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Wadud, Z orcid.org/0000-0003-2692-8299 and Chen, D (2018) Congestion impacts of shopping using vehicle tracking data. Journal of Transport Geography, 70. pp. 123-130. ISSN 0966-6923

https://doi.org/10.1016/j.jtrangeo.2018.05.001

Congestion impacts of shopping using vehicle tracking data

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Abstract

Shopping and retail trade play an important role in the economy, yet shopping activities and associated on-street parking and disruptions to traffic could substantially contribute to congestion in the megacities of the developing and emerging countries. This research investigates and quantifies the effects of shopping and related road-side frictions and disruptions on congestion in a city. We make use of minute by minute GPS tracking data of vehicles and a unique policy of different shopping closure days in different areas of the city, which allows the separation of shopping related congestion effects from commute and other effects. Results show that average speed increased by 18.5% on weekdays when shopping centres were closed. The differences in speed in the different zones can also be qualitatively related with the density of shopping centres in those zones.

Key words

Shopping; retail trade; congestion; speed; GPS tracking; impact assessment

1. Introduction

The retail trade (high street shopping, food and restaurants) plays a very important role in the economy. They generates large direct and indirect benefits to the economy through employment, income generation and contribution of the GDP. The contribution of shopping and similar retail services to the local or urban economy is even larger, and local shops and shopping centres often provide character to an area. Shopping is also a popular leisure activity. In the USA the retail sector is estimated to provide 16.1% of all jobs and 7.7% of GDP (Price Waterhouse Coopers 2014). In the EU, the retail trade is responsible for every 1 in 11 jobs (International Council of Shopping Centres 2015). However, these studies on the impact of shopping or retail trade on local, regional or national economy do not include the potential negative impacts of generating additional traffic and associated congestion and air pollution related health effects – possibly because of the essential nature of retail trade and shopping in modern economy.

Shopping is clearly a major traffic generator, e.g. in England nearly one-fifths of all car trips are shopping trips (Department for Transport 2016). While it is not uncommon to evaluate the traffic implications of a *new* shopping centre (e.g. through transport impact assessment) as part of a planning approval process, the overall contribution of shopping related activities to traffic and congestion in an area or a city is often overlooked in the benefit or impact calculations. This research aims to address this important gap, by quantifying the contribution of shopping on traffic congestion on a city or local area scale. In order to achieve this aim, we make use of GPS tracking data of vehicles in Dhaka, the capital of Bangladesh, and the uniqueness of its shopping scene, where different shopping districts are closed on different days of the week. The research is especially unique because shopping related activities in a developing country megacity do not only generate traffic but also aggravate congestion through other means such as on-street parking, and we consider these additional means in our effect estimate too. To our knowledge, this is the first study of this kind.

The paper is organized as follows. Section 2 provides a brief background of Dhaka, its chronic traffic congestion and how shops and shopping related activities aggravate it further. Section 3 provides a brief review of relevant literature. Section 4 describes the methods of analysis, data and hypotheses. Section 5 presents the results, while section 6 draws conclusions.

2. Background on Dhaka

Dhaka is the 11th largest city in the world in terms of population (United Nations 2017) and is one the most densely populated as well. Greater Dhaka is a megacity of more than 18 Million people and home to more than a third of the country's urban population. The city is the hub of all economic, political, administrative and cultural activities of the country, and has seen rapid growth since the independence of Bangladesh in 1971. Based on current trends, the city is expected to grow further and accommodate 35 million people by 2035 (Fan and Rama 2017). Unfortunately, because of poor planning and poor enforcement of existing plans and regulations, the provisions of infrastructure, basic services and amenities in Dhaka could not keep up with the rapid growth of the city, resulting in poor living conditions.

Transportation provides an important lens in understanding the rapid growth and deterioration of service provisions in the city. During a ten year period between 1995 and 2005, the population in Dhaka grew by 50% and road traffic by a massive 134%, yet the only accompanying improvements in infrastructure provision was a mere 5% increase in road surface (Fan and Rama 2017). Dhaka is also one of the few cities of similar size which does not have a mass rapid transit, bus rapid transit or suburban railway.[1] The result is not unexpected: the city is consistently ranked among the most congested cities in the world, with concomitant high air pollution adversely affecting human health. In the last 10 years, the average traffic speed has dropped from 21 km/hr to 7 km/hr, not too far

[1] The construction of the first mass rapid transit track has started recently, and is due to be completed in 2025

from average human walking speed of 5 km/hr. A recent survey of car and bus commuters shows that around 48% of the respondents had a commute time of above 1 hour, each-way for their most recent trips, while 22% of the bus commuters travel for more than 2 hours, each way (Wadud and Huda 2018).[2] Congestion results in a loss of around 3.2 million hours of productivity every day and is estimated to cost the city several billions USD every year.

Land use in Dhaka has become truly mixed over the last three decades of continuous growth. Previous regulations about commercial activities such as shopping centres, retail trade, restaurants and offices in residential areas were relaxed to accommodate the pressures for these amenities, resulting in a mixed land use. While such mixed land-use is encouraged to reduce traffic (Ta et al. 2016), residential location choice in Dhaka is often based on schooling of children, and not the commute distances or local amenities (Choudhury and Ayaz 2016), which calls into question the advantages of mixed land use. Especially, the proliferation of unplanned shops and shopping centres throughout the city is thought to be a major contributor to congestion. In a city like Dhaka, shopping activities can contribute to congestion in several ways as described below, although different combinations of these may be at play in different locations.

