BTU Cottbus - Senftenberg
SE: Urban Dynamics
Professor: J. M. Stevens
Module: Arts, Architecture
and Conservation (24-1-03)
WS 2015/2016

Survey Paper

USING NEW TECHNOLOGY TO MITIGATE TRAFFIC CONGESTION IN MEGA CITIES

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CONTENTS:

INTRODUCTION

For decades, the problem of traffic congestion has become an ever-increasing issue as the amount of motorized vehicles on roads increases. Traffic congestion is a prime contributor to many negative economic, environmental, and social effects along with being a major culprit behind climate change. While this problem is of course rampant in dense urban areas throughout the world, the problem also extends to smaller urban areas and even rural regions as well. Contributing factors to this problem include poor road management and aging infrastructure, insufficient public transport, lack of finances of local government authoritites, and an obvious increasing number of cars. Therefore, this survey paper aims to bring together the main issues, facts and numbers related to traffic congestion in broad context. Being a result of extensive literature overview and analysis of various examples, this paper deals with the main causes, consequences and preventive measures behind traffic congestion. It is also designed to demonstrate what innovative and smart solutions were undertaken recently to mitigate traffic congestion based on newer conceps behind the case studies of Stockholm, Singapore, and Eindhoven.

DEFINITIONS, CAUSES, AND CONSEQUENCES

Like the term "sustainability", there is no universally agreed definition of what the general term "traffic congestion" is. However, this term is generally discussed with respect to motor vehicle traffic on roads and therefore could be defined as a situation in which people using roads experience delays because the system is approaching capacity. Nevertheless, congestion also exists in airports and along certain stretches of the rail network. As an overall tendency a slow-down of the transport speed could be observed in all cases mentioned. Even though the problem of traffic congestion touches upon almost every corner of the world it is worsened in the European Union by the conflicting systems of the different member states not integrating fully, causing delays as vehicles move from the jurisdiction of one to that one of another (OECD Report on Traffic Congestion in Europe, 1999). *Figure 1* demonstrates 25 most congested cities in the Europe as of 2014 as it is provided in the INRIX Annual Report, 2014[1].

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[1] *INRIX* is a global software & data as a service company that provides a variety of Internet services and mobile applications pertaining to road traffic and driver services. INRIX provides historical, real-time traffic information, traffic forecasts, travel times, travel time polygons and traffic count to businesses and individuals in 40 countries (Wikipedia).

2014 Rank	2013 Rank	Metropolitan area	Hours wasted in traffic 2014	Difference in comparison to hours wasted in 2013
1	2	London commute zone	96	14
2	1	Brussels	74	-9
3	6	Cologne	65	9
4	3	Antwerp	64	-14
5	5	Stuttgart	64	4
6	10	Karlsruhe	63	10
7	7	Milan	57	1
8	13	Düsseldorf	53	4
9	15	Utrecht	53	5
10	9	Ghent	52	-2
11	16	Gr. Manchester	52	6
12	12	S Gravenhage	51	2
13	14	Hamburg	48	0
14	17	Munich	48	4
15	4	Rotterdam	48	-15
16	8	Paris	45	-10
17	26	Bonn	42	4
18	22	Ruhrgebiet	42	2
19	11	Amsterdam	41	-9
20	18	Lyon	40	-4
21	37	Nuremburg	38	6
22	24	Merseyside	37	-2
23	41	Freiburg im Breisgau	37	5
24	38	Frankfurt am Main	37	5
25	43	Gr. Belfast	37	6

Figure 1 Top 25 most congested cities in Europe in 2014

Traffic congestion also has proven to be a complex issue that is caused not only by simple increase of number of vehicles on the road. Considering the recent trends in urban dynamics and the proliferation of globalization, the number of drivers being caught in traffic is increasing. To give an example, among recent tendencies is a revitalization of economics from the recession of 2007-2013 and growing employment. Once urban areas come to life again, the pressing congestion problems worsen, "that impose negative externalities on commuters, business travellers and freighting companies who travel in and out of these urban areas" (INRIX Report on the future economic and environmental costs of gridlock in 2030, 2014). With this respect a GDP per capita plays an essential role as well. Its growth leads to higher standards of living and should result in upturn of disposable income to spend on leisure activities by an average family; thus, the possibility of longer distances being travelled to enjoy those leisure services and facilities is potentially higher.

