TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2013 Volume 28(2): 175–185
doi:10.3846/16484142.2013.803263

EXAMINATION OF STAGGERED SHIFTS IMPACTS ON TRAVEL BEHAVIOR: A CASE STUDY OF BEIJING, CHINA

Fang Zong[a], Zhicai Juan[b], Hongfei Jia[a]
[a]*College of Transportation, Jilin University, RenMin Street 5988, 130022 Changchun, China*
[b]*Institute of Transportation Studies, Antai School of Management, Shanghai Jiao Tong University, Fahuazhen Road 535, 200052 Shanghai, China*

Submitted 1 September 2011; accepted 12 October 2011

Abstract. Staggered shifts is one of the popular TDM (Transportation Demand Management) policies, which can reduce commute travel volume during the AM and PM peak periods, and relieve traffic congestion. In order to make effective staggered shifts program, it is necessary to examine the effect of the program on commute travel behavior. This paper takes Beijing (China) as an example to evaluate the validity of staggered shifts policy. Based on data investigation, the commute travel behavior and the commuters' preference for staggered shifts are analyzed. This paper makes four staggered shifts programs, and develops a commute departure time choice model with Multinomial Logit method to predict the influence of the programs on commute departure time, and develops a commute travel duration model to analyze the influence of the programs on commute travel time. Departure time prediction shows that Program B can reduce the traffic volumes in 6:30–8:30 period by 15.24%, and commute travel duration analysis indicate that Program B can reduce the home-to-work travel time by 21.73%. Therefore, Program B is proven to be the best staggered shifts program for Beijing. The results of this paper can provide valuable information on how to develop an effective staggered shifts program.

Keywords: staggered shifts; transportation demand management; commute trip; hazard function; travel duration.

Reference to this paper should be made as follows: Zong, F.; Juan, Z.; Jia, H. 2013. Examination of staggered shifts impacts on travel behavior: a case study of Beijing, China, *Transport* 28(2): 175–185. http://dx.doi.org/10.3846/16484142.2013.803263

Introduction

It is reported that the number of cars in Beijing is increasing by more than 600,000 every year since 2009. It is estimated that the total number of cars in Beijing will exceed 10 millions at the end of 2020. So many cars will undoubtedly result in travel demand growth, and cause many social problems, such as traffic congestion, energy consumption, and environmental pollution. During 2008 Olympic Games, the government took some measures to improve traffic conditions and environment quality, in which staggered shifts program was a major policy. These measures had obtained positive results during 2008 Olympic Games. As one of the measures to relieve the urban traffic congestion problem, staggered shifts program has also been implemented in several other cities in China recently, such as Changchun, Wenzhou, etc. This paper will take Beijing as an example to examine staggered shifts policy.

Staggered shifts is one of the popular TDM (Transportation Demand Management) policies, which can reduce commute trips during the AM and PM peak periods, and solve the traffic congestion problem. Previous researches have indicated that proper staggered shifts program can not only relieve peak-period traffic congestion, but also make ridesharing and transit use more feasible (Freas, Anderson 1991; Picado 2000). A staggered work hour program was initiated in downtown Honolulu in the USA, where 11,000 employees (18% the downtown work force) participated in. As a result, peak-period travel time was reduced up to 18% in Honolulu, depending on the route that commuters took (EPA 1998). In 2001, the Defense Supply Center Columbus (DSCC), a military supply facility, offered for its almost 2500 employees several commuter choices, including staggered shifts, carpools, and so on. These measures lessened the commute congestion obviously (Commuter Choice Primer 2003). Victoria Transport Policy Institute (VTPI 2010) studied the effect of Alternative Work Schedules, which include Flextime, Compressed Work Week, and Staggered Shifts. It is indicated that staggered shifts can reduce peak-period trips, particularly around large employment centers.

Corresponding author: Fang Zong
E-mail: zongfang@jlu.edu.cn

Table 1. The cases of staggered shifts in China

City	Implementation time	Industry type	Shifted job start time	Effects
Wenzhou	2002–2003	Government	7:30–9:00	Increased travel speed by 5 km/h on average
Hangzhou	2002–2005	Government; educational institutions; service industries	8:00, 8:30 or 9:00	Reduced peak-period traffic volumes; did not solve the traffic jam problem completely
Suzhou	2003–2004	Government; service industries	9:00	Reduced peak-period traffic demand
Wuxi	2003–2009	Government; service industries	9:00	Reduced peak-period traffic volumes by 12%
Hebei	2003–2012	Government	8:30	Relieved traffic congestion to some degree
Shenzhen	2003–2012	Government	9:00	Transferred traffic volumes from AM peak to off-peak period by 7÷10%, and volumes from PM peak to off-peak by 3÷7%
Jinan	2004–2001	Government	9:00	Reduced traffic volumes by more than 30%

Note: For all the industry types of all the cases, the job starting time before shifting is 8:00.

Recently, staggered shifts policy is becoming a popular subject in China, especially in large cities with a serious traffic congestion problem. We summarize the cases of staggered shifts in several cities in China, shown in Table 1 (Zong *et al*. 2007).

The cases in Table 1 illustrate that most of the staggered shifts programs have achieved good effects. Some programs have failed mainly because of the following problems: some commuters opposed to the program because of occupational characteristics, living habits, or other reasons; some programs result in the generation of new commute peak. Some researches also indicated that there were winners and losers under staggered shifts: those leaving early from work saved the most in travel time, while commuters who arrived at work later than usual actually lost travel time because they moved into the new peak period (Cao, Mokhtarian 2005).

