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Original Research Paper

Effects of odd–even traffic restriction on travel speed and traffic volume: Evidence from Beijing Olympic Games

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ABSTRACT

This paper reports the effects of using an "odd and even" traffic restriction policy in Beijing during the 2008 Olympic Games. Based on data from 529 traffic detectors on the expressway network and some main arterials in Beijing, China, a comparative analysis has been carried out on the following parameters: the total traffic volume within the expressway network, the total traffic volume on different ring expressways, the traffic volume and speed of a freeway segment, and an arterial street before and after the implementation of the traffic restriction policy. The results show that during the traffic restriction period, although more than 50% of vehicles were forbidden to travel in Beijing, the traffic volume was only reduced by 20%–40% while the travel speed had been increased by 10%–20%. This suggests that such traffic restriction policy may be an effective short-term management measure in dealing with increased transportation demand and congestion during major events, such as the Olympic Games. Results also indicate that vehicle travel demand does not decrease with the same proportion as the total vehicles forbidden, at least for the expressway and main arterials in a city.

1. Introduction

Given China's rapid socioeconomic development and urbanization, total operating vehicles growth during the past decade has risen quickly, with an average annual rate (AAR) over 10% in cities, especially for the number of private vehicles, which has increased from 3.58 million in 1997 to 28.76 million in 2007 (SSB, 2008). In big cities such as Beijing, the rate of vehicle ownership rises even more sharply. The latest government statistics show that, by the end of Dec., 2008, Beijing has approximately 3.5 million vehicles, compared to just 1 million in Feb., 1997. Additionally, about 1000 new vehicles hit the road every day (date collected from Beijing Traffic

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Management Bureau). Understandably, traffic congestion in Beijing has become increasingly severe over the last decade.

The 2008 Beijing Summer Olympic Games from Aug. 8 to Aug. 24. represent a significant international event that took place in the People's Republic of China. As a mega-event, the Summer Olympic Games also represented a world-wide transportation challenge. The unique characteristics of travel demand for such a special event posed great challenges to the Olympic transportation system managers.

To promote a transportation system ensuring reliable, effective, and safe conditions during international mega-events, host cities usually establish an integrated transportation strategy, that mainly includes the following (Bovy, 2006):

(1) Transportation facilities expansion, including the establishment of an Athletes Bus Network (Minis et al., 2006), expansion of subway and bus network, expansion of highway and railway networks, etc.
(2) Intelligent transportation systems, including traffic management and traveler Information system (Glazer and Cruz, 2003; Amodei et al., 1996), incident response management system, traffic management center, road/weather information system, etc. (Njord, 2002).
(3) Travel demand management (TDM), including free park-and-ride and park-and-walk lots, alternate work and delivery schedules for businesses, carpooling and ridesharing incentives, telecommuting, odd–even day vehicle operation schedules, etc. (Lee et al., 2003).

In order to improve the public transportation service and mobility during the 2008 Summer Olympic Games, the Chinese government placed a great deal of investment in new transportation systems to expand its transportation infrastructure network and improve Beijing's traffic management system. The city's capital international airport was expanded to include the new Terminal 3, and the Beijing south railway station was reopened after two years of construction to include the 120 km Beijing–Tianjin Intercity High-speed Rail. As for urban transportation, Beijing's subway network expanded to more than double its original capacity and overall size, and the road network also expanded significantly. In addition, ten intelligent traffic management systems were implemented before the Olympic Games to improve the performance of Beijing's road traffic network, mainly including advanced traffic management and control center, automatic incident detection system, closed-circuit television cameras, advanced area traffic signal control system, transit signal priority system, variable message signs, real-time traffic forecasting system, etc.

Since the 1970's, traffic demand management has become an important element of transportation policy, with the major focus on influencing the individual travel behavior (Ogunsanya, 1984; Meyer, 1999). Over the past 30 years, a variety of TDM measures, such as traffic congestion pricing flexible working hours, telecommuting, carpooling, etc., have been implemented or demonstrated all over the world (Eliasson and Mattsson, 2006; Hensher and Puckett, 2007; Odeck and Brathen., 2008). Implementation of these TDM measures improved road traffic operation conditions by enhancing the use of highly-efficient transportation modes and reducing private car usage. Researchers have investigated the effectiveness of various TDM measures mainly based on questionnaire results (Gärling et al., 2000), theoretic analysis (Nakamura and Kockelman, 2002), and case studies (Lee et al., 2003; Guo et al., 2008; Eliasson et al., 2009).

Lee et al. (2003) reported the influence of alternative driving prohibition using of odd–even numbered private vehicles during 2002 FIFA Korea–Japan Worldcup in Seoul, Korea. Results revealed those during those 15 d, traffic volume decreased by 19.2% on average, and traffic speed increased by 32.1% on average, with 90.5% of vehicles complied with this mandatory driving suspension regulation.

Guo et al. (2008) examined the influence of TDM measures on traffic operation during the Forum on China–Africa Cooperation in Beijing. The study examined the state preference survey data from bus and metro operating companies, as well as data from traffic detectors embedded in the road. The study results revealed that the average vehicle speed increased by 7.4% and 15.6% during morning and evening peak hours respectively.

During the 2008 Summer Olympic Games, traffic demand management strategies were also used to control the flow volume on road network. One strategy involved the temporary rationing of road space based on license plate numbers. Beijing's massive experiment to control traffic flow offered researchers a unique chance to evaluate the study in a urban setting.

Wang et al. (2008) investigated the effects of TDM measures during the 2008 Beijing Olympic Games, during with the traffic flow volume declined by 22.5%, and the average speed during the morning peak period increased by 28.5%. Wen et al. (2008) analyzed operating conditions based on floating car data, and results show that the average speed of the whole road network increased by 26.9% and 22.8% during the morning and the evening peak periods, respectively.

This paper analyzes the effects of the traffic restriction based on the field data from hundreds of traffic detectors in the expressway network and an arterial street operated by Beijing Traffic Management Bureau. Section 2 overviews the traffic restriction policy during the Beijing 2008 Olympic Games, and the data sources are introduced in Section 3. Section 4 analyses the changes of traffic volume and speed in the expressway network and arterial streets. Section 5 discusses the comparative analysis. Finally, Section 6 presents the conclusions along with recommendations concerning the design of future traffic management in Beijing.