1. Presence of a shopping mall or a series of roadside shops naturally increases traffic (both motorized and non-motorized) in nearby roads to accommodate the additional trips generated by potential shoppers. This is the typical generated traffic, which is often modelled ex-ante in a TIA process in many developed countries.
2. Nearly in all cases there is a shortage or a complete lack of parking in the shopping centres and roadside shops. This combined with the lack of adequate parking control and enforcement on the roads leads to cars, rickshaws (human-powered tricycle) or autorickshaws (three-wheeler taxi service) being parked on the streets, creating a bottle neck (Photo 1).
3. Lack of adequate drop-off and pick-up points also leads to bottlenecks from vehicles dropping off or picking up shoppers. This is especially visible for para-transits such as rickshaws and autorickshaws, which can be seen taking up road space near the entrances of major shopping centres – competing for passengers (Photo 2).
4. The pedestrian footpaths near some shopping hubs can often be occupied by street vendors forcing pedestrians to walk on the roads, either increasing side friction or creating bottlenecks, both reducing speed and flow (Photo 2). In some areas, the vendors' make-shift stalls could extend onto the road, too, further aggravating the conditions.

[2] This number has not been published in Wadud and Huda (2018), but derived from the raw survey responses used in that study.

5. Loading and unloading of goods for the shops also create bottlenecks. However, only light commercial vehicles are allowed in the city during the day, while larger trucks (above 5 tonnes payload) are allowed to enter after 8 pm.

Photo 1. Mirpur Road in front of Chandrima Super Market (with permission from William Veerbeek)

Photo 2. Mirpur Road in front of New Market (with permission from Rajib Dhar)

The importance of shopping on congestion is especially visible during the week before the biggest festival on the calendar, the Eid-ul-Fitr, when traffic comes to a near standstill. The area of New Market and Elephant Road – a major retail shopping district, had always appeared to be less congested during Tuesdays, when the shops were closed. Learning from this observation, the authorities devised an innovative plan to manage congestion in February 2010. The city was divided into seven different zones, and the shops and shopping centres in these regions were assigned five different pairs of weekly closure days: one day when the shopping centres will be fully closed, and one day when they will be open only half-a-day and will close at 2 pm. Compliance was excellent for the full-closure days, but half closures are observed less strictly. There was an immediate relief in traffic congestion in the regions where shops were closed, yet there was never an evaluation of the policy either at local or at the city level in terms of quantifying the effect. However, the policy offers a unique opportunity to understand the overall effects of shopping on road congestion.

Fig. 1 shows these different shopping closure districts or zones in Dhaka, while Table 1 presents the days when they are fully and half closed. Note that Fridays and Saturdays are weekends in Bangladesh, although many private offices and businesses may remain open on Saturdays.

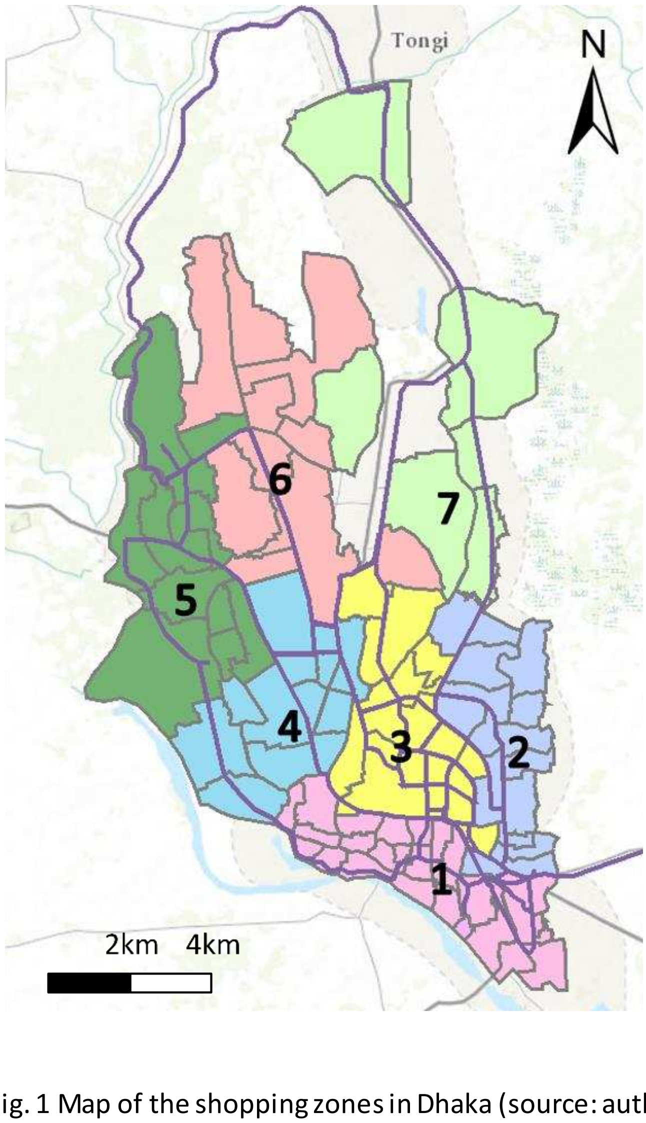


Fig. 1 Map of the shopping zones in Dhaka (source: authors' work using maps.google.com)

