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RESEARCH PAPER

# Benefit Evaluation Framework of Intelligent Transportation Systems

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**Abstract:** This study proposes a practical framework to assess the evaluable societal profitability of Intelligent Transportation Systems (ITS) projects, which are widely implemented in many cities of China. This work aims to estimate the whole economic benefit into an outcome figure which received great care from government authorities and transportation engineers. The initiative of proved framework is to maintain both the practicability in terms of data accessibility in societal reality and scalability in terms of its convincingness and academic value. A case study of assessing intelligent transportation management and control system in Beijing is conducted to further illustrate the proposed methodology. The investment for ITS can be enlarged more than 20 times, which shows significant "leverage effect" of ITS investment, and establishing intelligent transportation systems is an effective way to resolve the conflicts between sharply increasing motor vehicle amount and limited city land resources.

**Key Words:** intelligent transportation; evaluation framework; economic benefit; ITS project

## 1 Introduction

The application of information technology in transportation is concentrated in the generation and development of intelligent transportation system (ITS). With the development of urban intelligent transportation management and control system, people have to examine the transportation system with a broader perspective. Transportation system has not only been confined to the purpose of transferring people or object, but also for the realization of transferring service and information. The application of ITS can generate potential evaluable social economic benefits through improving road capacity, saving manpower, reducing the number of traffic accidents, and environmental pollution. However, just as the emerging technologies, most of the ITS are different from traditional infrastructure projects. With no sufficient experiences, their economic, social and environmental impacts are unpredictable and their risks and costs are difficult to determine. No authority method is formed yet to evaluate ITS projects as the traditional transportation evaluation methods. To sum up, it has become an urgent task to research and analyze the influence generated by the implementation of the urban ITS projects. Since 2000, the motor vehicle inventory has grown rapidly, with an average annual growth rate of 10.91%, but the average annual growth rate of the length of urban road in Beijing is only 3.64%. After the implementation of the ITS project in 2005, the conflict between a rapid growth of motor vehicle inventory and a slow growth of urban road has been alleviated to a certain extent. The system has played an important role in improving road capacity, saving human resources and reducing the number of traffic accidents. The evaluable social economic benefits from the implementation of the ITS project has got much attention and the leverage generated by the investment of the system needs further studies.

Through related literature retrieval, the closest research is the urban traffic control center benefit evaluation method put forward by Professor Wang Wei, from the Southeastern University[1]. By taking Suzhou traffic command center as an example, he made a quantitative analysis on the benefits generated by the implementation of the system. Prof. Wang is also very successful in the research for the sustainable development of urban traffic system[2] and motor vehicle emission factor[3]. Some domestic scholars have other ideas in

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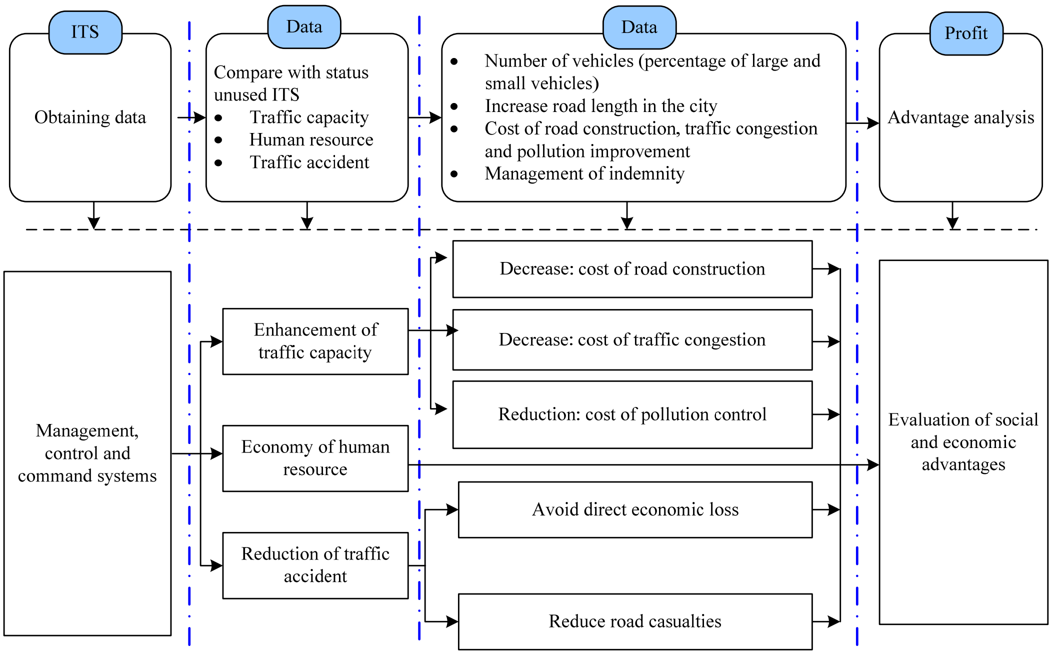