2. Traffic restriction policy

The transportation strategies and management measures caused to accommodate the travel demand during the 2008 Beijing Olympic Games, involved several categories. They include transportation infrastructure expansion, traffic demand management, traffic restriction, public transportation system expansion, Olympic traffic reserved system, and more. This paper focuses on the traffic restriction policy and public transportation system expansion. Traffic restriction measures for the Olympic event were only valid from Jul. 1 to Sept. 20, 2008.

2.1. *Odd–even numbers policy*

To alleviate the growing traffic congestion in urban areas of Beijing, traffic management policies have been carried out to improve transportation efficiency and expand infrastructure for 2008 Summer Olympic Games. The most important policy influencing road traffic conditions and air quality was the "odd–even numbers" policy, which stated that Beijing registered vehicles would be prohibited from traveling on roads alternating-days. In other words, cars with license plate numbers ending in an odd–even number were permitted to travel only on odd–even numbered dates.

During the first phase of traffic restrictions from Jul. 1 to Jul. 19, about 0.3 million high emission vehicles, which are also called "yellow-label vehicles" in China, as well as 30 percent of state or city owned vehicles, were banned from the roads. The municipal government also encouraged motorists to avoid using their motorcycles during this period.

During the second phase from Jul. 20 to Sept. 20 and in addition to the odd–even numbers policy, transportation authorities continued to ban "yellow-label vehicles" and created Olympic lane networks for cars with special designations. More government cars were taken off the roads at peak times, and their presence was reduced by 70 percent. These regulations will almost pull 2.0 million vehicles off the roads across Beijing (50% private cars, all "yellow-label vehicles" and 70% vehicles owned by state and city authorities). Over about 98% of vehicles complied with the policy, because all entrance roads within the 5th Ring Expressway were covered by automatic enforcement devices.

From Jul. 20 to Aug. 27, traffic restrictions were applied to the roads within the city's administrative areas, while from Aug. 28 to Sept. 20, the measures were limited to road networks within the 5th Ring Expressway.

Vehicles not subject to the odd–even numbers policy included police vehicles, fire trucks, emergency vehicles, PLA vehicles, armed police vehicles, buses, taxis, and Beijing Organizing Committee for the Olympic Games (BOCOG) approved special vehicles. In total, these vehicles equaled approximately 0.15 million.

Trucks and other heavy vehicles were not allowed in central Beijing. Their access was limited to the outer Ring Expressways. Postal vehicles did not fall under the alternate day driving policy, but postal cargo trucks were banned within the 6th Ring Expressway between 6:00 and 24:00. The same was applied to all cargo traffic. Tractors, low-speed trucks, and three-wheel automobiles were not allowed on the roads within the 6th Ring Expressway between 6:00 and 24:00.

2.2. *Expanded public transportation*

The public transportation network expansion was expected to absorb the demand created by vehicle restrictions. The influx of visitors was estimated to be more than 4 million extra passengers per day.

On Sunday, Jul. 20, ten Olympic buses started carrying the expected increased number of passengers to Beijing's major sports venues. Another 24 special bus routes for the Olympics were opened from Aug. 9 to Sept. 20. The new routes helped transport about 500,000 passengers daily.

Officials extended their service hours of the Beijing's 350 existing routes to accommodate Changes in trip patterns resulting from the odd–even numbers policy and visitor populations. With the additional buses and metro lines, the public transportation system moved more than 20 million passengers daily during the Olympics and Paralympics. In fact, after the implementation of the odd–even numbers policy, the percentage of public transportation volume in Beijing increased from 35% to 45%, about 20 million passengers per day.

3. Data source

3.1. *Field data from expressway detectors*

In the past decade, to alleviate the traffic congestion in Beijing and provide an efficient urban transportation system during the Olympic Games, various urban traffic management systems have been established. These efforts include an adaptive area traffic signal control system, video monitoring system, variable message signs, and expressway ramp meter system. By 2008, a traffic detection system had also been implemented to cover with eleven radial and three ring expressways, including the 2nd, 3rd, and 4th Ring Expressways. The detector locations are presented in Fig. 1. The distance between two adjacent detectors ranged from 300 m to 1000 m.

The expressway detection system collects traffic flow variables, including traffic volume, speed, and occupancy, using 592 microwave and ultrasonic detectors every 2 min. The system then transmits the data to the Traffic Management Center of the Beijing Traffic Management Bureau.

The field data selected for this study were derived from all the 592 detectors. The first data set includes three weeks of field data detected from Jun. 2 to Jun. 22. It reflects the traffic flow condition before deployment of the odd–even numbers policy. The second data set includes six weeks of field data detected from Jul. 21 to Aug. 30. This covers the Aug. 8–Aug. 24 period of the Olympic Games and reflects the traffic flow condition after deployment of the odd–even numbers policy.

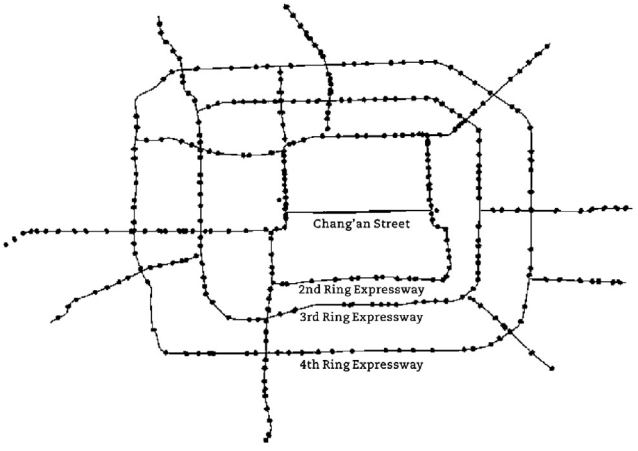

Fig. 1 – Detection points of Beijing's Expressway Network.

3.2. *Field data from arterial detectors*

Within the 4th Ring Expressway, important arterial streets experience has average daily traffic volumes of more than 60,000 veh/d, and a maximum daily traffic volume of 100,000 veh/d. Conventional inductive loop detectors were embedded in the pavement of these arterial streets to support traffic monitoring system and urban traffic signal control system. On these arterial streets, the traffic volumes and speed data accumulated in 30 s intervals at each detector station were extracted to transmit to Beijing's Traffic Management Center.

Field data selected for this study were taken from Jun. 1 to Aug. 30 and cover an important arterial street in Beijing's Chang'an Street, were from Fuxingmen to Jianguomen. This area is indicated in Fig. 1.