Therefore, before implementing staggered shifts, we should consider the following questions. Firstly, whether a commuter will adjust his/her commute time according to the new work schedule? For example, since a commuter will send children to kindergarten, he has to start before 8:00 am, although his/her job starting time has been changed to 9:00 am. Secondly, which industry is suitable for the policy? Finally, which is the best work schedule? Whether the new commute time of some industries will overlap with that of the others? All the above questions will directly influence the effect of staggered shifts. Therefore, it is necessary to analyze the commute travel behavior and examine the effect of the program.

The paper is organized as follows. In Section 1, the previous researches are reviewed. This is followed by method introduction and data analysis in Sections 2 and 3. Sections 4 and 5 develop a commute departure time choice model and a commute travel duration model respectively. The effects of some staggered shifts programs are examined in Section 6. Conclusions are in the final section.

1. Literature review

The researches on staggered shifts examination and commute travel behavior analysis will be reviewed respectively.

1.1. Staggered shifts examination

In terms of staggered shifts examination, some researches examined the effect of staggered shifts by means of statistical analysis of survey data. For instance, Picado (2000) found that staggered shifts can reduce peak-period trips, particularly around large employment centers. Freas and Anderson (1991) found that staggered shifts can make ridesharing and public transit use more feasible. Beers (2000) noted that the proportion of workers on staggered work schedule had grown more than double since 1985, when such data were first collected. Galinsky *et al*. (1998) reported that there is an excess demand for more staggered hours and schedules, over and above what employers have been able to supply.

Some researches developed mathematical model and predicted the effect of combination of some TDM strategies, including staggered shifts. Cao and Mokhtarian (2005) built a binary Logit model to examine the factors that influence the effects of 16 TDM policies, including staggered shifts and flextime.

Some other researches set up detailed scenario of staggered work hours. For example, Guo and Srinivasan (2005) developed a simulation-based framework to model day-to-day dynamics in network flows and evaluated the effects of some TDM policies including staggered shifts, telecommuting, and compressed workweek. In the study, the staggered work hours scenario was simulated by staggering the work starting time of a fixed fraction (5% in the low adoption level for small shift) to start earlier by 15 minutes, than they do nothing scenario, and another 5% of users to a start time 15 minutes later. The result indicated that staggered shifts strategy is likely to be more successful than other policies for congestion mitigation, especially at higher adoption levels.

1.2. Commute travel behavior analysis

Concerning commute travel behavior analysis, Small (1982) used MNL (Multinomial Logit) model to simulate arrival times of car commuters. The results indicated that people were willing to shift their schedules by one or two minutes earlier if they saved some travel time. Cervero and Griesenbeck (1988) analyzed the factors affecting commute choices in suburban labor markets, and found that the preferred traffic management program to solve the traffic congestion in commute peak period is to encourage the staggering of work schedules across, not within, companies. Sundo and Fujii (2005) found that two-hour increases in the compressed working week workday can make commuters reduce household activities by about one hour, sleeping time by about 20 minutes, and pre-work preparation time by about 30 minutes. Commuting times also significantly declined during the compressed working week. De Palma and Lindsey (2002) analyzed the morning and evening commute travel behavior by using Vickrey's bottleneck model and found that scheduling preferences for the morning are defined in terms of arrival time at work, whereas preferences for the evening are defined in terms of departure time from work. Vovsha and Bradley (2004) developed a hybrid model to predict discrete departure time choice and tour duration under the same framework. The variables considered in the paper included departure time and arrival time components, duration components, and a mode choice log-sum. Komma and Srinivasan (2008) developed a continuous-time model for the home-to-work commute timing decisions of flexible full-time workers using the hazard duration structure.

Some researches analyzed the influence of some factors on commute departure time, such as socio-demographic factors, trip chaining, commute mode, traffic condition, etc., but work schedule is not included as a factor. For example, Abkowitz (1981) used income, age, and transit mode as determinants of commute departure time choice behavior to build an MNL model for his analysis of the effects of these factors on commuters' arrival time to work. Teekamp *et al*. (2002) demonstrated the application of Reverse Engineering to obtain the preferred departure times of travelers and developed a departure time choice model to estimate the changes in time of travel choice due to changed travel conditions in the network. Li *et al*. (2004) used GPS-based disaggregate morning commute data of 56 drivers during a one-week period, examined the day-to-day variability of the journey-to-work trips, including the departure time, route choice, and trip chaining behavior. The results showed that commuters change departure times more frequently than routes, and trip a chaining has significantly impacted commuters' departure time and route choice behavior. Sinha and Thakuriah (2004) developed an MNL job starting time choice model to examine the relationships between job starting times and a set of socio-demographic, occupational, and industrial characteristics.

Some researchers paid attention to not only commute departure time and commute duration, but also to the other commute behavior such as a commute mode. For instance, Bhat and Sardesai (2006) used a Mixed Logit framework and revealed preference and stated preference data collected from a web-based commuter survey in Austin to examine the commute behavior, especially a commute mode choice behavior in Austin. Other studies by McCafferty and Hall (1982), Hendrickson and Plank (1984), and De Palma *et al*. (2001) demonstrated further modeling and policy developments in this area.

The above references show that the basic idea of staggered shifts evaluation is a commute travel behavior analysis. In terms of methodology, the disaggregate model, which is suitable for individual travel behavior prediction, is often used in staggered shifts evaluation. However, few researches have focused on staggered shifts evaluation by means of analyzing the influence of work schedule adjustment on the commute travel time. Moreover, most of the researchers consider the effect of staggered shifts programs only on the transportation system of the implementation area, not on the entire urban area. Most of the programs consider the effect only on the implementation industry or company, not on all types of industries. In fact, most of the staggered shifts programs in China are implemented at urban scale, including most of the industries and most of the commuters. As a result, the data survey and examination of staggered shifts should be at urban scale.

