Chapter 3
Comprehensive Travel Demand Analysis in Asian Developing Megacities

Junyi Zhang, Xuesong Feng, and Akimasa Fujiwara

Abstract Transportation issues in developing countries are complicated. To resolve these issues, land-use and transportation systems should be integrated, with an appropriate combination of push and pull measures from a long-term perspective in a comprehensive manner. To support such policy decisions, a four-step travel demand model with a full feedback mechanism is developed, in which trip generation and attraction steps are included in the feedback process by reflecting the influence of transport accessibility. The model is repeatedly estimated based on a much more efficient calculation algorithm. The full feedback mechanism allows us to incorporate the endogenous influence of induced travel demand on various aspects of travel demand. With the help of the above model, various urban and transportation policy scenarios consisting of urban form, public transportation systems, vehicle ownership control, and road networks are examined in the Jabodetabek metropolitan area of Indonesia and Beijing, China, based on a full-scale person–trip survey. Polycentric and transit-oriented urban forms are confirmed to be more environmentally efficient than other policy scenarios.

Keywords Feedback • Four-step travel demand model • Person trip data • Public transportation systems • Urban form

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3.1 Urban Transport Situation of Developing Cities

With the booms in the urban economies of developing countries, the numbers of motor vehicles in their cities have been greatly increasing, especially since the 1990s, because of increased urban populations, better economic conditions, commercial penetration, and probably an increasingly persuasive idea in the developing world of an international lifestyle in which a car is an essential element. In much of the developing world, the annual increase in the number of motor vehicles is more than 10 %, with the number doubling in 7 years (Gakenheimer 1999). Simultaneously, in developing cities, the dramatically increasing travel demands that are in large degree a result of rapid motorization have far exceeded the lagging development of urban transport infrastructure and facilities. The growth rate of urban transport motorization in Jakarta has exceeded 10 % per year, in contrast with increases in road infrastructure expenditure, which has not even reached an annual figure of 1 % (Soehodho 2007). For many reasons, including the imbalance between travel demand and supply, experiences of urban transport situations in developing cities have gone from bad to worse.

First, undeveloped urban transport systems, continuously increasing travel demand and increasingly serious traffic congestion in developing cities have generally increased urban travel time, with the number of destinations accessible within a limited time decreasing. In central Bangkok, traffic speeds have decreased by 2 % per year since the 1980s, and in Rio de Janeiro and Bogota, the average time of a journey to work increased to approximately 107 min and 90 min respectively in the 1990s (Gakenheimer 1999). Such mobility decreases because of serious traffic congestion are even more serious for bus users in developing cities. The average bus travel speed in Beijing decreased from 16.7 km/h in 1990 to 9.2 km/h in 1996, which increased the average travel time of passengers by 22 min (Mao et al. 2002). In 2000, the average bus travel time for one trip in Beijing decreased to approximately 58 min (BMCC and BTRC 2004). This was first because bus routes characteristically follow the highest-volume arteries, which are most afflicted with congestion. Moreover, it is an unfortunate fact that a policy emphasizing expanded road networks rather than improving the bus transit system often worsens this quandary. Decreased mobility has severely harmed the economic growth of these developing cities. For example, the annual economic loss caused by urban traffic congestion in the Jabodetabek metropolitan area of Indonesia, which is the most important economic and strategic metropolitan region, could reach US$0.33 billion for vehicle operating costs and US$0.28 billion for travel delays in 2002 (JICA and BAPPENAS 2004).

Furthermore, the bus systems in developing cities are almost ubiquitously overloaded, and the incomplete urban railway systems in these cities have not played the main role of urban passenger carriers. In Beijing, buses carried approximately 73.54 % of the total public passenger transit volume in 2000; by comparison, the metro carried only 11.51 %, and taxis carried some 14.94 % (BUPA 2002). This overcrowded bus network not only is more susceptible to increasing traffic jams than cars but also contributes greatly to serious traffic congestion. In addition, the inefficient urban railway system overburdens the road traffic network further. It is possible to relieve this congestion by managing buses' right of way, which generally refers to independent lanes or signaling that favors buses, but few cities have been successful simply by applying this, because urban transport in developing countries entails many aspects.

Moreover, the land-use characteristics of developing cities are incompatible with urban transport motorization. For instance, residential densities in the cities of China are as high as 200 to 250 people per gross hectare; however, in European cities, this figure is about 50 people per gross hectare. Streets in Chinese cities usually comprise approximately 10 % of the city area, rather than 25 % as in Western cities, and land use is likely to be more mixed and centralized than in Western cities (Gakenheimer 1999). These figures reveal not only the reasons for the serious traffic situation in developing cities but also the truth that changes in the transport system of a developing city, such as construction of a new highway, have a much greater impact on the travel behavior of citizens than the same changes in a developed city; conversely, the changed travel flows will accelerate the development in the urban structure of the developing city.

Furthermore, to some extent because of the mixed and centralized land-use characteristics explained above, various urban functions are generally distributed haphazardly in the central areas of developing cities. Worse for the cities of developing countries, there are very limited agreements on urban and transport planning approaches, whereas Western countries have cadres of engineers and planners with reasonably consistent perspectives on managing urban and transport problems. These cities tend to borrow methods and professional perspectives from elsewhere and to have professional communities that exchange ideas. This unstable consultation process means that a lack of consistent commitments often results in turbulence in the course of solving urban and transport problems, stalemates when parties attempt to marshal their strength for a particular solution, and rapid changes of strategies over time that prevents any strategy from succeeding. These unreasonable urban function distributions and ineffective urban and transport planning approaches are important reasons for serious traffic congestion, especially during peak traffic hours in developing cities. For instance, one can observe serious traffic concentration every day in DKI Jakarta, the central part of the Jabodetabek metropolitan area because urban functions are concentrated there (JICA and BAPPENAS 2004). This irrationally overcentralized distribution of urban functions and inefficient urban planning can very easily lead to preposterously unbalanced use of the whole traffic network; that is, some roads in the network are very crowded, while others are nearly useless, which exacerbates the lag in the supply of roads in developing cities and further deteriorates the already severe congestion. This disequilibrium in the use of traffic networks because of the prevalent and unreasonable urban structure of developing cities with only a single and overloaded central area can typically appear in the phenomenon of "Tide Traffic" in Beijing, usually occurring in rush hours because of centrally concentrated urban functions within its third ring road (BMCC and BTRC 2004).