Among other considerable contributors to traffic congestion include poor road management and a lack of proper infrastructure. As car ownership in the 20th century was growing, significant changes in the structure, planning and functioning of the cities as well as the allocation of funds were introduced (new roads were constructed and extended to handle an extra traffic). However, as it could be seen in practice, a simple extension failed to truly mitigate the traffic. The paradox is also in that provision of improved infrastructure could itself generate extra traffic and related problems.

As minor third factors severe weather conditions and construction projects (including accidents, breakdowns and special vehicle sizes) should also be mentioned.

NEGATIVE EFFECTS OF TRAFFIC CONGESTION

Assuming that even though the traffic congestion could be an indicator of active and vibrant urban places that prosper economically, it still carries with it more problems that benefits. As a general tendency those effects are considered in three main dimensions: environmental, economic, and social.

Affecting the natural environment and human health traffic congestion contributes to global warming and air pollution along with being a major culprit behind climate change. Traffic noise and the usage of non-renewable resources are also of concern. According to the Report of European Conference of Ministers of Transport traffic congestion contributes significantly onto formation of hydrocarbon and carbon monoxide (CO) emissions that could affect healthy individuals severely. By entering the bloodstream through the lungs CO emissions facilitate the accumulation of carboxyhemoglobin, a composit that restrains the blood’s capacity to transfer oxygens to organs and tissues. However, a current EU policy aims on reduction of CO emissions as a result of fuel use by 47% by 2040 (OECD Report on Traffic Congestion in Europe, 1999). Another factor that directly affects emissions includes fuel efficiency that is used in the context of energy efficiency of a particular vehicle and that also has its impacts in the economic dimension. Accepting the fact that stop-and-go conditions in comparison to other speeds increase significantly energy consumption and therefore lead to higher expenditures for fuel exhausted it is important to mention that more and more car manufacturing companies work towards production of high fuel-efficient cars. The Report also states a permissible speed of about 50 km/h to tolerate traffic noises by those living nearby congested roads.

As it was already mentioned in economic perspective traffic congestion relates to energy consumption. Besides it could be associated with late arrivals for business meetings, employment, and education that undoubtedly results into lost opportunities, disciplinary actions or other kinds of losses for traffic participants. Such costs of wasted time as well as wasted fuel could be defined as direct costs (Transport Economics, 2008). Operation costs, i.e. costs associated with maintenance, overhaul, labor, etc. should be considered in this dimension as well.

In addition to environmental and economic dimensions there are some other factors (f.e.

social) resulting from traffic congestion such as less time on productive activities and reduction of social contacts f.e. between relatives or friends over bigger distances. Such phenomena as a road rage and aggressive driving in general could be a direct result of being stuck in traffic congestion.

TRANSPORT MANAGEMENT: EFFECTIVE WAYS OF TACKLING TRAFFIC CONGESTION

In the last decades a huge variety of measures have been applied to tackle traffic congestion. Yet not all of those approaches and practices were successful enough to improve congested conditions. Nevertheless, we found strategies suggested by OECD Scientific Expert Group the most comprehensive and encompassing that are classified as follows:

- Land use and zoning
- Telecommunications Substitutes
- Traveller Information Services
- Economic Measures
- Administrative Measures
- Road Traffic Operations
- Preferential Treatment
- Public Transport Operations
- Freight Movements

However, in our research we want to concentrate our attention on one measure specifically and therefore go more into details onto economic strategy in our case studies.

CASE STUDIES/CONCEPTS

Now that we have discussed the primary causes and effects behind traffic congestion, it would make sense to introduce and discuss three primary concepts of combatting traffic congestion (Urban Congestion Charging, Predictive Analytics/Traffic Prediction tools) and present their case studies (Stockholm, Singapore, Eindhoven) and other examples that show these concepts in action and demonstrate their usefulness as viable solutions.