4. Effect analysis

4.1. *Estimation of the percentage of banned vehicles*

Owned vehicles in Beijing had reached 3.35 million before the Olympic Games and represent the following: 0.3 million yellow-label vehicles, which were entirely banned from the roads every day during the event; 0.3 million state and city owned vehicles, 70% of which were banned from the roads every day; 0.15 million special vehicles, which were not subject to the odd–even numbers policy; 2.6 million private cars and other kind vehicles, 50% of which were banned from roads every day. The number of vehicles banned from roads during 2008 Olympics is estimated to total approximately 1.81 million, which is 54% of vehicles registered in Beijing.

4.2. *Traffic flow volume comparative analysis of the expressway network*

The expressway network shown in Fig. 1 represents only about 5% of Beijing's total roadway network mileage, but it carries over 30% of all traffic. With the rapid increase of car ownership, congestion on the expressway network has become increasingly serious. The annual average speeds on the 2nd and 3rd Ring Expressways are shown in Fig. 2, from which we can see that the annual average speed on 2nd Ring Expressway decreased from 61.5 km/h in 2002 to 53 km/h in 2005, though there was a little increase in 2006. The 3rd Ring Expressway follows a similar trend. This paper focuses on how the odd–even numbers policy influenced the expressway traffic condition in Beijing, and includes a comparative analysis of the detected expressway network for the 2nd, 3rd and 4th Ring Expressways, respectively.

4.2.1. *The detected expressway network*

The total traffic flow volume detected by 592 detectors on the expressway network is considered here. Table 1 shows the total traffic flow volume in different days before the odd–even numbers policy was enacted.

Before the odd–even numbers policy, the total traffic flow volume of the 592 detectors was very steady during the same weekday, which can be seen in Table 1. The differences among the same weekdays only ranged from 0.4% (Fri.) to 4.25% (Mon.). The total traffic flow volume was the highest on Fri., which is the most congested weekday in Beijing, and experiences 16.2% more volume than Sun., which has the lowest daily traffic flow volume in Beijing.

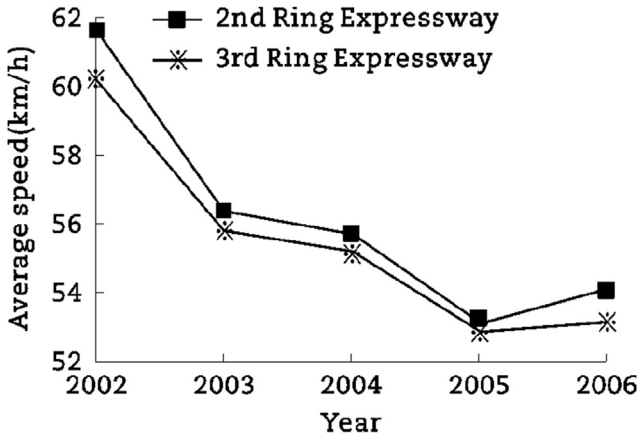

Fig. 2 – Annual average speeds on 2nd and 3rd Ring Expressways.

Table 1 – Total traffic flow volume data in 21 d, 2008, as measured by 592 detectors (1000 pcu).

Week	Jun. 2–8	Jun. 9–15	Jun. 16–22	Average
Mon.	27,252	26,441	27,617	27,103
Tues.	27,537	27,480	27,633	27,550
Wed.	28,571	28,287	28,711	28,523
Thur.	28,085	27,687	27,863	27,878
Fri.	30,162	30,283	30,243	30,229
Sat.	26,860	26,995	27,090	26,982
Sun.	25,704	26,210	26,129	26,014

Table 2 shows the decrease in percentage of the total traffic flow volume of 592 detectors in different days after the implementation of odd–even numbers policy, as compared to the normal average daily traffic flow volume shown in the fifth column of Table 1.

The six weeks during this period are divided into four different stages: Jul. 21–27, Jul. 28–Aug. 3, Aug. 4–24, and Aug. 25–30, with different characteristics.

During the period of Jul. 21–27, also known as the initial stage, the percentage decrease of the total traffic flow volume is at its lowest. This was especially true during Jul. 22–24, which experienced a maximum decrease of 4.92%. This surprising phenomenon may have been caused by policy violations.

The total traffic volume decreased during the second period, Jul. 28–Aug. 3, which can also be called the developing stage, but obviously smaller than that of the third period, which means that travelers gradually adapted to the traffic restriction policy.

During the third period, Aug. 4–24, which encompassed the summer Olympics schedule and can be called the steady stage, the total traffic flow volume of the 592 detectors was steady on the same day of the week. While for Aug. 8 and Aug.

Table 2 – Total traffic flow volume percentage decrease of 592 detectors in 41 d, 2008 (%).

Week	Jul. 21–27	Jul. 28–Aug. 3	Aug. 4–10	Aug. 11–17	Aug. 18–24	Aug. 25–30	Average (the last five weeks)
Mon.	12.16	28.58	34.48	37.33	35.83	45.70	36.38
Tues.	1.99	20.20	27.16	30.63	28.53	41.71	29.65
Wed.	1.35	20.14	27.61	27.68	27.10	39.11	28.33
Thur.	4.92	19.15	25.84	28.63	26.98	41.25	28.37
Fri.	21.78	24.16	38.85	25.45	21.60	38.68	29.75
Sat.	28.99	29.07	35.74	29.13	33.67	45.16	34.55
Sun.	30.70	37.21	40.50	38.90	49.99		41.65*
Average	14.56	25.50	32.88	31.11	31.96	41.93	32.40**

Note: "*" is the average of the last four weeks; "**" is the average of Jul. 28–Aug. 30; the shaded part of the table (Aug. 8–Aug. 24) represents the Olympic Games period.

24, the opening day and closing day of Olympic Games, some temporary traffic restriction strategies were deployed around the Olympic Village. Since vehicles were banned from certain expressway sections around the Olympic Village during the Opening and Closing Ceremonies, the total traffic flow volume decreased by 38.85% and 49.99%, respectively.

The most interesting observation is the large decrease in total traffic flow volume during Aug. 25–30, after Olympic Games. This time period can be called the post-Games stage. From column 7 in Table 2, we can see that each day's total traffic flow volume decreased more than that of the days before the Closing Ceremony in Aug. 24. This may be explained by the fact, that after the Olympic Games, thousands of special vehicles stopped running, and the car trips generated from the spectators ceased.

