London Congestion Charging: Successes, Gaps and Future Opportunities Offered by Cooperative ITS *

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Abstract — **The London Congestion Charging (LCC) scheme was initially introduced on 17 February 2003. Being the largest of its kind and employing advanced technology, it marked a major innovation in the field of urban road user charging and provided inspiration to several other cities worldwide. Nine years on, and following a number of operational changes that have taken place, this study analyzes successes and pitfalls, and identifies potential future opportunities in the light of latest technological developments in the field of cooperative Intelligent Transport Systems (ITS). The analysis concentrates primarily on the LCC scheme itself, but draws broader conclusions about the future of urban road charging in general.**

I. Introduction

On the website of Transport for London (TfL) it is stated that "traffic congestion clogs up roads, threatens businesses and damages London's status as a world thriving city" [1]. On the same website it is also stated that, when Ken Livingstone took office as the Mayor of London in the year 2000: (i) London suffered the worst traffic congestion in the UK and amongst the worst in Europe, (ii) drivers in Central London spent 50% of their time in queues, (iii) every weekday morning the equivalent of 25 busy motorway lanes of traffic tried to enter Central London, and (iv) it was estimated that London lost between GBP 2-4 million every week in terms of lost time caused by congestion. In this context, the London Congestion Charging scheme (LCC) was introduced in London on 17 February 2003. As reported by TfL [2], the scheme contributes directly to four of the Mayor's transport priorities, namely: (i) to reduce congestion, (ii) to make radical improvements to bus services, (iii) to improve journey time reliability for car users, and (iv) to make the distribution of goods and services more efficient.

It was the objective of a "Technology Trials" program by TfL [3] to examine how new technologies could support the existing LCC scheme by lowering costs, improving accuracy and making it more user-friendly, as well as more advanced congestion charging schemes (based, for example, on time of day, distance driven, specific roads etc), which might in future replace or supplement the existing system. In its final report in 2007 [4], the program concluded that, while such changes would be feasible, the technology allowing their implementation had not yet been fully developed, but greater potential was to be anticipated in the coming years.

Building on that and examining the scheme again nine years after its launch, the aim of this paper is to assess its successes and deficiencies, and to identify potential improvements using existing and emerging cooperative Intelligent Transport Systems (ITS) technologies. To this end, a primary research approach has been adopted, such that existing reviews on the vision of urban road charging in the next decades (such as [5]–[7]) have been complemented by telephone interviews with a panel of four experts on urban road charging and ITS. Compiling the answers and views of the experts, along with arguments from the literature and the authors' own views, an overall insight into the future of urban road charging and the LCC scheme is given.

The paper is structured as follows: Section 2 provides a physical and methodological description of the LCC scheme, while Section 3 documents its impacts, problems and lessons learnt. Section 4 then goes on to give a synthetic view of the successes, deficiencies and implementation gaps of the scheme, as well as of the possibilities and potential for improvements using existing and emerging cooperative ITS technology. Finally, the outcomes of the study are summarized in Section 5, where a number of conclusions are drawn.

II. The London Congestion Charging Scheme

A. Physical Description

The LCC scheme is classified as an "area-wide" road pricing scheme, according to which vehicles inside a zone are charged a specific amount. As such, the LCC zone introduced on 17 February 2003 was 22 km^2, enclosing the core shopping, government, entertainment and business districts, i.e. the whole of the City of London (financial district), the West End (London's primary entertainment and commercial center), as well as around 136,000 residents. The zone was extended westwards (Western Extension Zone – WEZ) on 19 February 2007 to a total 37 km^2, with the new zone also including two free through routes, but was subsequently reduced to its original boundaries on 24 December 2010, following a public consultation (Figure 1).

The initial scheme required the keepers of vehicles located on the public highway within the zone during its times of operation, i.e. between 7:00 and 18:30 on weekdays, to pay GBP 5 per day. The charge increased to GBP 8 in

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Figure 1. The London Congestion Charging zone [1]

July 2005 and to GBP 10 in January 2011, and the (subsequently scrapped) extension of the zone on 19 February 2007 modified the hours of operation to 7:00-18:00 on weekdays. Currently, the charge does not apply on weekends, English public holidays, evenings and nights (18:00-7:00), as well as on designated non-charging days, which include the period between Christmas Day and New Year's Day inclusive. The charge can also be suspended by TfL to cope with incidents (e.g. the suspension of the charge on 7-8 July 2005 in response to the terrorist attacks on the London transport network, and the suspension on 2 February 2009, in response to heavy snowfall).