Besides the above-mentioned factors, the reasons for the unsatisfactory urban transport situation in the cities of developing countries also include citizens' intense desire to own cars and their use in developing cities. According to government surveys, Chinese families are prepared to spend 2 years of income for a car that is expected to last for 10 years. In contrast, Americans spend about 27 weeks of their salaries for a car (Gakenheimer 1999). In addition to a lack of adequate road maintenance because of financial difficulties, policy limitations and poor driver discipline, although equally strong or stronger in many East Asian countries than in the West, also cannot be neglected as a cause of serious traffic congestion and accidents in developing cities. In Jabodetabek in 2002, some 9 % of traffic accidents occurred because of potholes and damage to roads, and approximately 73 % of traffic accidents on ordinary roads were caused by careless driving mistakes and violations of traffic rules (JICA and BAPPENAS 2004). Finally, the variety of vehicle types on the streets in developing cities creates difficult problems for efficiency and safety. Many developing cities have passenger vehicles ranging from human traction to high-speed sports cars, and various scales of freight vehicles. Such mixed urban traffic flows made up of various types of motor vehicles and nonmotorized vehicles have made studies of urban transport and management for the cities in developing countries much more difficult than for those in developed countries.

3.2 Study of Urban Transport in Developing Cities

Confronted with the poor state of urban mobility in developing cities because of their rapid development, researchers and planners in the field of transport planning and management have continually sought effective methodologies for analyzing and solving urgent transport issues in these cities. Advanced transport modeling approaches such as some of the disaggregate activity-based modeling methods (e.g., McNally 2000a), which have been efficiently applied to the study and improvement of urban transport conditions in cities in developed countries, have been used in attempts to analyze and resolve the problematic urban transport problems in developing cities. However, valid analyses of the urban transport studies of developing cities are very difficult, because elementary trip survey data are still quite scarce, and the available data mostly are of very poor quality and often are not shared among planning agencies (Boyce and Xiong 2007). Thus, advanced modeling techniques, which usually require more detailed trip and/or activity data, are very difficult to apply. Therefore, the conventional aggregate four-step modeling process, which is customarily estimated sequentially, is still the most widely applied method because of its practicability (McNally 2000b; Siegel et al. 2006).

The conventional four-step model includes the usually top-down estimated four steps of trip generation and attraction, trip distribution, travel modal split and

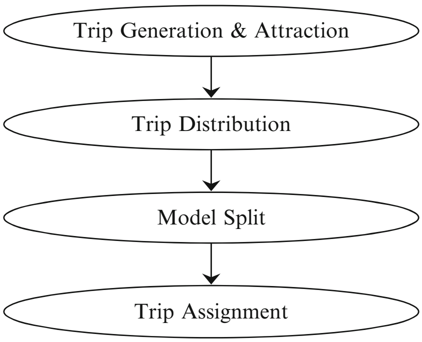


Fig. 3.1 Conventional four-step modeling approach

trip assignment, as shown in Fig. 3.1. The modeling process might be best viewed in two stages (McNally 2000b): (1) various characteristics of travelers and the land-use–activity system (and to a varying degree, the transport system) are "evaluated, calibrated, and validated" to produce a nonequilibrated measure of travel demand (or trip tables); (2) this demand is loaded onto the transport network in a process that amounts to formal equilibration of route choice only, not of other choice dimensions such as destination, mode, time of day, or whether a person travels at all. The initial development of models of trip generation, distribution, and diversion in the early 1950s led to the first comprehensive application of the four-step model system in the Chicago Area Transportation Study (Weiner 1997). The US federal legislation requiring "continuous, comprehensive, and cooperative" urban transport planning in the 1960s fully institutionalized the four-step model. In this four-step modeling framework, in theory derived from demand for activity participation, travel is modeled in practice with trip-based rather than activity-based methods. As the conventional forecasting sequence proceeds, the influence of activity characteristics decreases, and that of trip characteristics increases.

Because of the lack of a behavioral decision foundation, although it has been moderately successful at the aggregate level, the conventional four-step modeling approach has failed to perform in most relevant policy tests, on either the demand or the supply side. The application effect of the conventional four-step model adopted in the urban transport study of developing cities has always appeared unclear and unpersuasive when confronted with the more complicated urban transport situations in the cities of developing countries, as explained above. As a result, development is urgently required of new urban transport modeling techniques suitable for urban transport planning studies of developing cities facing many problems, such as trip survey data scarcity, financial difficulties and serious urban transport conditions.

3.3 Interdependencies in Urban Transport Planning Systems

To establish and apply an efficient means of studying urban transport in developing cities, the comprehensive urban transport planning system should be first analyzed and understood from an integrated viewpoint. In the urban transport planning structure introduced by Manheim (1979) and expanded by Florian et al. (1988), as shown in Fig. 3.2, travel demand (**D**) is determined by spatial distribution of land use and

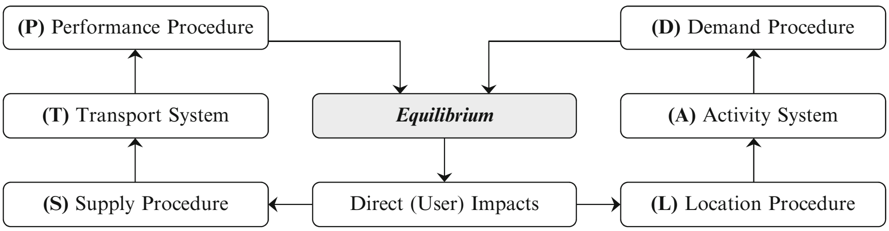


Fig. 3.2 Interdependent feedback mechanism in urban transport planning system

demographic and/or economic activities (**A**) that occur on that land, which are decided by an activity location choice procedure (**L**) influenced by transport actions impacted by dynamic travel flows in transport networks. Moreover, the actuality of the transport system (**T**) is, of course, the main factor in its performance (**P**) and is gradually formed by transport supply procedure (**S**), which can be regarded as a reflection of transport actions impacted by dynamic transport flows. Conversely, according to the equilibrium between travel demand (**D**) and performance (**P**) of the transport system, travel flows should directly impact the trip behavior of travelers. These successive impacts should be on the activity location choice procedure (**L**), transport supply procedure (**S**), activities on land used for particular purposes (**A**), the transport system (**T**),and finally on travel demand (**D**) and performance of the transport system (**P**). Consequently, a new equilibrium will be reached. Because of this interdependent feedback mechanism, various components of the urban transport planning system are integrated in a dynamic and general manner. Because of the urban transport development characteristics of developing cities, especially the fast and very distinct mutual effect between urban transport evolution and land-use changes, the behavior-based interactive feedback among various factors of the urban transport planning system discussed above could be much more evident. As a result, much greater importance should be attached to urban transport studies in developing cities.

