Evaluation of Odd–Even Day Traffic Restriction Experiments in Delhi, India

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During periods from January 1 to January 15 and April 15 to April 30, 2016, the Government of the National Capital Territory of Delhi, India, implemented an odd–even vehicle rule. Under this rule, between 08:00 and 20:00, only cars with even-numbered plates were allowed to operate on even-numbered dates of the calendar and only cars with odd-numbered plates on odd-numbered dates. In light of the varying experiences of vehicle restriction practices from around the world, this study evaluated the effects of both phases of the odd–even policy on transport patterns and vehicle use in Delhi. Observational surveys were carried out at four locations in Delhi to observe traffic flow and vehicle occupancy data. Speed data were extracted for 38 origin–destination pairs during the January phase and for 66 pairs for the April phase, with a sample of roads from all over Delhi and with Google Maps API (application programming interface) software. During the experimental periods, car flow rates on roads were reduced by less than 20%, but rates increased for motorized two-wheelers, buses, and autorickshaws. There was an insignificant rise in car occupancy rates: most car owners did not opt for carsharing. No improvements in levels of particulate matter with aerodynamic diameter < 2.5 μm ($PM_{2.5}$) were detected. These experiments show that the odd–even rule was not effective in reducing measureable $PM_{2.5}$ pollution in Delhi.

Delhi is the capital city of India with a population of 16.7 million in 2011 (*1*) and a population density of 240 persons per hectare (*2*). Between 1991 and 2011, the population of Delhi and its five adjoining cities more than doubled, from approximately 10 million to 22 million persons. Public transportation in Delhi is served by a combination of a 200-km metro system, buses, minibuses, and different forms of paratransit (autorickshaws). According to India Census data (*3*), work trips in Delhi show the following pattern: cars have a share of 13%, motorized two-wheelers (MTWs) have a share of 17%, and the rest is shared by pedestrians, cyclists, and public transport users. The vehicular fleet in Delhi runs on a mix of petrol, diesel, and compressed natural gas (CNG). In 2013, the share of cars running on diesel was 17% and on CNG was 30%, while the rest used petrol; MTWs run on petrol, and autorickshaws, buses (except intercity buses), and light commercial vehicles are CNG-based (*4*). Although the share of cars in commuting trips is relatively low in Delhi compared to many other cities in around the world, ambient pollution levels remain high in Delhi and the city is considered one of the most polluted in the world (*2*). This ranking has resulted in public, media, and political pressure on the government of Delhi to take action, to reduce ambient pollution levels in Delhi.

During the period from January 1 to 15, 2016, the Government of the National Capital Territory of Delhi (GNCTD), India, implemented an odd–even vehicle rule. Under this rule, between 08:00 and 20:00 daily, only even-numbered cars were allowed to operate on even-numbered dates of the calendar, and only cars with odd-numbered plates were allowed to operate on odd-numbered dates (odd–even policy, Phase 1). This policy was repeated in the period from April 15 to 30, 2016 (Phase 2). The following vehicles were exempted from adhering to this rule: all MTWs; vehicles running on CNG; those driven by women traveling alone or with children below the age of 12 or by handicapped persons; vehicles of officials such as parliamentarians; and ambulances, fire brigades, hospital vehicles, hearses, police cars, army vehicles, emergency services vehicles, and embassy vehicles.

This policy was officially announced by GNCTD on December 28, 2015 because "further steps are required to control vehicular pollution caused by non-transport four wheeled vehicles (motor cars, etc.)" in the interest of public safety (*5*). In the notification the background for the regulation includes the following statement: "Whereas the National Capital Territory of Delhi has more than nine million registered vehicles and the vehicular pollution has become a major source of air pollution in Delhi, and Whereas Hon'ble Supreme Court of India, Hon'ble High Court of Delhi and Hon'ble National Green Tribunal have passed various directions from time to time to take immediate action to control the alarming level of vehicular pollution in Delhi and all out efforts are being made to give effect to the directions of the Hon'ble courts" (*5*).

In the past several measures have been taken to control particulate matter with aerodynamic diameters < 10 μm and < 2.5 μm, respectively (PM_{10} and $PM_{2.5}$). These measures include the following: restriction on plying of goods vehicles during the daytime (1998), supply of only premix petrol with 2T oil to two-stroke engine vehicles (1998), entire city bus fleet and taxis (three and four wheels) converted to single-fuel mode on CNG (2001), and implementation of Bharat Stage 4 emissions standards, similar to European emissions standards (Euro 4) (2010). However, because levels of atmospheric $PM_{2.5}$ and PM_{10} remain unacceptable in Delhi (*6–12*), there is continuous public and political pressure on authorities to find remedies for the problem. The odd–even experiment was initiated as a result of such pressures from civil society and the courts in Delhi.