2. Methodologies

2.1. Departure time choice model

MNL model is chosen to forecast the commute departure time. MNL model has a major limitation, which is the correlation between the alternatives. It will affect the forecasting precision. This feature of MNL model is usually called Independence of Irrelevant Alternatives (IIA). However, the correlation between the alternatives of the commute departure time model is very weak, since there is no overlap among the departure time periods.

Mixed Logit and Probit models allow the correlation between the alternatives, but the models involve complex integral calculus, and a simulation method must be used in the parameters calibration. Therefore, although Mixed Logit model, Probit model, and MNL model are all widely recognized as the suitable methods in travel choice behavior predicting, an MNL model is introduced in this study for the simplicity.

According to the Random Utility Theory, the utility of a commuter n choosing departure time period i can be specified as follows:

$$U_{in} = V_{in} + \varepsilon_{in}, \tag{1}$$

where: U_{in} – utility of departure time period i for commuter n; V_{in} – deterministic component of utility i for commuter n; ε_{in} – random component of utility i for commuter n; and i – choice of departure time period.

The deterministic component of the utility can be written as:

$$V_{in} = \sum_{k=1}^{K} \theta_k X_{kin}, \tag{2}$$

where: k – number of variables; θ_k – corresponding coefficient; X_{kin} – variable k for commuter n and alternative i.

By assuming that the random component ε_{in} in Eqn (1) follows Gumbel distribution, independently and identically across alternatives, the probability that departure time period i will be chosen by commuter n is computer as:

$$P_{in} = \frac{\exp(V_i)}{\sum_{j \in J_n} \exp(V_i)}, \tag{3}$$

where: J_n – a set of available departure time periods for commuter n.

The parameters θ_k in Eqn (2) can be estimated with the Maximum Likelihood and Newton–Raphson method.

2.2. Travel duration model

A hazard duration model is chosen to predict the travel time of each home-to-work commute trip. Hazard duration models, which had their roots in biometrics and industrial engineering, are being increasingly used to model duration time in the fields of economics, transportation, and marketing (Kiefer 1988; Hamed, Mannering 1993; Hensher, Mannering 1994).

Let T be a non-negative random variable representing the duration of a home-to-work commute trip. The focus here is on continuous T. Accordingly, on the continuous-time-scale, the hazard at time t, $h(t)$, is defined in this problem as the instantaneous probability that the travel duration T will end in an infinitesimally small time period d after time t, given that the duration has elapsed until time t:

$$h(t) = \lim_{\Delta \to 0^+} \frac{P(t \le T < t + \delta | T > t)}{\delta}. \tag{4}$$

For the analysis of the "survivability" of contract durations, two distribution assumptions are typically considered. The simplest distribution to apply and interpret is the Exponential distribution. The Weibull distribution is a more generalized form of the Exponential distribution. This study supposes that travel duration T obeys Weibull distribution. That is, an accelerated failure-time model (AFT) will be used in the travel duration forecasting.

The hazard function of AFT model is:

$$h(t) = \gamma t^{\gamma - 1} \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i), \tag{5}$$

where: γ – the shape parameter of Weibull distribution ($\gamma = 1$ if travel duration T obeys Exponential distribution); x_i – variable i, which influences the travel duration; β_i is the corresponding coefficient.

3. Commute travel behavior analysis

3.1. Data survey

A revealed preference (RP) and a stated preference (SP) survey was conducted in September 2004. For RP survey, we selected 1700 households that are uniform distributed in five districts within the forth ring of Beijing. All the respondents in the RP survey who are commuters were asked to fill a SP survey frame. After data processing, the valid RP data include 9864 trips of 4436 people from 1608 households, and the valid SP data include 1919 commuters' trips. Based on the two kinds of data, we will analyze the commute behavior and develop the predicting model in the following section.

3.2. Data analysis

3.2.1. Distribution of commute time

Based on the survey data, the current distributions of the departure time from home and from work are calculated, and the results are given in Tables 2 and 3 respectively. The results indicate that there are obvious morning and evening commute peak periods. The AM peak period is 6:30–8:00. The PM peak period is 16:30–18:00, in which, more than 40% commuters depart from work in the period of 16:30–17:00. For commuters who depart from home before 6:00, 68% commuters have something to do on the way to work. More than 6% commuters who depart from work before 16:00 have something to do on the way home. In terms of industry type, about 50% commuters who leave home before 6:00 are workers in manufacturing

Table 2. Current distribution of the departure time from home

Industry type	≤6:00	6:00–6:30	6:30–7:00	7:00–7:30	7:30–8:00	8:00–8:30	8:30–9:00	>9:00
Government (%)	0.62	1.87	13.26	25.74	27.61	17.16	6.40	7.33
Service industries (%)	7.94	6.07	9.81	22.90	20.09	10.28	7.94	14.95
Manufacturing industry (%)	10.38	9.84	26.83	26.48	16.64	5.72	1.07	3.04
Educational institution (%)	1.57	14.57	36.57	31.57	6.00	1.71	1.14	6.86
Medical institution (%)	0.00	11.11	27.78	38.89	18.06	1.39	1.39	1.39
Others (%)	6.12	5.05	17.19	25.13	19.44	9.13	6.34	11.60
All types of industries (%)	3.59	7.03	21.08	26.62	17.89	9.25	5.05	9.49

Table 3. Current distribution of the departure time from work

Industry type	≤16:00	16:00–16:30	16:30–17:00	17:00–17:30	17:30–18:00	18:00–18:30	18:30–19:00	>19:00
Government (%)	6.51	7.55	45.57	21.88	9.64	2.34	2.08	4.43
Service industries (%)	13.25	3.13	32.05	21.45	15.66	3.13	3.37	7.95
Manufacturing industry (%)	10.78	10.59	48.51	14.31	7.25	2.60	2.04	3.90
Educational institution (%)	7.53	15.59	39.78	24.73	6.99	1.61	2.15	1.61
Medical institution (%)	2.78	15.28	62.50	9.72	1.39	1.39	2.78	4.17
Others (%)	9.29	2.60	30.48	19.33	18.59	5.20	4.09	10.41
All types of industries (%)	9.60	7.83	41.31	19.05	11.00	2.90	2.68	5.63

industry. About 19% commuters who leave home after 9:00 are in service industries. Regarding departure time after 19:00, 19% commuters are in service industries.