Fig. 1 Evaluation framework of ITS

the analysis on the ITS efficiency which are as follows: considering the three aspects as the delay cost, fuel cost, as well as emission module and through the changes before and after the completion of the system[4,5]. Foreign researchers have studied the multiple influences generated by the implementation of ITS projects from the perspective of simulation[6]. At the same time, some scholars have analyzed the efficiency of investments on traditional transportation infrastructures and the ITS project through actual examples[7]. Other scholars established cost-benefit analysis forms to encapsulate established relevant evaluation models[8].

## 2 Evaluation framework of ITS project

The aforementioned studies have given out some different perspectives and solutions in ITS projects assessment and can be used in different circumstances but with limitations. However, the problem is that neither of them is organized in a whole-to-part and top-down structure; instead, they mostly go in a bottom-up and part-to-whole way. Thus, when it comes to other real cases that have different structures in systems' application or different bottom-level features to evaluate, or simply cannot provide specific detailed data, they fail to work. In a word, these studies specialize in unique cases yet all bear a lack of universality and practicality in reality applications. This is why the authors do not apply any of these to evaluate Beijing intelligent transportation management and command system; while instead, we try to establish a universal framework in the first place.

Combing with experience in ITS design and construction, we have provided an evaluation framework of ITS for assessing social and economic advantages, and this evaluation method has been used by Beijing Traffic Management Bureau for evaluating advantages of intelligent transportation management and command system. The evaluation framework of ITS is shown in Fig. 1.

First, the most important indexes are chosen to compare the traffic system's performances before and after the ITS project is implemented. Different with the above-mentioned evaluation methods, these indexes can be obtained from official sources easily and they can also represent advantages of implementing ITS. In our research, the enhancement of traffic capacity, the economy of human resources and the reduction of traffic accidents are indexes of ITS.

Second, the ITS benefit evaluation is not a simple addition of the above-mentioned three kinds of indexes, since the unit of these indexes are all different. For solving this problem, these indexes should be converted into economic advantages with the same unit. The enhancement of traffic capacity stands for the saving cost of road construction, traffic congestion and pollution control; the application of ITS can lead to the reduction of law enforcement officials, which can save the cost of human resources; traffic accidents will also decrease because the intelligent transportation management and command system is applied, and the reduction of traffic accidents can avoid direct economic loss and reduce road casualties.

Finally, ITS social and economic advantages can be calculated through accumulating each index's economic advantages.

Table 1 Formulas for calculating ITS benefits

| Formula | Symbol | Meaning (Unit) | Expression |
|---|---|---|---|
| (1) | $\Delta C$ | Cost of traffic congestions decreased (Yuan/(month·cars)) | $EB = \Delta C \times T \times \sum_{i=2006}^{2008} N_i$ |
| | $T$ | Time (month) | |
| | $N_i$ | Vehicle inventory in the year $i$ (10,000 cars) | |
| | $EB$ | Economic benefit (billion Yuan) | |
| (2) | $R$ | Average contribution rate | $EB = R \times \sum_{i=2006}^{2008} I_i \times P$ |
| | $P$ | Percentage share of investment | |
| | $I_i$ | Investments in environmental protection in the year $i$ (100 million Yuan) | |
| | $EB$ | Economic benefit (100 million Yuan) | |
| (3) | $\Delta I$ | Police forces decreased (people/year) | $EB = \Delta I \times \sum_{i=2003}^{2008} W_i$ |
| | $W_i$ | Per capita wages in the year $i$ (10,000 Yuan) | |
| | $EB$ | Economic benefit (million Yuan) | |
| (4) | $\Delta C_i$ | Evaluable saved compensation in the year $i$ (100 million Yuan) | $EB = \sum_{i=2005}^{2008} \Delta C_i$ |
| | $EB$ | Economic benefit (100 million Yuan) | |

Table 2 Cost of road construction in Beijing (Unit: 10,000 Yuan)

| | Expressway | Main road | Subsidiary road |
|---|---|---|---|
| Land acquisition | 2 000 | 1 000 | 550 |
| Building road | 5 000 | 2 500 | 1 350 |
| Supporting facilities | 3 000 | 1 500 | 800 |
| Summation | 10 000 | 5 000 | 2 700 |