The fact that the GNCTD chose to implement the odd–even policy was a bit curious, because similar experiments in other parts of the world have not been particularly successful. Vehicle control measures have been attempted in Buenos Aires, Argentina; Manila, Philippines; Bogota, Colombia; Caracas, Venezuela; Mexico City,

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Mexico; Lagos, Nigeria; and most recently in Beijing during the 2008 Olympic Games (*13, 14*). The Latin American experience suggests that driving restriction policies in cities may sometimes be effective in reducing congestion and pollution in the short run, but can have negative consequences in the long run as people learn to cope with the regulations by buying older second cars, shifting to MTWs, and changing their travel patterns (*15*). The experiences from Manila suggest that when cars are banned from plying the streets, commuters still use their cars by shifting use to other times of the day and congestion has not been reduced considerably (*16, 17*). The car restriction policies in Beijing had mixed results. Banning high-emitting vehicles and the travel restrictions imposed by use of odd–even licenses during the Olympic Games had significant effects on the reduction of vehicular emissions of carbon monoxide, hydrocarbons, oxides of nitrogen, and PM_{10} in China (*18*) in the short term. However, Wang et al. report that the restriction policy in Beijing did not have significant influence on individuals' decisions to drive and rule-breaking behavior was constant and pervasive (*13*). The authors found that 47.8% of the regulated car owners did not follow the restriction rules, and drove "illegally" to their destination places (*13*).

Results of earlier studies and estimates for Delhi indicated that just decreasing the presence of cars by 50% may lead to a theoretical decrease in ambient $PM_{2.5}$ by less than 3% (*19*). In light of the varying experiences of vehicle restriction practices from around the world, this study evaluates the effects of both phases of the odd–even policy on the actual transport patterns and vehicle use in Delhi and its effect on ambient pollution (measured by official agencies in Delhi) as compared to the predictions.

METHODS

The odd–even rule was implemented in Delhi during the first phase from January 1 to January 15, 2016, and the second phase from April 15 to April 30, 2016. During those two periods, only odd-numbered passenger cars were allowed to operate on odd-numbered dates and even-numbered cars on even-numbered dates between 08:00 and 20:00. The rule did not apply on Saturdays and Sundays, and the following vehicles were exempted: all taxis, passenger cars operating on CNG and electric power, cars with only women passengers, and all MTWs. All schools were closed during the first phase but were open during the second phase. Traffic and speed data were collected for periods around the two phases to assess the effect of the experiments. The details are given below.

Observational Surveys for Traffic Data

Observational surveys were carried out at four locations (Figure 1): Jia Sarai at Outer Ring Road (JAS), South-Ex at Ring Road (SOX), Sai Mandir at Khel Gaon Marg (SAM), and the Income Tax Office at Vikas Marg (ITO). The four locations represented (*a*) a major arterial road for intracity traffic without much local commercial activity (JAS), (*b*) a main arterial with significant local commercial activity (SOX), (*c*) a local artery with business and commercial activity (SAM), and (*d*) a major junction of two main arterials (ITO).

The study team consisted of two individuals for each of the locations. For the SOX, SAM, and ITO locations, one individual carried out videography as well as observation for odd- and even-numbered cars from an overhead pedestrian bridge, and another individual stood at the median of the road and observed occupancy levels for each vehicle. At JAS, the same individual carried out observations for occupancy as well as for odd and even numbering. The videography at JAS was 3 h long (8:00 to 11:00) and was 1 h long (10:00 to 11:00) everywhere else. The JAS videography was carried out from atop a building located on the side of the road. Observations for odd and even numbers, as well as for car occupancy, were carried out for the lane closest to the median and for one direction of traffic. Observations were made for every fifth car, which allowed adequate time to record the numbers.

Video recordings were used to calculate traffic volume statistics in the laboratory, and manual observations were used to estimate volumes of odd- and even-numbered cars and the occupancy rates of vehicles. A count of the first 200 consecutive fifth cars was used to

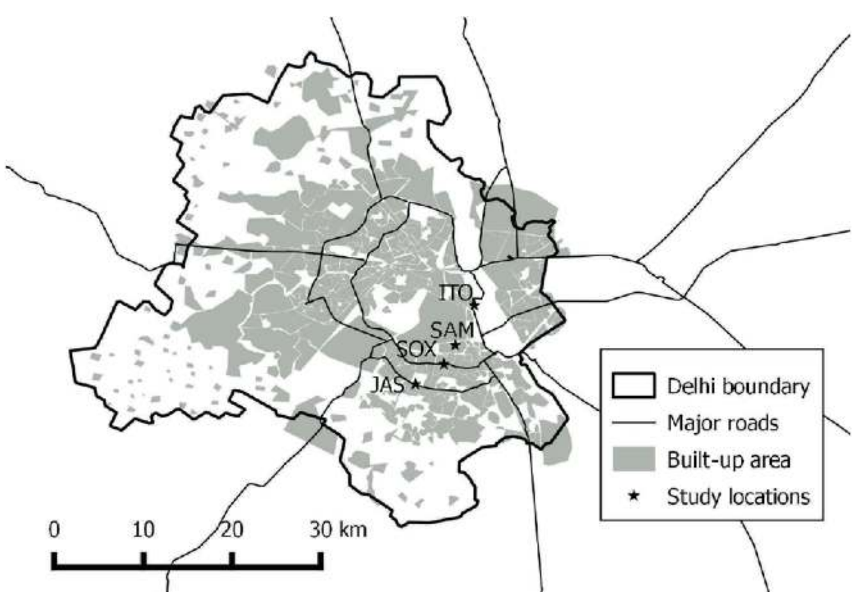

FIGURE 1 Locations where observational surveys for traffic data were conducted.