3. Literature

There is little literature on the impact of shopping on traffic and congestion. While there are some studies on the interaction between shopping and transportation, they are primarily trip based: e.g. trip generation for shopping purposes (Department for Transport 2016), mode choice for shopping trips (Ibrahim 2005), effects of congestion charge on shopping trips (Schmocker et al. 2006) or reduction in carbon emissions from shopping trips (Li et al. 2015). There are planning guidelines and

Table 1: Shopping zones and their closure days

Zones	Area	Fully closed	Half closed
Zone 1	Ahsan Manjil, Banglabazar, Bangsal, Dholaikhal, Gandaria, Gulistan (south), Jatrabari (west), Wari	Friday	Saturday
Zone 2	Jatrabari (Part), Banasree, Demra, Kamlapur, Malibagh, Rampura, Saidabad	Sunday	Monday
Zone 3	Azimpur, Baily Road, Dilkusha, Dhaka University Area, Eskaton, Moghbazar, Malibagh, Motijheel, Noyapolton, Gulistan (north), Tikatuli	Thursday	Friday
Zone 4	Dhandmondi, Elephant road, Farmgate, Hazari Bag, Hatirpul, Indira Road, Karwan Bazar, Kataban, Lalmatia, Manik Mia Avenue, Nilkhet, Pilkhana, Sobhanbag, Tejgaon	Tuesday	Wednesday
Zone 5	Asad Gate, Gabtoli, Lalmatia, Mirpur-1 & 2, Mirpur Zoo Area, Mohammadpur, Shyamoli	Thursday	Friday
Zone 6	Agargaon, Banani, Cantonment, Gulshan-1, Gulshan-2, Kachukhet, Kakoli, Mirpur-10, 11, 12, 13 & 14, Mohakhali, New & Old DOHS, Mohakhali, Sherebangla Nagar	Sunday	Monday
Zone 7	Ashkona, Bashundhara(R/A), Dakhin Khan, Joar Sahara, Jagannathpur, Kuril, Khilkhet, Satarkul, Sahjadpur, Nikunjo-1& 2, Uttar Khan, Uttar Badda, Uttara Model Town	Wednesday	Thursday

Source: Alormela (2017)

regulations in most developed and many developing countries, which regulate the quantity of parking to be made available in a new shopping facility (e.g. in the UK, USA). Transport Impact Assessment (TIA) is also mandatory in several countries, which requires ex-ante modelling of the impact of new shopping (or other large construction) projects on traffic and congestion level as part of the planning permission process. TIA is not applied during the planning process of a new shopping centre in Dhaka, however, the number of parking in any *new* proposed shopping centre has to follow the city's planning codes, but this does not apply to individual shops. Also, the TIA approach is not applicable here since we are interested not on the trips generated by each shopping centre (or many shopping centres), rather on the collective congestion impacts from the additional shopping trips as well as other shopping related frictions and disruptions outlined earlier.

The effects of e-shopping on traffic is an active research area within the transport community, with a growing literature (e.g. Braithwaite and LCP consulting 2017, Cairns 2005, Rotem-Mindali and Weltevreden 2013). However, the primary focus of this strand of research is the trade-off between the reduced trips or traffic generated by the shoppers versus the increased trips or traffic generated by the delivery services, again making them not very useful here. License plate based bans on cars during different weekdays directly ration the road space and appear to have some similarity with the policy in Dhaka, yet, these are quite distinct policies. Car bans on alternate days or different days of the week, as implemented in Mexico City, Bogota, Beijing or Athens, have primarily been implemented to control air pollution. Different shopping closure days in Dhaka allocate road space only indirectly, and was primarily a traffic management tool. As such the metric of evaluation is quite different and not comparable.[3]

The use of GPS based vehicle tracking data for decision making (both instantaneous and longer term) is become increasing popular in the transportation domain. Their most popular use has been in real time vehicle routing and directions and tracking vehicles, goods or parcels in the ridehailing, logistics and courier services. GPS data has also been used to detect congestion – both in real time (Yong-Chuan et al. 2011) or for understanding patterns for longer term planning (Jimenez-Meza et al. 2013, Zhang et al. 2017). While attempts have been made to reveal land use patterns from GPS tracking data (Zhang et al. 2017, Liu et al. 2012), our interest is the opposite, the effects of land use (shopping facilities and activities) on traffic and congestion. The closest relevant literature is possibly by Ta et al. (2016), which uses a questionnaire survey combined with GPS tracking to understand the effect of the built environment on commuting efficiency and still quite different from our research question, or method.

There is a large literature on impact assessment of various transportation related initiatives. The most popular is the before-after study whereby a specific metric is measured before and after a policy or treatment that affects travel pattern; examples include speed or crashes on a corridor before and after traffic calming measures, as in Huang and Cynecki (2000) or safety effects of a transport infrastructure project as in Elvik et al. (2001). The before-after studies could control for other factors or not, but lack of control may lead to imprecise effect estimates. While there are other methods to determine the effects of a policy such as intervention analysis and similar statistical procedures, before-after studies are simple and especially suited to conditions when data availability is limited, which is often the case in developing countries. However, we are not directly interested in the effects of the shopping closure policy on overall traffic, congestion or speed, making them less relevant here.