Table 2 indicates that the AM peak period of manufacturing industry is a little early (6:30–7:30), the AM peak period of other industries is almost the same (7:00–8:00). The distributions of the PM peak period for all types of industries are almost the same (16:30–17:00).

3.2.2. Commute mode distribution

The commute mode distribution is given in Figure 1. About 47.6% commuters adopt non-motorized modes (walk and bike), 30.8% adopt public transit modes (bus, railway, and taxi), and 20.1% drive private car.

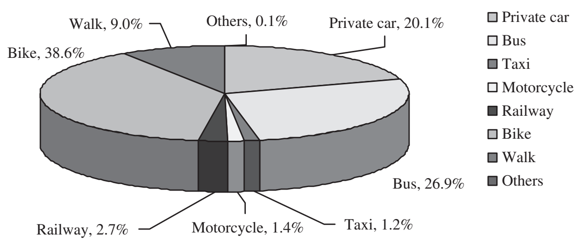

Fig. 1. Commute mode distribution

3.2.3. Commute travel distance distribution

Du *et al.* (2004) proposed that the factor of commute travel distance will influence the effect of the staggered shifts. The reason is that most of the commuters with short-distance trip (SD trip) can choose walking mode which is not influenced by the traffic condition. And the commuter is probably unwilling to change his/her habitual commute time if his/her commute trip is a SD trip. On the contrary, for long motorized commute trip, the traffic congestion will affect whether the commuter arrives the workplace on time, so the commuter prefers to accept the staggered shifts program. The commute survey data in Beijing shows that the average distance of commute travel by walk is 0.75 km. Therefore, we define that the distance of SD trip is no more than 0.75 km. The commute travel distance distribution in Beijing is shown in Table 4.

3.2.4. Intermediate stop

About 1% respondents have intermediate stop on the way to work, and 7% on the way home. More than

Table 4. Distance commute travel distance distribution

Travel distance	≤0.75 km (SD trip)	0.75÷3 km	3÷5 km	5÷10 km	>10 km
Percent	17	38	15	17	13
Typical mode	Walk, bike	Bike, walk, car	Bike, bus, car	Bike, car, bus	Car, bus, bike

91% respondents who have intermediate stop think that the affair has to be dealt with during the commute travel. Generally, they have to send their children to school (the reasons for about 87% intermediate stops), or to take family members to work (the reasons for about 11% intermediate stops). Their commute times are influenced by the intermediate stop. For these commute trips with intermediate stop, 38% respondents drive private car, 38% by bike, and 3% with public transit. This indicates that the commute travel with private car or bicycle is more likely to cause intermediate stop.

3.3. Commuter's preference analysis

3.3.1. Policy acceptability analysis

About 44% respondents have heard of staggered shifts. Most of them recognize that the policy can reduce the traffic volume in peak period and solve the traffic congestion problem. There are less than 4% respondents whose enterprise have implemented or will adopt the policy.

In general, only about 20% respondents are willing to have their work schedule shifted. Data statistics shows that men, younger, and long-distance traveler prefer to have their work schedule shifted.

Concerning the commuters who are unwilling to adopt the policy, about 26% think that the traffic problem is not very serious; 10% have intermediate stop; 56% think that the work schedule shift can probably disturb their normal life; 8% think that their occupations are not suitable for the policy. About 32% respondents who are unwilling to adopt the policy are in manufacturing industry, 23% in some public service organizations (such as banking, call centers, etc.), and 5% in medical institution. This indicates that occupational characteristic is a major factor which influences commuter's preference.

The acceptability of the policy in terms of industry type is shown in Table 5. It indicates that, comparing with other industry types, commuters in government prefer to accept the policy; commuters in medical institution do not prefer to accept the policy. A study noted that for manufacturing industry, compressed work week policy is much more suitable than flextime or staggered shifts (EPA 1998).

3.3.2. Policy expectation

About 32% respondents think that the policy can obviously improve the traffic condition; 54% think the policy can partly relieve the traffic congestion; 14% think that the policy will almost have no effect. For respondents who hold optimistic attitude, the expected saving time is 18.13 and 10.14 minutes on average in the morning and evening commute respectively.

For respondents who accept the policy, about 26% think that the job start time should be earlier, 74% hold the opposite opinion; 48% think that the job end time should be earlier, 52% hold the opposite opinion.

The above analysis indicates that the acceptability of the staggered shifts in Beijing is not satisfying. The reasons are probably as follows:

- staggered shifts policy has not attached much attention;
- staggered shifts policy has not been implemented on a large scale in China;
- some commuters have not recognized the disadvantages of the traffic congestion in peak periods;
- some people are a little conservative in accepting advanced technology and management measure.