estimate the odd–even proportions and the first 100 consecutive fifth vehicles for occupancy rates at each location. Data were collected two times a day at each location as follows:

Phase 1. Six days before the experiment and 4 days each for odd and even numbers during the experiment and

Phase 2. Three days before the experiment and 1 day each for odd and even numbers during the experiment.

Data collection days were reduced during Phase 2 because experiences from Phase 1 demonstrated that the results were very stable from day to day.

Traffic Speed Data

Speed data were extracted for 38 origin–destination pairs by using a sample of roads from all over Delhi and using Google Maps Distance Matrix API (application programming interface) software for Phase 1, and for 66 origin–destination pairs during Phase 2. The API provides real-time travel time between a given pair of locations, from which travel times speeds are calculated. These data were extracted by using the API every half-hour during the period from 06:00 to 22:00 from December 28, 2015, to January 22, 2016, and from 05:00 to 22:00 from April 15 to May 5, 2016. The period for Phase 1 covered 4 days before the odd–even policy implementation, 15 days during the experiment, and 5 days after the experiment; for Phase 2, the period covered 15 days during the experiment and 5 days after the experiment. These average vehicle speed estimates were free of observer bias and allowed the authors to present data for roads representing various locations of the city. The authors believe that average speeds calculated by this method give a more reliable estimate of speed changes in the city than do other methods using probe vehicles or measuring spot speeds on the roads. The roads were classified into four groups—arterial roads, intercity roads, commercial roads, and ring roads—to obtain a better idea of locations where the effects of the experiment were more noticeable.

RESULTS

Proportion of Odd- and Even-Numbered Cars on the Road

The proportions of cars with odd- and even-numbered registration plates before, during, and after the experimental 2-week periods in January and April are given in Tables 1 and 2.

On normal days, the proportions of cars with odd- and even-numbered plates were similar. On both odd- and even-numbered days, however, about 23% to 27% of vehicles not showing the appropriate registration number were probably on the roads as a result of exemptions and partly as a result of noncompliance. These data show that the odd–even policy did not reduce car use proportions by 50% but by about 35%, and show that there was no significant difference in behavior by car users during the January and April experiments.

Car Occupancy Rates

Tables 3 and 4 show the occupancy rates of cars observed before and during the experiment at four locations in Delhi for both phases in January and April 2016. The results show that car occupancy rates

TABLE 1 Proportions of Odd- and Even-Numbered Cars at Four Locations in Delhi Before and During Phase 1

	Before Experiment[a] (%)		During Odd Car Days[b] (%)		During Even Car Days[b] (%)	
Location	Odd	Even	Odd	Even	Odd	Even
JAS	49	51	77	23	25	75
SOX	48	52	71	29	24	76
SAM	51	49	77	23	23	77
ITO	52	48	81	19	20	80
Average	50	50	76	24	23	77

[a]N = 2,400.
[b]N = 1,600.

TABLE 2 Proportions of Odd- and Even-Numbered Cars at Four Locations in Delhi Before and During Phase 2

	Before Experiment[a] (%)		During Odd Car Days[b] (%)		During Even Car Days[b] (%)	
Location	Odd	Even	Odd	Even	Odd	Even
JAS	49	51	74	27	27	74
SOX	50	51	73	27	28	73
SAM	51	49	76	24	30	71
ITO	54	47	70	30	24	76
Average	51	49	73	27	27	73

[a]N = 1,200.
[b]N = 400.

TABLE 3 Average Occupancy Rates of Cars at Four Locations in Delhi Before and During Phase 1

	Number of Occupants Per Car		
Location	Before Experiment[a]	During Experiment[b]	Change in Occupancy During Experiment (%)
JAS	1.71	1.89	10.5
SOX	1.77	1.76	–0.6
SAM	1.62	1.71	5.6
ITO	1.82	2.04	12.1

[a]N = 2,400.
[b]N = 2,000.

TABLE 4 Average Occupancy Rates of Cars at Four Locations in Delhi Before and During Phase 2

	Number of Occupants Per Car		
Location	Before Experiment[a]	During Experiment[a]	Change in Occupancy During Experiment (%)
JAS	1.84	1.79	–2.7
SOX	1.93	1.98	2.6
SAM	1.72	1.80	4.4
ITO	2.07	1.95	–5.8

[a]N = 800.

increased by less than 12% during the first phase at three locations and decreased by 0.6% at one location. During the second phase, the increase in occupancy was less and even decreased at two locations. It is possible that these differences might have been the result of small sample errors and that the odd–even policy did not influence car occupancy rates significantly. This is an interesting result because the Government of Delhi had instituted a public information campaign encouraging people to shift to carsharing.