The decrease percentage on each weekday and weekend is different, and the highest percentage occurred on Sunday (41.65%) with the second highest percentage on Mon., while similar percentage decreases for other days.

4.2.2. *The 2nd Ring Expressway*

The 2nd Ring Expressway is the central artery in Beijing and surrounds the Forbidden City, Xidan and Wangfujing business districts, Beijing Railway Station, and many other daily trip generation sites. It also crosses the Central Business District (CBD). The traffic on the 2nd Ring Expressway is overcrowded every day, with peak hours lasting longer than six hours a day. This expressway is always as crowded during daytime and the weekdays (Fig. 3). Fig. 3 illustrates one week's traffic flow volume of a detector located between Fuchengmen Interchange and Yuetanbei Interchange, which represents the most congested segment of the 2nd Ring Expressway. Lower traffic flow volume between 18:00 and 19:00 during weekdays is mainly caused by the serious congestion on the 2nd Ring Expressway.

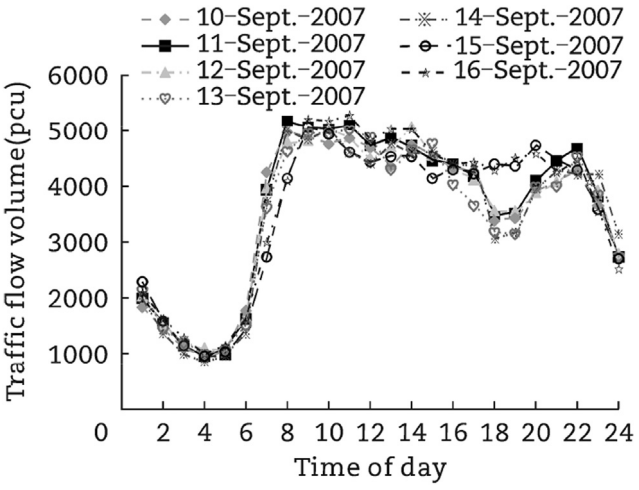

Fig. 3 – Weekly traffic flow volume in a detector location between Fuchengmen Interchange and Yuetanbei Interchange.

Table 3 shows the total traffic flow volume detected by 114 detectors on the 2nd Ring Expressway in different days before the implementation of the odd–even numbers policy.

Similar to the detected expressway network, the total traffic flow volume on the 2nd Ring Expressway is very steady during the same weekday before the odd–even numbers policy was established. The differences between the same weekdays only ranged from 0.95% (Thur.) to 3.18% (Mon.).

Table 4 shows the percentage decrease of total traffic flow volume collected by the 114 detectors in different days during the implementation of odd–even numbers policy.

Similar with the expressway network, for the 2nd Ring Expressway, the six weeks can also be divided into four different stages. There is a slight difference in the fourth stages, during which the traffic volume decrease is not as significant as that of the expressway network, only from −2.98% (Wed.) to 6.34% (Fri.) compared to the last week before policy implementation. This can be attributed to the absence of reserved traffic lanes during the Olympic on certain sections of 2nd Ring Expressway, including the section from Dongzhimengbei Interchange to Fuxingmen Interchange, the section from Guangming Interchange to Jianguomen

Table 3 – Total traffic flow volume of 114 detectors in 21 d, 2008 (1000 pcu).

Week	Jun. 2–8	Jun. 9–15	Jun. 16–22	Average
Mon.	5967	5836	6028	5944
Tues.	5967	6013	6046	6009
Wed.	6155	6096	6146	6132
Thur.	6106	6103	6048	6086
Fri.	6171	6281	6117	6190
Sat.	6014	6098	6102	6071
Sun.	5776	5862	5844	5827

Table 4 – Total traffic flow volume percentage decrease of 114 detectors on 2nd Ring Expressway in 41 d, 2008 (%).

Week	Jul. 21–27	Jul. 28–Aug. 3	Aug. 4–10	Aug. 11–17	Aug. 18–24	Aug. 25–30	Average (the last five weeks)
Mon.	13.72	28.12	38.18	43.23	46.29	48.30	40.82
Tues.	1.80	20.93	32.66	39.47	42.75	44.96	36.15
Wed.	2.21	21.99	33.15	39.20	43.30	40.32	35.59
Thur.	3.47	21.69	31.04	39.48	42.87	45.53	36.12
Fri.	20.38	24.06	43.86	34.91	32.45	38.79	34.82
Sat.	28.58	32.69	44.08	39.38	44.46	48.48	41.82
Sun.	28.58	39.08	45.64	47.14	52.27		46.03*
Average	14.11	26.94	38.37	40.40	43.48	44.40	38.55**

Note: "*" is the average of the last four weeks; "**" is the average of Jul. 28–Aug. 30.

Table 5 – Total traffic flow volumes of 123 detectors on 3rd Ring Expressway and 118 detectors on 4th Ring Expressway in 21 d, 2008 (1000 pcu).

Week	3rd Ring Expressway				4th Ring Expressway			
	Jun. 2–8	Jun. 9–15	Jun. 16–22	Average	Jun. 2–8	Jun. 9–15	Jun. 16–22	Average
Mon.	5617	5445	5653	5572	6442	6238	6527	6402
Tues.	5739	5681	5688	5703	6502	6486	6446	6478
Wed.	6111	6038	6137	6095	6505	6369	6437	6437
Thur.	5747	5672	5693	5704	6838	6594	6627	6686
Fri.	6412	6426	6389	6409	7294	7282	7292	7289
Sat.	5646	5612	5649	5636	6215	6229	6085	6176
Sun.	5466	5534	5491	5497	5768	5821	5811	5800

Table 6 – Total traffic flow volume percentage decrease of 123 detectors on 3rd Ring Expressway in 41 d, 2008 (%).

Week	Jul. 21–27	Jul. 28–Aug. 3	Aug. 4–10	Aug. 11–17	Aug. 18–24	Aug. 25–30	Average (the last five weeks)
Mon.	12.42	26.63	34.87	39.78	41.75	44.95	37.60
Tues.	−1.44	17.11	27.53	35.90	38.01	43.67	32.44
Wed.	−0.90	19.93	31.21	37.85	41.17	41.53	34.34
Thur.	−1.26	16.42	27.01	35.28	37.40	43.19	31.86
Fri.	17.41	23.05	43.99	32.81	30.20	40.22	34.05
Sat.	26.42	29.12	41.14	36.42	40.14	45.54	38.47
Sun.	29.90	37.79	44.74	45.83	49.46		44.46*
Average	11.79	24.29	35.78	37.70	39.73	43.18	35.93**

Note: "*" is the average of the last four weeks; "**" is the average of Jul. 28–Aug. 30.