4. Departure time choice model

Compared with the departure time from home, commuters choose their departure time from work mainly according to the job end time. The other factors, such as intermediate stop and travel distance, have little influence on the departure time from work. Therefore, to simplify the model construction, we will only develop a model to predict the departure time from

Table 5. Policy acceptability in terms of industry type

Acceptability	Government	Service industries	Manufacturing industry	Educational institution	Medical institution	Other industries
Willing (%)	23	21	22	21	18	11
Unwilling (%)	77	79	78	79	82	89

Table 6. Estimation results of the departure time choice model

Model variable		≤6:00	6:00–6:30	6:30–7:00	7:00–7:30	7:30–8:00	8:00–8:30	8:30–9:00
Constant	θ_1	68.019[a]	63.930[a]	58.086[a]	48.499[a]	38.094[a]	26.976[a]	12.960[a]
	t_1	25.736	24.866	23.225	19.942	16.196	12.431	6.042
Commute travel distance	θ_2	0.488[a]	0.427[a]	0.362[a]	0.219[a]	0.115[a]	0.033[c]	–
	t_2	13.556	12.939	11.677	7.552	4.423	1.375	–
Commute mode	θ_3	0.229[a]	0.264[a]	0.221[a]	0.269[a]	0.220[a]	0.147[a]	0.084[b]
	t_3	3.053	4.328	4.093	5.275	4.583	3.419	2.400
Job start time	θ_4	−13.539[a]	−11.594[a]	−9.639[a]	−7.417[a]	−5.464[a]	−3.699[a]	−1.775[a]
	t_4	−28.684	−28.486	−26.051	−21.436	−16.812	−12.799	−6.431
Intermediate stop from home	θ_5	–	4.600[a]	3.946[a]	3.124[a]	2.151[a]	1.751[a]	1.901[a]
	t_5	–	4.060	4.771	4.216	3.104	2.690	2.898
Hit ratio (%)		83.1	66.1	69.7	70.9	58.0	44.5	97.4
Cox and Snell pseudo R^2		0.830	0.833	0.833	0.833	0.833	0.833	0.803

Notes: [a]Significant at 1% level; [b]significant at 5% level; [c]significant at 10% level; Cox and Snell pseudo R^2 is a scalar measure which varies between 0 and 1. It is an attempt to imitate the interpretation of multiple R^2 based on the likelihood, much like the R^2 in a linear probability model. The values of Cox and Snell pseudo R^2 in this model indicate that the model performs fairly well.

home. The departure time from work can be regarded as the job end time.

4.1. Variables and alternatives

Time periods (shown in Table 6) are defined as the alternatives of the departure time choice model. Based on the former commute behavior analysis, job starting time, commute travel distance, commute mode, and intermediate stop from home are chosen as the explanatory variables. Since commuter's socioeconomic attribute, such as age and sex, have some influences on the existed variables such as commute mode and intermediate stop, they will not be considered in the model.

4.2. Model estimation

Table 6 shows the estimation results of the departure time choice model by using the software of SPSS. The results indicate that with the increasing travel distance,

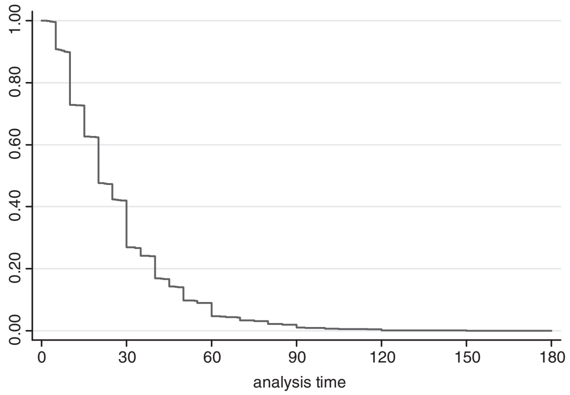

Fig. 2. The Kaplan Meier survival curve of home-to-work travel duration

Table 7. Estimation results of the travel duration model

Model variable	β_i	t
Constant	3.1680	91.17
Departure time	−0.0589	−9.69
Commute mode	0.0220	6.12
Commute travel distance	0.0001	23.64
γ	0.530	
Prob > *chi*2	0.0000	

commuter prefers to leave home early. Among all the factors, job starting time has the most important influence on the choice of departure time. The estimation result of intermediate stop from home indicates that commuter with intermediate stop on the way to work prefers to leave home early.

5. Home-to-work travel duration model

Data analysis indicates that the change of departure time will influence the travel duration. And the travel duration is certainly expected to be short, for more travel time, more generalized travel cost. Therefore, to evaluate the effect of staggered shifts, besides analyzing the change of departure time, the change of travel duration should be also analyzed.

The Kaplan Meier survival curve of home-to-work travel duration of the sample data is shown in Figure 2. The survival curve indicates that with the increase of the travel duration, the survival rate decreases gradually. The average travel duration is 27.01 minutes.

Table 8. Commute time distribution after implementation of the programs for each industry

Implementation industry	Program	≤6:00	6:00–6:30	6:30–7:00	7:00–7:30	7:30–8:00	8:00–8:30	8:30–9:00	>9:00
Government	Before implementation	0.62	1.87	13.26	25.74	27.61	17.16	6.40	7.33
	Program A	0.00	0.31	4.84	31.36	46.96	15.44	0.94	0.16
	Program B	0.00	0.00	0.94	6.26	29.26	40.06	15.34	8.14
Educational institution	Before implementation	1.57	14.57	36.57	31.57	6.00	1.71	1.14	6.86
	Program A	0.58	13.50	60.09	24.53	1.31	0.00	0.00	0.00
	Program B	0.15	0.73	17.85	58.06	21.63	1.60	0.00	0.00
	Program C	0.00	0.14	1.16	23.19	52.32	21.59	1.45	0.14
Service industry	Before implementation	7.94	6.07	9.81	22.90	20.09	10.28	7.94	14.95
	Program A	0.00	0.00	0.47	2.80	23.83	43.93	18.69	10.28

Table 9. Departure time analysis of the integrated programs

Program		≤6:00	6:00–6:30	6:30–7:00	7:00–7:30	7:30–8:00	8:00–8:30	8:30–9:00	>9:00
Before implementation		89	174	522	659	443	229	125	235
Program A	After implementation	85	162	441	542	451	373	182	240
	Rate of Change (ROC)	−4.49	−6.90	−15.52	−17.75	+1.81	+2.88	+45.60	+2.13
Program B	After implementation	69	150	423	491	461	447	205	230
	ROC	−22.47	−13.79	−18.97	−25.49	+4.06	+95.20	+64.00	−2.13
Program C	After implementation	66	152	660	574	418	289	140	177
	ROC	−25.84	−12.64	+26.44	−12.90	−5.64	+26.20	+12.00	−24.68
Program D	After implementation	62	141	581	449	428	435	197	183
	ROC	−30.34	−18.97	+11.30	−31.87	−3.39	+89.96	+57.60	−22.13

Based on the former travel duration analysis, the departure time, commute travel distance, and commute mode are chosen as the explanatory variables. Table 7 shows the estimation results of the home-to-work travel duration model by using the software of *Stata*.