The GBP 10 charge is payable up until midnight on the day of travel into the zone, either pre- or post-trip. The charge can also be paid on the following day at an increased cost of GBP 12. Payments can be made through a variety of ways (online, by SMS, by phone, at a shop or by post) and it is possible to pay for one day, one week, one month or one year (the latter two at discounted rates), or for selected dates in the future. In case of non-payment, a penalty charge notice (fine) is issued, whose amount varies from GBP 60 to GBP 180, according to when the notice is paid.

Discounts and exemptions are granted to certain categories of vehicles. Motorbikes, taxis, emergency service vehicles, vehicles used by disabled and public transport vehicles are automatically exempt from the scheme, while so-called "greener" vehicles (alternative fuel, electrically propelled, etc), minibuses with more than nine seats, motor tricycles and roadside recovery vehicles are entitled to a 100% discount subject to a registration process. Residents of the zone, as well as residents of some areas adjacent to the boundary of the zone, are entitled to a 90% discount, and a reduced charge of GBP 9 is available for individual vehicles and vehicle fleets registered for the "Congestion Charging Auto Pay" scheme [1].

Regarding signage, traffic signs and road markings make it clear when drivers are approaching, entering and leaving the zone (Figure 2). In addition to those, additional signage is provided to assist road users. More specifically, signs indicating the hours of operation are located at or near all entry points to the zone (a), and signs indicating the end of the zone are located at all exit points (b). Within the zone, red "C" markings and signs reminding drivers that they have to pay the charge (c) are often placed close to entry points. Directional signs and/or road markings indicate which routes take drivers into the zone and which do not on approach to a junction, and some lanes leading to the zone are marked with a white "C" symbol (d). Finally, advance information is provided on the main approach roads at various distances from the zone, reminding the drivers of the hours of operation and of the amount they have to pay (e).

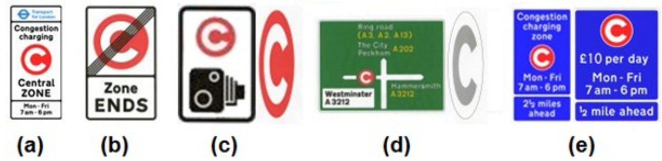

Figure 2. LCC signs [1]

B. Method and Technology Employed

The most innovative part of the LCC scheme, however, is the method of enforcing the charge, i.e. checking whether the charge for a vehicle entering the zone has been paid. As opposed to conventional road charging schemes, the LCC scheme does not involve any toll booths or barriers, and no physical tickets or passes are required [1]. Instead, the system used is video-based, and relies on the accurate reading of license plates as the primary means of identifying, charging and enforcing vehicles in a congestion charging scheme [5].

Namely, a network of 197 camera sites monitoring the entry and exit points of the zone has been installed. This is complemented by monitoring journeys (patrols) made within the zone by vans mounted with cameras. Each camera site consists of at least a color camera and a monochrome camera for each lane of traffic being monitored, the former of which takes a "contextual" image of the relevant vehicle and the latter of which takes a close-up image of the vehicle number plate. The images captured by the cameras form the so-called "evidential record" for any contraventions in the zone, which means the compilation of images providing evidence that the vehicle was in the zone during the charging hours (Figure 3).

The images captured by the cameras are then processed through an integrated Automatic Number Plate Recognition (ANPR) computer system; the evidential record is produced at the roadside, and subsequently encrypted and transmitted to the LCC data center over a dedicated secure broadband link. At the data center, appropriate software checks whether the license plate of a detected vehicle is included in the database of paid charges for the specific day, i.e. if the charge for the vehicle has been paid. If it has been paid or if the vehicle is exempt or subject to a 100% discount, then the image is deleted from the core system. A final check is carried out at midnight of the following charging day, where the vehicle registration numbers that should have been paid for but have not been are highlighted. The recorded images are then manually checked and penalty charge notices are issued for the vehicles, for which the charge has not been paid. The evidential records of fined vehicles are retained to support the notices, and are deleted 13 months after the penalty charge has been paid.