3.4 The Reality of Urban Transport Planning in Developing Cities

Besides analyzing the urban transport planning system, it is necessary to understand the reality of urban transport planning in developing cities to improve studies of urban transport planning in cities in developing countries. Typically, it is discovered that urban transport infrastructure improvement is the primary factor in the development of a city. In other words, land used for construction of urban transport infrastructure facilitates urban transport activities and as a result boosts the prosperity of the urban economy. Furthermore, a prosperous urban economy will stimulate other urban activities, such as recreation activities, which will develop the land used for these activities and deservedly improve travel demand and in turn require more urban transport infrastructure. This interactive circle has become the driving force for urban growth of cities in developing countries, which could be utilized by their governments to build a more efficient urban transport system, or conversely could create a vicious cycle in which road construction can never catch up with the increasing demand for travel, and with more roads, much more serious traffic jams would occur. According to a study of the Ayala Planned Area of Makati in the Philippines, transport infrastructure in this area was developed not only to increase accessibility to/from and within the area but also to guide and support the other designated urban land uses (Kishiue et al. 2005). In contrast, in Beijing, because insufficient attention was paid to integrated urban land-use and transport planning, the urban traffic situation has worsened with the completion of the fifth ring road.

For the developing cities that currently face urgent and complex urban transport problems because of a lagging transport infrastructure supply and continually increasing travel demand resulting from rapid development, it is essential to decide exactly whether a large-scale transport infrastructure construction project would yield the maximum benefit and avoid the above vicious cycle owing to lack of comprehensive design. Therefore, the most important issue for urban transport research on cities in developing countries is to consider the interactive relationship among different ingredients of the urban transport planning system; that is, the interdependent feedback mechanism discussed above, especially the evident interaction between land use and transport. The simple application of the traditional four-step model without feedback would certainly be insufficient to analyze quite complicated urban transport issues, much less to resolve them.

3.5 Feedback Modeling Study for Developing Cities

As can be seen from the above discussion, it is necessary to import the behavior-based feedback interdependence among factors of the urban transport planning system into the study and decision-making process, especially for developing cities confronted with serious and complicated urban transport development problems. To achieve this, advanced disaggregate modeling studies using data directly collected from individual travelers have been developed and improved since the late 1970s. However, as explained above, these new methods require more detailed trip and/or activity data that are very difficult to collect in developing cities. The collection of such data suffers from poor data quality, and budget and human resource constraints related to survey implementation. Because even poor-quality survey data are extremely limited and not adequately shared, it is quite difficult to apply these advanced approaches to urban transport studies of developing cities and to obtain valid analysis results. Moreover, many other integrated models have previously been developed to consider the interactive relationships between urban transport and land use comprehensively, but these integrated models also require a good deal of detailed input data. On the other hand, although popular in practice, the trip-based and usually top-down estimated conventional four-step modeling procedure, generally estimated sequentially with serious propagated uncertainties (Zhao and Kockelman 2002), has unreasonably disregarded the feedback mechanism shown in Fig. 3.2. Therefore, it generally does not perform satisfactorily in urban transport studies of developing cities.

In view of the severe data limitation and the urgent need for integrated consideration of the interrelationship among essential aspects of urban transport planning systems in the analysis of decision making in developing cities, the feedback mechanism discussed above is feasible, reasonable and necessary. The effectiveness of the travel demand model with feedback has been confirmed since the 1950s in the context of developed countries (Levinson and Kumar 1993; Boyce and Xiong 2007; Boyce 2002). Boyce et al. (2008) further conducted a sensitivity analysis of different convergence methods to estimate the feedback model and emphasized the contemporary importance of improving feedback models. On account of the rapid growth of developing cities today, frequently influenced by urban transport development and rapidly changing land use in these cities, people's travel behavior swiftly changes within a quite short time. Thus, travel behavior can have a reverse effect on urban transport improvements and the transformation of land use. From an alternative macro perspective, trip generation and attraction volumes in urban areas, trip origin and destination choice, and shares of various travel modes are easily affected by the immediate performance of the improved transport networks. Because of these characteristics of urban transport in developing cities, the feedback computation is first iteratively imported into all four steps of the conventional modeling process in this study. The study now establishes a new aggregate four-step travel demand prediction model with a feedback process.

In this research, the iterative importation of the feedback into each of the four steps of the modeling analysis is a different process from formulating the model components at all these steps as an optimization problem solved directly using convex combination methods, as proposed, for example, by Safwat and Magnanti (1988). The feedback model proposed here is also different from previous iterative feedback models such as those by Levinson and Kumar (1993), Boyce et al. (1994), Walker and Peng (1995) and Boyce and Xiong (2007), which always exclude the step of trip generation and attraction from the feedback procedure. In this study, a trip generation and attraction analysis is introduced into the feedback procedure by applying the indicator of transport accessibility for each trip analysis zone to give more comprehensive consideration to the urban transport characteristics of cities in developing countries. As to the feedback procedure convergence of the proposed model, the Direct Feedback (DF) solution presents a more efficient result than the alternatives. This is in contrast to the dominant opinion that DF is the worst, or at least not the best, approach to feedback procedures (e.g., Boyce et al. 1994; Walker and Peng 1995; Lan et al. 2003; Boyce et al. 2008).

Furthermore, improvement of transport networks usually leads to improved transport accessibility and consequent spatial distribution changes in such factors as population and car ownership, which are used to explain trip generation and attraction in the proposed feedback model. Such influences may be even more remarkable in developing cities. Nevertheless, the proposed feedback model deals exogenously with these explanatory variables in the step of trip generation and attraction and cannot logically represent distribution changes resulting from changes in transport networks' performance. As a result, the proposed feedback model is further improved to create an integrated travel demand forecast model by adding an Aggregate Multinomial Logit (A-MNL) model to describe endogenously the distributions of the variables used to interpret trip generation and attraction, which are easily influenced by the performance of transport networks.

Because the urban transport issues discussed above are typical of both the Jabodetabek metropolitan area and Beijing, and quite high-quality Person Trip (PT) survey data for these two areas can be obtained, these were selected as the target study areas for this research. PT data for Jabodetabek in 2002 and Beijing in 2000 were provided by the Japan International Cooperation Agency (JICA). The analyses of the validities of the proposed feedback and integrated model estimations and applications were mainly performed with the *TransCAD* software.