It is necessary for $|t| > 1.96$ which indicates that the variable has significant effect (95% confidence interval) on travel duration T, and the value of $Prob > chi2$ to be less than 0.05.

6. Staggered shifts programs evaluation

The effects of the staggered shifts programs for each industry will be examined separately, then the integrated programs. According to the staggered shifts cases in several cities of China and policy acceptability analysis in Section 3.3.1, we choose government, educational institution, and service industries to implement staggered shifts program.

6.1. Programs for government

Two programs are developed for government. The job starting time is 8:30 and 9:00 respectively. Based on the departure time choice model, the new distributions of the commute start time are predicted and shown in Table 8. The results indicate that when job starting time is 8:30 (Program A), the probability that commuters leave home between 7:00 and 8:00 increases

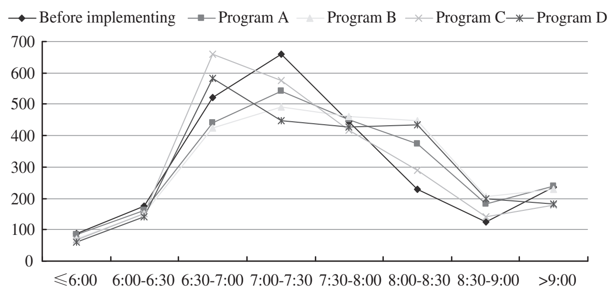

Fig. 3. Evaluation results of the integrated programs

Table 10. Travel duration analysis of the integrated programs

	Before implementation	Program A	Program B	Program C	Program D
Average travel time (minute)	27.01	25.38	21.14	27.80	23.20

greatly. This period is involved in the peak period of all types of industries (6:30–8:00). Concerning Program B, the commute volume in the periods of 8:00–8:30 and 8:30–9:00 increases greatly, and the probability that people leave home in the period of 7:00–7:30 decreases obviously. This means that Program B is helpful to reduce the commute volume during the AM peak period of 6:30–8:00. Therefore, compared with Program A, Program B is a better choice for government.

6.2. Programs for educational institution

Three programs are developed for educational institution. The job starting time is 7:30, 8:00, and 8:30 respectively. After implementation of Program A, the probability of leaving home after 7:30 decreases obviously. In terms of Program B, some commute trips in the period of 6:00–7:00 shift to 7:00–8:00, so that the AM peak period of educational institution change to 6:30–8:00, which is just the peak period of all the industries. Regarding Program C, the traffic volume in the period of 6:00–7:00 decreases obviously and the traffic volume in 8:00–8:30 increases obviously. This is helpful to make the peak period of all the industries move backward, so that the congestion problem in the period of 7:00–7:30 will be relieved. Based upon the above analysis, Programs A and C are better than Program B.

6.3. Programs for service industries

Analysis of the survey data shows that the job starting time of service industries concentrates on the period of 7:30–8:30. If it is changed to 9:00, the commute traffic volume in the period of 8:30–9:00 increases, and the commute traffic volume in 6:30–7:30 decreases. This indicates that the program has a positive effect on the traffic condition during the AM peak period.

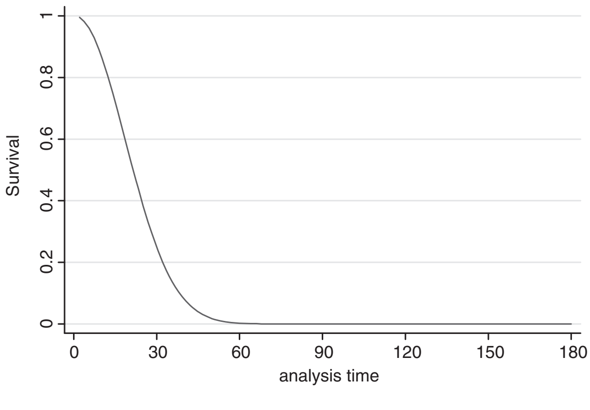

Fig. 4. The predicted survival curve of the home-to-work travel duration of Program A

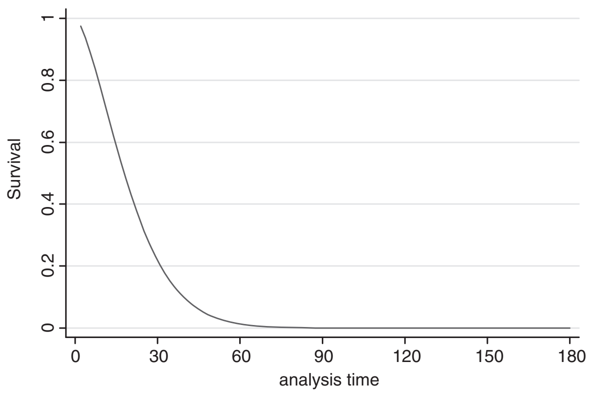

Fig. 5. The predicted survival curve of the home-to-work travel duration of Program B

