Research Article

Analysis of ITMS System Impact Mechanism in Beijing Based on FD and Traffic Entropy

Ailing Huang, Wei Guan, Yimei Chang, and Zhen Yang

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

Correspondence should be addressed to Ailing Huang, alhuang@bjtu.edu.cn

Although more attention has been attracted to benefit evaluation of Intelligent Transportation Systems (ITS) deployment, how ITS impact the traffic system and make great effects is little considered. As a subsystem of ITS, in this paper, Intelligent Transportation Management System (ITMS) is studied with its impact mechanism on the road traffic system. Firstly, the correlative factors between ITMS and the road traffic system are presented and 3 positive feedback chains are defined. Secondly, we introduce the theory of Fundamental Diagram (FD) and traffic system entropy to demonstrate the correlative relationship between ITMS and feedback chains. The analyzed results show that ITMS, as a negative feedback factor, has damping functions on the coupling relationship of all 3 positive feedback chains. It indicates that with its deployment in Beijing, ITMS has impacted the improvement of efficiency and safety for the road traffic system. Finally, related benefits brought by ITMS are presented corresponding to the correlative factors, and effect standards are identified for evaluating ITMS comprehensive benefits.

1. Introduction

1.1. Background

Intelligent Transportation Management System (ITMS) is an advanced system for traffic control, traffic management, and decision-making deployed by road traffic administration. It utilizes technologies and methods of Intelligent Transportation Systems (ITS) to manage the urban road traffic system efficiently, systematically and scientifically, to ensure the traffic system is safer and traffic flow is smoother, promote the environmental protection, and realize energy resource saving. ITMS is one of the research fields of ITS and is one type of ITS applications in road traffic management. The ITMS of Beijing was started to deploy in 2004 and was established and put into practice entirely in 2008. It consists of 1 center and
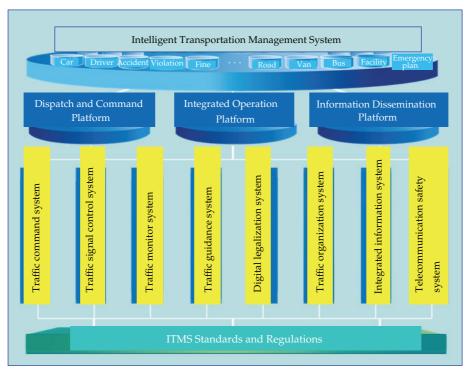
Figure 1: Architecture of ITMS in Beijing.

3 platforms, including the Traffic Management Data Center, the Dispatch and Command Platform, the Integrated Operation Platform, and the Information Dissemination Platform (shown in Figure 1). Based on these center and platforms, 8 related informationized support systems and 99 application subsystems are integrated and developed to mainly function on command and dispatch, traffic signal control, comprehensive supervision, information-provided service, and so forth. With its deployment within the 5th Ring Road in Beijing, the traffic congestion has been alleviated effectively, and some benefits have appeared, such as enhancing traffic capacity, improving service level and road safety, increasing the response to traffic accidents, and reducing environmental pollution. Therefore, more attention has been attracted to study the impacts of ITMS application in Beijing.

1.2. Related Works

The analysis of ITS impact has been a subject of interest for many years; however, the literature mainly emphasized on evaluating ITS benefits qualitatively or quantitatively. On evaluation methods and procedures, in [1], the authors proposed that physical logical structure, market cost, and information interaction structure should be established according to subsystems of ITS, so as to explain the relationship between ITS and estimate socio-economic benefits. Haynes and Li [2] introduced the Probabilistic Multidimensional Scaling Algorithm to evaluate the questionnaires and deploy the subsystems of ITS. The method of Multicriteria Analysis was also applied in ITS impacts evaluation [3]. Both cost-benefit analysis and data envelopment analysis (DEA) [4], one type of multicriteria appraisals,

were applied to analyze the socioeconomic impact of convoy driving systems. A computable general equilibrium (CGE) model was put forward to analyze the impact of ITS on Japan's economy [5]. In addition, a simulation was used to assess the impacts of ITS on the traffic system [6, 7]. Dotoli et al. [8] provided a modeling approach by Petri nets to analyze the impact of Information and Communication Technologies (ICT) on real-time management and operation, as well as the impact on the infrastructures of intermodal transportation systems. Wang et al. [9, 10] brought forward a methodology for model-based digital driving dependability analysis in ITS, which represents an activity in the direction of safety assessment to ITS and gives a new idea how to model digital driving reliability and safety. Recently, Cantarella [11] presented a day-to-day dynamic model, whose application shows that this proposed approach can be applied to model the effect of ITS based both on the value of user surplus and its stability over time.

On ITS impacts and benefits, existing researches such as [12–16] mainly focused on the quantitative evaluation of ITS socioeconomic benefits, and some focused on safety, for example, [7, 17, 18]. Farooq et al. [19] pointed out that ITS affect not only the transportation industry, but also other industries with a quantitative economic analysis through a Leontief's Input-Output (I-O) model [20]. The comprehensive effects, including the environmental and safety benefits, have also been considered in related researches, for example, [21–23].