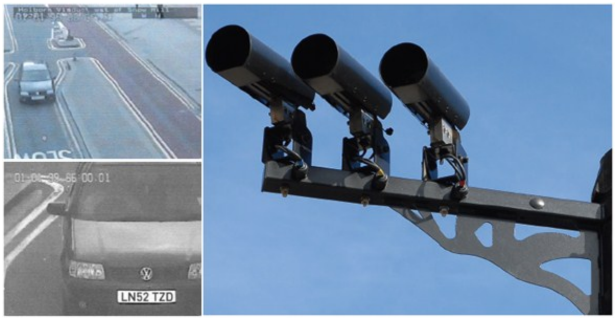

Figure 3. LCC cameras and evidential records [1]

III. IMPACTS AND LESSONS LEARNT

A. *Impacts*

The impacts of the LCC scheme were observed by TfL within the framework of a five-year monitoring program, and as such six annual reports have been produced [8]–[13], the latest being in July 2008. The monitoring program assessed the impacts of the LCC scheme on traffic (traffic levels, delays, accidents etc.), public transport (bus, underground and rail patronage), business and the economy (business journeys, operational costs), society (travel patterns, household motoring costs) and the environment (visual, noise or atmospheric pollution).

Starting with congestion, measurements within the LCC zone indicated reductions averaging 30% [9]–[10], which meant more reliable and predictable journey times. This was the main expected benefit of the LCC scheme. In subsequent years, however, increases in congestion were reported in the zone, despite reduced traffic levels. These were nevertheless attributed to the longer-term trends to congestion in central London, and the conclusion was that the LCC scheme had helped counteract the negative trend of increasing congestion within and outside of the zone [12]–[13].

Regarding traffic patterns, TfL had projected that the introduction of the LCC scheme would reduce the volume of traffic by 10-15% within the zone, and that it would also induce changes in the time drivers would take their trips, as well as changes to the composition of traffic [8]. These expectations were met, as it was reported that traffic entering the zone had reduced by 18% and traffic circulating within the zone by 15% [9]–[10]. Further changes to the scheme (increase of the charge from GBP 5 to GBP 8 in 2005, and the introduction of the WEZ in 2007) introduced further reductions in traffic [11]–[13].

The LCC scheme also resulted in an increase in public transport patronage as a result of both car users shifting to public transport and users shifting between public transport modes (e.g. from rail and underground to bus), as well as of large scale improvements to the bus network [8]–[9], such that in 2003 a 38% increase in bus patronage and a 23% increase in service provision were recorded; about half of the increased patronage was attributed to the LCC scheme. In parallel with that, the reliability of bus services improved markedly, with waiting times dropping by 30%, delays due to traffic falling by 60% and bus speeds increasing by 6% [9]. Subsequent measurements [10]–[12] showed that bus patronage continued to increase and that the public transport capacity provided accommodated the increased demand successfully. The introduction of the WEZ resulted in further increases in public transport usage, though no significant improvement of reliability was detected [13].

The introduction of congestion charging had an impact on travel behavior, as well as some secondary effects such as road traffic accidents, parking and pedestrian activity. As such, initial reports showed that out of the total number of car trips that ceased to be made into the zone, 50-60% transferred to public transport, 20-30% diverted around the zone and 15-25% made other adaptations, such as changing the timing of trips [9]. Also, the LCC scheme resulted in a substantial reduction in the number of road accidents, which complemented the already decreasing trends by additional net reductions of 40-70%. On the other hand, no significant impacts on the more vulnerable road users in or around the charging zone were reported [10]–[11].

According to TfL, the LCC scheme was not expected to alter significantly the overall economy or competitive position of London, with the expected benefits in terms of faster and more reliable journeys being offset by the financial implications of the charge [8]. The monitoring program indeed showed that the direct impact of the LCC scheme on business was broadly neutral [9]–[13].

In terms of social impacts (effects of the LCC scheme on people's attitudes, perceptions, abilities and behavior in relation to their travel choices and daily lives), the most frequently anticipated perceived benefits of the LCC scheme were reduced traffic, better public transport and improved air quality, while the most frequently anticipated disadvantages were increased travel costs, increased traffic at some locations around and outside the zone and more crowding and discomfort on public transport. Overall, a relatively significant proportion of drivers in the zone (even residents entitled to a discount) expected to either make some change in their itinerary or to cease driving in the zone altogether [8]. The monitoring of the social impacts showed that the actual effects on individuals were of generally smaller magnitude than expected, and that a large proportion of the people affected were positive about the scheme [10]. This was not, however, the case for the subsequently introduced WEZ, which led to its removal.

