# Design and Implementation of Bus Monitoring System Based on GPS for Beijing Olympics

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## Abstract

*To guarantee the safety of public transport and effectiveness in dispatching buses, overall solution on Beijing Bus Monitoring System (BJ-BMS) based on GPS is put forward in this paper. The system is composed of communication control and GIS subsystems, each of which was independently developed in the beginning and integrated in the end. The key technologies of the system are described in detail. In addition to some fundamental functions such as real-time monitoring, some featured functions tightly combined with the daily operations in Beijing Bus Company are realized in the BJ-BMS. Finally, the status of system implementation and maintenance are introduced, which have proven to be very effective in practical applications during 2008 Beijing Olympics.*

## 1. Introduction

During 2008 Beijing Olympic Games, the people flow during the rush hour through different gyms amounted to 1.15 million per day. The number even reached a top level of 414000 around the Olympic Park. The required time for evacuation for large-scale games such as football is no more than 90 min [1]. Moreover, during the opening ceremony, no private parking space was available. All these added to the difficulty of the operations and organization of public transit. In order to guarantee the trip safety and improve the convenience of the public transit service, vehicle monitoring system is quite indispensable.

Beijing Bus Company launched 34 Olympic special lines besides approximate 500 regular ones. They carried more than 10 million passengers a day. Beijing Bus Monitoring System (BJ-BMS) based on GPS can tell the exact location, speed, alarm condition and information of overall distribution of the buses which were equipped with the GPS terminals. It was of vital importance for the trip safety, emergence handling and rational dispatching.

The system introduced in this paper was specially designed for Beijing Bus Company to be applied in the Beijing Public Transport Control Center (BJPTCC) and other control rooms for dispatching Olympic special lines. It provided crucial technical support for the bus monitoring and dispatching during the Olympics.

## 2. System design

### 2.1 Principles

In the process of system design, it follows the principles as follows:

**2.1.1. Applicability.**

In practice, there exist several vehicle monitoring systems few of which can be applied to the field of public transport operations directly though. Therefore, the combination with the operations of public transport enterprises is taken into account to large extent. There are several featured functions such as sending scheduling plan messages, browsing dispatching information in addition to some basic functions.

**2.1.2. Convenience.**

According to the organization structure of Beijing Bus Company, there are three types of users including managers in main or branched companies and dispatchers in the fleets. Due to the busy operations and different levels of computer skills, the system does its best to make the operations easy to master for the users.

**2.1.3. Stability.**

In the beginning, there existed about 1200 buses equipped with GPS terminals. After the Olympic Games, more GPS terminals would be seen at the buses of Beijing Bus Company finally summing up to approximate 5000 in the end while more than 200 dispatching rooms of the fleets would make use of the BJ-BMS. In order to guarantee the massive applications and data transmissions, it is crucial of the stability of the system.

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DOI 10.1109/CSIE.2009.9

### 2.2 The overall design

The BJ-BMS is composed of GPS satellite positioning system and ground moving control system. And the ground moving control system can be divided as on-board GPS terminals, GPRS mobile communication network, transmission center server, client background program and GIS interface. It chooses GPRS network for its superiority in transmitting speed, its forever on-line character and most importantly its reasonable cost [2].The system sets GPS satellites as its data source and GIS as its basis, aggregating information through internal network of Beijing Bus Company. Such architecture is illustrated schematically in Figure 1.

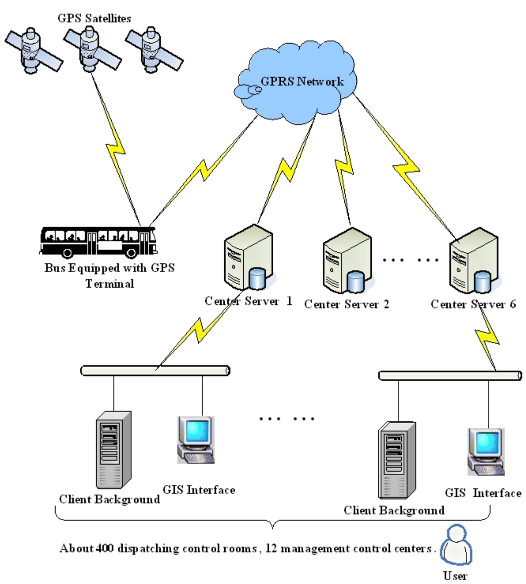


**Figure 1. System overall structure**

### 2.3 Software architecture

System software platform is composed of two subsystems: GIS subsystem and communication control subsystem, the software architecture can be seen in Figure 2.