These efforts have been limited in what ITS effects are and how to evaluate them, but did not refer to how ITS impact the traffic system and why they make effects. Although Newman-Askins et al. [24] pointed out that there was presently little understanding of the causal relationships between ITS projects and their impacts and often it may not be appropriate to transfer results in space and time, they only provided a state-of-practice summary of ITS evaluation methods and impact measurement efforts, without quantitative analysis of the relationship and impact mechanism.

1.3. Motivation and Contribution

To evaluate the influences of ITMS in Beijing comprehensively, it's necessary to identify the impact mechanism of ITMS on the road traffic system, and then define the evaluation content and evaluation system of ITMS effects. The paper is organized as follows. In the next section, we discuss the correlative factors between ITMS and the road traffic system and present 3 positive feedback chains by systemic dynamics theory. In Section 3, according to correlative factors, the intrinsic impact mechanism of ITMS on the road traffic system is studied based on 3 positive feedback chains, respectively. Firstly, the ITMS impact mechanism on travel velocity is illuminated through the Fundamental Diagram (FD) theory. Then with the entropy theory of traffic system, the ITMS impacts on the disequilibrium of road network load and traffic accidents are investigated. Consequently, in terms of the impact mechanism, the effects and benefits brought by ITMS are identified and related evaluation standards are defined in Section 4, which will lay the pretheoretical basis for comprehensive evaluation of ITMS system benefits. Conclusions and an outlook are given in Section 5.

2. Correlative Factors between ITMS and Road Traffic System

It is known that with socioeconomic acceleration of urban development, the vehicle maintenance number increases rapidly and various types of traffic demands expand greatly. Those factors have resulted in the increase of road traffic flow and decrease in traveling speed,
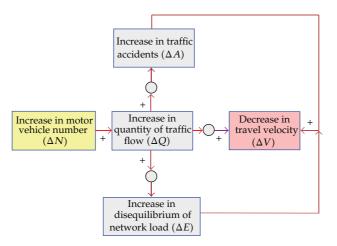
Figure 2: Correlation framework of traffic systematic factors.

and then boosted the occurrence of traffic accidents and enhanced the disequilibrium of road network load. Conversely, the increase of traffic accidents and disequilibrium of network load further impact the decline of traveling speed. We take these factors into consideration and analyze their interactions by the theory of system dynamics. Then we can obtain 3 positive feedback chains as follows:

(1) the growth in motor vehicle number (ΔN) $\rightarrow$ the increase in quantity of traffic flow (ΔQ) $\rightarrow$ the decrease in travel velocity (ΔV),

(2) the growth in motor vehicle number (ΔN) $\rightarrow$ the increase in quantity of traffic flow (ΔQ) $\rightarrow$ the increase in disequilibrium of network load (ΔE) $\rightarrow$ the decrease in travel velocity (ΔV),

(3) the growth in motor vehicle number (ΔN) $\rightarrow$ the increase in quantity of traffic flow (ΔQ) $\rightarrow$ the increase in traffic accidents (ΔA) $\rightarrow$ the decrease in travel velocity (ΔV).

The correlation and interaction between above factors in detail is shown in Figure 2.

Based on above analysis, we introduce the ITMS system into this correlation framework to study its influence. There is no doubt that the deployment of ITMS will exert significant influences on controlling the traveling speed, reducing traffic accidents, and decreasing the disequilibrium of road network load. In all 3 positive feedback chains, ITMS plays a role of negative feedback factor as shown in Figure 3.

According to the ITMS impact mechanism described in Figure 3, we will collect the urban road traffic-related data of Beijing to analyze these 3 feedback chains in the next section.

3. Impact Mechanisms of ITMS on Road Traffic System

3.1. Positive Feedback Chain: $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$

We introduce the ITMS impact into the feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$, as shown in Figure 4. As a negative feedback factor, we can find that ITMS plays a role to restrain the decrease of traveling speed.
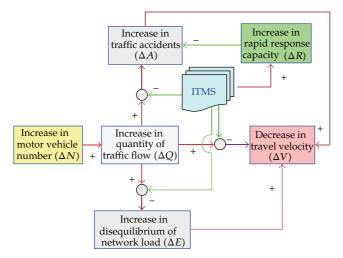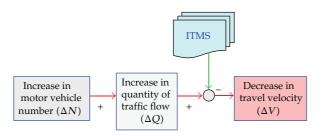
Figure 3: Correlation framework of traffic systematic factors with introducing ITMS as a negative feedback factor.
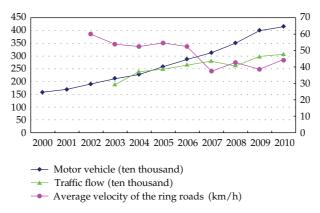

Figure 4: The positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$ with the ITMS impact.
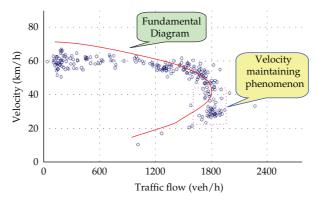
In order to study further the impact of ITMS on the urban traffic system, we will analyze the changes in traffic flow and speed against the growth of motor vehicles.

