# Geographic Information Systems for Positive Train Control: Issues and Prospects

## 능동적 철도차량제어를 위한 지리정보시스템의 활용방안: 현황 및 주요 쟁점

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### 초 록

본 논문은 철도안전운행을 위하여 능동적으로 철도차량을 제어를 지리정보시스템기법을 활용하는 방안을 제시하고 있다. 이를 위해서는 철도차량의 위치를 얼마나 정확하게 추적 및 표출이 가능한지를 검토해 보았다. 구체적으로는 GIS의 정의와 기능을 살펴보고 GIS기법을 활용한 능동적 철도차량제어의 예시를 정리하였다. 능동적 철도차량을 제어를위한 핵심요소인 철도차량 위치자료의 정확성을 수치지도의 축적별로 분석하였다. 최종적으로는 능동적으로 철도차량을 제어를 지리정보시스템기법을 활용하기 위해 칠요한 주요쟁점사항을 정리하였다.

## 1.Geographic Information Systems: An Overview

### 1.1. Introduction

During the last decade, geographic information systems (GIS) have been widely applied in areas of planning, programming, operation, and project development and implementation. GIS can be defined as a system that uses a spatial database to provide answers to queries of a geographic nature.

The distinguished characteristic of GIS technology for handling geographic data fits the needs of transportation planning in general, and railroad operations in particular. It is a newly emerging and promising technology that can be integrated into existing transportation planning, operation, maintenance and analysis tools in order to provide timely and acceptable solutions for transportation problems.

It seems that there are at least two important roles that GIS can play in positive train control (PTC) systems. The first role is to use GIS in processing geographically related data, representing spatial relationship among spatial grouping. It has been proven that GIS is a very powerful tool in providing spatially related data and integrating the data in various ways. The second role is the use of GIS for performing spatial analysis, not only for obtaining new information, but also to augment decision support by allowing "what-if" scenarios.

The purpose of this paper is to examine the fundamental functions of GIS in order to identify issues and problems in applying GIS to PTC, and to suggest agenda for overcoming such problems.

### 1.2. GIS Defined

The generic GIS can be viewed as a number of specialized spatial routines laid over a standard relational data base management system (Goodchild 1985). With GIS, it becomes easy to capture, store, retrieve, query, process, analyze, visualize, and report spatial data. GIS identifies a spatial entity by its

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location, pattern, or shape based on continuous multi-dimensional space.

In a nutshell, GIS is a data base management system (DBMS). Its fundamental function is data processing (Antenucci et al. 1991) and it provides an efficient and effective means to handle spatially referenced data with which an ordinary DBMS model finds difficult to handle. Spatial data usually contains information such as location, entity shape and spatial relationships among entities. GIS' functions include visualization for displaying shapes, patterns of objects and illustration of spatial analysis results (see Figure 1).

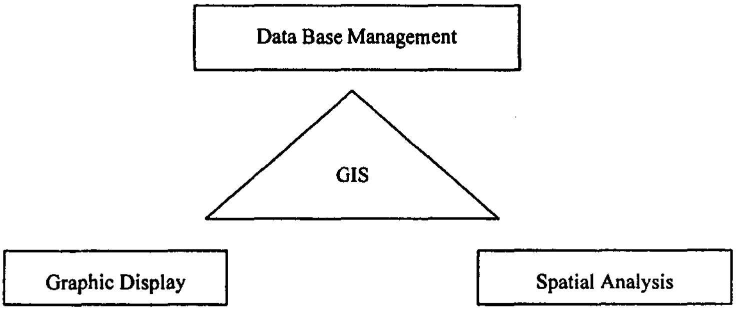

Fig.1: Three Basic Functions of GIS

There are two ways that GIS can represent spatial information. One is called a raster database and the other is a vector database (see Gould, 1990 for a more detailed comparisons of raster and vector databases). While raster databases have been proved to be better for representing land use data, topological relationships among spatial entities can best be represented in a vector database. In fact, vector databases more accurately represent linear spatial phenomena, such as transportation networks, than raster databases.