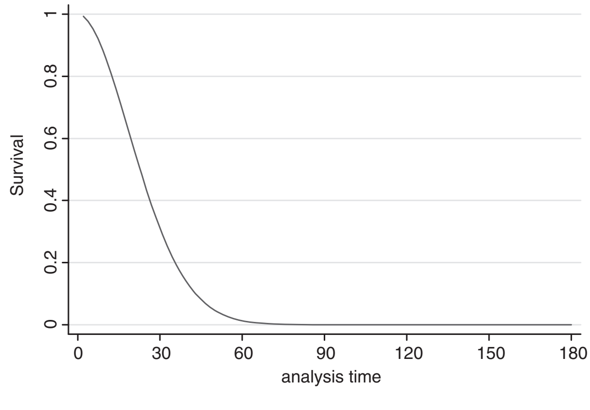

Fig. 6. The predicted survival curve of the home-to-work travel duration of Program C

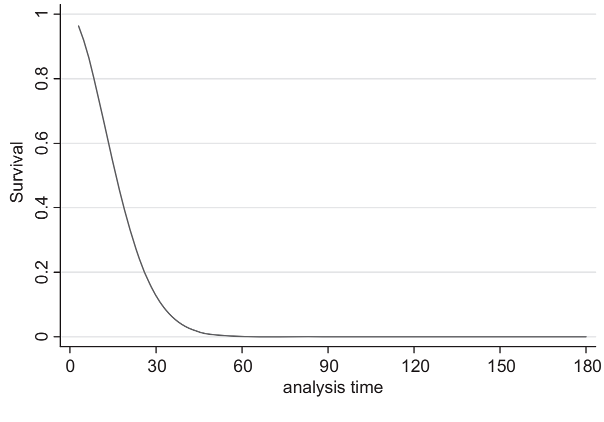

Fig. 7. The predicted survival curve of the home-to-work travel duration of Program D

6.4. Integrated programs

6.4.1. Departure time analysis

Four integrated programs are developed, considering the following factors: current job starting time of each industry (according to the SP and RP survey data), current commute departure time distribution (Table 2), and the implementation effect of the above programs for each industry (Table 8):

- Program A: the job starting time for government is 9:00, for the other industries is not changed;
- Program B: the job starting time for government and service industries is 9:00, for other industries is not changed;
- Program C: the job starting time for educational institution is 7:30, for government is 8:30, and for service industries is 9:00;
- Program D: the job starting time for educational institution is 7:30, for government and service industries is 9:00.

The commute departure time distributions after implementation of the above programs are predicted using the departure time choice model. The results are given in Table 9 and Figure 3.

The departure time analysis indicates that all the programs have positive effects. Program C transfers some traffic volumes from the period of 7:00–8:00 to 6:30–7:00 and 8:00–8:30. But the AM peak is still obvious. Program D transfers some traffic volumes from the period of 7:00–7:30 to 8:00–9:00, but makes a new peak (6:30–7:00). Both Programs A and B make no obvious peak period. However, the peak-period volumes of Program B are less than that of Program A. Moreover, Program B makes the volumes in 6:30–8:30 period distribute almost uniformly. Program B improves the traffic condition in the AM peak period obviously.

6.4.2. Travel duration analysis

The home-to-work travel time after implementation of each programs are predicted using the travel duration model. The results are given in Table 10. The predicted survival curves of the home-to-work travel duration of Programs A–D are shown in Figures 4–7 respectively.

The travel duration analysis indicates that the implementations of Programs A, B, and D reduce the average home-to-work travel time of all the commuters, while Program C increases the average travel time. Among the three positive programs, Program B is the best because of the shortest travel time.

Therefore, Program B is chosen as the staggered shifts program for Beijing. Prediction with the developed commute departure time model shows that this program can reduce the traffic volumes in the period of 6:30–8:30 by 15.24%. A similar program in Wuxi City in 2003 reduced traffic volumes in peak period by 12% (Zong *et al.* 2007). Prediction with the travel duration model indicates that the program can reduce the home-to-work travel time by 21.73%.

As we know that commuters will choose their departure time from work mainly according to the job ending time. Therefore, we regard the departure time from work as the job end time. Moreover, according to the current PM peak period of 16:30–17:30 (shown in Table 3) and the job starting time Program B, it can be determined that the job ending time of government and service industries is 17:30–18:00. Therefore, the best staggered shifts program for Beijing is that the work schedule for government and service industries are 9:00–18:00, for the other industries are not changed.

Conclusions

An evaluation process of TDM policy can be summarized in light of this study, which contains six steps:

(1) data survey;
(2) travel behavior analysis;
(3) development of travel behavior forecasting model;
(4) making TDM programs;
(5) predicting travel behavior after implementation of the programs;
(6) TDM programs examination.

In addition, to make an efficient staggered shifts program, it is crucial for the government to take some necessary measures to ensure the effective implementation of the policy. The government should cooperate with concerned industries on the program. Meanwhile, the government should coordinate staggered shifts with the other TDM policies, such as carpools and public transport priority. It is proposed for the government to implement a pilot program for three to six months before implementing the final program.

Future work should be done using the alternative departure time forecasting models, such as Mixed Logit and Probit models, in order to improve the forecasting precision and solve the IIAproblem of an MNL model.

Acknowledgments

The research is funded by the Doctoral Program of Higher Education of China (200801831088) and the National Natural Science Foundation of China (50908099). The authors would like to thank two anonymous reviewers for their valuable comments and suggestions for improvement of the manuscript.

References

Abkowitz, M. D. 1981. An analysis of the commuter departure time decision, *Transportation* 10(3): 283–297. http://dx.doi.org/10.1007/BF00148464

Beers, T. M. 2000. Flexible schedules and shift work: replacing the '9-to-5' workday?, *Monthly Labor Review* 123(6): 33–40.