According to Figure 5, it is found that although the motor vehicle number increases rapidly from the year of 2000 to 2010 in Beijing, the growth rate of traffic flow does not maintain consistent with the rate of motor vehicle increase correspondingly. In particular, we can observe that since 2004 when ITMS was begun to deploy in large scale, in spite of the rapid increase in vehicle number, the growth rate of traffic flow was slowing gradually, and there was an obvious decrease in 2008 when Beijing held the Olympic Games. In addition, the decline rate of ring roads' average velocity did not keep pace with the increase rate of motor vehicle. Since 2004, the decline rate of average velocity was also slowing down. Although in 2007 the average velocity of ring roads dropped to the minimum in recent years, in 2008, it began to rebound and was increasing with ITMS being put into practice in a row.

To explain this phenomenon further, based on the traffic data collected from ring roads of Beijing, we use the FD theory to describe the relationship between travel velocity and traffic flow (shown in Figure 6). According to the forecast by the FD theoretical curve, once traffic flow quantity reaches the saturation value, there will be a sudden drop in average velocity; however, in terms of the real data in Beijing's ring roads, we find that after traffic flow quantity reaches the saturation value of 1,800 veh/h, there is no sudden drop in average

Figure 5: The development trends of motor vehicle maintenance number of Beijing, average traffic flow, and average travel velocity of the 2nd, 3rd, and 4th Ring Roads in Beijing from the year of 2000 to 2010.

Figure 6: Microcosmic data (denoted by "°") of average traffic flow and velocity of the 2nd, 3rd, and 4th Ring Roads in Beijing.
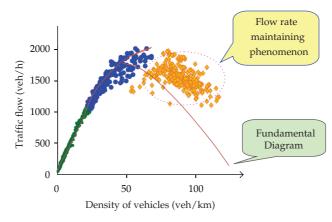
velocity, but there is maintaining in a certain range, which we call it *velocity maintaining phenomenon*.

Likewise, we analyze the relationship between average traffic flow and vehicle density (shown in Figure 7). We also find that when the density of vehicles reaches 100 veh/km saturation value, the real traffic flow in Beijing does not decline as rapidly as what is predicted by the FD theory, but is maintaining in a certain range, which we call it *flow rate maintaining phenomenon*.

Based on above empirical analysis of Figures 4, 5, and 6, abstractly, we can consider that ITMS, as a negative feedback factor, has a damping function on the coupling relationship of positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$. To describe this damping function, we put forward the concepts of *speed maintaining capability* and *flow rate maintaining capability*. The definitions are identified as follows.

3.1.1. Speed Maintaining Capability C_v

Speed maintaining capability C_v means below the critical speed of saturated traffic flow, a rate of traffic flow samples that are with velocity maintaining phenomenon on the overall

Figure 7: Microcosmic data (denoted by "∘") of average traffic flow and vehicle density of the 2nd, 3rd, and 4th Ring Roads in Beijing.

population. It indicates how much traffic flow can maintain in a certain velocity range without a sudden drop after traffic flow quantity reaches the saturation value. C_v is demonstrated as

$$C_v = \frac{n(v,q)\big|_{v \in [v_c - \Delta v, v_c]}}{N(v,q)\big|_{v \leq v_c}} \times 100\%,$$

(3.1)

where $v_c : v\big|_{q=q_{\max}}$ is the critical speed when traffic flow quantity $q = q_{\max}$. Here, v_c, $q_{\max}$ can be defined by a approach presented by one of our authors—Guan and He [25]; Δv demonstrates the increment of velocity; $n(v,q)$ is the sample size of traffic flow when $v \in [v_c - \Delta v, v_c]$; $N(v,q)$ is the overall population when $v \leq v_c$.

3.1.2. Flow Rate Maintaining Capability C_q

Flow rate maintaining capability C_q is a rate of the traffic flow samples with flow rate maintaining phenomenon on the overall population over vehicle critical density. It reflects a degree which the quantity of traffic flow can maintain in a certain flow rate range without a sudden drop since the density of vehicles is larger than the saturation value. C_q is demonstrated as

$$C_q = \frac{n(q,\rho)\big|_{\rho \geq \rho_c, q \in [q_{\max} - \Delta q, q_{\max}]}}{N(q,\rho)\big|_{\rho \geq \rho_c}} \times 100\%,$$

(3.2)

where $\rho_c : \rho\big|_{q=q_{\max}}$ is the critical density when traffic flow quantity $q = q_{\max}$. Here, ρ_c can be defined by [25]; Δq demonstrates the traffic flow increment of volume; $n(q,\rho)$ is the sample size when vehicle density $\rho \geq \rho_c$ and traffic flow quantity $q \in [q_{\max} - \Delta q, q_{\max}]$; $N(q,\rho)$ is the overall population when $\rho \geq \rho_c$.