4. Methods & data

The different weekly closure days in Dhaka offer a unique opportunity to understand the effects of shopping and retail trade on congestion by disentangling not only the non-shopping traffic from

[3] For example, a quick literature search shows that most of the literature on the effect of Mexico City's 'Hoy No Circula' programme, which is one of the earliest of its kind, focus on emissions or ambient air quality before and after the policy.

shopping traffic, but also the other non-trip related effects around shopping centres as mentioned earlier. Had the shops been closed during the typical weekends, we would not have been able to separate these shopping related impacts from other regular travel related impacts during the weekdays. Taking advantage of the policy, there are two ways the effects of shopping on congestion can be analysed. The first is a before-after study which is quite common in policy evaluation. This approach relies on the temporal changes before and the after the zonal shopping closure policy has been implemented. However, the temporal differences will likely be only able to retrieve the direction of changes (congestion increase or decrease), and not suitable for quantification of shopping effects since these numbers would also include the natural growth in traffic over that period, which is non-linear in nature. The second approach is to compare differences between the days of the week when shopping is closed or not using data from only post-policy era. We principally follow this second method, but also apply the first approach to seek a qualitative validation of the result.

The measurement of congestion is an important element in our research. Various metrics have so far been used in the literature to measure congestion. These include simple metrics such as travel speed or its inverse travel rate, travel time, delay, level of service, volume/capacity ratio to more complex indices such as travel time index, travel index, buffer index, roadway-congestion-index, lane-mile duration index, etc. (Rao and Rao 2012). The choice of a metric depends on the purpose of the study, ease of use and relevance of the metric, as well as availability of underlying data to measure the metric. Rao and Rao (2012) evaluates some of these metrics against seven criteria (simplicity, ease of data collection, stability, repeatability, magnitude of congestion, city comparison, continuous value) and find speed to be the best one among those reviewed. As such we use mean speed as the metric to represent congestion in this study.

Unfortunately, no regular monitoring of traffic speed or count is undertaken by the city authorities. The only speed measurement data is available on an occasional basis, generally tied to a transport project and are often quite local in nature. However, GPS tracking services by commercial providers have been available in Dhaka since 2006. While bus and truck fleet operators were the primary consumers of this service, given the prevalence of chauffeur driven cars, some car owners also subscribed to these GPS tracking services. Essentially, the service contains installation of a GPS device in the vehicle which sends a location signal to the service provider twice every minute, which is made available live to the customer via a password protected site on the internet. In the process, the service provider also collected and stored the location data of the vehicles at 30 second intervals. Our initial dataset contains such high-resolution GPS tracking data of 70 anonymised vehicles in and around Dhaka for the years 2009 and 2010, kindly made available by one commercial

GPS service provider. This dataset contains information on vehicle id, track id, time stamp, GPS coordinates, speed and direction of travel, area where the vehicle is plying, and whether the engine is turned on or off. While such a rich dataset can be used to reveal a variety of patterns, our current objective is to use the tracking data to detect average vehicle speed on roads in different areas during different days of the week.

In order to prevent any unusual traffic flow pattern affect our results, we discarded data from those days when traffic flow is not usual. The month of Ramadan is an obvious example, when the predominantly Muslim population of Bangladesh fast during the day and working hours and travel patterns are altered throughout the country. We also drop the tracking data during the government holidays. Also, since some of the vehicles in our dataset were trucks which regularly drove out of the city, we focus on the vehicles which regularly plied the streets of Dhaka. Our final dataset contains location data for 40 vehicles over those two years. In addition, data from the regions where major road construction or improvement projects were taking place are not considered. Also, instead of taking average speed of all vehicle tracks over an entire zone, we investigate only major arterial roads in different zones. This is to avoid the speed data on narrow streets, which could be quite volatile from day to day, affecting the mean speed estimate. Also, this allows us to circumvent the potential non-representativeness of the vehicle tracks to represent the zones.[4] Note that we are not necessarily interested in zones, and the zonal closure days simply help us test our hypotheses (below), which can be based on information on specific roads too.

Each road is defined by a series of contiguous narrow rectangles and the vehicle number, GPS position and time stamp of each vehicle location at 30 second interval is collected. Average speed is then calculated as the distance between two such signals divided by the differences in time stamp and converted to kph (kilometres/hour), and averaged over the 24 hour period.[5] With the cleaned GPS data, we set out to investigate the following hypotheses:

1. For a working week, average speeds on the days when the shops are closed will be higher than the days when they are open. The differences between these speeds would reflect the effects of shopping on congestion, which is our main interest.
2. The differences in the average speeds between open and closed shopping days vary depending on different zone or road types – primarily due to the variation in the density and types of shops and shopping centres in these zones or along these roads.