### 1.3. Capabilities of GIS

The following summarizes the major capabilities of GIS:

1) GIS can provide a tool that describes spatial features accurately and that enables the user to ask and answer "where and what" questions.
2) Once spatial data are stored in a GIS database, it becomes easy, inexpensive, and quick to update, maintain, retrieve, map, and generate reports.
3) The display functions of GIS are helpful for checking spatial errors, for manipulating data, and for interpreting results.
4) GIS can provide spatial relationship such as topology and metric relations that are necessary for spatial analysis. With these spatial relation information, spatial statistical analysis such as spatial autocorrelation and surface trend analysis can be efficiently performed.
5) The capabilities of GIS in spatial analysis, in turn, can generates new information that is needed for spatial decision making and spatial policy analysis by providing easy access for alternative analysis and simulation.
6) The dynamic segmentation function in GIS provides efficient means to handle and process linear geographic data. Locational data on a link such as accident locations, pavement conditions, railroad crossing points, and traffic volume can now be analyzed and displayed along with link attribute data.

The dynamic segmentation provides the following additional GIS capabilities:

1) linking spatial and attribute data by relating records of linear spatial objects and distancereferenced attribute data,
2) creating spatial objects (points or linear) through a query based on chosen attributes and values needed for the specific application, and
3) explicitly referencing a two dimensional spatial framework of the attributebased linear objects resulting from the linkage and segmentation tasks.

## Ⅱ. GIS for PTC: A Preliminary Assessment

### 2.1. Introduction

Railroads have historically been faced with managing both spatial and non-spatial data ranging from real estate information to track topology. One of the latest technologies in the railroad industry is " Positive Train Control (PTC). " PTC is a railroad version of Intelligent Transportation Systems (ITS) and represents one of the most important potential GIS applications.

The purpose of PTC is to improve railroad safety through the enhancement of movement authority and speed, with additional collision protection features and on-board decision capabilities aided by such a tool as GIS. The PTC system does this while maintaining the current level of operational productivity and providing growth to precision train control and advanced GIS-based railway management capabilities.

### 2.2. Current Status of GIS Applications in Railroading

This section is heavily based on the report by ARINC (1998) which reports that the current status of GIS application. Generally, certain individual railroads have identified singular applications with map production needs and are moving in that direction.

Some roads already acknowledge the high cost and limited availability of base map data. Public maps are often expensive and lacking in sufficient data quality. Examples of base map inadequacy are maps of insufficient resolution for a particular GIS application, maps whose data sources or gathering techniques are not documented, or maps which have not been verified. The cost of maintaining base map data, as well as collecting railroad asset and location data, has proved to be significant. In general, it is believed to be that the costs of data collection, compilation, and conversion comprised over 90% of the lifecycle cost of the GIS system. Associated hardware and software accounted for less than 10% of the system costs! Mergers, acquisitions, and line sales instantly create large volumes of data maintenance, keeping the situation dynamic. Although railroad data standards may mitigate this somewhat, they do not exist at this time (ARINC, 1998).

### 2.3. PTC Operations that could be enhanced by GIS Applications

Here are a few PTC functions that may be enhanced by GIS applications:

- View trains/vehicles en-route,
- Monitor train operational parameters such as geography, topography, planning data including schedules, speed, and length,
- Overlay with operational impact data including weather and temporary operating conditions such as " slow orders " ,
- Data feed for safe braking algorithm, and
- Data for positive end-of-train location determination.

In order to support those PTC functions, the following spatial data are required for effective operations of PTC:

- Locations of all active trains and other mobiles,
- Track locations of switches, control points, grade crossings, bridges, curves, grades, etc.,
- Track structure, information including critical defects and track condition,
- Location and types of track appliances and signals (wayside and grade crossing),
- Permanent and temporary speed and weight restrictions,
- Locations of work blocks,
- Location of work gangs waiting for track access,
- Indications from wayside sensors and defect detectors,
- Blocked tracks and switches,
- Bulletin information by location, and
- Location of problems such as accidents and derailment.

### 2.4. Critical Issues in Applying GIS to Support PTC

Positive Train Control represents one of the most important potential GIS applications. As a control (vs. management) application, its data needs are particularly acute - requiring precise, validated data. Even though railroads may possess large amounts of legacy spatial data, at a minimum it will need to be validated and possibly converted to a standard format. The need to develop a standard location referencing system for PTC is a must. This standard referencing system will be required to ensure the interoperability of PTC system(s) between railroad lines and companies (ARINC, 1998).

From these viewpoints, the critical issues in applying GIS to support successful operations of PTC include at least the following:

- Positional Accuracy of Spatial Data,
- Standards and Interoperability of GIS Functions.