Traffic Flow Data

Phase 1

Tables 5 and 6 show the results of vehicle counts done before and during the two odd–even experiment periods at four locations in Delhi during the morning and afternoon peak flow times. During the first phase, car volumes were reduced by 9% to 17% at the four locations, but during the second phase reduction was seen at only one location and small increases at others. The reductions in flow rates are much less than what would be expected if 35% of the cars with wrong digits were off the road. It is possible that people made higher use of the cars available during peak hours. It is possible that if data were collected for the whole period of the restriction in the day, a larger decrease in car flow rates would be shown.

There was a general increase in numbers of MTWs, autorickshaws, and buses during the odd–even experiment days. This was expected, because those who could not use their cars during the restriction days would likely shift to other modes of transport. This may also be the reason why car speeds did not increase dramatically during the experiments. The authors are unable to explain the large variations in autorickshaw rates at two locations and bus rates at one location during the second phase.

TABLE 5 Number of Vehicles Observed at Four Locations in Delhi During Phase 1 of Odd–Even Experiment

Location	Before Experiment	During Experiment	Change During Experiment (%)
MTWs			
JAS	3,409	3,401	–0.2
SOX	3,847	3,886	1.0
SAM	552	679	23.0
ITO	2,675	3,417	27.7
Cars			
JAS	6,359	5,250	–17.4
SOX	6,627	6,020	–9.2
SAM	939	850	–9.5
ITO	4,617	4,029	–12.7
Autorickshaws[a]			
JAS	1,166	1,313	12.6
SOX	2,555	2,512	–1.7
SAM	475	596	25.5
ITO	1,496	1,684	12.6
Buses			
JAS	137	130	–5.1
SOX	550	579	5.3
SAM	68	79	16.2
ITO	226	251	11.1

[a]Three-wheeled scooter taxis.

TABLE 6 Number of Vehicles Observed at Four Locations in Delhi During Phase 2 of Odd–Even Experiment

Location	Before Experiment	During Experiment	Change During Experiment (%)
MTWs			
JAS	1,699	1,980	16.5
SOX	2,233	2,426	8.6
SAM	354	381	7.6
ITO	1,683	2,205	31.0
Cars			
JAS	3,452	3,502	1.4
SOX	3,350	3,278	–2.1
SAM	519	546	5.2
ITO	2,586	2,892	11.8
Autorickshaws			
JAS	604	727	20.4
SOX	1,027	1,892	84.2
SAM	252	252	0.0
ITO	1,492	864	–42.1
Buses			
JAS	157	165	5.1
SOX	223	297	33.2
SAM	51	39	–23.5
ITO	87	168	93.1

Phase 2

Figures 2 to 4 show speed data comparisons for Phases 1 and 2 of the odd–even experiment in Delhi. Average speeds decreased by a small amount from 08:00 to 11:00 in most locations during the experiment, compared to periods before or after the experiments. There was a slight increase in average speeds between 11:00 and 17:00 during the experimental periods. The maximum increase in average speeds during the experiment was 9%, compared to the before period, in a few locations. However, in many locations the change in speeds was less than 5% and was not significant statistically.

After 20:00, the speed difference between the before period and during the experiment and between the after period and during the experiment is also not statistically significant. This is likely an indication of the staggering of traffic movement because some car drivers may have started before 08:00 and returned after 20:00 to avoid the odd–even rule. The speed increment of the period during the experiment, compared to the period before, is lower than the increment of the period during the experiment compared to the period after. This outcome is probably because schools were closed before and during the experiment in Phase 1.

Table 7 shows average speed data for the same data set as used in Figure 3, in which the 38 road segments are divided into four groups: (*a*) arterial roads, (*b*) intercity roads, (*c*) commercial roads, and (*d*) ring roads. Arterial roads are major roads within the city. Intercity roads are the arterial roads that provide direct connectivity