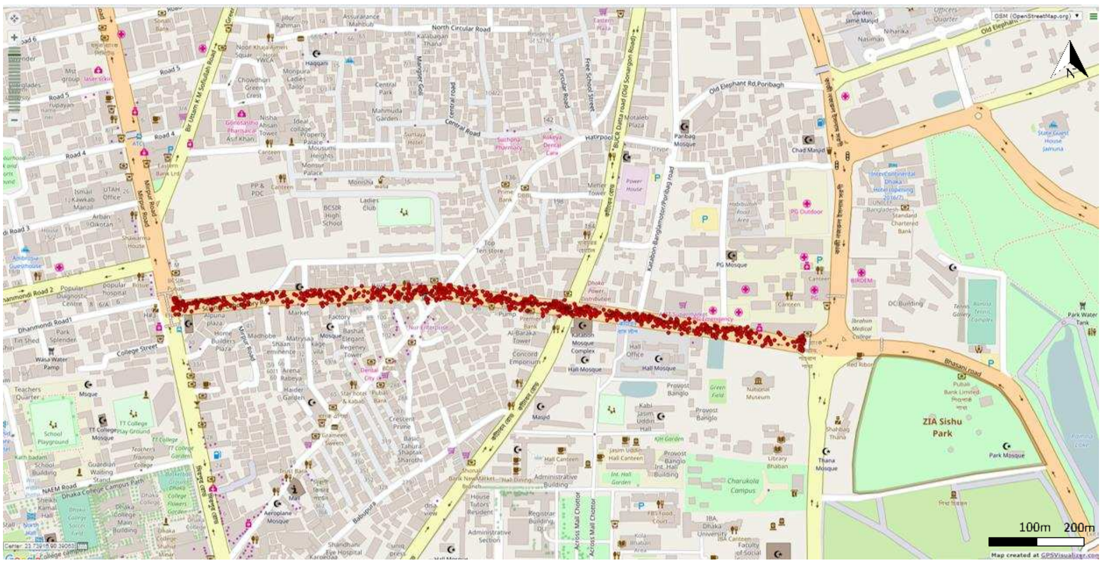
[4] Given the lack of monitoring, there is no way of knowing the average speed of the zones or roads in Dhaka to which our results could be compared to in order to test the representativeness of the sample tracks.
[5] Although speed is directly logged by the tracking device as well, instantaneous speed data is known to be error-prone, so we calculate speed independently.

3. The differences in the average speeds between open and closed shopping days would narrow in the longer term. This would reflect adaptation from the travellers as some non-essential trips are switched to the days when shops are closed (diverted traffic) because of lower congestion.
4. The reduction in speed from 2009 to 2010 (due to overall growth in traffic in the city) will be less for days when the shops are closed, compared to those when the shops are open.

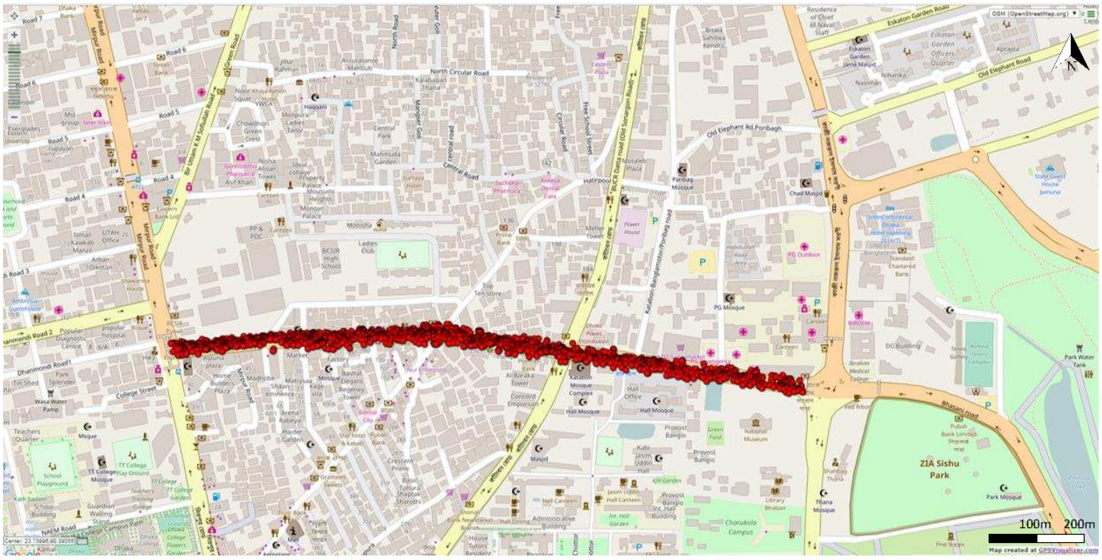
Once the speed differences as in hypothesis 1 is established, we use these numbers to determine additional congestion costs using simple literature derived relationships at an aggregate level.

5. Results & discussion

Figs. 2(a) and 2(b) present twenty random GPS tracks on the Elephant Road during the same time slots on a Tuesday (when the shopping centres are fully closed) and a Monday (a regular weekday), which clearly show that there are more tracking points on a Monday. Given the points are spread at a constant time interval, more points reveal that more time is spent on a Monday to cover the same distance, i.e. the average speed is slower and the road is more congested on a Monday.



(a) Tuesdays (shopping closed)



(b) Mondays

Fig. 2 GPS tracking points for 20 random tracks on Elephant Road in zone 4 on two weekdays, between 2 pm and 7 pm (source: authors' work using www.gpsvisualizer.com)

Table 2 presents the average speeds on different days of the week on selected major roads in the seven different shopping zones within Dhaka city. The markets in zone 1 close during the weekends (Friday full and Saturday half). As such the effects of shopping on the increase in speed on a Friday (11.12 kph) cannot be separated from that resulting from commute and other regular traffic. The average speeds for each of the five working days, also shows the least variation of seven zones. We also observe the largest speed differences (5.1 kph) between Fridays and weekdays in zone 1, since the Friday traffic here does not include either of shopping or commute traffic. The relatively low average speed compared to other zones is due to the presence of many slow-moving rickshaws on the roads in this zone. Since the shopping closure days and the wee kends are the same, we do not discuss the results from this zone further in later sections.