Urban Congestion Charging: Congestion charging (or pricing) refers to charging vehicles a fee for using roads and streets at certain times. According to a report by the Congressional Budget Office, congestion pricing can be classified into two main types: corridor and cordon congestion charging. Simply put, corridor charging involves implementing charges on a single road, tunnel or bridge, while cordon charging entails pricing vehicles to use the roads in a designated area (CBO, 2009). We will deal with two case-studies involving the practice of cordon charging: Stockholm and Singapore.

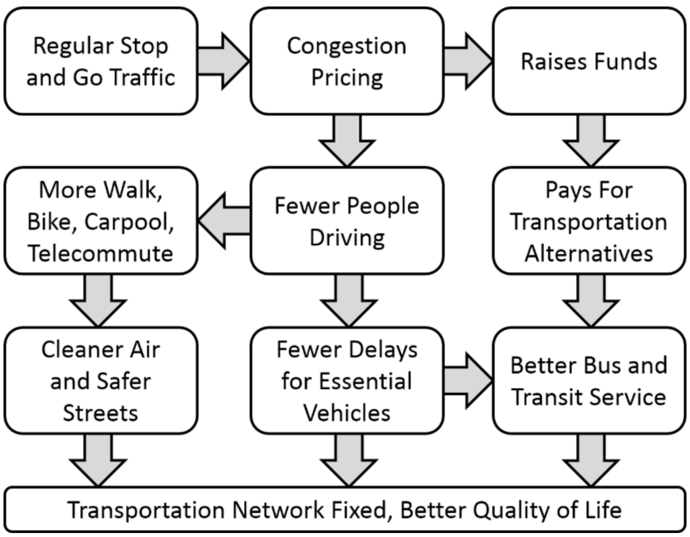

Figure 2 Flow Chart describing the basic benefits of congestion charging (Wikipedia)

Congestion charging carries with it a number of positive effects following its implementation. Congestion charging has been shown to substantially reduce congestion, decrease travel time, and reduce carbon emissions into the atmosphere (CBO, 2009). In addition, the money gained from the charges levied can be used by the local government to improve infrastructure and invest more heavily in alternative means of transport such as public transportation, thereby providing a sustainable solution to the congestion problem (CBO, 2009, Figure 1).

Stockholm: Stockholm, home to approximately two million people, has long struggled with its problem with rampant traffic congestion. At various times, the city has ranked worse in terms of waiting in traffic times than London, Los Angeles, or San Francisco with annual waiting times amounting in upwards of 13 days (the local, 2013). In 2006, 560,000 vehicles were entering the inner city each day coupled with annual vehicle ownership increase of 2.5% per year (IBM, 2006). Furthermore, the traffic situation in Stockholm is worsened by its numerous bridges which connect the inner city with the surrounding area which creates traffic bottlenecks, serving as one of the primary culprits behind the city’s congestion woes (Eliasson, 2007). It was clear to the city’s inhabitants, as well as the local government, that something needed to be done.

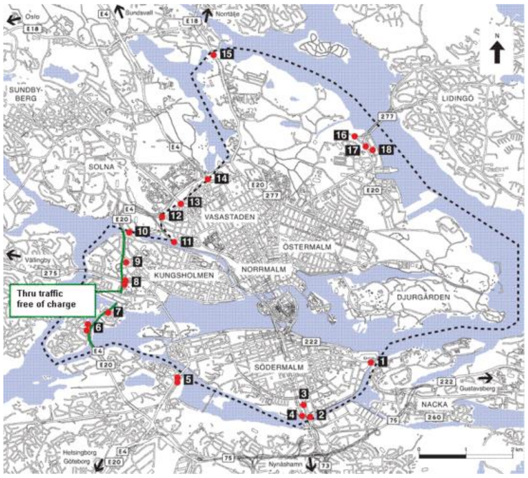

Figure 3 Map of the control points in Stockholm during the trial (Eliasson 2006)