Interchange from Aug. 25, and the section from Jianguomen Interchange to Dongzhimenbei Interchange from Aug. 28.

4.2.3. *3rd and 4th Ring Expressways*

Table 5 shows the total traffic flow volume detected by 123 detectors on the 3rd Ring Expressway and by 118 detectors on the 4th Ring Expressway in different days before the odd–even numbers policy.

From Table 5, it can be seen that the total traffic volume on the 3rd Ring Expressway or the 4th Ring Expressway is also very steady on the same weekday before implementation of the odd–even numbers policy.

Table 7 – Total traffic flow volume percentage decrease of 118 detectors on 4th Ring Expressway in 41 d, 2008 (%).

Week	Jul. 21–27	Jul. 28–Aug. 3	Aug. 4–10	Aug. 11–17	Aug. 18–24	Aug. 25–30	Average (the last five weeks)
Mon.	11.63	30.22	33.94	34.81	30.16	47.17	35.26
Tues.	4.86	21.94	26.38	25.78	20.81	42.06	27.39
Wed.	1.03	20.06	24.16	19.14	15.77	37.61	23.35
Thur.	8.48	20.25	23.66	22.29	17.72	40.89	24.96
Fri.	24.59	25.66	36.00	19.69	15.75	39.83	27.39
Sat.	31.13	28.98	32.56	23.64	28.53	45.67	31.88
Sun.	32.95	39.08	38.49	34.33	52.00		40.97*
Average	16.38	26.60	30.74	25.67	25.82	42.21	29.85**

Note: "*" is the average of the last four weeks; "**" is the average of Jul. 28–Aug. 30.

Table 8 – Comparison of traffic flow volumes before and during the implementation of the odd–even numbers policy, 2008

Week	Jun. 9–14 (pcu)	Jul. 28–Aug. 2 (pcu)	Decrease percent (%)
Mon.	103,608	81,508	21.33
Tues.	124,728	93,674	24.90
Wed.	136,851	101,643	25.73
Thur.	135,856	108,061	20.46
Fri.	166,804	108,468	34.97
Sat.	142,345	73,896	48.09

Tables 6 and 7 show the percentage decreases of the total traffic flow volumes of 123 detectors on 3rd Ring Expressway and 118 detectors on 4th Ring Expressway in different days after the implementation of the odd–even numbers policy, respectively.

Except for two obvious features, the change in traffic flow volume on the 3rd and 4th Ring Expressways has the same trend with the expressway network. Firstly, the traffic flow volume on the 3rd Ring Expressway increased after the policy was implemented (Jul. 22–24). Secondly, the traffic flow volume on the 4th Ring Expressway decreases much more during Aug. 25–30 than that in the proceeding weeks. It is highly likely that there were many Olympic competition venues near the 4th Ring Expressway which attracted many touring trips during Olympic Games, including National Stadium, National Aquatics, National Indoor Stadium, etc. These trips disappeared after the Olympic Games.

From Tables 2, 4, 6 and 7, we can see that the average percentage decreases of the detected expressway network, the 2nd Ring Expressway, the 3rd Ring Expressway and the 4th Ring Expressway were 32.40%, 38.55%, 35.93% and 29.85%, respectively.

4.3. *Comparison analysis of expressway segment*

We chose a detector on the 3rd Ring Expressway (between Nongzhanguan Interchange and Changhong Interchange) to compare the traffic flow volumes before and during the