3.6 An Improved Four-Step Travel Demand Model with Feedback

Considering that all the conventional four steps of the modeling framework are interrelated in a behavior-based mechanism, it is necessary to incorporate the feedback procedure into each step to reflect properly the behavioral interdependence among the various components of urban transport planning systems, especially for urban transport studies of developing cities. Accordingly, establishment of a new travel demand model has been attempted, with each prediction step linked in two-way manner through an iterative feedback practice. This is quite different from the traditional four-step model allowing only for a one-way sequential process. The general configuration of this new aggregate feedback model is presented in Fig. 3.3. The model is briefly explained below; for details, refer to Feng et al. (2007).

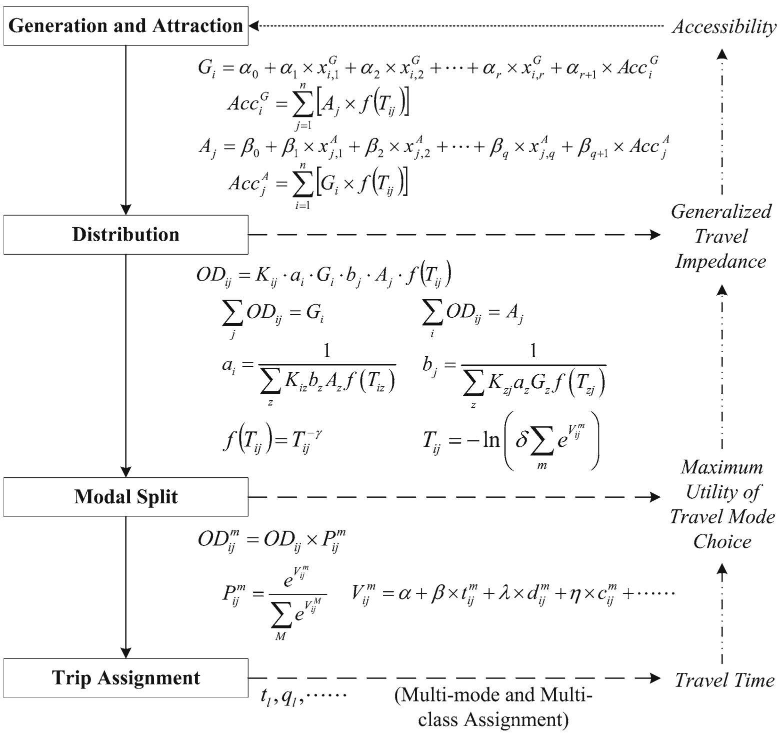


Fig. 3.3 The proposed feedback travel demand model

The first step of the feedback process in the proposed model shown in Fig. 3.3 is modal split, represented using the Multinomial Logit (MNL) model. The inclusive values of various travel modes (i.e., *maximum utility of travel mode choice*) are used to represent the overall performance of transport networks. Subsequently, an inverse power function of these inclusive values is introduced into the Doubly Constrained Gravity (DCG) model adopted in the trip distribution step to generate the *generalized travel impedance* between each OD (origin–destination). Next, this generalized travel impedance is used to calculate the transport *accessibility* of each Trip Analysis Zone (TAZ). Thereafter, *accessibility* is incorporated into the trip generation and attraction step as an explanatory variable of the Multiple Linear Regression (MLR) models applied to the study of trip generation and attraction at each TAZ. With the estimation of the MNL, DCG and MLR models successively completed, the process obtains new estimates of trip generation and attraction, trip distribution, modal split shares, and finally trip assignment results. For the trip assignment study, with a view to mixed traffic flows typically consisting of various kinds of motor vehicles and labor vehicles in developing cities, a link-based Multimode and Multiclass Assignment (MMA) method (Caliper Corporation 2004) is applied. This considers not only the interaction between bus and road networks with the bus preassignment results preloaded onto road networks but also the interactive effect among different types of vehicles. Passenger car equivalence for all vehicles was established using the Highway Capacity Manual (NRC 1985). Based on the results of trip assignment using this MMA method, *maximum utility of travel mode choice* is changed according to the new *travel time* on each link of the road network. Now, the next iteration of this feedback estimation process can begin. This iterative process continues until certain convergence criteria are achieved.

In contrast, the conventional four-step model is usually estimated in a top-down manner from the trip generation and attraction step by estimating the MLR models according to variables such as present population and availability of jobs in each TAZ. Based on the results of predicted trip generation and attraction in each TAZ and the DCG model calibrated according to present trip distribution, it is possible to derive a new estimate of the OD matrix that is imported into the MNL model to obtain OD matrices for various travel modes. Finally, these OD matrices are assigned to transport networks. It is obvious that such a one-way sequential estimation procedure without feedback cannot represent the behavior-based interdependence mechanism explained above, which is especially important for studies of modern urban transport in developing cities. Moreover, it is also found that in addition to the same data input into the top-down estimation procedure of the conventional four-step model, no additional data are required for the iterative estimation process of the newly developed feedback model, which is very important for such studies in view of the serious lack of research data for most developing cities.

Furthermore, all four steps from trip generation and attraction to trip assignment in the proposed feedback model in this study are incorporated and estimated using the iterative technique explained above. This is different from formulating the model components from each of the four steps in the modeling approach as an optimization problem solved directly based on convex combination methods, as proposed by Safwat and Magnanti (1988), for example. For the comprehensive urban transport studies of the cities in developing countries confronted with serious restrictions to research data, as explained above, it is difficult to find efficient, feasible and practical solutions to such optimization problems in the management of urban transport.

In addition, the feedback process of the newly developed feedback model described above differs quite significantly from most estimation procedures in the conventional iterative feedback models previously proposed by, for example, Levinson and Kumar (1993), Boyce et al. (1994), Winslow et al. (1995), Miller (1997), Boyce (2002), Bar-Gera and Boyce (2006) and Boyce and Xiong (2007). Their estimation procedures are initiated from the trip distribution step according to an initially assumed travel impedance matrix and the initial input of trip generation and attraction. Then the estimation process proceeds in a backward manner (step by step) until trip assignment. Depending upon whether a link-based or a route-based assignment algorithm is adopted, either the impedances of the shortest routes or the average impedances of routes used (usually travel time and travel cost) are only returned to the travel impedance matrix in the trip distribution step. Without the incorporation of the trip generation and attraction analysis into the feedback process, the iterative procedure continues between the steps of trip distribution and trip assignment until convergence is achieved. Simply considering the influence of the changes of travel impedances between TAZs on trip distribution, the feedback processes in previous feedback models have neglected the notable effect on the trip matrix of the continually changing trip generation and attraction volumes, especially in the TAZs of developing cities with soaring travel demand because of their prosperous urban economies and rapid urban growths.