During the initial trial period conducted in 2006, 18 control points (figure 3) were established at the aforementioned bottleneck locations at the entrances into the inner-city cordon. Cameras at these points photograph the license plates of the vehicles after and the bills for payment sent by mail or if vehicles are registered into the automatic payment system and are equipped with the corresponding transponder, the charge will automatically be paid (Eliasson, 2006). During the trial, the charging period was set between 6:30am to 6:30am with graduating prices during the twelve-hour period. The prices ranged from 10, 15 to 20 SEK depending on the time, with the highest charging occurring during the morning and evening rush hour periods (Eliasson 2006). Charges were not implemented on nights, weekends, public holidays or the day before a public holiday (Eliasson, 2006).

In concert with the new charging scheme, the local government in Stockholm greatly expanded public transport in the city by adding 16 new lines and deploying 197 new buses on the streets in order further encourage public transport use as an alternative to driving (Eliasson, 2006).

The results and benefits of this trial are self-evident. Public transportation ridership increased by 40,000 per day and this further climbed to 65,000 three years after the trial was conducted, which shows a considerable amount of lasting success (IBM, 2009). Traffic has been lowered in upwards up 18% with CO2 emissions decreasing between 14 and 18% (IBM, 2009). According to Eliasson, the local commuters in Stockholm were able to adapt quickly to the new changes, not noticing a change in their daily travel habits between before and after the trial was conducted and up to 6 months after. Thus, Stockholm has become a model city for effective implementation of congestion charging.

Singapore: With a population of 5.5 million and one of the world's highest population densities at 7,697km2, the affluent island city-state has long had to cope with a chronic congestion problem (IBM 2015, CIA 2016). In order to maintain order and ensure that vehicles can always keep moving, the government of Singapore has long been aware of the need to maintain the number vehicles that travel its roads. There has been a vehicle quota system in place since May 1990 in order to limit vehicle numbers by making car owners obtain a "certificate of entitlement". The number of vehicle owners allowed to obtain a certificate of entitlement is calculated every three months and takes into account the number of existing vehicles on the road already (Singapore Government, 2016). Given the great need to highly regulate vehicle traffic on the island, Singapore has needed to become innovative in its quest control traffic congestion.

Singapore has a long history of congestion charging. In 1975, Singapore implemented its first congestion charging system which levied flat a rate on vehicles driving in the inner-city (DAC, 2015). While effective to a certain point, the manned tollbooths served partly to further exacerbate the congestion problem and caused headaches for commuters who had to wait in long lines to pay their fee (DAC, 2015). Therefore, in 1998, the Electronic Road Pricing System (ERP) was born.

Figure 4 Map of Singapore with ERP/Gantry Locations (onemonitoring, 2016)

The system effectively did away with tollbooths and replaced them with high-tech gantries placed at various strategic points in the inner-city that do not require vehicles to slow down. All registered vehicles are required to have an onboard unit (OBU) installed in the car while the payments are made through a special "cash card" that is inserted into the OBU onto which drivers can load credit (DAC, 2015, Singapore government, 2016). Foreign vehicles are also required to have such installed devices; they can either rent an OBU at the border, or elect to also have a permanent unit (SLTP, 2004).

When vehicles approach within 10 meters of the ERP gantry, sensors communicate with the onboard unit and determine the charge which is then withdrawn from the cash card. If a vehicle is not equipped with an onboard unit or if the gantry fails to communicate with the onboard unit, the gantry photographs the vehicle license plate and, like in Stockholm, a bill is sent in the mail instead (SLTP, 2004).

Since the implementation of the ERP system in 1998, congestion has been reduced and traffic levels are down by 15%. In addition, there has been a 20% increase in public transport use, with approximately 65% of commuters going to work using alternative means of transportation other than driving (DAC, 2015). CO2 emissions have also been reduced along with improvements in air quality. Less vehicles on the road also has a tremendous alleviating effect on Singapore's precarious road infrastructure, allowing the roads to operate at the maximum efficiency possible.

Future plans are also in place to further improve the existing system. In 2020 the new ERP II system is set to be introduced. The new system will rely on satellite and cellular technology to levy congestion charges, eliminating the need for physical gantries, thus further improving the efficiency of the system (todayonline 2014).