In the rest of this section, we will calculate C_v and C_q by above equations, based on the traffic flow data of the 2nd, 3rd, and 4th Ring Roads that are collected by Remote
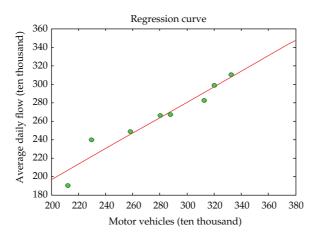
Figure 8: Linearity correlation between motor vehicle number and traffic flow quantity in Beijing.

Traffic Microwave Sensors (RTMS) set up in Beijing, and make an analysis for the computing results. Before computing C_v and C_q, the data outliers have been preprocessed in advance with a method that is presented by Guan and He [26]. Here, the impacts by changes of roads' condition are not considered.

Firstly, through the regression analysis, it is not difficult to find that the two parameters of vehicle number and traffic flow quantity are highly coupled, and the correlation coefficient is 0.96 (shown in **Figure 8**), which indicates that each vehicle in Beijing has nearly traveled one trip on the 2nd, 3rd, or 4th Ring Road every day on average.

Secondly, according to the phase identification of traffic flow on urban freeways [25] in Beijing, we can define q_{max} = 2000 veh/h and then v_c is 40 km/h. Thus, when v_c = 40 km/h, the *speed maintaining capability* C_v of ring roads is calculated as follows:
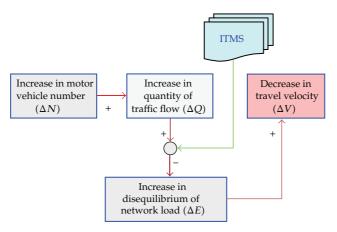
(i) when Δv = 5 km/h, C_v = 17.0%;

(ii) when Δv = 10 km/h, C_v = 45.3%;

(iii) when Δv = 15 km/h, C_v = 90.6%.

This means, for example, after the flow rate reaches its maximum value (q_{max} = 2000 veh/h), the sample data whose speed is between 25 km/h to 40 km/h account for nearly 90% of total population. It reflects that more than 90% of traffic flow still can travel quite smoothly without a sudden transform to stop status after traffic flow quantity reaches the saturation value.

Thirdly, when ρ_c = 50 veh/km (q_{max} = 2000 veh/h), the *traffic flow maintaining capability* C_q of ring roads are as follows:

(i) when Δq = 500 veh/km, C_q = 47.0%;

(ii) when Δq = 800 veh/km, C_q = 83.1%.

This means that when the density is larger than the critical density (ρ_c = 50 veh/km), the sample data whose flow rate is between 1500 veh/h to 2000 veh/h account for 47% of total population, and the sample data whose flow rate is between 1200 veh/h to 2000 veh/h account for 83% of total population. The computing results show that although the density is over the critical value, quite large numbers of traffic flow can maintain in a certain flow rate range without a sudden drop.

Figure 9: The Positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta E \rightarrow \Delta V$ with the ITMS impact.

Consequently, we can draw a conclusion that ITMS, as a negative feedback factor, has a damping function on the coupling relationship in positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$.

3.2. Positive Feedback Chain: $\Delta N \rightarrow \Delta Q \rightarrow \Delta E \rightarrow \Delta V$

In the positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta E \rightarrow \Delta V$, we also introduce the ITMS factor (shown in Figure 9).

Similarly, we need to study the effect and nature of ITMS on the coupling relationship in the positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta E \rightarrow \Delta V$. Here, the *entropy* of the system science theory will be introduced to analyze ITMS impact on this positive feedback chain as follows.

The *entropy* is a state function to indicate the rate of absorbed heat on temperature for material during a reversible process (by Rudolf Clausius in 1865). It is a parameter used to reflect the disorder degree for a system. The larger the entropy is, the more chaotic a system would be. The *entropy ds* of an open system consists of two parts: one is the entropy increase called *entropy production $d_i s$* that is caused by a irreversible process within the system itself; the other is the entropy exchange called *entropy flow $d_e s$* that is caused by exchanging the energy and substance between the system and the outside. The total entropy change ds of an opened system is the sum of *entropy production* and *entropy flow*, that is,

$$ds = d_i s + d_e s. \tag{3.3}$$

In the research field of traffic flow, the entropy theory has been introduced to investigate the traffic systematic characteristics and applied in different cases. For example, on modeling research, the traffic system model based on thermodynamics entropy was constructed to reflect the traffic conditions in [27]. Karmakar and Majumder [28] presented the entropy maximization technique to maximize the flow rate at a given continuous traffic stream, so as to illustrate the flow-concentration relationship. Furthermore, Li et al. [29] considered that trip distribution problems can be modeled as entropy maximization models with quadratic cost constraints, then they proposed an entropy maximization model with