Table 3 Motor vehicle emission factors and average speed in Beijing (Unit: g/km)

| Average speed (km/hour) | Motor vehicle emission | Passenger vehicle | Cargo vehicle |
|---|---|---|---|
| 15 | HC | 11.4 | 31.3 |
| | CO | 66.5 | 186.8 |
| | $NO_x$ | 2.0 | 9.6 |
| 25 | HC | 6.9 | 14.3 |
| | CO | 45.6 | 123.3 |
| | $NO_x$ | 1.8 | 4.5 |
| 45 | HC | 4.3 | 9.4 |
| | CO | 21.8 | 78.2 |
| | $NO_x$ | 1.9 | 5.1 |

## 3 A case study of Beijing ITS economic advantages evaluation

According to the evaluation framework of ITS, an evaluable social economic benefit analysis method for the Beijing urban intelligent transport management and control system can be used. After being put into use, the system has reached certain achievements in improving highway capacity, saving manpower, and reducing traffic accidents. An improvement in highway capacity can help reduce the cost of urban road construction, traffic congestion and the control of environmental pollution. Through these three aspects, we can estimate the social profitability arising from the improvement in road capacity. Although the number of motor vehicles in Beijing has kept increasing rapidly, without a decline in the level of service, manpower is saved due to the implementation of the ITS project and thus the cost of human resources is reduced. At the same time, the casualties caused by traffic accidents has been reduce significantly and substantive losses are avoided. We can evaluate the social economic benefit produced after the implementation of the ITS project by colligating the three aspects mentioned earlier. According to the above-mentioned three aspects, the formulas for calculating ITS economic advantages are shown in Table 1.

### 3.1 Social economic benefits from the improvement of road capacity

In this part of the section, the improvement of road capacity posed by the Beijing intelligent transportation management and control system and correspondingly its convertible social economic benefits are studied and calculated thoroughly. The effect of the road capacity improvement can actually be separated into three aspects that have no overlapped part in terms of their economic benefits.

From 2000 to 2008, the average annual increase rate of motor vehicles is calculated to be 10.91 %.The average annual increase rate of the length of urban roads in Beijing is merely 3.64%. Thus, the increase rate of motor vehicles is much greater than that of urban roads, with a difference of 7.27%. Because of the urban geographical conditions, it is impossible to meet the need of the rapid increase in motor vehicle inventory only by construction of roads. Beijing urban roads include the center city expressways, the center city roads, and city sub-roads. Table 2 shows the average construction cost of these kinds of roads. The average construction cost of urban roads in Beijing is calculated to be 59 million Yuan per kilometer.

To maintain the traffic conditions, the newly constructed road lengths in terms of percentage should be the same as motor vehicles as in traditional transportation infrastructure solutions, which means that the ITS project's social economic benefits in this counterpart is worth 267 km. To sum up, in the aspect of road construction, the maximum evaluable social economic benefits since the operation of the system can be calculated, which is 15.57 billion Yuan in total.

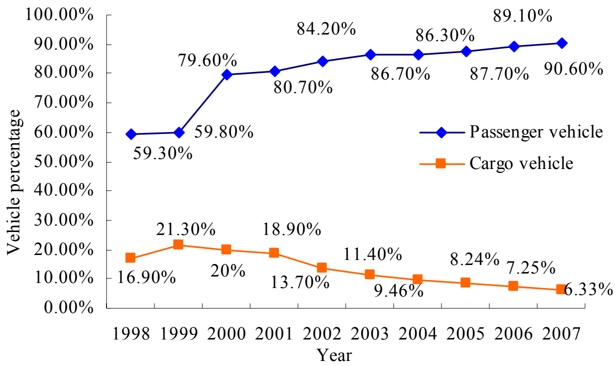


Fig. 2 Percent of passenger and cargo vehicles in Beijing from 1998 to 2007

Table 4 Several indexes of motor vehicle emission in Beijing

| Motor vehicle emission | Decline percent | Sharing rate | Contribution rate |
|---|---|---|---|
| HC | 15% | 83% | 12.45% |
| CO | 11.5% | 78% | 8.97% |
| NOx | 5% | 46% | 2.3% |