The reductions in congestion and traffic levels were expected to also have positive impacts on the environment in terms of vehicle emissions, air pollution, road traffic noise and visual intrusion, leading thus to a noticeable improvement in the quality of central London as a place to live, work and visit [8]. Initial measurements suggested reduced emissions from road traffic inside the zone, together with valuable savings in greenhouse gases and fossil fuels, though no evident changes to local noise levels [9]–[12]. Modest beneficial impacts to emissions were also recorded post-implementation of the WEZ [13], though no data have been publicly released for after its removal.

B. *Socioeconomic aspects*

The original LCC scheme found wide acceptance in the general public and can be hence considered to be a success from a political point of view. London Mayor Ken Livingstone, who introduced the scheme, was re-elected in 2004, even with an agenda including the WEZ [14]. Nevertheless, the WEZ did not find great acceptance among London's population and had therefore negative political impacts; Ken Livingstone was not re-elected in 2008, while the new mayor, Boris Johnson, had said during his pre-electoral campaign that he would hold a public consultation on the future of the WEZ.

The consultation took place in November 2008 and included individual respondents living within the WEZ, within the original LCC zone, within the rest of London and also outside London, as well as business respondents affected. The respondents were presented with three options: (i) keep the WEZ as it is, (ii) remove the WEZ and (iii) change the way the scheme operates. Despite supporting the original LCC scheme, the vast majority of the respondents (69%) opposed the WEZ and backed option 2 of the consultation [15]. The WEZ was, thus, removed in 2010, while the original LCC zone remained as it was.

In terms of economic aspects, the scheme has had both positive and negative feedback. For example, a paper by Prud'homme and Bocajero [16] pointed out that while the original LCC scheme was a great technical and political success, it seemed to be an economic failure, even defining it as a "mini Concorde". A response was given by Mackie [17], whose analysis showed that the characterization of the scheme as an economic failure went too far, though it was pointed out that it was necessary to continue to assess the economic impacts of the scheme and to keep looking for methods to reduce the operating costs. A further comment by Raux [18] suggested that the results of [16] should not justify indefinite postponement of the implementation of congestion charging in other conurbations.

C. *Problems and Lessons Learnt*

The implementation of the LCC scheme has been fairly smooth, with few problems arising whatsoever. For example, a problem of the system has been that the ANPR agent has been unable, in some cases, to read vehicle number plates appropriately (e.g. different shapes and sizes, non retro-reflective, poor weather, non-standardized fonts etc) and to match them with the database of vehicles paid for, and as such fines have been issued to drivers unfairly. On the other hand, it has also been impossible, in some cases, to trace unpaid vehicles and issue them with a fine; this has often been the case with foreign-registered vehicles. Developments in technology are expected to resolve these issues.

Regarding other problematic issues, having otherwise been characterized as a success (with the exception of the WEZ), the most ambiguous aspect of the scheme was its economic viability, as it has been argued that the operating costs were too high. The removal of the WEZ reduced the operating costs of the scheme, as the zone was significantly smaller, thus, requiring less labor, but the issue still remains, and therefore new technologies and policies aiming to reduce the costs have been and continue to be investigated.

Another lesson learnt from the LCC scheme is that no scheme can be implemented without public acceptance, even though it may initially have been a political success. In a consultation prior to the western extension of the LCC zone it was found that people opposed it despite having elected Ken Livingstone again. Nevertheless, the WEZ scheme still went ahead, and in the next election a new mayor was elected. The reason was that the LCC scheme had started being criticized as having deviated from its original purpose, having been converted from a counter-congestion measure to a money-making scheme.

IV. Successes, Deficiencies and Future Opportunities

A. *Synthetic View of Successes and Deficiencies*

Looking at the successes of the LCC scheme, the most important one that can be identified is the "proof" that it is actually possible to implement congestion charging in a large western city. Though urban road pricing had been used before in some Scandinavian cities, this had only been done to a much smaller scale. The system has been found to be relatively easy to operate and simply understood by the public, it has been generating revenue reliably and regularly, its level of revenue has been exceeding the cost of operation and it has had some effect on the traffic, though the benefits on the latter have gradually eroded since its introduction. Furthermore, the scheme's publicity has been right: there has not been any great public outcry about it, it has been smoothly operating for a number of years and it is now accepted as part of the life of London.