The feedback model described above was estimated and its effectiveness confirmed empirically based on data collected from the Jabodetabek metropolitan area in 2002 and Beijing in 2000 (Feng et al. 2007). With these estimation results, it is now possible to construct simulation analyses of various integrative scenarios for the comprehensive urban and transport developments of these two megacities in the future. With the distinct scenarios having contrasting effects, this study explores some sustainable urban and transport policies from the perspectives of protection against traffic emissions and relief from serious traffic congestion. Some scenarios are assumed based on information from published governmental sources, and others are best practice policies. To evaluate the effects of policies, those scenarios without any policy implemented (BAU: Business As Usual) are taken as a reference.

3.7 Analysis of Urban Transport Development in Jabodetabek Metropolitan Area

3.7.1 Scenarios for Urban Transport Development to 2020

Regarding the future comprehensive urban transport development of Jabodetabek, a total of eight simulation scenarios are assumed for 2010 and 2020, which are two targeted planning years for this metropolitan area (JICA and BAPPENAS 2004).

Table 3.1 Scenarios for the urban transport development in Jabodetabek till 2020

Scenarios	Road network	Urban form	Motorcycle ownership	Public transport systems
S1	Undeveloped	Uncontrolled	Uncontrolled	Unimproved
S2	Developed	Uncontrolled	Uncontrolled	Unimproved
S3	Developed	Uncontrolled	Uncontrolled	Improved
S4	Developed	Uncontrolled	Controlled	Unimproved
S5	Developed	Compact City Development (CCD)	Controlled	Unimproved
S6	Developed	Transit-Oriented Development (TOD)	Controlled	Unimproved
S7	Developed	Poly-Center Development (PCD)	Controlled	Unimproved
S8	Developed	Poly-Center Development (PCD)	Controlled	Improved

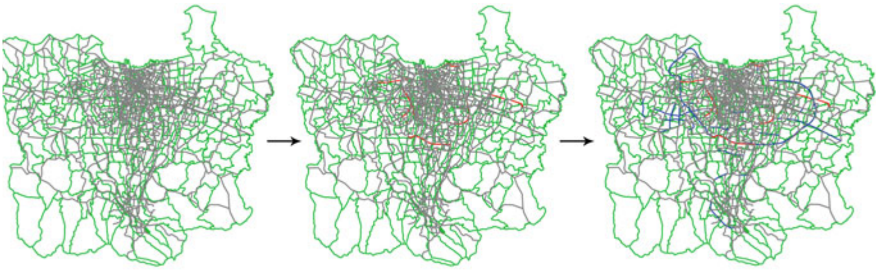


Fig. 3.4 Development of the road network in Jabodetabek in 2010 and 2020

These scenarios are summarized in Table 3.1. First, the "Undeveloped" *Road Network* shown in this table indicates that the road networks in Jabodetabek in 2010 and 2020 will remain the same as in 2002. Conversely, the "Developed" case assumes that the road network in Jabodetabek will be developed according to the governments' plans for 2010 and 2020, which are shown in Fig. 3.4. In this figure, the red and blue lines represent new roads (some ring roads and connector roads to the city center) to be constructed successively until 2010 and 2020 respectively.

The "Uncontrolled" *Urban Form* refers to the case in which daytime population, households and employment in each of the 336 TAZs will grow at an average annual rate of 5 %. As a result, the total number of households in Jabodetabek is assumed to increase from 5,857,931 in 2002 to 8,016,983 in 2010 and 11,867,093 in 2020, the secondary employed population from 1,342,982 in 2002 to 2,116,203 in 2010 and 3,241,933 in 2020, and the daytime population from 19,969,575 in 2002 to 23,397,540 in 2010 and 28,521,471 in 2020, respectively. In comparison, Compact City Development (CCD) refers to the population growth in central urban areas, Transit-oriented Development (TOD) assumes that growth of future population will be observed only along the bus and railway lines, and Polycenter Development (PCD) means that future growth of the population will be concentrated in the four subcenters in suburban areas. Specifically, the above-mentioned total net increase of population (e.g., 3,427,965 = 23,397,540 in 2010—19,969,575 in 2002 for the

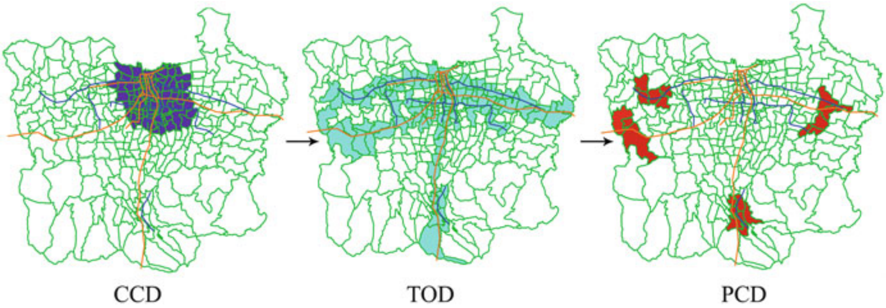


Fig. 3.5 Controlled urban forms for the development of Jabodetabek till 2020

daytime population) will be distributed evenly in the zones in central urban areas under CCD, in the zones along the bus and railway lines under TOD, and in the four subcentral areas under PCD. These controlled urban forms are shown in Fig. 3.5.

Moreover, the annual rate of increase in the number of motorcycles in each TAZ is selected as an important policy factor in the comprehensive urban transport development scenarios presented in Table 3.1. With respect to *Motorcycle Ownership* shown in Table 3.1, the "Uncontrolled" scenarios indicate that the growth ratio of motorcycles in each TAZ is set at 5 % annually from 2002 to 2020, and the "Controlled" ones indicate that the growth ratio is assumed to decrease by 1 % annually.