chance constraint and proved it is convex. Lu et al. [30] constructed the entropy solutions for the Lighthill-Whitham-Richards (LWR) traffic flow model with a piecewise quadratic flow-density relationship, which may be used for predicting traffic or as a diagnosing tool to test the performance of numerical schemes. One of latest researches on entropy is that an entropy space method is based on a 3D-space built on a flow-packet level by Velarde-Alvarado et al. [31]. And they modeled the network traffic by using Gaussian Mixtures and Extreme Generalized Distributions. By integrating this model in an Anomaly-Based Intrusion Detection System, anomalous behavior traffic can be detected easily and early. Ngoduy and Maher [32] put forward an effort to find global optimal parameters of a second order macroscopic traffic model using a cross entropy method. On entropy-based applications on traffic system, Montemayor-Aldrete et al. [33] introduced a new concept of the production rate of entropy due to traffic flow. With the use of such a concept, the percentage of increase in the fuel consumption rate due to velocity fluctuations on the traffic flow can be easily determined. Tapiador et al. [34] provided a new measure of Intermodal Entropy to help to characterize high speed train stations (HSTS) and improve their intermodal performance. This variable can also be integrated into models of regional accessibility to take into account the intermodality of HSTS within a single comprehensive estimate. Murat et al. [35] used Shannon Entropy Approach to deal with the determination of black spots' traffic safety levels. In addition, the entropy was applied in traffic assignment problems in [29, 36, 37] and the cross entropy method was used to optimize signal [38]. Chi et al. [39] assumed that each cell of the transportation subnetwork O-D flow table contains an elastic demand function and then proposed a combined maximum entropy-least squares (ME-LS) estimator, by which O-D flows are distributed over the subnetwork so as to maximize the trip distribution entropy, while demand function parameters are estimated for achieving the least sum of squared estimation errors. Although the above entropy-based methods and models are different in different studies, they all show that the essence of entropy could be used to reflect a system's characteristics as an effective approach.

Here, based on the dissipative structure theory, we assess the disequilibrium of road network load in terms of the changes in order degree of an open traffic system by value of system entropy [40].

(1) If $ds > 0$, it shows that traffic system entropy has an increase and the order degree of system will decrease, so it indicates the disequilibrium of road network load will boost;

(2) If $ds < 0$, it reflects that the external environment has provided negative *entropy flow* to the system, and if $d_e s < -d_i s$, the system entropy has a decrease and order degree will increase, so it means the disequilibrium of road network load will decrease;

(3) If $ds = 0$, it indicates that the order degree of system, that is, the disequilibrium of road network load, is essentially invariable.

In order to calculate the value of entropy in a traffic system, the following will introduce the definition of *information*. *Information* is a measure to the degree of uncertainty for a system. For a given random variable X, the probability of the event x_i is $p(x_i)$, then the *self-information* $I(x_i)$ of the event x_i is defined as, [41],

$$I(x_i) = -C \log_{10} p(x_i), \quad x_i \in X, \tag{3.4}$$
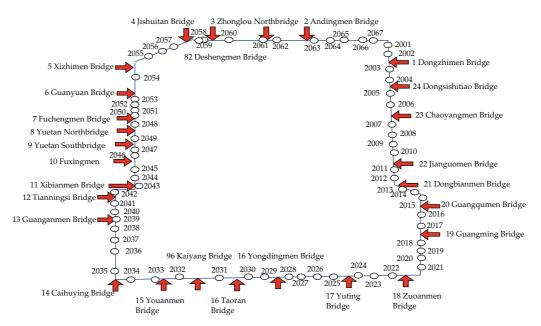
where C is a constant.

Figure 10: The 2nd Ring Road in Beijing marked with 24 sections.

In 1948, Claude Elwood Shannon introduced the *entropy* into the concept of *information*. And the *entropy* $H(x)$ of a discrete random variable X is identified as

$$H(x) = -C \sum_{i=1}^{n} p(x_i) \log_{10} p(x_i), \tag{3.5}$$

where C is a constant.

It can be found that the *entropy* is a statistical probability-weighted average of *self-information* in terms of (3.4) and (3.5). The *self-information* $I(x_i)$ and *entropy* $H(x)$ are the functions of probability and unrelated to the value of the variables.

According to the above definitions, we use the concept of *traffic entropy* to estimate the disequilibrium of road network load. The *traffic entropy* $E(t)$ is demonstrated as, [42],

$$E(t) = -C \sum_{i=1}^{n} k_i \cdot p_i \cdot \log_{10} p_i, \tag{3.6}$$

where $E(t)$ is the entropy of a road traffic system, and C is a constant; k_i is the weight of the road section i, $\sum_{i=1}^{n} k_i = 1$; $p_i = \{\Delta \lambda_i / \sum_{i=1}^{n} \Delta \lambda_i, i = 1, 2, 3, \ldots, n\}$ is distribution of congestion deviation 9, $\sum_{i=1}^{n} p_i = 1$; $\Delta \lambda_i = \max\{(\lambda_i - 0.8), 0\}$ is congestion deviation of the road section i; λ_i denotes the average congestion degree, and it is a rate of traffic flow on capacity in section i; and $\lambda = 0.8$ is threshold of congestion.

Then we will illustrate the meaning of *traffic entropy* by calculating entropy of the 2nd Ring Road of Beijing in 2004 and 2008, respectively. The 2nd Ring Road shown in Figure 10 is marked with 24 sections, that is, $i = 1, 2, \ldots, 24$.
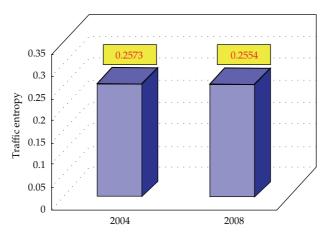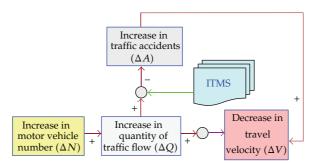
Figure 11: Traffic entropies of the 2nd Ring Road in 2004 and 2008 in Beijing.