From a technological point of view, a major success of the scheme is that it was demonstrated that it is possible to operate an urban road user charging system based on ANPR alone, but also that it is possible to put in place a fairly advanced system that enables the users to buy the congestion charge in person, over the phone or on the internet. In addition, the system has been benefitting from a reasonably successful enforcement regime, as no "mass evasion" phenomena have been observed. The novel database system that enables matching genuine reads with genuine people's records, and also retaining the records to successfully track those people if an action is required from their part (e.g. fine) has played an important role in this success. Overall, an important accomplishment has been the fact that the use of this technology has made the implementation of the system possible without the need of having anything in the car.

On the other hand, the main deficiency of the system can be identified in the high cost of operation. With a cost to revenue ratio being estimated as high as 35%, the LCC scheme has not been the "big earner" that was thought would be before its launch. The main reason behind the high costs is the fact that accidental evasion is very easy to occur due to the simplicity of the system (it is possible to drive into the zone without noticing), and as a result a large mechanism tracking the users who did not pay is needed. This involves significant additional work in order to manually check the records that were not picked up by the ANPR system.

A further deficiency of the LCC scheme can be found in the fact that the scheme covers a relatively small area and, being essentially an enforcement system, the technology is not particularly scalable. As such, any desired expansion of the scheme requires installing more enforcement equipment (cameras etc.), and it can be foreseen that the time will come when it will be more beneficial to move to a new technology instead of using the existing system in possible future expansions. In addition to that and despite the fact that enforcement is very advanced, it is still possible to "defeat" the system, as it is likely that a vehicle is not recorded by the cameras.

Another deficiency of the LCC scheme can be located in the fact that the existing fixed charging policy can be unfair for certain drivers, though this is a problem in every cordon-based scheme and is not specific to the one in question. Finally, an issue relating to the overall situation of road charging is the fact that there is currently no common standard at the cross-border level and charging systems are not transparent to the customer. As such, a driver starting from one city or country and going to another will have no information on the charges he/she will have to pay upon arrival, unless he/she has looked into the issue on his/her own beforehand.

B. Possibilities Offered by Existing Cooperative ITS

Looking at the possibilities and potential for improvements offered by existing cooperative ITS applications, and mainly vehicle-to-infrastructure (v2i) communications, these could potentially offer significant improvements to the LCC scheme and urban road charging systems in general. Namely, the most common and well-established technology of this kind is 5.8 GHz Dedicated Short Range Communications (DSRC), making use of a tag and beacon infrastructure, which has been successfully applied in many places around the world, such as Singapore and Stockholm. An advantage of this technology is the fact that it does not rely on ANPR, which makes enforcement much simpler and also reduces the cost of maintaining the cameras. In contrast to that, the ANPR system could remain in place as a secondary system to track those vehicles that are not equipped with a tag. On the downside, however, DSRC requires additional roadside infrastructure, along with a strategy of creating incentives to obtain a tag, as road pricing is highly unpopular; these introduce additional costs.

Another existing cooperative ITS technology that could be implemented in the LCC scheme and urban road user charging systems is geographical positioning, where the vehicle is a "thin client" being only equipped with a positioning device and can be tracked in both space and time. This would make time-distance-position charging possible, whereby users could be charged according to which parts of the road network they drove on and when. Such a charging form would be more attractive, as it would not only allow for increased charging on highly congested roads, but also for charging according to environmental criteria (e.g. higher charges at locations with lower desired emissions). Fairly sophisticated charging schemes could thus be created, however subject to being able to achieve good positional accuracy. The latter issue is of particular importance, as it has been generally observed that in urban areas simple satellite positioning is not accurate enough, and in the case of a charging zone it is a matter of a few meters to incorrectly charge or not charge a vehicle. However, this has great potential of being improved in the next years, as besides introducing more advanced satellite positioning systems, ground-based correction technologies (differential GPS, pseudolites, mobile phone network…) are increasingly being implemented in order to make the positioning accuracy better. These could also make positioning possible in places where no satellite reception is available, such as tunnels, building "canyons", car parks etc.