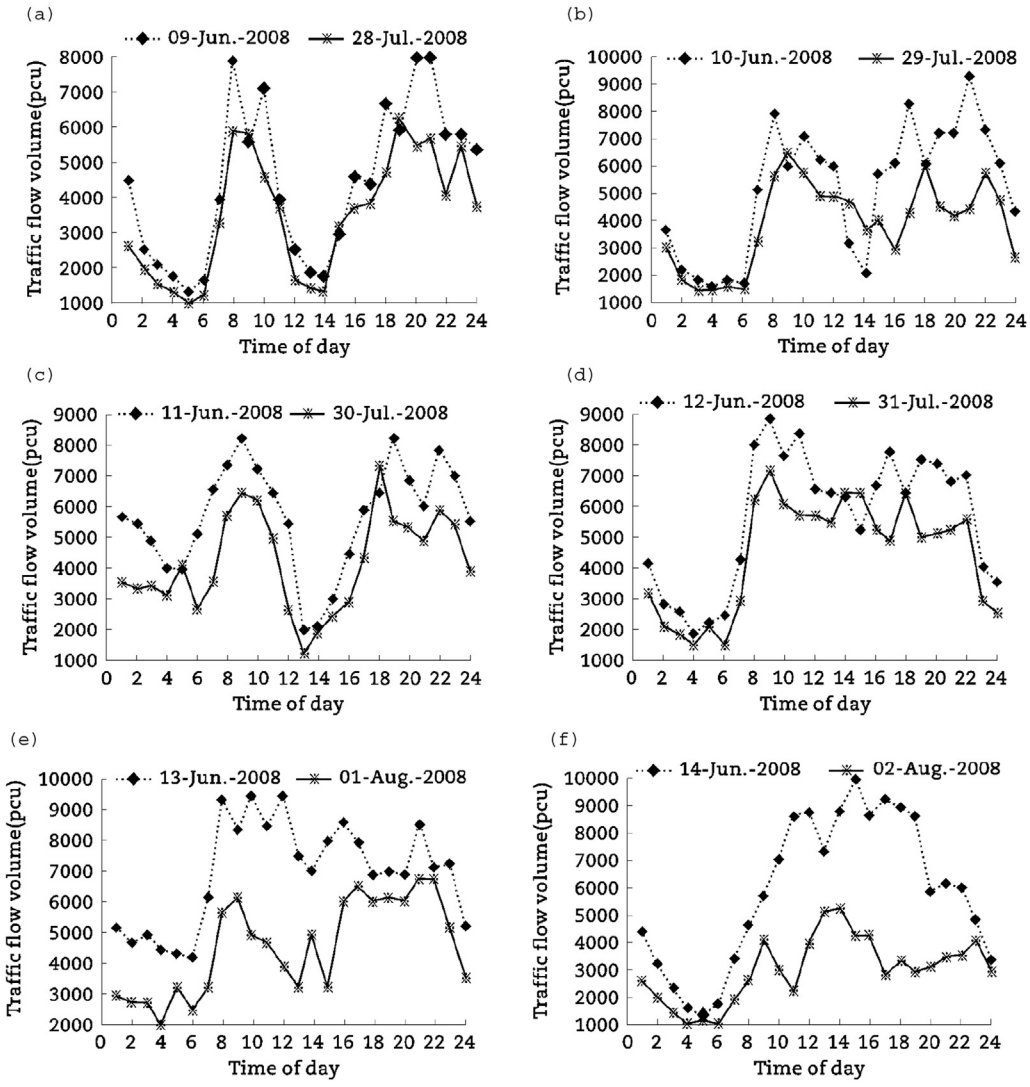

Fig. 4 – Comparison of hourly traffic flow volumes before and during the implementation of the odd–even numbers policy. (a) Mon. (b) Tues. (c) Wed. (d) Thur. (e) Fri. (f) Sat.

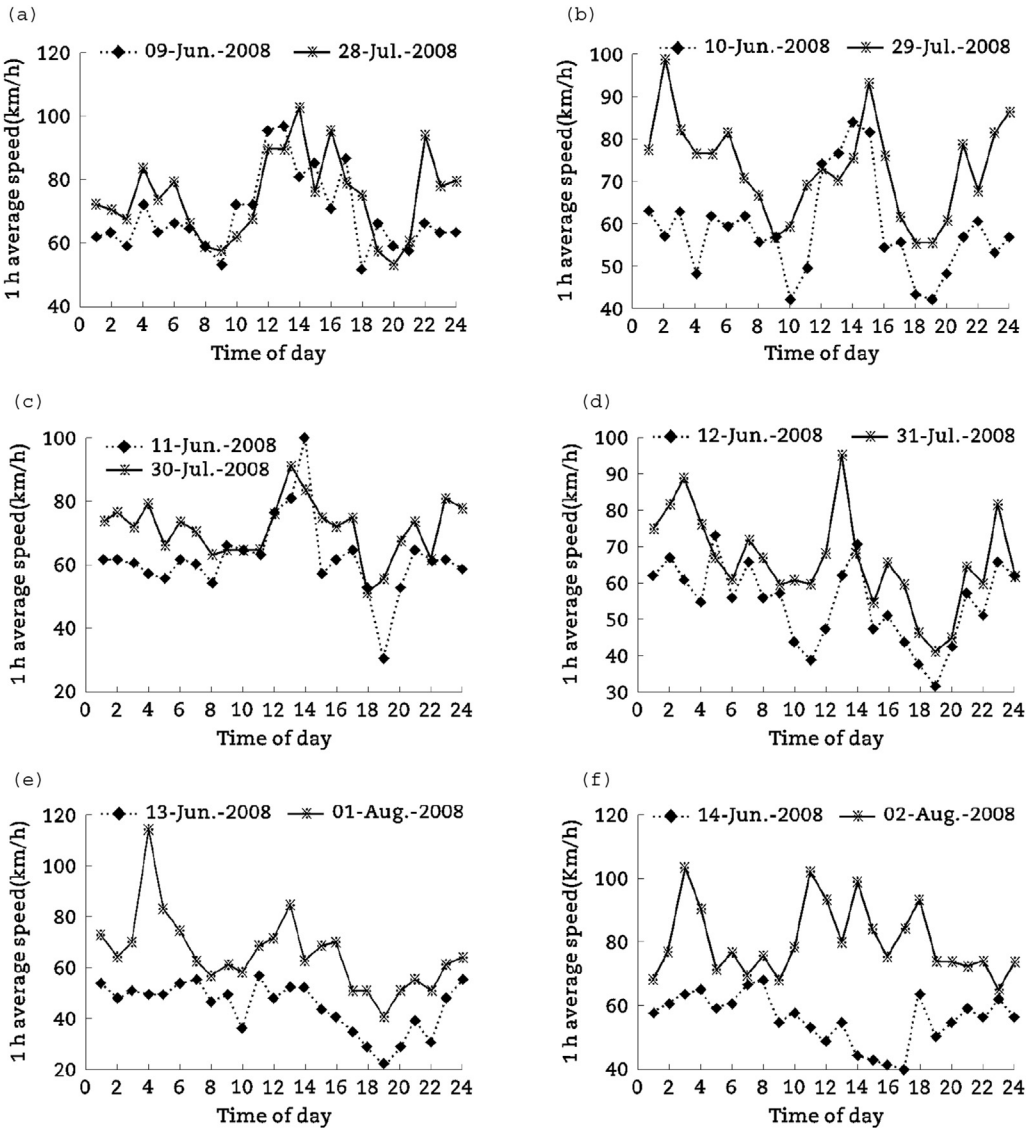

Fig. 5 – Comparison of hourly average speeds before and during the implementation of the odd–even numbers policy. (a) Mon. (b) Tues. (c) Wed. (d) Thur. (e) Fri. (f) Sat.

implementation of the odd–even numbers policy. This detector is a typical one with moderate daily traffic volume. The daily traffic volume is shown in Table 8, which also indicates the similar trend with the total traffic volume on 3rd Ring Expressway. Fig. 4 compares the hourly traffic flow volumes before and during the implementation of the odd–even numbers policy.

It can be seen from Fig. 4 that, overall, the hourly traffic flow volume before the odd–even numbers policy is obviously larger than the hourly traffic flow volume during the implementation of the policy. However, in certain periods, especially during the afternoon peak period (e.g., 18:00 on Tues., Wed., or Thur.), the hourly traffic flow volumes before the odd–even numbers policy were smaller than the hourly traffic flow volume after the policy was implemented.

Fig. 5 shows that, overall, the one-hour average speed before the odd–even numbers policy was higher than the average speed after the policy was implemented, except for certain non-peak periods, such as 10:00–13:00 on Mon., 13:00,14:00 on Tues., etc.

Table 9 – Daily traffic flow volume on Chang'an Street in 28 d, 2008 (1000 pcu).