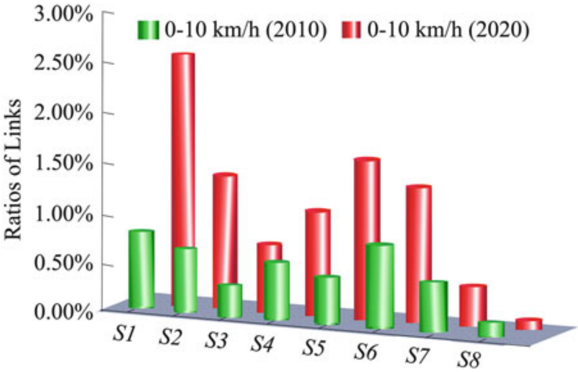
Finally, the "Improved" scenarios for *Public Transport Systems* in the future assume that 50 % of the people taking car and motorcycle trips in 2002 will change to bus and railway services in the future. Such a modal shift could be realized by improving service levels, such as in terms of travel time, cost, frequency, sanitation, safety, and service manner.

3.7.2 Distinct Performances of Different Scenarios

Although many indicators of degree of congestion (e.g., travel speed and volume:capacity ratio of each link on the traffic network) and average daily traffic emissions (of CO, NO_x, SO_x, HC and PM) have been calculated to compare the assumed outcomes of the eight simulation scenarios shown in Table 3.1, because the change in their values shows similar patterns and trends, only the forecast results of travel speeds on each link of the road network and the total amounts of traffic emission of CO (one of the main representative traffic emission pollutants in Jabodetabek) are compared in Figs. 3.6 and 3.7, respectively, for these eight scenarios. The values of the emission factors adopted here are in accordance with the work of Purwanto (2001).

As shown in Figs. 3.6 and 3.7, *S8* performs best in increasing travel speed and reducing traffic emission from both short (the year 2010) and long (the year 2020) runs. In other words, if possible, the implementation of the full policy package is the best option in the case of Jabodetabek. (As for scenario *S8*, controlling the number

Fig. 3.6 Ratios of road links with speeds lower than 10 km/h in Jabodetabek; Unit: %



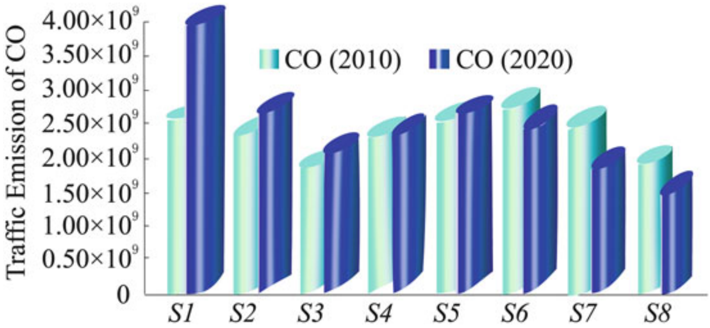


Fig. 3.7 Total volumes of average daily traffic emission of CO in Jabodetabek; Unit: gram

of motorcycles influences trip generation; PCD impacts the main locations of trip generation and attraction, and consequently the whole trip distribution, affecting such aspects as spatial distribution of population and employment. Changing mode shares affects public transport systems, and developing road networks affects trip assignment results. In addition, these actions contribute simultaneously in an integrated manner through the feedback procedure.) Obviously, such a complete policy package is costly. Considering that it may be difficult to realize a 50 % shift from private automobiles to public transport systems, scenario *S7* can be regarded as the second best option, especially from the long-term perspective. Scenario *S3* has very similar effects to *S7*, which suggests that if we could increase the share of using public transport systems, environmentally sustainable transport could also be realized without restricting urban growth or motorcycle ownership within the urban area. To balance the increase in travel speed and the reduction of environmental emissions, scenario *S4* seems promising in the sense that promoting improvement in road networks while controlling motorcycle ownership effectively could also have a satisfactory effect. Comparing scenarios *S5* and *S6*, one can observe that TOD and CCD have similar effects. The stronger effects of PCD suggest that development of subcenters in suburbs could contribute more than CCD or TOD.

Table 3.2 Comparison between the feedback model and the conventional model

Scenarios	0–5 km/h (‰)	5–10 km/h (‰)	10–15 km/h (‰)	15–20 km/h (‰)	20–25 km/h (‰)	25–40 km/h (‰)	CO (gram)
Conventional travel demand model without feedback mechanisms							
S1	27.9	54.1	39.6	40.8	38.4	140.7	6.37E+09
S2	24.4	22.3	18.2	21.0	20.8	107.1	5.23E+09
S2-S1	−3.6	−31.9	−21.3	−19.9	−17.6	−33.5	−1.15E+09
Proposed travel demand model with feedback mechanisms							
S1	6.2	19.7	27.4	29.6	25.8	101.1	3.94E+09
S2	5.1	8.4	8.5	9.3	10.7	51.6	2.67E+09
S2-S1	−1.1	−11.4	−18.9	−20.3	−15.1	−49.5	−1.27E+09

To confirm the difference between the application of the newly devolved feedback model and that of the traditional four-step model without incorporating a feedback mechanism, results of simulations of scenarios *S1* and *S2* were compared with those forecasted by the traditional four-step model. The results are compared in Table 3.2. It is obvious that the simulations of *S1* and *S2* by the conventional model without feedback underestimate the changes in total traffic emission volumes of CO, overestimate changes at lower travel speeds (0–15‰) and underestimate the average changes at higher speeds.

3.8 Analysis of Urban Transport Development in Beijing

3.8.1 Scenarios for Urban Transport Development Until 2020

Concerning the future urban transport development in Beijing, seven comprehensive scenarios are assumed and shown in Table 3.3 for the year 2020. The "undeveloped" *Road Network* and "unimproved" *Public Transport Systems* shown in this table indicate that the road network and the bus and subway lines in the year 2020 will remain unchanged from the year 2000. In contrast, the "developed" and "improved" cases for *Road Network* and *Public Transport Systems* are shown in Fig. 3.8, in which the gray lines represent the road network, and the blue and red lines mean the bus and subway lines respectively.