Aside from positioning, a further cooperative ITS technology that could potentially play an important role in the LCC scheme and urban road user charging in general is mobile phones, due to the increasing internet connectivity of such devices through the mobile phone networks and wireless LAN. Namely, road charging could be made possible using a platform supporting multiple applications (such as a Smartphone), where a dedicated application would determine, based on the user's position, the charge to be paid and automatically debit the user's credit card. Of course this would introduce a few technical problems, such as determining accurately the user's location, ensuring that the user is driving a vehicle and is not riding a bus or cycling, and selecting a specific mobile phone from a vehicle with more than one passenger to associate with the charge. Nevertheless, these are issues that could be resolved relatively easily if a scheme to use mobile phones for urban road user charging is put in place.

Some possibilities are also offered by existing vehicle-to-vehicle (v2v) communication technologies. Namely, v2v applications could potentially contribute to more advanced mobile enforcement vehicles, but also through the transfer of data through platoons of vehicles in form of an ad-hoc network, which could also estimate levels of congestion on the road. However, at the current point in time such an option seems impractical, as simpler forms of road user charging need to be implemented before more sophisticated applications can be introduced.

C. Possibilities Offered by Emerging Cooperative ITS

Considering the possibilities offered by emerging cooperative ITS, a number of applications are possible, though the way towards their implementation is indeed a difficult one, not because of technical problems but due to organizational and political reasons.

A promising emerging technology for LCC and urban road user charging is the use of a mobile ad-hoc wireless network, which has been tried mostly in an environmental context so far; this makes use of sensors mounted on lampposts, continuously communicating with vehicles and as such tracking them throughout a larger urban area. The potential of this technology in urban road user charging lies in the fact, that it gives the option of fairly accurate wide-area charging, but without the need of relying on accurate positioning. The downside, naturally, is the need for investing in the infrastructure in a similar way to DSRC.

Another emerging area of potential interest to the future is charging based on so-called “booking slots” or “allowances to use the road”. This relies on “auction-based” charging, whereby the driver “bids” to buy a slot on the road in advance of travelling, with a fixed number of slots being available in each area, road or time period. Such schemes may in future be combined with or even replaced by a certain carbon permit or allowance scheme, such that instead of paying a price to use the road, the driver will be using up his/her allowance. A vehicle-based device would thus measure the total emissions’ level and compare it to the vehicle’s allowance, and if the latter runs out within a certain time period then the owner would need to buy an additional one from the open market. That could use both in-vehicle and v2i technologies.

A further interesting technology is an extension of Intelligent Speed Adaptation (ISA), which offers external speed advice and control to vehicles, according to the road they are currently travelling on. At the moment ISA is done using speed limits stored in the map database of a vehicle’s navigation system, but due to the changes in the network it is very hard to maintain such a database up to date. For that reason it is likely that the architecture of ISA will change in the near future to be based on a regularly updated off-board database (e.g. Google Maps), from which the vehicle will download updates either when reaching a specific road or at the start of a route. Based on such an architecture, extensions of ISA will be made possible, with each road possibly having a “certificate” containing road-specific information (e.g. ISA, access control, low CO_2 etc), and only being available to the vehicle if its certificate meets certain standards. Road user charging could be an attribute of that certificate, such that the driver would be given the cost of the charge that he/she would need to pay from his/her navigation system or mobile phone and would also be charged automatically.

V. Conclusions

Overall the biggest success of the LCC scheme is the fact that it was proven possible to be implemented and accepted, whereas the main disadvantage seems to be its high cost of operation. Further advancements to the system using existing cooperative ITS could be achieved through DSRC, but also through improvements in positioning systems and mobile phones. v2v communication could also play a part in this, though this is more likely to happen in the more distant future. Possibilities could also be offered by emerging cooperative ITS (such as ad-hoc wireless or ISA) and novel charging techniques (such as auction-based or allowance-based charging).

Over the next decades, urban road charging technology will become more robust, readily available and cheap, and many improvements will thus become possible. However, while technology is one factor on which the future of the LCC and other urban road charging schemes depends, the other – equally important – factor is political willpower, both at a domestic and at an international level. With current systems being city-center-focused, it would be interesting to see how the traffic management challenges in booming suburbs of cities could be addressed, especially considering the fact that the modal split in those areas is in favor of the car and not of public transport. Also, a further challenge that needs to be taken up is the changing fuels situation, as the introduction of lower carbon technologies will make car travel more attractive, solving the emissions’ problem but at the same time aggravating the traffic problem. As such, a more general plan for managing road traffic as part of the urban environment as a whole rather than on its own is needed. What is left to be seen is whether this is to remain at the national level or whether it will move across borders.

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