GIS subsystem is mainly used to visualize bus line and stop information on the map according to the user's authority and preference. Then the system can realize the functions of real-time monitoring, tracking bus running process, handling the abnormal information sent by the on-board GPS terminals, and supporting the contrail replay of buses.

Communication control subsystem can realize the functions of transmitting the data packet sent from on-board GPS terminals to the client program, at the same time it will restore the location data to the GPS database after decompressing the data packet with recording work log.

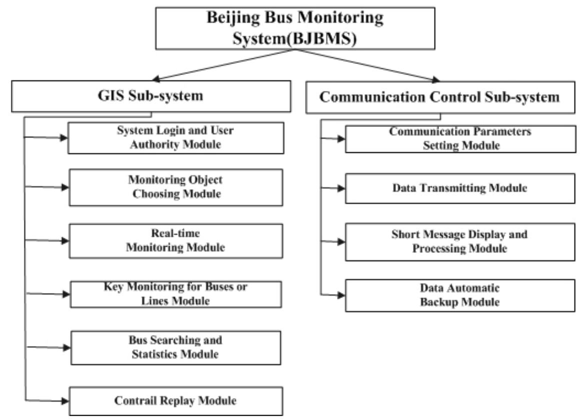


**Figure 2. System software structure**

### 2.4 Data processing cycle

GIS subsystem and communication control sub-system altogether comprise the software platform of BJ-BMS. It receives information by messages from on-board terminals and shows the visual locations and distributions of buses on the digital map to the users [3].These two sub-systems can not be separated. Actually, they should be seen as a whole and their interactions and data flow can be illustrated in Figure 3. Communication control subsystem can be divided as transmitting center server and client. Client is the background of GIS subsystem, which serves for the vehicle display and communication operations.

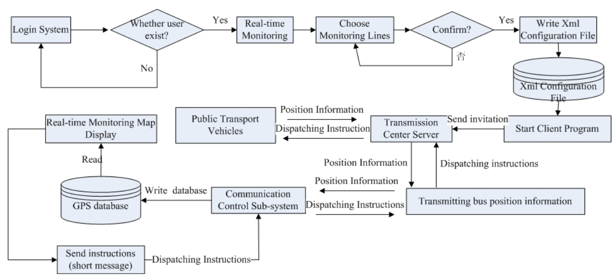


**Figure 3. System data flow chart**

## 3. Key technologies

### 3.1 GPS-dispatching flow design

1) When going to work, the driver sends short message "registration" to the dispatching room using the GPS terminal. As long as the message is

successfully received, the driver would get the short message saying "X Bus has already been registered." as a feedback showing that the dispatcher has already known the driver is on the job.

2) The dispatcher at the control room starts out the bus and sends short message of bus scheduling plan to the driver.

3) Once receiving the message of bus scheduling plan, the driver should leave the station on time and send short message "Starting bus" by quick key to the dispatchers identifying that the bus has already started.

4) The bus would send GPS location messages to the control room automatically at a requested interval.

5) When getting into the station, the driver would send the short message of "In station" to the dispatcher by quick key on the GPS-terminal. After that, the monitoring system in the control room would do the in-station processes after identifying that the bus is already in the station by the location analysis of the bus and stations.

6) The dispatcher starts out the bus based on scheduling plan and real-time location information and, if necessary, can send the short messages for reminding or dispatching.

7) The driver would send the short message of "Start out" as a feedback. It begins the cycle of GPS-dispatching processes again. The whole cycle can be seen in Figure 4.