For the *Urban Form* shown in Table 3.3, the TOD represents future population growth, mainly in the TAZs along the bus and railway lines. Because the bus lines are able to serve each of the 340 TAZs in the urban area of Beijing, as clearly shown in Fig. 3.8, TOD is defined according to population, number of students and employment in each TAZ, with average annual rates of increase of 1.33 %, 1.50 % and 0.50 %, respectively. These rates are estimated according to the development statistics of Beijing in recent years. Consequently, it is assumed that the total population of Beijing will increase from 13.82 million in 2000 to 18.00 million in 2020. In contrast, CCD is represented by assuming that future population growth will occur

Table 3.3 Scenarios for the urban transport development in Beijing till 2020

Scenarios	Road network	Urban form	Car ownership	Public transport systems
S1	Undeveloped	TOD	Uncontrolled	Unimproved
S2	Developed	TOD	Uncontrolled	Unimproved
S3	Developed	TOD	Uncontrolled	Improved
S4	Developed	TOD	Controlled	Unimproved
S5	Developed	CCD	Controlled	Unimproved
S6	Developed	PCD	Controlled	Unimproved
S7	Developed	TOD	Controlled	Improved

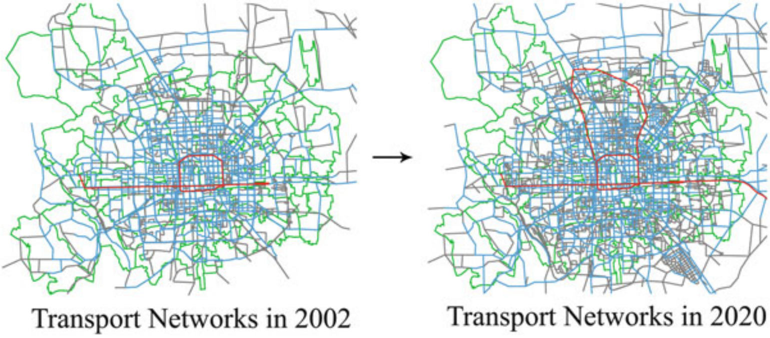


Fig. 3.8 Hypothetical transport networks development in Beijing from 2000 to 2020

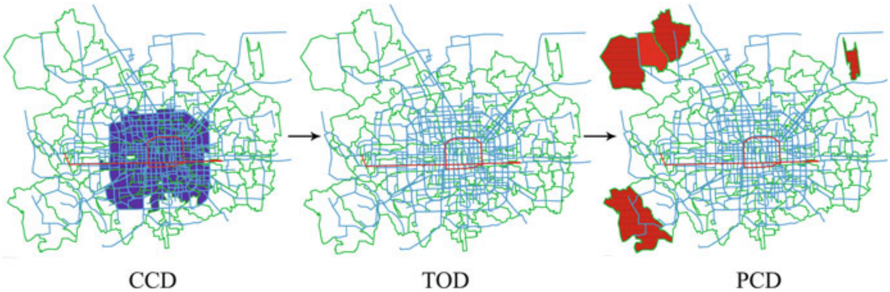


Fig. 3.9 Controlled urban forms for the development of Beijing till 2020

mainly in the TAZs in the central urban area. PCD assumes that population growth will be concentrated mainly in the TAZs of three suburban subcenters. The above-mentioned net average increases in total population are distributed to the TAZs in the central urban area for CCD and the three subcentral areas for PCD, respectively. These controlled urban forms of urban transport development in Beijing are shown in Fig. 3.9.

With respect to *Car Ownership* shown in Table 3.1, the "uncontrolled" scenario indicates that the rate of increase for each TAZ is set at 5.94 % annually from 2000

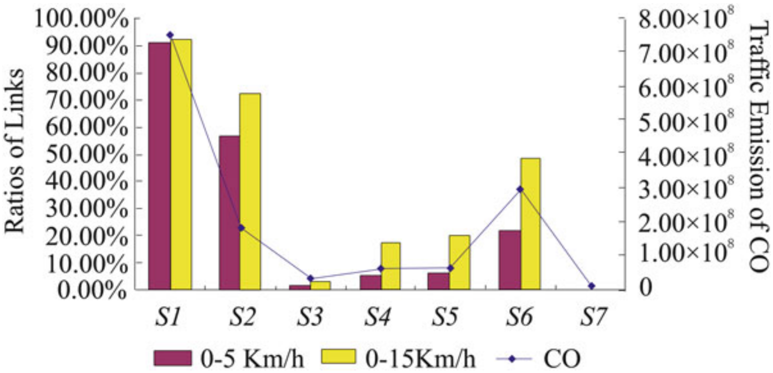


Fig. 3.10 Ratios of road links with low speeds and total volume of CO from traffic emission; Unit of ratios of road links: %, Unit of CO volume: gram

to 2020, a figure based on annual rates of increase in motor-vehicle ownership in Beijing in recent years. Under the "controlled" scenario, the growth ratio is assumed to decrease by 1 % annually.

3.8.2 Distinct Performances of Different Scenarios

To compare the effects of scenarios on urban transport development in Beijing until 2020, changes of travel speed at each link and the total amount of traffic emissions of CO (also one of the main traffic emission pollutants in Beijing) are taken as two indicators. The values of emission factors adopted here are calculated based on studies by He and Wang (2006) and Wang et al. (2005). The predictions of the scenarios presented in Table 3.3 are compared in Fig. 3.10.

According to the study results shown in Fig. 3.10, scenario *S7* is most effective in relieving traffic congestion and protecting the environment. That is, the full implementation of such a policy package is the best option in the sustainable urban transport development of Beijing to 2020. Because the full policy package could be costly and scenario *S3* has similar effects, the improvement of public transport systems could result in an environmentally sustainable transport society, even without control of urban growth and car ownership within the urban area of Beijing. Moreover, by balancing the increase in travel speed and the reduction of emissions, scenario *S4* also seems promising in the sense that promoting the improvement of road networks and effective control of car ownership could provide a satisfactory solution. In addition, comparing the scenarios *S4* and *S5*, it can be observed that TOD and CCD have similar effects. Finally, considering the quite poor PCD effects caused by the huge traffic flows between the subcenters and the main central area, it can be concluded that TOD is more suitable as a future urban development form for Beijing.

3.9 Different Sustainable Urban Forms of Jabodetabek Metropolitan Area and Beijing

According to this study of the application of a proposed feedback model for sustainable urban transport development in Jabodetabek and Beijing, it is first found that without effective action, overall urban transport conditions in both these megacities will deteriorate in terms of not only aggravated traffic congestion but also exacerbated air pollution. Therefore, comprehensive implementation of various policies including construction of new roads, decisions on suitable urban form, restriction of increases in motor-vehicle ownership and improvement in public transport systems is the best way to prevent the current severe urban transport situations in these two developing cities from becoming much worse and to develop their urban transport systems in a sustainable manner. Considering that an integrated policy package would be costly and therefore quite difficult to implement fully in view of the parlous financial state of most developing cities, efficient improvement of public transport systems is an economic and effective means of achieving sustainable urban transport development in developing cities.