Table 2. Average speed (and standard deviation) on selected roads in different zones

		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
1	Sunday	5.42 (6.26)	***13.72 (12.49)***	5.33 (9.44)	8.79 (10.26)	11.23 (11.43)	***10.84 (11.58)***	13.55 (18.52)
2	Monday	6.39 (7.69)	*11.33 (11.28)*	5.19 (9.21)	8.88 (10.65)	10.27 (11.58)	*8.88 (11.20)*	12.60 (16.96)
3	Tuesday	5.71 (7.03)	11.54 (14.99)	5.64 (9.58)	***11.30 (12.55)***	9.71 (10.72)	8.40 (10.51)	13.27 (18.57)
4	Wednesday	6.70 (6.92)	10.34 (10.48)	5.37 (8.97)	*8.24 (10.25)*	10.63 (11.52)	8.83 (11.30)	***15.16 (17.75)***
5	Thursday	5.89 (6.18)	12.16 (12.58)	***6.08 (9.61)***	7.84 (10.08)	***11.42 (11.77)***	9.51 (11.19)	*12.56 (16.20)*

6	Friday	***11.12 (9.88)***	16.94 (14.87)	*8.32 (11.96)*	12.87 (13.03)	*12.55 (14.28)*	14.86 (16.12)	16.20 (18.69)
7	Saturday	*7.11 (8.82)*	14.10 (12.15)	6.23 (9.89)	7.83 (9.57)	12.66 (12.80)	14.48 (14.00)	14.26 (19.14)
8	Average weekday speed (all 5 days)	6.02 (6.86)	11.82 (12.36)	5.52 (9.30)	9.01 (10.31)	10.65 (11.31)	9.29 (11.05)	13.43 (17.56)
9	Range of average weekday speed (all 5 days)	(5.42, 6.70)	(10.34, 13.72)	(5.19, 6.08)	(7.84, 11.3)	(9.71, 11.42)	(8.40, 10,84)	(12.56, 15.16)
10	Average weekday speed-shopping open	6.02 (6.86)	11.34 (11.53)	5.38 (9.31)	8.44 (10.33)	10.46 (11.32)	8.90 (10.98)	12.99 (17.94)
11	Average weekday speed-shopping closed	11.12* (9.88)	13.72 (12.49)	6.08 (9.61)	11.30 (12.55)	11.42 (11.77)	10.84 (11.58)	15.16 (17.75)
12	Difference in speed (11)-(10)	5.10	2.38	0.70	2.86	0.96	1.94	2.17
13	One sided t-test stat (p)	16.98 (<0.01)	11.71 (<0.01)	4.60 (<0.01)	11.71 (<0.01)	2.25 (0.03)	7.37 (<0.01)	3.98 (<0.01)
14	Wilcoxen test statistic (p)	12.49 (<0.01)	7.84 (<0.01)	7.71 (<0.01)	7.84 (<0.01)	1.02 (0.31)	6.60 (<0.01)	5.73 (<0.01)
15	Speed difference in per cent	86.5%	17.4%	13.0%	33.4%	9.1%	22.3%	16.0%
16	No. of speed observations	9657	5202	33148	18757	4967	13812	11977

Bold, italic, dark shade: full day closed; italic, light shade: half-day closed; light font: weekends

* not a weekday speed

As Table 2 and Fig. 3 show, in all the other six zones, the average speed during the weekdays when the shopping centres are fully open are larger than the speed on the day when shopping is fully closed (we do not include half-closure days given poor enforcement on those days). The differences in speed are statistically significant at 99% confidence level for six of the zones and at 95% confidence for zone 5 using the one-sided t-test. Using the Wilcoxen non parametric test, the speed differences are statistically significant at 99% confidence for the same six zones. These results clearly support our first hypothesis that the staggered shopping closures reduced the congestion and improved average traffic speed. Overall, the average speed increased by 1.84 kph or 18.5% in the major roads in those six zones (not including zone 1), when the shopping centres were fully closed. As such, around 15.6% of the congestion (or reduction in speed) on weekdays can be attributed to shopping related travel and shopping centre related frictions and disruptions.

Fig. 3 Average weekday speed when shopping is fully closed or fully open

The reduction in speed resulting from shopping related activities and disruptions can be used to calculate the associated costs, although it is difficult to calculate from first principles, given a lack of data on the value of travel time saved and traffic volume in the individual roads or zones. Using an average speed of 9.7 kph on a regular weekday, 11.4 kph on a weekday when shops are closed and an assumed free flow speed of 30 kph, the congestion costs increases by 9.5%.[6] There are no government estimates for the costs of congestion in Dhaka, but other estimates range from USD 0.8 Billion to USD 2.8 Billion a year (Wadud 2014). Therefore, shopping related activities and traffic flow disruption results in an additional congestion costs of between USD 69 Million and 243 Million a year in Dhaka.[7] Note however, that our sample may not be representative of the individual zones and the city as a whole; and as such these additional costs of congestion is indicative only.