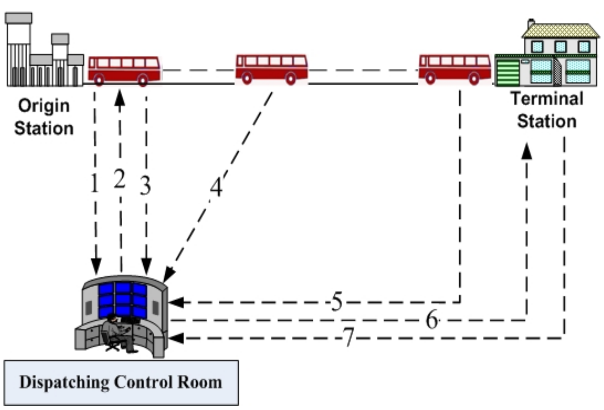


**Figure 4. GPS dispatching flow chart**

### 3.2 Information process for transferred meaning

The communication protocols between GPS terminals and center server are fundamental to realize the BJ-BMS.

In this system, it is ruled that every piece of protocols starts with symbol "[" and ends with symbol "]" with comma as the separator symbol of different data. The format of the communication protocols could be illustrated in Table1.

**Table 1. Format of communication protocols**

| Start Symbol | Type of Information | Sequential Number | Message Content | End Symbol |
|---|---|---|---|---|

The character for transferred meaning makes use of hexadecimal ASCII character set. Except for the start symbol and end symbol, it is compulsory to do the processes for transferred meaning where such symbol as "[" (5BH) or "]" (5CH) appears.

Message-sender needs to do the transfer before sending the message while message-receiver needs to restore the processed information to its original state.

Transferring method can be described as follows: Before sending messages, the program would browse all the characters from the start symbol to the end symbol. Once meeting the character needed to be transferred, the program would combine it with the symbol "]" (5CH) by using the Boolean XOR operator [4]. Then the result would replace the original value where transferred character "\" should be inserted afterwards.

In contrast, the restoring method is processed in the reverse way.

### 3.3 Map-matching method

After comparing different characteristics of data structures and algorithms, the map-matching algorithm based on topology of road network is used in BJ-BMS described as follows [5].

1) To restore the bus location messages received by GPS terminals in the map coordinates.

2) To identify the ID number of the road segment on which the bus is running and then obtain the spatial data of the start code number, end code number and all the code numbers on the road segment.

3) To calculate the nearest point from the bus position to the road segment and draw the point instead of the original bus location point ruled by the principles as follows:

$$\min(\sqrt{(X-X_i)^2+(Y-Y_i)^2})$$

where (X,Y) refers to the GPS coordinates of bus and （Xi, Yi ）refers to one point on the road segment.

## 4. System development

GIS subsystem and communication control subsystem were developed independently during the earlier period of the system development and were integrated in the end.

The BJ-BMS chooses C/S (Client/Server) development mode in order to quicken the software's response speed and satisfy the user's personalized requirements simply and conveniently [6].

### 4.1. Development environment

The programmers of BJ-BMS use Visual C# as the general development language. Visual C# (Microsoft products), is an excellent and stable Windows programming tool, and is the recommended development language for Visual Studio 2005 platform. It is full-featured and well-suited for the requirements of module design, with full support on object-oriented development and advantages of fast compiling and efficient code generation.

SQL Server 2005 is selected to manage the attribute database, for it is a powerful relational database management system in support of .NET environment, with its advantages such as strong flexibility, easy management, low cost and its fault-tolerance ability [7].

### 4.2. Database design

In the BJ-BMS, there are two major categories of data types: spatial data (e.g. roads, bus stop, and bus route) and attribute data (GPS real-time positioning data and operational data). The system manages the spatial data and attributes data by MapInfo Professional 7.0 and SQL Server 2005 respectively.

The spatial data is actually MapInfo table files which record the attribute information of the spatial elements. Such filename extension is .tab. When creating a file of spatial data, MapInfo Professional 7.0 would create a table as well which is composed of two types of files: one contains the data structure; the other embraces the original data.