At the same time, it is also apparent that polycenter development is better than the alternative urban forms for urban transport in Jabodetabek. This will supposedly result mainly from changes in the distribution of land-use factors. In comparison, the application of the polycenter urban form in Beijing according to the proposed feedback model cannot effectively guide the reasonable distribution of land use, especially that of employment, and consequently it has a quite poor effect because of the huge traffic flows between subcenters and the main central area. The simulation results thus suggest that a transit-oriented urban form is more suitable. The appropriate forms of sustainable urban transport development in Jabodetabek and Beijing require further study and substantiation in future research.

3.10 Conclusions and Future Perspectives

3.10.1 What We Have Done?

Owing to the prosperity of urban economies in most cities in developing countries, especially since the 1990s, the rapidly increasing travel demands in these cities because of the rapid progress of urban transport motorization have far exceeded the seriously lagging development of urban transport infrastructure and facilities. Mainly because of such imbalances between travel demand and supply, urban transport conditions in most developing cities have gone from bad to worse. Severe traffic congestion and vast amounts of traffic emissions have led to substantive economic losses. As a result, in view of these urban transport planning characteristics, extreme lack of survey data, and urgent need for integrated consideration of behavior-based relationships among various essential elements of the urban transport planning system, it is necessary, reasonable and feasible that studies should incorporate feedback mechanisms into models of urban transport planning and decision-making analyses of developing cities confronted with serious urban transport issues.

In this research, a new four-step travel demand prediction model with feedback has been developed. It differs from the conventional four-step model, which, irrationally, is estimated in a top-down sequential manner but is still widely applied because of its practicability. Moreover, the iterative importation of feedback in this study is also dissimilar to previous feedback modeling studies, which are traceable to the feedback method proposed by Evans in 1973 and 1976 (Lan et al. 2003) and categorized by Lam and Huang (1992) into: (1) formulations of the model components as an optimization problem solved directly based on convex combination methods, and (2) iterative feedback modeling usually excluding the trip generation and attraction step from the feedback procedure. The trip generation and attraction analysis here is introduced into the feedback procedure of the proposed model through an indicator of transport accessibility for each trip analysis zone. This feedback model provides a more practical way to reflect appropriately the behavior-based interdependence between transport networks and various aspects of travel behavior using a four-step modeling framework. This method is reasonable and necessary for urban transport studies of modern developing cities with rapid urban growth. Moreover, a multimode and multiclass assignment method is adopted to consider the interactions between types of trips on different networks. As a result, the goodness-of-fit indices for the model estimation of the proposed feedback model are much more satisfactory than the estimation results of the traditional four-step model.

The forecasts of the proposed feedback model for sustainable urban transport development of Jabodetabek and Beijing show that if no effective action is taken, traffic congestion and air pollution in both these megacities will worsen considerably. Therefore, comprehensive implementation of various policies is the best way to prevent the current severe urban transport conditions in these two developing cities worsening and to develop their urban transport systems in a sustainable manner. Considering that an integrated policy package would be costly and therefore quite difficult to implement fully in view of the parlous financial state of most developing cities, efficient improvement of public transport systems is an economic and effective means of achieving sustainable urban transport development in developing cities. At the same time, it is also apparent that polycenter development performs better than the other urban forms for the sustainable urban transport development of Jabodetabek. This is attributable to changes in the distribution of land-use factors. In comparison, the application of the polycenter urban form in Beijing in the proposed feedback model cannot effectively direct the reasonable distribution of land use, especially the distribution of employment, and consequently has a quite poor effect because of the huge traffic flows between subcenters and the main central area. The simulation results suggest that the transit-oriented urban form is more suitable for the development of sustainable urban transport in Beijing.

3.10.2 Further Improvement

1. Adding a New Step to the Four-Step Feedback Model
   An important issue ignored in the feedback modeling approach is the influence of transport networks on changes in the numerical values of the explanatory variables such as population factors and car ownership, of the trip generation and attraction models. Improvements in transport networks usually lead to improved accessibility, which consequently may result in changes in residential and workplace choice behavior across urban space. Such influences may be remarkable, especially in developing cities. To represent such distribution changes and to reflect behavioral mechanisms in a logical manner, Feng et al. (2009) improved the four-step model with feedback by adding the step of spatial population distribution based on the concept of spatial autocorrelation (Getis et al. 2004), where the spatial population distribution is further reflected in the influence of accessibility. With the same person trip data collected in Beijing in 2000, it is empirically confirmed that the integrated model is more accurate than either the feedback model or the conventional model (i.e., the sequentially estimated traditional four-step model). In particular, it is revealed that ignoring the added spatial population step can result in underestimation of environmental emissions. Using the model estimation results, several comprehensive policy scenarios for the future urban and transport development of Beijing are compared using the feedback and integrated models. It is consistently confirmed by both models that comprehensively improving public transport systems and road networks while restricting car ownership is best for the sustainable development of Beijing in terms of urban traffic congestion relief as well as environmental protection.
2. Backcasting Analysis
   Regarding both sustainable and efficient urban transport development, especially in developing cities facing numerous difficulties and challenges, a new backcasting approach with synthesized forecasting techniques has been established by Feng (2009). In this backcasting analysis framework, the integrated travel demand model developed by Feng et al. (2009) is applied to study urban and transport planning policies regarding traffic emissions from the perspective of environmental protection. Moreover, from the viewpoint of sustainable growth of a developing city, the Stochastic Frontier Analysis (Kumbhakar and Lovell 2000) has been adopted to analyze further the environmental efficiency of primary alternatives that satisfy basic traffic emission control targets. Following the proposed backcasting approach, a sustainable path can be found for the environmentally efficient urban transport evolution of Jabodetabek from 2002 to 2050. This path consists of CCD with construction of new roads and uncontrolled household growth from 2002 to 2020, PCD controlling increases in the number of households from 2020 to 2030, TOD with controls on the rise in the number of households from 2030 to 2040, and further PCD, controlling increases in the number of households from 2040 to 2050. This backcasting analysis of the Jabodetabek case confirms that such an approach can offer a practical and reasonable method of

studying and informing the urban transport development of a developing city in a more environmentally friendly manner. However, this backcasting analysis framework is not perfect. Because the abandoned subpaths for a given planning period are unconnected with the results of the policy applications in the next period, the backcasting framework cannot absolutely ensure that the decided path will optimize urban transport development. This shortcoming needs further improvement in future research.

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