Figure 12: The positive feedback chain $\Delta N \to \Delta Q \to \Delta A \to \Delta V$ with the ITMS impact.

Based on the empirical data, we estimate the traffic entropies of the 2nd Ring Road in 2004 and 2008 by (3.5). The comparison of these two entropies is shown in Figure 11.

Figure 11 shows that the traffic entropy of 2008 does not increase, but decrease slightly comparing with that of 2004, which means that the order degree has increased and the disequilibrium of road network load decreased despite the rapid growth in vehicle number. Therefore, we can get a conclusion that ITMS, as a negative feedback factor, has a damping function on the coupling relationship of positive feedback chain $\Delta N \to \Delta Q \to \Delta E \to \Delta V$.

3.3. Positive Feedback Chain $\Delta N \to \Delta Q \to \Delta A \to \Delta V$

In the same way, we introduce the ITMS impact into the positive feedback chain $\Delta N \to \Delta Q \to \Delta A \to \Delta V$, which is shown in Figure 12.

In terms of the statistic date, the number of traffic accidents in 2008 has decreased from 5,425 to 1,960 comparing with that of 2004 (shown in Figure 13), with the decreased accidents accounting for about 62.03% of 2004; while the number of vehicles is growing increasingly, the total length of road has extended from 4,064 km to 6,186 km and the total area of road from 64.17 million m^2 to 89.40 million m^2. It indicates that the safety of urban traffic system has been improved with ITMS deployment and application. So we can draw a conclusion
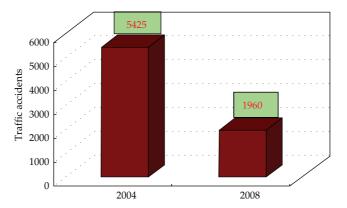
Figure 13: Comparison of traffic accidents number between 2004 and 2008 in Beijing.

that ITMS has a damping function on the coupling relationship of positive feedback chain $\Delta N \rightarrow \Delta Q \rightarrow \Delta A \rightarrow \Delta V$ as a negative feedback factor.

4. Benefits and Evaluation Standard of ITMS on Road Traffic System

Based on above analysis, it can get a conclusion that with the deployment of ITMS in Beijing, the negative influence on traveling speed, road traffic safety, and the disequilibrium of network load aroused by the increase of traffic flow have been weakened efficiently. ITMS has effects on improving road traffic efficiency, alleviating traffic congestion, and enhancing road service capacity. According to the impact mechanism, the benefits brought by ITMS can be concluded in 4 aspects: socioeconomic benefit, energy resource and environmental benefits, traffic safety, and management efficiency.

For each benefit aspect, we identify standards for evaluating benefits of ITMS. The evaluation standards of socioeconomic benefit can be mostly derived from the increase of travel velocity, mainly including (1) reduction in vehicles' operational cost, (2) reducing traveling time, and (3) investment reduction on land resource and transportation infrastructure (shown in Figure 14). And the standards of energy resources and environmental benefits consist of (1) decrease in traffic noise, (2) decrease in vehicle tailpipe emission, (3) greenhouse gas emission, (4) reduction of energy resource, and (5) improvement on consumption structure of energy resource, which are also brought mainly because of the increase in travel velocity (shown in Figure 14).

For evaluation standards of traffic safety benefits, because of the decrease in traffic accidents and improvement on vehicle safety, they can be denoted by (1) reduction in vehicle loss, (2) loss of vehicle stolen or robbed, (3) decrease in loss of personal casualty, and (4) loss of social public institution service (shown in Figure 15). The management efficiency for road administrations can be indicated by the increase in response time for alarm (shown in Figure 15).

5. Conclusion

Summing up, in this paper, in order to investigate the ITMS impacts on road traffic system, we have introduced 3 positive feedback chains to analyze the correlative factors between
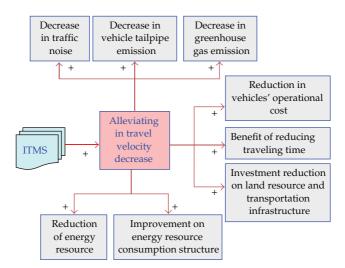
Figure 14: Benefits of social economy, energy resource and environment, and related evaluation standards.
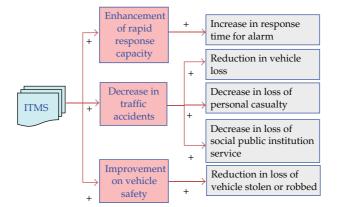

Figure 15: Benefits of traffic safety and management efficiency and related evaluation standards.