The concentration of the shopping centres and markets are not uniform throughout the city and our second hypothesis is about the existence of spatial variations in the congestion or speed effects. Zones or roads with few or no shopping centres neither generate the additional shopping traffic nor hinder the flow of existing traffic through on-road parking and other disruptive activities. A priori expectation is that zones or roads with fewer markets will experience smaller differences in speeds between days when shopping is open and closed. Given the lack of data on market density along the

[6] $Additional\ costs\ of\ congestion = \frac{speed\ on\ shopping\ closed\ weekdays - speed\ on\ regular\ weekdays}{free\ flow\ speed - speed\ on\ shopping\ closed\ weekdays}$

[7] Note that the original congestion cost estimates, which are summarised by Wadud (2014) from other studies, have several limitations and care must be exercised in using these numbers.

roads or in zones, we choose two roads with visibly different densities of shopping along them. The ring road in zone 5 appears to have the least concentration of shopping facilities and markets in our dataset.[8] The road also has the least congestion among all the roads investigated here, although that is not necessarily due to lack of shopping centres (this road is among the smaller arterials). The average speed during the weekday when the markets are closed is only 9.1% larger than the average speed during other weekdays, which is the smallest increase among all of the zones. In addition, this difference is not statistically significant using the Wilcoxen non parametric test (significant at 95% confidence using the one-sided t-test). On the other hand, the Elephant Road in zone 4, which is lined by a large number of shopping centres on both sides of the road (possibly the highest concentration of shopping centres among the roads considered here), shows the largest speed difference of nearly 33.4% between weekdays when shopping centres are open and closed (not including zone 1). This does indicate that the density of shopping centres have a substantial role in congestion.

One open question about the policy is its longer term effectiveness. The different shopping closure days release some road capacity in different zones on different weekdays. This means reaching a destination is quicker on the days when markets are closed (whether the destination is in that zone or whether one has to travel through that zone to reach the destination). Over time, this information is expected to enter the decision making process of the travellers and may encourage them to adjust their travel patterns and switch some of their discretionary or non-time sensitive trips to the days when the markets are closed and there is less congestion on the road. As such – depending on the share of trips that are flexible enough to be moved to another day – the speed differences between the days when the markets are closed and not will likely narrow over time. Comparing absolute speed differences from two different months is problematic given the potential seasonality of speed data (due to e.g. school holidays) and overall increasing trend in traffic over time. As such we use the ratio of speed during weekdays when shopping is fully closed and when it is fully open (again excluding half-closure days) as the metric of comparison. A priori, this ratio should fall over time if there is sufficient flexibility in the overall travel pattern.

We calculate the speed ratio over two three month periods at the beginning and end of our sample period: March 1 to May 31 and Sept-10 to December 10, which is presented in Fig. 4. The ratio falls between the initial and final three months of our observation sample for five of the seven zones. For zone 6 it remains nearly the same, while for zone 2 the ratio increases. Note however, the narrowing

[8] Although it is called a 'ring road' it is not a peripheral ring road around the city in the traditional sense. Dhaka does not have a peripheral ring road.

of speed ratios over time does not necessarily mean that the policy is ineffective in the long run. Switching the discretionary trip from a congested weekday when shops are open to a less congested weekday when they are closed still should reduce traffic on the congested weekdays. The redistribution rather points to a new equilibrium whereby the capacity is utilized to the fullest during all the weekdays. Also, it is not entirely impossible that the narrowing is only a seasonal effect due to differences in travel patterns over the year. As such it is difficult to make a robust conclusion over the temporal effects without further data.

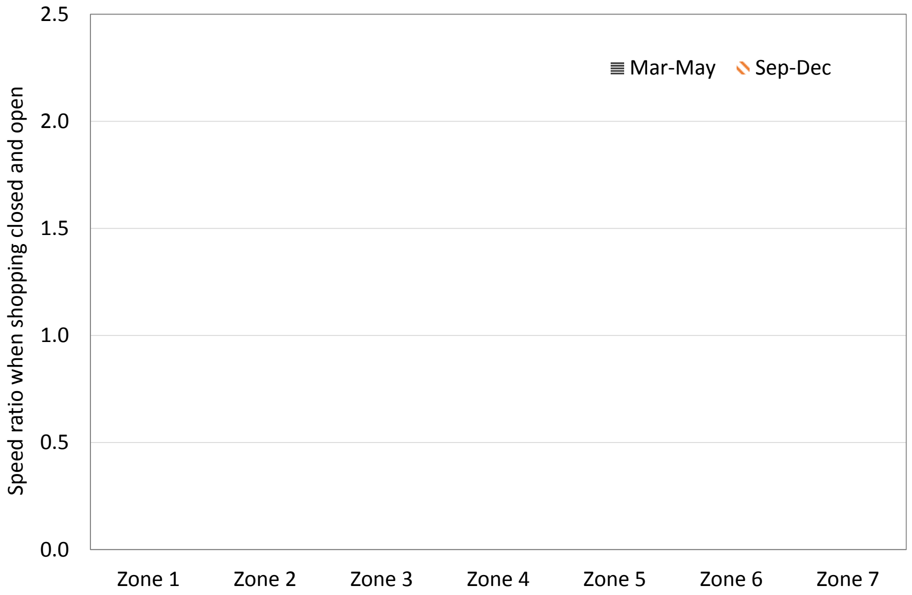


Fig. 4 Temporal changes in the ratio of speed during shopping closed and open days by different zones

Our last analysis compares 2009 speed data with 2010. For three roads in three zones, we calculate the average speeds during the seven days in the week, but weekdays are again our prime focus. The daily average speeds in 2010 is expected to fall, given traffic has increased between the years. A priori, our expectation is that this reduction in speed will be smaller during the days when the shops are closed, compared to the days when they are open. While the 'less' reduction is a flawed metric to capture the quantitative impact of shopping (as mentioned earlier), it can still provide qualitative support from a different perspective. Table 3 presents the results of this analysis. The mean daily speed decreased between 23% and 32% from 2009 to 2010 during Tuesdays, Wednesdays and Thursdays in zone 6, with an average reduction of 28%. However, the average speed fell by only 14% on Mondays, when the shops are closed, clearly showing a lower reduction. The results are even more encouraging in some other zones. In zone 4, the average speed on Sundays, Mondays and Thursdays each fell between 2009 and 2010, yet the average speed on Tuesdays, when the shops are closed, actually increased in 2010. In zone 5, daily mean speed fell by more than 10% on each of