Week	Jun. 2–8	Jun. 9–15	Jun. 16–22	Jun. 23–29	Average
Mon.	107	90	104	101	100.50
Tues.	110	104	106	107	106.75
Wed.	111	101	110	111	108.25
Thur.	115	102	109	110	109.00
Fri.	115	99	113	117	111.00
Sat.	100	97	101	109	101.75
Sun.	93	92	96	101	95.50

Table 10 – Total traffic flow volume percentage decrease on Chang'an Street in 35 d, 2008 (%).

Week	Jul. 21–27	Jul. 28–Aug. 3	Aug. 4–10	Aug. 11–17	Aug. 18–24	Average
Mon.	−6.09	13.77	15.46	8.28	6.46	7.57
Tues.	16.64	11.70	17.83	16.45	10.22	14.56
Wed.	21.10	17.25	25.21	15.11	14.07	18.54
Thur.	17.45	17.63	15.43	17.56	13.58	16.30
Fri.	21.97	16.63	47.75	16.36	12.71	23.08
Sat.	21.21	22.81	19.05	13.02	12.05	17.62
Sun.	13.76	16.17	19.26	7.29	20.65	15.42

4.4. *Comparison analysis of an arterial street (Chang'an Street)*

With Tiananmen Tower and Tiananmen Square in its center, Chang'an Street stretches 46 km between Tongzhou Canal Square in the east and the eastern gate of Beijing Capital Steel (Shougang) Group in the west. In Fig. 1, only Chang'an Street's central segment on the 2nd Ring Expressway is shown, which is in particular for this paper. As one of the widest, longest streets in China, Chang'an Street serves as the political and cultural hub of China. Many central government department, along with a host of cultural sites, occupy both sides of the boulevard. Chang'an Street experiences the highest daily traffic flow volume of all arterial streets in Beijing, accommodating nearly 0.11 million vehicles per day.

Table 9 shows the daily traffic flow volume on Chang'an Street before the odd–even numbers policy was implemented.

Before the odd–even numbers policy, the total traffic flow volume on Chang'an Street was unsteady in the same weekday, and can be seen from column 2 to column 5 in Table 9. The differences between the same weekdays ranged from 5.8% (Tues.) to 21.1% (Mon). The unstable traffic volume may have been caused by the temporary restrictions, as the national government offices are located at the side of the Chang'an Street.

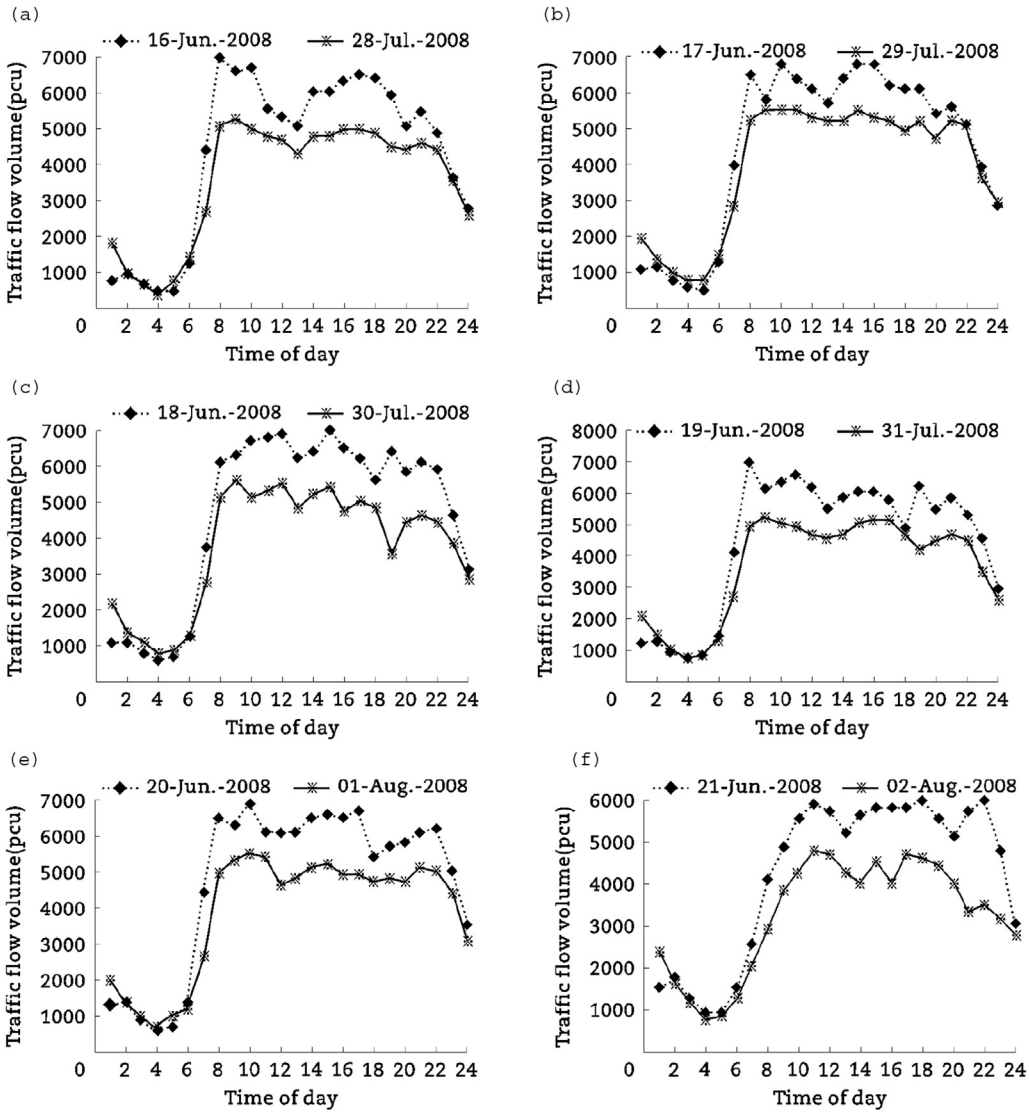

Fig. 6 – Comparison of hourly traffic flow volumes on Chang'an Street. (a) Mon. (b) Tues. (c) Wed. (d) Thur. (e) Fri. (f) Sat.

Table 10 shows the percentage decrease of total traffic flow volume on Chang'an Street in different days during the implementation of the odd–even numbers policy, compared with the average daily traffic flow volume before the odd–even numbers policy.