Singapore has proved itself as another example of highly efficient congestion charging in order to combat and reduce traffic congestion. The success of the ERP system as well as the congestion charging scheme in Stockholm, further add weight to the concept as being a viable economic solution to mitigate traffic congestion. As cities such as these further prove themselves as role models in this regard, more cities across the world will surely follow suit.

Prediction/Monitoring tools: Now that we have touched upon some examples of an economic solution to fighting against traffic congestion, it would be wise to discuss alternative means that can be used and implemented at the governmental and personal level. We will address the basic concept of predictive analytics and discuss some examples of it being studies in action with regards to traffic congestion, and then address new monitoring/data-gathering tools such as was tested in Eindhoven, Netherlands in 2013, along with some new tools that can be used at the personal level such as the Inrix travel smartphone application.

General idea: The term "predictive analytics" is a very broad term that can be applied to many different fields and applications. As a general definition, predictive analytics entails analyzing and gathering massive amounts of data and using said data to develop predictive models and determine future actions (Eckerson, 2007). To give an example of how this can be used in the context of mitigating traffic congestion, computer analysists were able to tap use the commonly available public map websites such as Google and Bing maps' traffic monitoring overlay to determine the likelihood of severe traffic congestion at certain points of time for the Chicago Metropolitan area. By recording the flow-intensity (intensity of traffic congestion or clear traffic) of Bing maps over a several-day period, they were able to develop a an accurate GIS map and create predictive models identifying the highest levels of traffic in certain parts of the city at any given time (Tostes et al., 2013). Such data could be used by the local government and other traffic management authorities in order to better analyze areas of high traffic and make judicious interventions when necessary.

Eindhoven: The practice of monitoring individual vehicle movements was put to the test in 2013 in a cooperative pilot test between IBM and NXP in the Eindhoven region in the Netherlands, 200 vehicles were installed with GPS telematics chip developed by NXP that transmits data from the central communications systems of a vehicle to the central traffic authority (IBM, 2013). Such sensory data, such as that detected from potholes, bad weather conditions, or other road problems is transmitted. These GPS devices work in tandem with navigation tools in the car that can alert the driver to hazards or bad traffic conditions so that their routes can be redirected to prevent an exacerbation of already severe traffic congestion.

To quote the EU project manager Ab Oosting, the results of the trial project can be summed up, "The trial successfully showed that anonymous information from vehicles can be analyzed by local traffic authorities to resolve road network issues faster, reduce congestion and improve traffic flow" (IBM, 2013). Over the 12-month period, a total of 1.8 billion sensor signals detected and recorded over 48,000 incidents from which the central traffic authority was able to better dispatch emergency response teams and collect massive amounts of data on incident concentration and use this to better coordinate response efforts and infrastructure interventions in the future (IBM 2013).

The pilot was shown of smart GPS chip demonstrates the effectiveness of a relatively simple device to collect large amounts of useful data that can be utilized for a variety of solutions.

While the Eindhoven device was wired into the cars' sensor systems and transmitted directly to the central traffic authority, many other tools such as smartphone applications are being used to better inform drivers about traffic conditions and make better driving decisions. The INRIX traffic app is a software application available in various smartphone operating systems that not only gives real-time traffic information but can also redirect drivers to sensible detours and warn drivers about unexpected events such as weather conditions or other local happenings that drivers would otherwise not consider (INRIX 2014).

Conclusions: Through our rather cursory overview of the causes and effects behind traffic congestion, it is clear that the problem as a whole is highly complex and that there is not one solution that will solve it for good. The most obvious solution of simply increasing road capacity or building new ones does not always serve as a long-term remedy. Instead, new methods of combatting the problem as we have seen through various mediums of congestion charging, analytics and monitoring tools are proving effective at reducing traffic congestion and further mitigating its negative effects. Although many of these newer methods are not yet practiced on a very wide scale, they will keep serving as examples and role-models that can be expanded, refined, and emulated elsewhere on a larger level.

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