## **III. Positional Accuracy of Spatial Data**

The contents of this section are heavily drawn from Ordinance Survey (1998). Accuracy of the published information has been a prime concern of both producers and users of data. This still remains the case today with a wider range of conventional and digital products. With GIS continuing to stimulate business, academic and consumer use of mapping, it is clearly in the interest of supplier and consumer that the accuracy of different map data sets is both appropriate to users needs and that the defined accuracy is clearly stated and monitored. Accuracy in this context includes spatial accuracy, currency, completeness, descriptor/attribute accuracy and geometric fidelity (Goodchild and Gopal 1989; Chrisman 1991).

This section deals with one aspect of overall accuracy - positional accuracy. The map accuracy usually deals with two-dimensional (bivariate) data. This involves some important differences to the better known properties of univariate data (a single variable such as height).

There are two distinctive terms in accuracy: absolute accuracy and relative accuracy. Absolute accuracy is the most basic measure and refers to the position of a point compared to its 'true' position. As the true position can never be known this statistic is quoted relative to some best known position determined by precise methods.

Relative accuracy deals with the position of a point relative to a neighbouring point. It compares the scaled distance between features measured from map data, with distances measured between features on the ground. The distance over which the statistic applies is relevant but is often not quoted. In the limit, that is when the distance encompasses the whole population (or map series), this statistic tends to the same numerical value as absolute accuracy.

There are many measures that can be used for the measurement of positional accuracy. However, a well known statistical measure is Root Mean Square Error (RMSE). RMSE is defined as below:

RMSEx = sqrt [ sum ( xdata,i - xcheck,i)^2 / n ]
RMSEy = sqrt [ sum ( ydata,i - ycheck,i)^2 / n ]

American Society for Photogrammetry and Remote Sensing (ASPRS) defined Accuracy Standards for large-scale maps as following (Federal Geographic Data Committee, 1998):

| Class1 Planimetric Accuracy, limiting RMSE (meters) | Map Scale |
|---|---|
| 0.0125 | 1:50 |
| 0.025 | 1:100 |
| 0.050 | 1:200 |
| 0.125 | 1:500 |
| 0.25 | 1:1,000 |
| 0.50 | 1:2,000 |
| 1.00 | 1:4,000 |
| 1.25 | 1:5,000 |
| 2.50 | 1:10,000 |
| 5.00 | 1:20,000 |

Recently, the National Standard for Spatial Data Accuracy (NSSDA) implemented a testing and statistical methodology for positional accuracy of fully georeferenced maps and digital geospatial data, derived from sources such as aerial photographs, satellite imagery, and ground surveys. It provides a common language for reporting accuracy to facilitate the identification of spatial data for geographic applications.

**Horizontal Accuracy** = 2.4477 * RMSEx = 2.4477 * RMSEy (if RMSEx = RMSEy )
For 95% confidence level.

If RMSEx is not equal to RMSEy and RMSEmin / RMSEmax is between 0.6 and 1 where RMSEmin is the smaller value between RMSEx and RMSEy and RMSEmax is the larger value, then,

**Horizontal Accuracy** becomes approximately ~ 2.4477* 0.5 * (RMSEx + RMSEy )
With 95% confidence level with 39.35% circular standard error.

What does it mean if one states that a data set (or map) has an accuracy of 0.4 m? It should be clear that it does not mean that there are no errors on the map in excess of 0.4 m. This would be to imply that the statistic has a confidence level of 100%. Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value such as 0.4 m. A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications. If fewer than 20 points can be identified for testing, use an alternative means such as deductive estimate, internal evidence, or comparison to source.

Whatever decisions are made as to the extent and nature of accuracy improvements to core databases such as the rail crossings, users will be keen to ensure that such improvements are fully justified and flagged well in advance of implementation. We must recognize that, taken in isolation, attempts to 'improve' the absolute accuracy of a particular geographical area may also result in a significant short-term cost to users - in that their asset positions may also move. The longer-term gain for users, however, will be in the improvement in overall consistency. This will bring benefits to the growing band of GIS users, in terms of known parameters, working with and integrating multiple data sets and identifying the 'best' data.

## IV. Recommendation of Workable Strategies for Applying GIS for PTC

Based on the survey analysis results, a set of workable strategies is to be developed and recommended in order to achieve standardized and interoprable GIS applications to PTC. These strategies would include:

1) specifications for positional and locational accuracy,
2) standard for linear referencing,
3) standards to ensure interoperability of GIS which include
    - Conformance and Testing Standard
    - Data Quality Principle Standard
    - Metadata Standard
    - Quality Evaluation Standard
    - Standard for Portrayal of Geographic Information
    - Terminology Standard

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