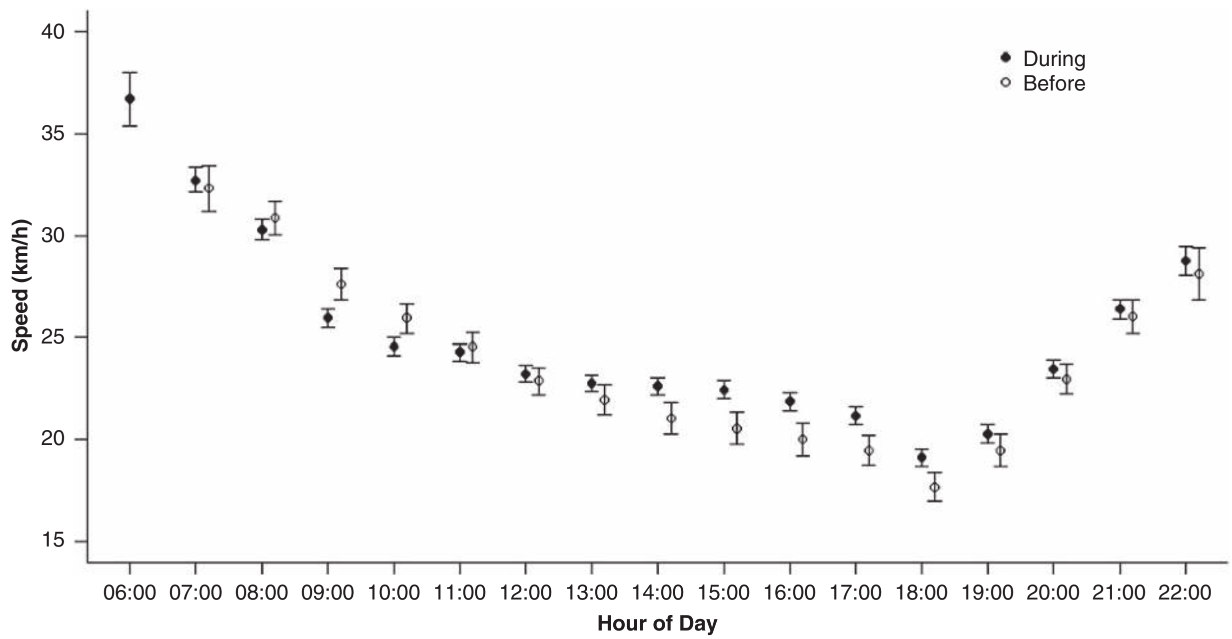

FIGURE 2 Hour-specific average speed showing 95% confidence intervals for speeds before and during odd–even experiment for 38 origin–destination pairs, Phase 1 (overlapping interval bars for each hour indicate that speeds are not different statistically, with 95% confidence limits).

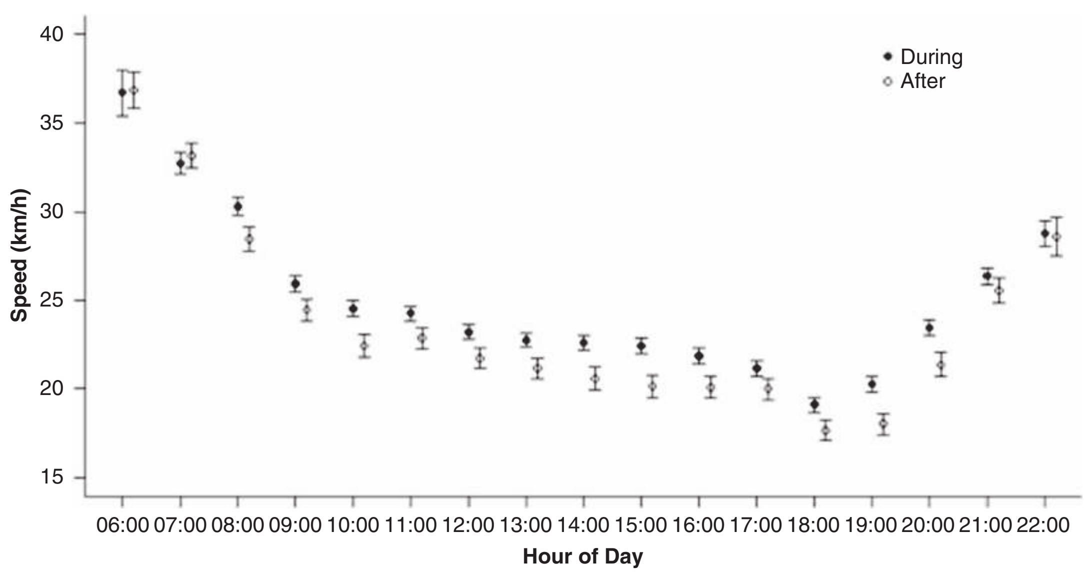

FIGURE 3 Hour-specific average speed showing 95% confidence intervals for speeds during and after odd–even experiment for 38 origin–destination pairs, Phase 1.