ITMS and road traffic system. The results show that ITMS has damping functions on the coupling relationship of 3 positive feedback chains $\Delta N \rightarrow \Delta Q \rightarrow \Delta V$, $\Delta N \rightarrow \Delta Q \rightarrow \Delta E \rightarrow \Delta V$, and $\Delta N \rightarrow \Delta Q \rightarrow \Delta A \rightarrow \Delta V$ as a negative feedback factor. This indicates that with its deployment in Beijing, ITMS has impacted significantly the improvement on road traffic efficiency, alleviation of traffic congestion, and enhancement of road service capacity. Accordingly, in terms of this impact mechanism, the benefits of ITMS deployment have been presented and related evaluation standards are identified, which provides a comprehensive evaluation framework for subsystems of ITS. Such analyses would provide richer information for ITS benefits evaluation. Indeed, some policy factors, such as traffic regulation and limitation of vehicle use during period of 2008 Olympic Games, are not taken in account to analyze the impact mechanism. But our paper present an approach to study the ITS impacts from a new view point. Given more data, future work would focus on considering the above policy factors and quantifying the impact benefits.

Acknowledgments

References

[1] H. Lo, M. Hickman, and S. Weissenberger, "Structured approach for ITS architecture representation and evaluation," in *Proceedings of the 6th Vehicle Navigation and Information Systems Conference*, pp. 442–449, August 1995.

[2] K. E. Haynes and M. Li, "Analytical alternatives in intelligent transportation system (ITS) evaluation," *Research in Transportation Economics*, vol. 8, pp. 127–149, 2004.

[3] K. D. Brucker, A. Verbeke, and C. Macharis, "The application of multicriteria -analysis to the evaluation of intelligent transport systems," *Research in Transportation Economics*, vol. 8, pp. 151–179, 2004.

[4] Z.-C. Juan, J.-P. Wu, and M. McDonald, "Socio-economic impact assessment of intelligent transport systems," *Tsinghua Science and Technology*, vol. 11, no. 3, pp. 339–350, 2006.

[5] T. Kawakami, P. Tiwari, and M. Doi, "Assessing impact of ITS on Japan's economy using a computable model," *Research in Transportation Economics*, vol. 8, pp. 525–547, 2004.

[6] H. Liu, L. Chu, and W. Recker, "Performance evaluation of ITS strategies using microscopic simulation," in *Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems (ITSC '04)*, pp. 917–921, Washington, DC, USA, October 2004.

[7] M. Vanderschuren, "Safety improvements through Intelligent Transport Systems: a South African case study based on microscopic simulation modelling," *Accident Analysis and Prevention*, vol. 40, no. 2, pp. 807–817, 2008.

[8] M. Dotoli, M. P. Fanti, A. M. Mangini, G. Stecco, and W. Ukovich, "The impact of ICT on intermodal transportation systems: a modelling approach by Petri nets," *Control Engineering Practice*, vol. 18, no. 8, pp. 893–903, 2010.

[9] W.-H. Wang, H.-W. Guo, H. Bubb, and K. Ikeuchi, "Numerical simulation and analysis procedure for model-based digital driving dependability in intelligent transport system," *KSCE Journal of Civil Engineering*, vol. 15, no. 5, pp. 891–898, 2011.

[10] W.-H. Wang, *Vehicle's Man-Machine Interaction Safety and Driver Assistance*, China Communications Press, Beijing, China, 2012.

[11] G. E. Cantarella, "Day-to-day dynamic models for intelligent transportation systems design and appraisal," *Transportation Research Part C*. In press.

[12] L. K. Pekka and L. H. Jukka, "Profitability evaluation of intelligent transport system investments," *Journal of Transportation Engineering*, vol. 128, no. 3, pp. 276–286, 2002.

[13] Y. J. Nakanishi and J. C. Falcocchio, "Performance assessment of intelligent transportation systems using data envelopment analysis," *Research in Transportation Economics*, vol. 8, pp. 181–197, 2004.

[14] T. Moore and R. Pozdena, "Framework for an economic evaluation of transportation investments," *Research in Transportation Economics*, vol. 8, pp. 17–45, 2004.

[15] A. Stevens, "The application and limitations of cost-benefit assessment (CBA) for intelligent transport systems," *Research in Transportation Economics*, vol. 8, pp. 91–111, 2004.

[16] W. Chris and M. Mahmoud, "Transportation benefit-cost analysis: lessons from CAL-B/C," in *Proceedings of the 87th Annual Meeting of Transportation Research Board*, pp. 79–87, Washington, DC, USA, 2004.

[17] T. Vaa, M. Penttinen, and I. Spyropoulou, "Intelligent transport systems and effects on road traffic accidents: state of the art," *IET Intelligent Transport Systems*, vol. 1, no. 2, pp. 81–88, 2007.

[18] R. Kulmala, "Ex-ante assessment of the safety effects of intelligent transport systems," *Accident Analysis and Prevention*, vol. 42, no. 4, pp. 1359–1369, 2010.

[19] U. Farooq, M. A. Siddiqui, L. Gao, and J. L. Hardy, "Intelligent transportation systems: an impact analysis for michigan," *Journal of Advanced Transportation*, vol. 46, pp. 12–25, 2012.