Bhat, C. R.; Sardesai, R. 2006. The impact of stop-making and travel time reliability on commute mode choice, *Transportation Research Part B: Methodological* 40(9): 709–730. http://dx.doi.org/10.1016/j.trb.2005.09.008

Cao, X.; Mokhtarian, P. L. 2005. How do individuals adapt their personal travel? Objective and subjective influences on the consideration of travel-related strategies for San Francisco bay area commuters, *Transport Policy* 12(4): 291–302. http://dx.doi.org/10.1016/j.tranpol.2005.03.003

Cervero, R.; Griesenbeck, B. 1988. Factors influencing commuting choices in suburban labor markets: a case analysis of Pleasanton, California, *Transportation Research Part A: General* 22(3): 151–161. http://dx.doi.org/10.1016/0191-2607(88)90033-7

Commuter choice primer: an employer's guide to implementing effective commuter choice programs [online] 2003. [cited 5 September 2010] Available from Internet: http://ntl.bts.gov/lib/jpodocs/repts_pr/13669.html

De Palma, A.; Fontan, C.; Mekkaoui, O. 2001. Trip timing for public transportation: an empirical application, in D. Hensher (Ed.). *Travel Behaviour Research: the Leading Edge*. Pergamon Press, 503–525.

De Palma, A.; Lindsey, R. 2002. Comparison of morning and evening commutes in the Vickrey bottleneck model, *Transportation Research Record* 1807: 26–33. http://dx.doi.org/10.3141/1807-04

Du, H. B.; Chen, J. C.; Guo, J. F. 2004. Feasibility analysis on implementing different working hour of Beijing, *Urban Transport of China* 2(4): 64–67.

EPA. 1998. *Transportation control measures: work schedule changes* [online]. TRAQ Technical Overview, EPA420-S-98-014. United States: Environmental Protection Agency. 7 p. [Cited 12 October 2010] Available from Internet: http://www.epa.gov/otaq/stateresources/rellinks/docs/S98014.pdf

Freas, A. M.; Anderson, S. M. 1991. Effects of variable work hour programs on ridesharing and organizational effectiveness: a case study, Ventura County, *Transportation Research Record* 1321: 51–56.

Galinsky, E.; Bond, J. T.; Swanberg, J. E. 1998. *The 1997 National Study of the Changing Workforce*. Families and Work Institute. 176 p.

Guo, Z.; Srinivasan, K. K. 2005. Investigating the effect of user behavior factors and transportation control measures on day-to-day network evolution and trip time reliability, *Transportation Research Record* 1926: 152–161. http://dx.doi.org/10.3141/1926-18

Hamed, M. M.; Mannering, F. L. 1993. Modeling travelers' postwork activity involvement: toward a new methodology, *Transportation Science* 27(4): 381–394. http://dx.doi.org/10.1287/trsc.27.4.381

Hendrickson, C.; Plank, E. 1984. The flexibility of departure times for work trips, *Transportation Research Part A: General* 18(1): 25–36. http://dx.doi.org/10.1016/0191-2607(84)90091-8

Hensher, D. A.; Mannering, F. L. 1994. Hazard-based duration models and their application to transport analysis, *Transport Reviews* 14(1): 63–82. http://dx.doi.org/10.1080/01441649408716866

Kiefer, N. M. 1988. Economic duration data and hazard functions, *Journal of Economic Literature* 26(2): 646–679.

Komma, A.; Srinivasan, S. 2008. Modeling home-to-work commute-timing decisions of workers with flexible work schedules, in *Proc. of the Transportation Research Board 87th Annual Meeting*, January 13–17, 2008, Washington, DC, 25 p. (DVD).

Li, H.; Guensler, R.; Ogle, J.; Wang J. 2004. Using GPS data to understand the day-to-day dynamics of the morning commute behavior, in *Proc. of the Transportation Research Board 83rd Annual Meeting*, January 11–15, 2004, Washington, DC, 18 p. (CD).

McCafferty, D.; Hall, F. L. 1982. The use of multinomial logit analysis to model the choice of time to travel, *Economic Geography* 58(3): 236–246. http://dx.doi.org/10.2307/143512

Picado, R. 2000. A question of timing, *Access* 17: 9–13.

Sinha, A. K.; Thakuriah, P. 2004. Relationship between occupational, industrial, and sociodemographic characteristics and job start times: evidence from current population survey, *Transportation Research Record* 1894: 67–74. http://dx.doi.org/10.3141/1894-08

Small, K. A. 1982. The scheduling of consumer activities: work trips, *The American Economic Review* 72(3): 467–479.

Sundo, M. B.; Fujii, S. 2005. The effects of a compressed working week on commuters' daily activity patterns, *Transportation Research Part A: Policy and Practice* 39(10): 835–848. http://dx.doi.org/10.1016/j.tra.2004.06.001

Teekamp, R.; Bezembinder, E. M.; Amelsfort, D. H.; Berkum, E. C. 2002. Estimation of preferred departure times and changes in departure time patterns, in *Proc. of the Transportation Research Board 81st Annual Meeting*, January 13–17, 2002, Washington, DC, 23 p. (CD).

Vovsha, P.; Bradley, M. 2004. Hybrid discrete choice departure-time and duration model for scheduling travel tours, *Transportation Research Record* 1894: 46–56. http://dx.doi.org/10.3141/1894-06

VTPI. 2010. *Alternative Work Schedules: Flextime, Compressed Work Week, Staggered Shifts* [online]. Victoria: Transport Policy Institute. Available from Internet: http://www.vtpi.org/tdm/tdm15.htm

Zong, F.; Juan, Z.; Liu, B. 2007. Accessibility of the staggered shifts policy, in *Proc. of the International Conference on Transportation Engineering*, July 22–24, 2007, Chengdu, China, 3076–3081. http://dx.doi.org/10.1061/40932(246)505