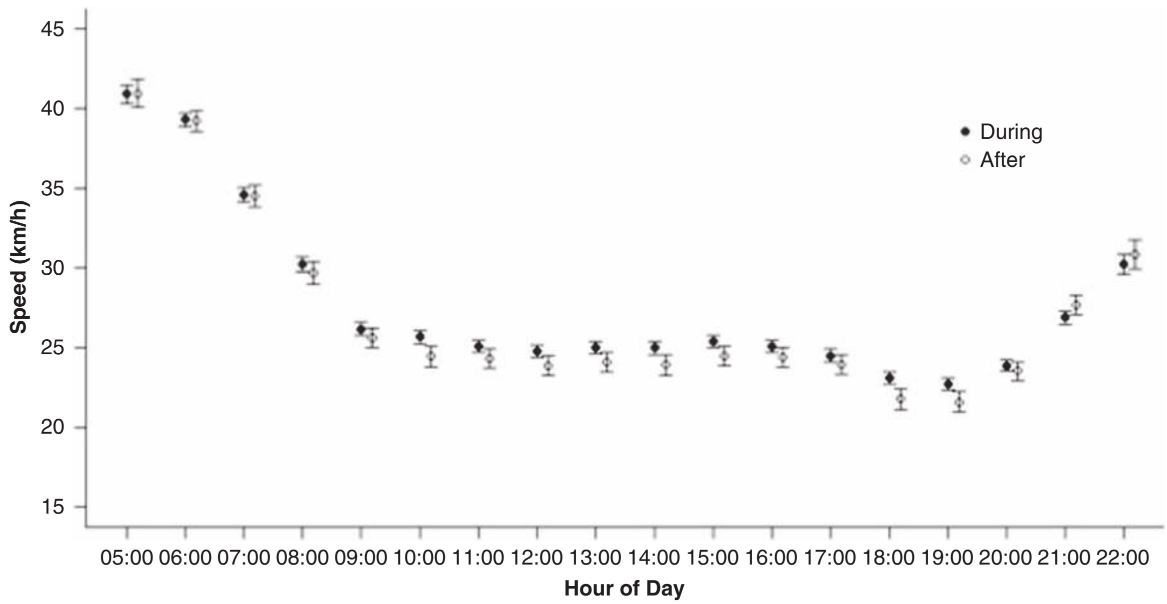

FIGURE 4 Hour-specific average speed showing 95% confidence intervals for speeds during and after odd–even experiment, Phase 2.

TABLE 7 Average Speeds on Four Categories of Roads from 38 Origin–Destination Pairs in Delhi During Time Periods Around Phase 1

Time Period	Before Phase 1 (km/h)	During Phase 1 (km/h)	After Phase 1 (km/h)	Change Compared with Before Phase 1 Experiment (%)	Change Compared with After Phase 1 Experiment (%)
Arterial Road Segments					
06:00–08:00	29	30	31.3	3	–4
08:00–11:00	24.3	23.1	21.9	–5	6
11:00–17:00	19.3	20.4	18.6	6	10
17:00–20:00	16.8	18.2	16.6	9	10
20:00–22:00	22.9	23.3	21.8	2	7
Intercity Roads					
06:00–08:00	31.9	33.7	34.2	6	–1
08:00–11:00	26.7	26.5	23.9	–1	11
11:00–17:00	23.4	24.5	22.2	5	10
17:00–20:00	21.9	22.5	21	3	7
20:00–22:00	26.4	26.3	25	0	5
Commercial Road Segments					
06:00–08:00	30.3	30.9	32	2	–3
08:00–11:00	25.6	24.9	23.9	–3	4
11:00–17:00	18.4	19.5	18.6	6	5
17:00–20:00	15.9	17.3	16.6	9	4
20:00–22:00	22.4	23.3	23.7	4	–2
Ring Road Segments					
06:00–08:00	41.2	42.6	43.2	3	–1
08:00–11:00	35.2	33.8	31.1	–4	9
11:00–17:00	26.7	28.6	26.2	7	9
17:00–20:00	23.9	25.4	22.8	6	11
20:00–22:00	32.1	32.4	30.4	1	7

of Delhi with other neighboring cities. Commercial roads are major roads located in the central business district and other office locations in the central part of Delhi, and ring roads consist of segments on Ring Road and Outer Ring Road.

The first time period (06:00 to 08:00) is before rush-hour traffic begins. The second period (08:00 to 11:00) accounts for the morning rush hour period. The third period (11:00 to 17:00) accounts for time between the two rush hours. The fourth period (17:00 to 20:00) accounts for the evening rush hour. The fifth period (20:00 to 22:00) accounts for time after the odd–even rule ceases to apply. The first and the last categories are outside the time period when the odd–even rule was applicable. These data show that the increase in speeds was higher during the time between the morning and evening peak periods (11:00 to 17:00), especially on arterial roads in those parts of Delhi with less significant presence of commercial establishments.

DISCUSSION OF RESULTS

The overall results of this study indicate that during the experimental odd–even days, the volume of cars on the roads was reduced by less than 20% at best, but that the influence of these reductions on speeds and traffic volume was not as significant. In general, the average speeds did not increase by more than 10% during off-peak periods and increased by even less during the rush hour periods. However, the reduction in car presence was offset by increases in numbers of MTWs, autorickshaws, and buses during peak hour periods. Such offsetting increases were probably the result of car owners shifting to other modes of transport; carsharing was not that common, as indicated by very small increases in vehicle occupancy. This increase in use of modes other than car probably offset some of the pollution reduction caused by fewer cars on the road. Increases in numbers of those vehicles may also have been responsible for the small increases in speeds seen during the experiments.