[20] W. Leontief, "Quantitative input and output relations in the econometric system of the United States," *The Review of Economic Statistics*, vol. 18, pp. 105–125, 1936.

[21] B. J. Kanninen, "Intelligent transportation systems: an economic and environmental policy assessment," *Transportation Research A*, vol. 30, no. 1, pp. 1–10, 1996.

[22] J.-C. Thill, G. Rogova, and J. Yan, "Evaluating benefits and costs of intelligent transportation systems elements from a planning perspective," *Research in Transportation Economics*, vol. 8, pp. 571–603, 2004.

[23] F. Shi, J. Lu, and W. Wang, "Method of benefits evaluation for urban traffic command center and its application," *Computer and Communications*, vol. 22, no. 2, pp. 43–46, 2004.

[24] R. Newman-Askins, L. Ferreira, and J. Bunker, "Intelligent transport systems evaluation: from theory to practice," in *Proceedings of the 21st ARRB and 11th REAAA Conference, Transport Our Highway to a Sustainable Future*, pp. 1011–1026, May 2003.

[25] W. Guan and S.-Y. He, "Statistical features and phase identification of traffic flow on urban freeway," *Journal of Transportation Systems Engineering and Information Technology*, vol. 7, no. 5, pp. 42–50, 2007.

[26] W. Guan and S.-Y. He, "Statistical features of traffic flow on urban freeways," *Physica A*, vol. 387, no. 4, pp. 944–954, 2008.

[27] C.-Y. Sheng, Y.-L. Pei, and L.-N. Wu, "Traffic entropy characteristics at on-ramp junctions on urban freeway," *Journal of Jilin University*, vol. 37, no. 6, pp. 1273–1277, 2007.

[28] K. Karmakar and S. K. Majumder, "Maximum entropy approach in a traffic stream," *Applied Mathematics and Computation*, vol. 195, no. 1, pp. 61–65, 2008.

[29] X. Li, Z.-F. Qin, L.-X. Yang, and K.-P. Li, "Entropy maximization model for the trip distribution problem with fuzzy and random parameters," *Journal of Computational and Applied Mathematics*, vol. 235, no. 8, pp. 1906–1913, 2011.

[30] Y.-D. Lu, S. Wong, M.-P. Zhang, C.-W. Shu, and W.-Q. Chen, "Explicit construction of entropy solutions for the lighthill-whitham-richards traffic flow model with a piecewise quadratic flow—density relationship," *Transportation Research B*, vol. 42, pp. 355–372, 2008.

[31] P. Velarde-Alvarado, A. F. Martínez-Herrera, and A. Iriarte-Solis, "Using entropy spaces and mixtures of gaussian distributions to characterize traffic anomalies," *Procedia Technology*, vol. 3, pp. 97–108, 2012.

[32] D. Ngoduy and M. J. Maher, "Calibration of second order traffic models using continuous cross entropy method," *Transportation Research C*, vol. 24, pp. 102–121, 2012.

[33] J. A. Montemayor-Aldrete, P. Ugalde-Vélez, M. D. Castillo-Mussot, C. A. Vázquez-Villanueva, G. J. Vázquez, and A. Mendoza-Allende, "Steady state traffic flow, entropy production rate, temporal fluctuations and fuel consumption," *Physica A*, vol. 361, no. 2, pp. 630–642, 2006.

[34] F. J. Tapiador, K. Burckhart, and J. Martí-Henneberg, "Characterizing European high speed train stations using intermodal time and entropy metrics," *Transportation Research A*, vol. 43, no. 2, pp. 197–208, 2009.

[35] Y. S. Murat, "An entropy (shannon) based traffic safety level determination approach for black spots," *Procedia Social and Behavioral Sciences*, vol. 20, pp. 786–795, 2011.

[36] H. Bar-Gera, "Traffic assignment by paired alternative segments," *Transportation Research B*, vol. 44, no. 8-9, pp. 1022–1046, 2010.

[37] S. Lu and Y. Nie, "Stability of user-equilibrium route flow solutions for the traffic assignment problem," *Transportation Research B*, vol. 44, no. 4, pp. 609–617, 2010.

[38] M. Maher, R.-h. Liu, and D. Ngoduy, "Signal optimisation using the cross entropy method," *Transportation Research Part C: Emerging Technologies*. In press.

[39] X. Chi, K. M. Kockelman, and T. Waller, "A maximum entropy-least squares estimator for elastic origindestination trip matrix estimation," *Procedia Social and Behavioral Sciences*, vol. 17, pp. 189–212, 2011.

[40] W.-T. Fan, W. Jia, and Y.-M. Ding, "A possible approach to the framework of the fundamental theory of system science: part ten," *System Engineering Theory & Practice*, vol. 8, pp. 19–20, 2002.

[41] Z.-X. Ye, *Basic Information Theory*, Higher Education Press, Beijing, China, 2003.

[42] W. Nie, C.-F. Shao, and L.-Y. Yang, "Study on the application of dissipative structure and entropy change theory in regional transportation system," *Journal of Highway and Transportation Research and Development*, vol. 23, no. 10, pp. 1–10, 2006.