From Table 10, it can be seen that the traffic flow volume percentage decrease on Chang'an Street is not similar to the expressway. It fluctuated during the period of Jul. 21–Aug. 24, except on Aug. 8, which marked the Opening Day of Olympic Games, when some temporary traffic restriction strategies were deployed around the Tiananmen Square near the Chang'an Street. Since vehicles were banned from Chang'an Street during particular hours, the total traffic flow volume was markedly decreased by 47.75%.

Fig. 6 shows the comparison of hourly traffic flow volumes on Chang'an Street before and during the implementation of the odd–even numbers policy. There is a strange condition that before 6:00 a.m., the hourly traffic flow volume after the policy implemented was higher than that before in most hours, which is different from the expressway. During the commuting period (8:00–20:00), the hourly traffic volume during the implementation of the odd–even numbers policy was always lower than the hourly traffic volume before the policy. This may partly have been caused by the reserved traffic lane on Chang'an Street.

Fig. 7(a) shows that 1 h average speed increased obviously during morning (8:00–9:00) and evening (17:00–19:00) peak hours during the implementation of the odd–even numbers policy. For Chang'an Street its average speed was increased about 10%–20% during morning and evening peak hours. It can be seen that during the commuting time (8:00–20:00), the 1 h average speed increased during the implementation of the odd–even numbers policy, except 14:00 with a little decrease.

In Beijing, the most congested traffic conditions always occur during Fri. evening peak hours. Fig. 7(a) illustrates that the 1 h average speed with the odd–even numbers policy got the greatest improvement during Fri. evening peak hours, indicating that the odd–even numbers policy was effective.

5. Discussion

1) Under the restrictive odd–even numbers policy, even though more than half of all licensed vehicles in Beijing were kept from being used, the percentage decrease of daily traffic volumes on expressways and main arterial streets ranged from 20% to 40%. This shows that the number of cars traveling on-road was reduced, but the odd–even numbers policy led to an increase in the total daily trip mileage of each vehicle, or induced a larger proportion of vehicles to the main road, including expressway and main arterials, compared with that before the policy.

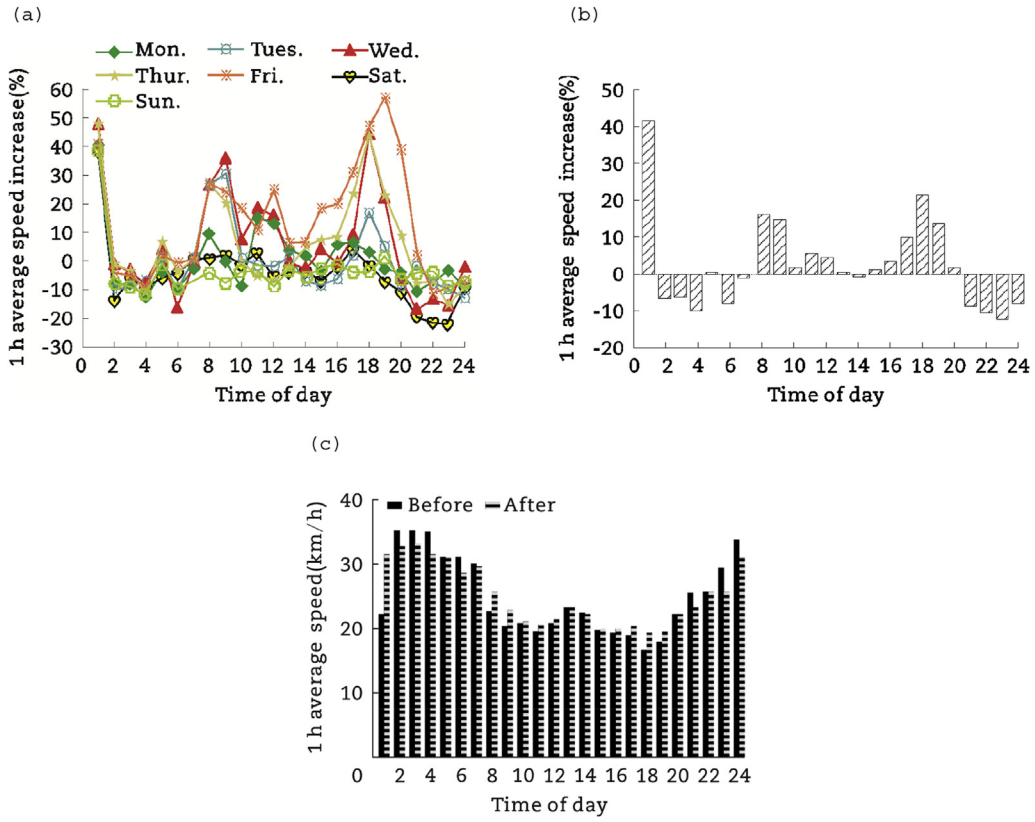

Fig. 7 – Comparison of speeds during the implementation of the odd–even numbers policy. (a) 1 h average speed increase than before on each weekday. (b) Percentage of 1 h average speed increase than before in a week. (c) Hourly average speed compared with before in a week.

The reason may be that the alleviated congestion condition attracted more vehicles that had not been used the expressway and main arterials before.

2) Tables 2, 4, 6 and 7 demonstrate the impact, which was more notable during weekends than weekdays, of the odd–even numbers policy on expressway traffic. The discrepancy may be due to the inflexibility of weekday trips and flexibility of weekend trips.
3) In general, the odd–even numbers policy reduced the traffic volumes on road segments and increased the average speed, and the degree of the impact depended on the time of day. During certain periods of the day, traffic volumes increased and the speed decreased. One possible reason is that drivers chose to travel on the expressways because they expected the restrictions to reduce travel time.
4) For the most important arterial street in Beijing (Chang'an Street), the odd–even numbers policy reduced the traffic volume during the commuting time period by 20%–30%. At the same time, speed was increased, especially during morning and evening peak hours by 10%–20%.

6. Conclusions

This paper uses Beijing's transportation experience during the 2008 Summer Olympics as a case study to provide guidelines on organizing similar events in other cities. Short-term traffic demand management measures can provide support for mega-events. However, based on the analysis in this paper, the degree of traffic reduction is not proportional to the number of vehicles restricted. To successfully implement odd–even numbers policy for future mega-events, a detailed analysis with network modeling and simulation should be carried out. Coordinated management measures should also be taken into consideration.

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