Sundays, Tuesdays and Wednesdays and only marginally increased on Mondays (1.8%) – overall the speed reduced by 12.8% on average during these four working days. On the other hand, on Thursdays, when the shops are closed, the speed increased by 3.7% between 2009 and 2010. All of these three inter-year comparisons clearly point to the overall congestion impacts of shopping.

Table 3. Comparison of average speed (and standard deviation) on different days in 2009 and 2010

	Zone 4			Zone 5			Zone 6		
	Speed 2010	Speed 2009	Speed change	Speed 2010	Speed 2009	Speed change	Speed 2010	Speed 2009	Speed change
Sunday	8.79 (10.26)	9.10 (10.99)	-3.5%	11.23 (11.43)	13.00 (13.63)	-13.6%	***10.84 (11.58)***	***12.70 (12.97)***	***-14.6%***
Monday	8.88 (10.65)	9.25 (11.29)	-3.9%	10.27 (11.59)	10.09 (12.07)	1.8%	*8.88 (11.20)*	*11.72 (12.23)*	*-24.3%*
Tuesday	***11.30 (12.55)***	***10.24 (11.84)***	***10.4%***	9.71 (10.72)	12.88 (12.34)	-24.6%	8.40 (10.51)	12.37 (12.75)	-32.1%
Wednesday	*8.24 (10.25)*	*8.13 (10.40)*	*1.4%*	10.63 (11.52)	12.48 (12.29)	-14.9%	8.83 (11.30)	12.54 (12.70)	-29.6%
Thursday	7.84 (10.25)	9.86 (11.92)	-20.5%	***11.42 (11.77)***	***11.01 (12.02)***	***3.7%***	9.51 (11.19)	12.43 (13.06)	-23.5%
Friday	12.87 (13.03)	12.97 (14.94)	-0.7%	*12.55 (14.28)*	*12.48 (12.67)*	*0.5%*	14.86 (16.12)	17.27 (16.98)	-13.9%
Saturday	7.83 (9.57)	8.67 (10.72)	-9.7%	12.66 (11.09)	12.95 (12.17)	-2.2%	14.48 (14.00)	15.79 (14.55)	-8.3%

Bold, italic, dark shade: full day closed; italic, light shade: half-day closed; light font: weekends

6. Conclusions

This research quantifies the effects of shopping-related activities on traffic congestion in a developing country mega city, Dhaka. While the presence of shopping and retail trade facilities generates additional traffic, in cities like Dhaka – where parking control and enforcement is inadequate – shopping related activities can also lead to substantial bottlenecks on the roads, slowing traffic and aggravating congestion. The unique policy of having different weekly closure days in different parts of the city, combined with high frequency GPS tracking data of vehicles allowed us to decipher the contribution of shopping and retail trade on congestion in the city.

There was clear, statistically significant, finding that congestion eased substantially (i.e. average speed increased) during the days when shopping was closed. The speed difference was more pronounced in areas or on roads with higher concentration of shopping activities. We also find some evidence that over time some of the weekday traffic switches to the days when shopping centres are closed, indicating a readjustment of travel pattern taking advantage of the higher speed in those days. It is not clear whether the advantages of weekday closing times has narrowed even further in recent years, given the absence of recent data. However, even after seven years of implementing the policy, anecdotal evidence suggests that the roads still remain less congested when the shops in that zone are closed. Even if the traffic is redistributed so that average speed becomes similar during all weekdays, it would mean substitution away from days when the shops are open, improving congestion marginally during those days. As such different shopping closure dates is not necessarily a temporary fix.

Over the different zones shopping trips and related parking/bottlenecking disruptions were responsible for a 15.6% reduction in average speed in Dhaka, which translates to between USD 69 Million and USD 242 Million a year of additional congestion costs. The benefits of new shopping centres should be calculated against these unintended costs. On the other hand, given the policy of different weekday closure of the shopping centres is relatively straight forward and easy to implement, it could be a quick and practical solution to mitigating congestion in other developing megacities which often suffer from chronic congestion, lack of parking control and planning zones and lack of mass rapid transit, like Dhaka. The congestion benefits from such a policy needs to be balanced against the potential loss of business during those days, though.

The analysis can be improved in several ways. We did not have access to data on the density of markets in different zones, their size or patronage, presence or absence of underground (or good) parking facilities. Correlating the reduction in speed to these variables could improve the research substantially. Controlling for weather, especially rainfall (which can result in waterlogging), can refine the understanding of temporal variations in shopping-induced congestion. Also the number and locations of the vehicles tracked may not be representative of the city as a whole, which can be a limitation when overall congestions costs are attributed to shopping activities. In all of these cases, scarcity of resources and related data are the biggest challenges in a developing country context.

Acknowledgements

We thank Mr. Kaashif Reza Choudhury and the vehicle tracking company for sharing the tracking data. Thanks are also extended to Dr. Karl Ropkins for his suggestions to improve the paper.

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