Table 5 Investments in environmental protection in Beijing from 2006 to 2008 (Unit: 100 million Yuan)

| Year | Investments | Percent of GDP (%) |
|---|---|---|
| 2006 | 250.4 | 3.24 |
| 2007 | 248.2 | 2.76 |
| 2008 | 265.7 | 2.53 |

Table 6 Per capita wages in Beijing from 2003 to 2008 (Unit: Yuan)

| Year | Per capita wages |
|---|---|
| 2003 | 25 312 |
| 2004 | 28 800 |
| 2005 | 32 808 |
| 2006 | 36 097 |
| 2007 | 39 867 |
| 2008 | 45 000 |

### 3.2 Cost of traffic congestion

As the international union of public transport (UITP) estimated, the annual economic loss by traffic congestions in the world is 500 billion dollars in average, including 3.5 billion dollars in London, and 6 billion dollars in Paris[9]. According to the Living Mobility Index Report of Chinese Residents, which is issued by the Zero Point Research & Consultancy Group and the Forland automobile company in 2005, motor vehicle owners have paid 375 Yuan per month for traffic congestions in average[10].

After the implementation of the ITS projects in 2005, the average travel time has decreased by 13.38% through the improvement of road capacity. Thus, the decrease in the cost of traffic congestions is 375×13.38%=50 Yuan per vehicle per month in average. On the basis of the motor vehicle inventory (as shown in Fig. 2), the economic benefit from the decrease in the cost of traffic congestions from 2006 to 2008 can be calculated as formula (1), which reaches 5.7 billion Yuan.

### 3.3 Control of urban environmental pollution

The relationship between motor vehicle emission factors and the average speed in Beijing is shown as Table 3[11]. According to statistics, the average speed of motor vehicles in Beijing has increased from 17.92 km/h to 21.46 km/h after the implementation of the ITS project. By integrating the result with the proportion of passenger vehicles and cargo vehicles (Fig. 2), declines in the proportion of pollutant emissions due to the enhancement in average speed that is caused by the improvement of the road capacity are calculated, and the results are shown in Table 4. It also shows the share rates of pollutants emitted by motor vehicles in Beijing[12], and the effects of the enhancement of the average speed of motor vehicles in lowering the emissions of major urban pollutants. Colligating the information given in Table 4, after the implementation of the ITS project, the enhancement in average speed results in an average contribution rate of 7.9% to the decline in urban pollutants in Beijing. According to Bulletin of Beijing Environmental State and a report published by Beijing Environmental Protection Agency, the total amount of investment in environmental protection in Beijing from 2006 to 2008 and the percentage share of GDP are shown in Table 5. The data shows that two-thirds of the investment is used to control air pollution[13].

Based on above-mentioned analysis, a calculation formula (2) is formed (shown Table 1), through which we can calculate the social economic benefits generated by reducing costs in environmental pollution control after implementation of the ITS project, which reach 3.985 billion Yuan.

### 3.4 Social economic benefits generated by saving human resources

According to the statistics, by a gradual adoption of the intelligent transport management and control system from 2003 to 2008, 1600 in all has been preserved in terms of police forces, with an average of 267 per year. Table 6 is about the per capita wages in Beijing from 2003 to 2008.

Based on the data in the table, the economic benefits generated by saving human resources as the system has gradually been put into operation can be calculated with formula (3), which amount to 56 million Yuan.

### 3.5 Social economic benefits generated by decreasing frequency of traffic accidents

(1) Avoidance of direct economic losses

Figure 3 shows the data of direct economic losses from traffic accidents in Beijing from 1998 to 2007, which is from Beijing Statistical Yearbook. Before the implementation of the system (1998–2004), the average annual economic losses due to traffic accidents were 92.24 2million Yuan, which is

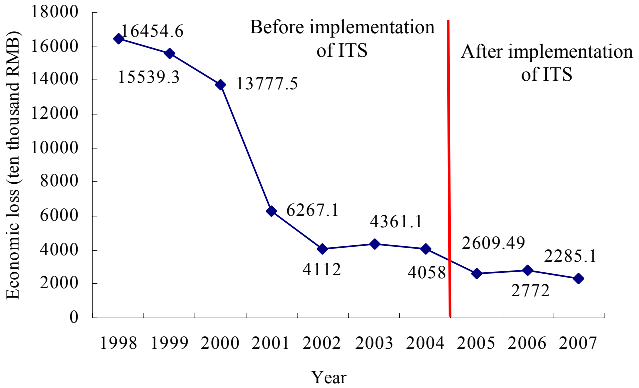


Fig. 3 Direct economic losses from traffic accidents in Beijing from 1998 to 2007