As for attribute data, due to its real-time refreshing characteristics of GPS location information, it is planned to set two databases respectively to manage the GPS location information (real-time data and historical data for contrail replay) and fundamental operational information such as staff, bus, route and stop.

### 4.3. System functional module

In addition to some fundamental functions such as real-time monitoring, some featured functions tightly combined with the daily operations in Beijing Bus Company such as in-station processing based on GPS are realized in this system. The functions of the BJ-BMS are described in details in Table 2.

**Table 2. List of system functions**

| Functional Module | Description |
|---|---|
| Selection of monitoring object | Selecting fleets or lines |
| | Producing bus Line and stop on the map |
| Real-time monitoring | Real-time monitoring on actual map and logical map |
| | Map-matching calculating |
| | Viewing bus conditions |
| | Listing of bus information |
| Key monitoring | Key monitoring for single bus or selected lines |
| Storage and contrail replay | Contrail replay of actual map |
| | Contrail replay of logical map |
| Alarm response | Automatic tracking of alarmed bus |
| | Canceling alarm condition |
| Bus statistics | Statistics of all the on line buses or selected buses |
| Communication and interacting | Sending scheduling or dispatching messages |
| | Receiving messages from buses |
| Real-time dispatching | GPS in-station processing |
| | Automatically formatting traveling records |
| | View and management of buses in station |

## 5. System implementation

Implementation and maintenance of management information system are as important as system design and development. In order to guarantee that the BJ-BMS can be implemented successfully, the project group sets up a special team for system implementation, whose members work in bus stations of the Olympic special bus lines and control centers for real-time dispatching.

Although it is not convenient to maintain and update the system which is developed by C/S mode, the BJ-BMS offers the service of downloading installation file and updating latest program patch through publishing them on specific websites for different fleets. Besides, it can download the version number of the software automatically before starting the system in order to compare it with the latest version and, if necessary, download the new one for updating.

After testing and modifications for about half a year, the system tends to be much stable and played an important role in dispatching buses and commanding public transit operations during 2008 Beijing Olympics. The GIS interface of BJ-BMS can be seen in Figure 5 where the distribution of buses around the Olympic Park can be clearly seen when the opening ceremony of Beijing Olympics was coming to the end on August 9th, 2008.

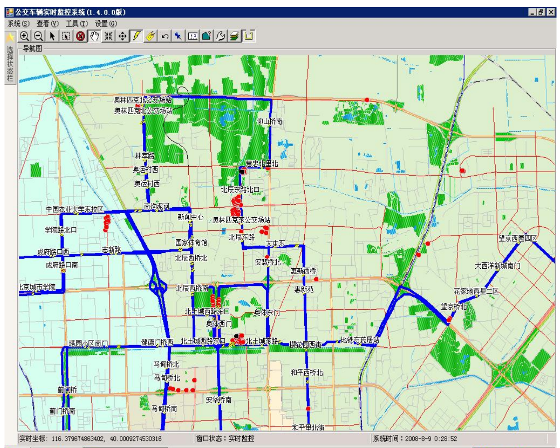

**Figure 5. GIS Interface**

## 6. Summary

The successful development of BJ-BMS for Beijing Olympics gave quite a lot help to promote the service level and quality of public transport and played an indispensable role in guaranteeing the security of the operating buses.

During the Olympics, this system was applied in Beijing Public Transport Control Center (BJPTCC) and dispatching rooms of 34 Olympic special bus lines. There were approximate 1200 buses having GPS on-board terminals totally during the Olympic Games. It is planned that about 5000 buses in Beijing will be equipped this kind of device, and more than 200 dispatching rooms will begin to use the BJ-BMS by the end of 2008.

The BJ-BMS works stably and has been operated well by the users after finishing the previous development and a series of training, implementation, modification and maintenance processes, which have achieved anticipated goals and effects.

## 7. Acknowledgements

This paper is sponsored by National High-Tech R&D Program (863 Program with grand No. 2006AA11Z212), National Key Technologies R&D Program (973 Program with grand No. 2006CB705507) and Key Research Program of China Ministry of Education (grand No. 106031).

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