The study's results regarding effect of the odd–even experiment on travel speeds are supported by another study using Google API data, which reports that on a trip that would normally take 40 min, there was a 1.7-min average reduction in travel time during the experiments (*20*). The Energy and Resources Institute Delhi also evaluated the odd–even policy for both phases (*21, 22*) and reported a 21% reduction in numbers of cars at two locations during Phase 1 and of 17% at six locations during Phase 2. Such reductions in car counts are greater than those observed in this study and may be the result of differences in locations and times of counting. In any case, the reductions in car presence appear to be less than 20% during the experimental periods. The Energy and Resources Institute staff monitored average speeds of cars using a GPS on a selected route, traversing through a total distance of about 90 km, and reported that speeds increased by 17% during Phase 1 and by 13% during Phase 2. Such values are higher than those measured in this study and a study by Kreindler (*20*)—probably because a vehicle was used on limited routes—and are probably less reliable than the values reported in this study.

EFFECTS OF ODD–EVEN POLICY ON EMISSIONS

Three recent studies have estimated the contribution of vehicular traffic to levels of $PM_{2.5}$ emissions in Delhi (*10–12*). While Pant et al. (*11*) and Sharma and Dikshit (*12*) used chemical analysis to determine the contribution of various sources, Guttikunda and Calori used the emissions inventory modeling approach (*10*), and the studies suggest that vehicular traffic contributes at most to 30% of the $PM_{2.5}$ load in Delhi. Further, these studies report that cars on the whole do not contribute more than 15% of the vehicular share of the $PM_{2.5}$ load. This report suggests that the cars' share of $PM_{2.5}$ emissions is not likely to be more than 4.5% of the total $PM_{2.5}$ in the atmosphere of Delhi. The odd–even experiment would theoretically reduce $PM_{2.5}$ emissions by a maximum of 2.3% at best, if the reduction in cars were 50%. However, the actual reduction as reported in this study and others appears to be less than 25%, at best, in a few locations. This means that the expected reduction in $PM_{2.5}$ levels resulting from the odd–even policy would have to be less than 2%.

The ambient air quality of Delhi was monitored through a set of Continuous Ambient Air Quality Monitoring Systems and manual stations spread across different locations in Delhi. Two reports were submitted by the Central Pollution Control Board of Delhi evaluating the effect of the odd–even experiments on pollution in Delhi. The first report on Phase 1 shows that $PM_{2.5}$ levels before, during, and after the odd–even phase were 52 to 298 $\mu g/m^3$, 79 to 507 $\mu g/m^3$, and 76 to 342 $\mu g/m^3$, respectively (*23*). Because these data do not really show any reductions in overall pollution during Phase 1, the report concluded that "a single factor or action cannot substantially reduce air pollution levels in Delhi" (*23*). The second report for Phase 2 shows that average levels of $PM_{2.5}$ monitored at 17 stations before and during the odd–even phase were 45 to 143 $\mu g/m^3$ and 63 to 182 $\mu g/m^3$, respectively, and that the average levels increased at 13 stations during the experiment (*24*). The report concluded that "the air quality is affected by various meteorological factors . . . besides emission from various sources including vehicles. The decrease in vehicular emission was not a dominant enough factor to impact observed data" (*24*).

CONCLUSIONS

The odd–even vehicle rule, under which only even-numbered cars were allowed to operate between 08:00 and 20:00 on even-numbered dates of the calendar, and only cars with odd-numbered plates were allowed to operate on odd-numbered dates, was implemented in Delhi for periods of 15 days each in January and April 2016. The results of this study show that during the experimental periods, car flow rates on roads were reduced by less than 20%, but flow rates for MTWs, buses, and autorickshaws increased. There was an insignificant rise in car occupancy rates, showing that most car owners did not opt for carsharing. In the long term, the increase in use of two-wheelers can also result in more road accident injuries and deaths. Speeds increased by up to 11% on some roads during off-peak hours, but decreased in some places before and after the odd–even rule period.

The odd–even experiment in Delhi did not show any conclusive evidence in reduction of overall levels of $PM_{2.5}$ in the atmosphere, probably because the contribution of cars to $PM_{2.5}$ levels is less than 5% of the total. International experience also suggests that when such restrictions remain in place for a longer period, people tend to buy more cars and motorcycles and to change travel patterns, thus offsetting the small advantages in congestion demonstrated over short periods. Therefore, these experiments show that the implementation of the odd–even rule was not effective in reducing measurable levels of $PM_{2.5}$ in the atmosphere of the city.

