance to the results of a Public referendum indicating that the vast majority (79%) of voting Milan citizen wanted to potentiate public transports and to limit traffic-related pollution, the measure met with some resistances during the trial phase. Thanks to the dialogue and public feedback with all the parties affected by the measure, some needs coming from citizens have been accepted and the most tenacious resistances have been overcome. Several events to boost the city trade have been promoted to mitigate the social impact of the measure. In particular, on Thursday the duration of the measure was reduced of 1 hour (from 7:30 am to 6:30 pm) to meet trade needs. Incentives to users of the private parking lots located inside the 'Area C' Ltz were arranged in order to meet private parking owners requests and, at the same time, to obtain a reduction of the public space occupation for on-street parking and dedicate it to other forms of sustainable mobility (cycling routes, etc). An agreement with the private parking owners association was subscribed in October 2013 with the result of some fee discounts for users of the conventioned private parking lots located inside the Congestion Charge zone: 'Area C' Ltz entrance ticket at 3 euro instead of 5 euro; discounted tariff (max 4 euro/hour) for parking inside the conventioned private parkings, valid even for cars exempted from payment of the 'Area C' Ltz entrance ticket (See Section 5 too).

An other change of the measure introduced to meet Area C Ltz users is the widening of the deadline for paying the entrance ticket: now it is possible to pay the standard entrance ticket (5 euro) up to the midnight of the following day or to activate an extra-ticket (of the value of 30 euro) paying within a week (next 7 days). Furthermore some facilities are granted to users that register on the dedicated web site www.myareac.it.

A survey carried out in April 2013 analyzing the perception of the citizens of Milan stated that 58% of residents expressed favorable views of ‘Area C’ measure.

Possible perspectives of road pricing schemes in Milan are going to be discussed in the Sustainable Urban Mobility Plan (SUMP).

11.2 ENVIRONMENTAL CONCERNS

‘Area C’ Ltz has halved the most pollutant vehicles and increased the more cleaner vehicles.

Vehicular traffic emissions have dropped from 10 to 42% depending on the pollutant. In particular CO_2 emissions had a sharp decline after four years in which there were not relevant changes.

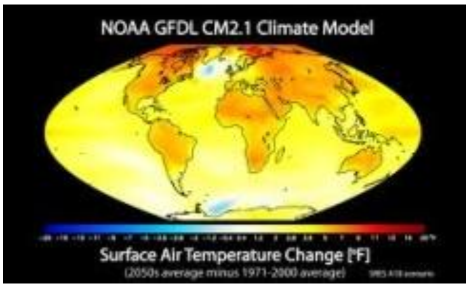
Ambient concentration of the pollutants doesn’t always respond to emission reductions in a 'linear' way; it depends on the kind of the pollutant: only ‘primary pollutants’ emission reductions can have a linear response in term of concentration, while ‘secondary pollutants’ - being subject to chemical transformations in atmosphere - can’t reduce at the same extent of the precursor emission reductions. When an emission control measure works on toxic primary pollutants a reduction in ambient air concentration of toxic primary compounds can be expected.

Milan’s Black Carbon experience in the framework of Area C Ltz showed that monitoring a toxic primary pollutant is possible to demonstrate how local interventions on traffic circulation can produce important effects on airborne toxic traffic-related pollutants, reducing direct proximity and residential exposure.

In fact, even though no change in PM concentrations (characterized in Milan by an important secondary fraction), a statistically significant difference was found in Black Carbon concentrations inside Area C LTZ, both at kerbside and residential roadside sites, with an improvement of one to three BC epidemiological 'change units' (Janssen *et al*., 2011); this means a remarkable difference in terms of personal exposure to traffic particulate toxic emissions and related expected mortality and morbidity, with health benefits for resident population and city users.

Results at a glance:

- ❑ Mathematical models results show that the Area C Ltz based on a **Congestion Charge scheme reduces dramatically CO_2** and the other vehicular pollutant emissions directly linked to driven kilometers.
- ❑ **Monitoring ‘Black Carbon’**, **primary pollutant** and **excellent tracer of 'traffic proximity‘ exposure** and **short-lived climate-forcers**, offers the possibility to verify the **effectiveness of mobility policies (Congestion Charge, Urban Traffic Plan, Sustainable Urban Mobility Plan,** etc) with regard:
  - ✓ the **health effects** on ***‘local’ scale***;
  - ✓ the city's contribution on ***‘global’ scale*** to **climate change effects**.



12 DISSEMINATION

The Area C Ltz experience results are disseminated by website, TV and Radio broadcast, international meetings or main events on the environmental, mobility and transport issues.

Area C technical reports related to both traffic and environmental issues are public and available for citizens at the City’s web site: http://www.areac.it, at the Section ‘*Risultati attesi e monitoraggio*’ (Figure 52).

As far as in concern of Black Carbon monitoring experience results have been presented at the following Scientific Conferences:

- ✓ **PM2012** - Fifth National Conference on Particulate Matter, Perugia, Italy, May 16th-18th, 2012 (Moroni et al.,
- ✓ **16th ETH Conference** on "*Combustion Generated Nanoparticles*", Zurich, Switzerland, June 24th-27th, 2012
- ✓ **TAP 2012 Conference**, "*Transport and Air Pollution Conference"*, Thessaloniki, Greece, November 26th-27th, 2012
- ✓ **17th ETH Conference** on "*Combustion Generated Nanoparticles*", Zurich, Switzerland, June 23rd-26th, 2013
- ✓ **ISEE, ISES and ISIAQ** *"Environment and Health" Conference,* Basel, Switzerland, August 19th-23rd, 2013
- ✓ **ERS Annual Congress**, "*European Respiratory Society Annual Congress 2013"*, Barcelona, Spain, September 7th-11th, 2013
- ✓ **RESPIRAMI**,"*International Seminar on Air Pollution and Respiratory Diseases",* Milan, Italy, October, 19th, 2013
- ✓ **China's Cities Forum**, "*International Forum on Economic Policies for Traffic Congestion and Vehicle Emissions Control*", Hangzhou, China, December 12th-13th, 2013.

Technical reports and scientific conferences proceedings containing the 'Area C' Black Carbon monitoring Project results and the Urban Traffic Plan's SEA findings (see References: 26-27, 41-47, 4) are available at the dedicated website (Figure 53):
http://www.amat-mi.it/it/ambiente/qualita-aria/il-progetto-di-monitoraggio-del-black-carbon/.

Figure 52 - City of Milan's Area C Ltz web site: Reports on Traffic and Environmental monitoring

Figure 53 - AMAT, Agency for Mobility Environment and Land Use web site: Reports on Black Carbon monitoring

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