Table 7 Death toll per 10,000 motor vehicles in Beijing from 2003 to 2008

| Year | Death Toll per 10,000 Motor Vehicles |
|---|---|
| 1998 | 11.5 |
| 1999 | 10.8 |
| 2000 | 9.8 |
| 2001 | 8.8 |
| 2002 | 7.9 |
| 2003 | 7.73 |
| 2004 | 7.59 |

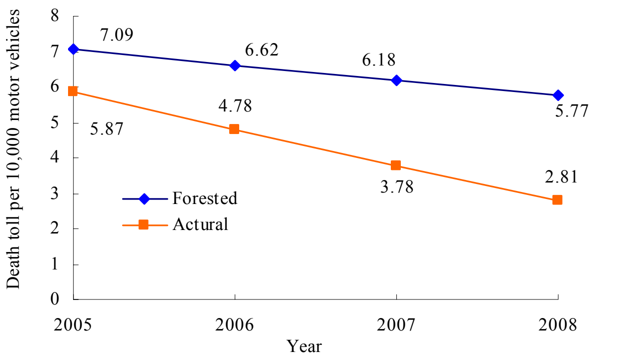


Fig. 4 Comparative analyses on death toll per 10,000 motor vehicles from 2005 to 2008.

Table 8 Evaluable saved compensation

| Year | Reduction of road casualties | Disposal income of Beijing people (Yuan) | Summation (100 million Yuan) |
|---|---|---|---|
| 2005 | 315 | 1 7653 | 1.11 |
| 2006 | 529 | 1 8670 | 1.97 |
| 2007 | 750 | 1 9978 | 2.99 |
| 2008 | 1 037 | 2 1989 | 4.56 |

reduced to 25.55 million Yuan after the completion of the system (2005–2007). With the system, direct economic losses have been reduced to 67 million Yuan per year in average and thus the evaluable socio-economic benefits from the decrease in traffic accidents frequency should be 67×3=201 million Yuan. As defined in the Ministry of Public Security's document No. 113 in 1991, namely, A Notice about the Management of Traffic Statistical Work, direct economy losses are cash converted by direct losses of vehicles and properties, and the compensation for personal injuries or deaths are not included.

(2) Reduction of casualties

Table 7 shows the data of death toll per 10,000 motor vehicles in Beijing from 1998 to 2004, which is from Beijing Statistical Yearbook. With an average annual decline rate of 6.6%, a comparative analysis between the estimated death toll per 10,000 motor vehicles from 2005 to 2008 and the actual data based on the implementation of the ITS project is shown as Fig. 4. With reference to the data about motor vehicle inventory in Beijing from 2005 to 2008, the system has saved 2631 lives in four years, with an average of 526 per year.

The current standard of compensation for deaths caused by traffic accidents is ruled as follows: the victim could be compensated by 20 times of the annual per capita disposable income in urban area or aggregate net income in rural area depending on where the lawsuit had been brought. In Table 8 summarizes the per capita disposable income of urban residents in Beijing from 2005 to 2008, the difference between predicted number and the actual one of deaths in traffic accidents in Beijing from 2005 to 2008 as well as the evaluable compensation that has been saved. Since the implementation of the Intelligent Transport Management and control System in Beijing, the amount of saved evaluable compensation reaches 1.063 billion Yuan, which is calculated as in the following formula (4).

## 4 Conclusions

Except for putting forward an evaluation framework of ITS, a case study of Beijing urban intelligent transportation management and control system's social and economic advantages evaluation has been done. Some useful conclusions about how to evaluate urban intelligent transportation management and control system's social and economic advantages can be drawn from the above analysis.

(1) Leverage effect analysis on the ITS

The total investment about Beijing Urban Intelligent Transportation Management and Control System from 2005 to 2008 is about 1.2 billion Yuan, and the evolution of the systems' social and economic advantages is about 26.8 billion Yuan, so the investment for ITS is enlarged by more than 22 times, and the leverage effect of the ITS investment is also significant. It is proved that the Intelligent Transportation System is an effective method to resolve conflicts between the rapid enhancement of the number of annual motor vehicles and the limited city land resources.

(2) A survey of evaluation data sources

Different from traditional evaluation methods, indexes used for evaluating can be obtained from the official websites or publications easily, for example, the website of Beijing Municipal Environment Protection Bureau and Traffic Management Bureau, the Statistical yearbook, the publication papers and books. We can use this evaluation framework to assess ITS advantages of other cities through corresponding cities' data.

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