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REFERENCES

1. Census of India. *Provisional Population Totals 2011.* Office of the Registrar General and Census Commissioner, New Delhi, India, 2012.
2. Guttikunda, S. K., R. Goel, and P. Pant. Nature of Air Pollution, Emission Sources, and Management in the Indian Cities. *Atmospheric Environment,* Vol. 95, 2014, pp. 501–510. https://doi.org/10.1016/j.atmosenv.2014.07.006.
3. Census of India. B-28 "Other Workers" by Distance from Residence to Place of Work and Mode of Travel to Place of Work–2011 (India/States/UTs/District). Registrar General of India, Government of India, New Delhi. http://www.censusindia.gov.in/2011census/population_enumeration.html. Accessed 2016-06-15, 2016.
4. Goel, R., and S. K. Guttikunda. Role of Urban Growth, Technology, and Judicial Interventions on Vehicle Exhaust Emissions in Delhi for 1991–2014 and 2014–2030 Periods. *Environmental Development,* Vol. 14, 2015, pp. 6–21. https://doi.org/10.1016/j.envdev.2015.03.002.
5. Government of National Capital Territory of Delhi. Notification: Control of Vehicular Pollution. Gazette Notification No. F.3 (218)/MRTS/Tpt./2O15/302, 2015.
6. National Ambient Air Quality Status 2007. Report NAAQMS//2008-09, Central Pollution Control Board, Ministry of Environment and Forests, Delhi, India, 2008. pp. 1–142.
7. *Epidemiological Study on Effect of Air Pollution on Human Health (Adults) in Delhi.* Central Pollution Control Board, Ministry of Environment and Forests, Delhi, India, 2008.
8. Sahu, S. .K., G. Beig, and N. S. Parkhi. Emissions Inventory of Anthropogenic PM2.5 and PM10 in Delhi During Commonwealth Games 2010. *Atmospheric Environment,* Vol. 45, No. 34, 2011, pp. 6180–6190. https://doi.org/10.1016/j.atmosenv.2011.08.014.
9. Guttikunda, S. K., and R. Goel. Health Impacts of Particulate Pollution in a Megacity—Delhi, India. *Environmental Development,* Vol. 6, 2013, pp. 8–20. https://doi.org/10.1016/j.envdev.2012.12.002.
10. Guttikunda, S. K., and G. Calori. A GIS Based Emissions Inventory at 1 km × 1 km Spatial Resolution for Air Pollution Analysis in Delhi, India. *Atmospheric Environment,* Vol. 67, 2013, pp. 101–111. https://doi.org/10.1016/j.atmosenv.2012.10.040.
11. Pant, P., A. Shukla, S. D. Kohl, J. C. Chow, J. G. Watson, and R. M. Harrison. Characterization of Ambient PM2.5 at a Pollution Hotspot in New Delhi, India and Inference of Sources. *Atmospheric Environment,* Vol. 109, 2015, pp. 178–189. https://doi.org/10.1016/j.atmosenv.2015.02.074.
12. Sharma, M., and O. Dikshit. *Comprehensive Study on Air Pollution and Green House Gases (GHGS) in Delhi (Draft Report).* Government National Capital Territory of Delhi, New Delhi, 2015, p. 266.
13. Wang, L., J. Xu, and P. Qin. Will a Driving Restriction Policy Reduce Car Trips?—The Case Study of Beijing, China. *Transportation Research Part A: Policy and Practice,* Vol. 67, 2014, pp. 279–290. https://doi.org/10.1016/j.tra.2014.07.014.
14. Elsom, D. M. Urban Air Quality Management and the Role of Traffic Management Measures. World Clean Air Congress, Vol. 1, 1998.
15. Gallego, F., J.-P. Montero, and C. Salas. The Effect of Transport Policies on Car Use: Evidence from Latin American Cities. *Journal of Public Economics,* Vol. 107, 2013, pp. 47–62. https://doi.org/10.1016/j.jpubeco.2013.08.007.
16. Redigor, J. R. F. Traffic Congestion in Metro Manila: Is the UVVRP Still Effective? *Philippine Engineering Journal,* Vol. 34, No. 1, 2013, pp. 66–75.
17. Gueta, G. P., and L. B. Gueta. How Travel Pattern Changes After Number Coding Scheme as a Travel Demand Management Measure Was Implemented? *Proceedings of the Eastern Asia Society for Transportation Studies,* Vol. 9, 2013, pp. 1–9.
18. Yao, Z. L., Y. Z. Zhang, X. B. Shen, X. T. Wang, Y. Wu, and K. B. He. Impacts of Temporary Traffic Control Measures on Vehicular Emissions During the Asian Games in Guangzhou, China. *Journal of the Air and Waste Management Association,* Vol. 63, No. 1, 2013, pp. 11–19. https://doi.org/10.1080/10962247.2012.724041.
19. Urbanemissions. Delhi—Emissions Analysis for Odd/Even Days. http://www.urbanemissions.info. Accessed April 17, 2016.
20. Kreindler, G. Driving Delhi? Behavioural Responses to Driving Restrictions. Working Paper, Massachusetts Institute of Technology, Boston, 2016. p. 30.
21. Sharma, S., J. Malik, and P. Ghosh. *Analysis of Ambient Air Pollutant Concentrations: Before and During Odd-Even Scheme in New Delhi (24th Dec 2015 to 14th Jan 2016).* Energy and Resources Institute, New Delhi, India, 2016.
22. Sharma, S., J. Malik, R. Suresh, and P. Ghosh. *Analysis of Odd-Even Scheme Phase-II.* Energy and Resources Institute, New Delhi, 2016.
23. *Assessment of Impact of Odd-Even Scheme on Air Quality of Delhi.* Central Pollution Control Board, New Delhi, India, 2016.
24. Ministry of Environment. Report on Ambient Air Quality Data During Odd and Even Period. In *New Delhi, 2016,* Central Pollution Control Board Delhi, New Delhi, India, 15th to 30th April, 2016.

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