The Digitised Railway Facility Management System and the Application of GIS and GPS to Railway Operations

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Abstract: The railway facility management system that incorporates a geographic information system (GIS) is now widely used in Japan’s railway sector. This system was originally developed in Japan for the maintenance and management of railway facilities by digitising asset information. Digitising asset information facilitated a seamless flow of data for railway engineering projects and the different sections and organisations of the railways. As operating railways through vertical separation has become the norm, this system can be utilised to share data among organisations. Moreover, the application of a global positioning system (GPS) made it possible to detect train locations, which resulted in developing train location and train driving support systems. The experiences in Japan demonstrate that the operation and management of railways can be improved by digitising asset information and using the GIS and GPS.

Keywords: Asset Management, Digitised Drawings, Kilometrage, Vertical Separation, GIS, GPS

1. INTRODUCTION

Efficient management of the various facilities is vital for the effective operation of railways. Originally, railway companies managed their assets using various paper-based drawings. Generally, each division made and owned these drawings. This practice caused several problems related to, for example, the dispersion of information and smooth crosswise utilisation of the drawings.

To solve these problems, in 2004 a railway facility management system incorporating a geographic information system (GIS) was developed by JR East Consultants Company (JRC), a company affiliated to East Japan Railway Company (JR East). In addition to the original objective of digitising paper-based alignment plans, the system has improved the operations and management of the railways in various ways. As the experiences in the Japanese railway sector are seemingly applicable to railways in other countries, this paper examines the background of the digitised asset management system in terms of its development. Further, it presents an outline of the system and its benefits and recent applications, including the application of the GPS in the railway sector.

2. PROBLEMS IN TRADITIONAL FACILITY MANAGEMENT

Traditionally, railway companies managed their facilities using paper-based drawings. However, this method had several disadvantages:
1) **Difficulties in identifying and obtaining the latest information**
When railway facilities were managed using paper-based drawings, each section maintained a copy of these drawings. When facilities underwent modifications in their engineering works, revising all the copies was practically problematic. Therefore, identifying the latest information regarding the modified facilities was difficult. Further, when attempting to obtain the latest information, the transfer of information was usually a lengthy process if the railway was managed using paper-based drawings.

2) **Difficulties in sharing information among different sections**
If the facility’s data was managed using the traditional asset management system or paper-based drawings, it was difficult to access the data produced by the company’s different sections. Furthermore, sharing the accumulated data among the varied sections posed a problem.

3) **Difficulties in managing the maintenance and upgrading of data**
When implementing maintenance works, the fundamental data of the works were required to be recorded in a ledger. Further, if the facilities were upgraded, the drawings were to be accordingly revised. Occasionally, the paper-based drawings and ledger system faced difficulties in reflecting all the maintenance and upgrading-related work.

4) **Difficulties in developing coordination with train operations**
As long as the facilities were managed using paper-based drawings, it was difficult to link the data to the GIS and GPS. Hence, it would have been difficult to develop the related digitised systems, such as the train location system and driving support system, due to lack of requisite supporting systems.

3. **DIGITISED RAILWAY FACILITY MANAGEMENT SYSTEM**

3.1 **Problems with the Traditional Digital Mapping Technique**
When developing the digitised railway facility management system, there were several issues to be managed for constructing the system.
Firstly, it was quite difficult at the beginning of the process to digitise the maps and drawings. Digitising the large-scale alignment plans was particularly challenging.
Secondly, a number of railway facilities had neither the coordinate representations nor the detailed maps required for identifying their absolute locations.
Consequently, when attempting to utilise coordinate representations to digitise the large-scale alignment plans and other railway facilities, significant difficulties emerged:
1) Practically, it was difficult to allocate the coordinate representations to the alignment and the various assets that did not have coordinate representations.
2) Allocating the coordinate representations is a costly process.
3) As the railway companies did not formerly manage their facilities using coordinate representations, practical usage of the completed system in the railway sector will be complicated.
4) The completed data becomes too cumbersome to manage.

3.2 **Characteristics of the System Appropriate for Railways**
Because of the problems involved in using the traditional digital mapping technique, JRC devised an appropriate system for railway facility management that avoided the constraints of
the traditional mapping technique. The main characteristic of this new asset management system is that all facilities are linked to the kilometrage of the rail lines.

Certainly, railway facilities comprise various elements, such as stations, tunnels, bridges, tracks, railway crossings, traffic signals, various pole braces, kilometre post signs, centralised traffic control (CTC) devices, train radio base stations and other equipment. However, as a distinct characteristic of railway facilities, the data related to all these elements are recorded in terms of their locations on the line in kilometres. Thus, for developing this system, this distinct characteristic of railway assets was focused on, and a new digitised asset management system was established.

Based on the abovementioned railway characteristics, the database system was configured such that each facility’s data includes kilometrage as a data attribute, and this data can be utilised to identify assets. That is, a facility’s registered database is configured to link each facility’s data, such as electric maps and digitised records, to the appropriate kilometrage. This simplification could relieve the development process from linking each facility’s data to the coordinate representations and thus make the system more effective and less expensive. Thus, it has become possible to complete digital maps at one-tenth (1/10th) of the cost of utilising the traditional method with coordinate representations. In fact, the development of this system has become technically and economically feasible. (Kobayashi, 2014a)

3.3 Functions of the System

As drawings and maps could be efficiently digitised, JRC established the digitised asset management system. First, JR East introduced the system in 2004, digitising paper-based alignment drawings covering 7,500 km of lines and station plans—both of which were succeeded from the Japanese National Railways. Next, the system was introduced to JR Kyushu, which had 2,100 km in alignment plans. A similar system had already been introduced to other JR companies and private railways. The original asset management system featured the following functions (Kobayashi, 2007):

1) Display functions:
The system displayed the recorded data of railway assets. The type of data could be varied and included drawings, pictures and maintenance records.

2) Retrieval functions:
The system could retrieve drawings from the address or kilometrage of the line. It could also display the ledger based on the facilities’ icons.

3) Interaction functions:
Using a site inspection information terminal, it was possible to register inspection plans and records, and the system could be utilised for on-site inspection/maintenance work.

4) Ledger management functions:
The ledger system could record inspection and maintenance reports in the form of photos and display its recorded information by year and structure.

5) Condition-assessing functions:
The system was also useful for asset management of the railway facilities, as it could be utilised for assessing assets’ conditions and estimating asset deterioration.

6) Memorandum functions:
The system could record other information concerning facilities and engineering works.
3.4 Effects and Utilisation of the System

The new digitised management system successfully replaced the paper-based system and solved the former problems connected with the traditional system. Further, it offered several advantages:

1) As the updated data are recorded to the database, the latest information can be easily identified.
2) As the data are electronically recorded, it can be retrieved in a timely manner.
3) For construction and maintenance work, the digitised asset information provided a smooth and seamless data flow unlike a system that utilised paper.
4) As it has become much easier to share updated information among different departments, the system has contributed to improving railway operations and management.
The advantages of the digitised system have proven effective in several unusual cases. For example, the system facilitated early recovery from the damage caused by disasters, such as the 2004 Niigata Chuetsu Earthquake and the 2011 Tohoku Earthquake. During these earthquakes, many engineers were dispatched from the Tokyo area to work in the recovery effort of the affected engineering works. Owing to the digitised system, it was possible to prepare accurate alignment and facility plans in a short time. Then, during the recovery of the engineering works, the managers who remained in Tokyo could view the updated reports along with the new plans recorded by the dispatched engineers. Owing to the new system, they could easily share the accurate updated information. Thus, the system greatly contributed to the early recovery of areas affected by these disasters. As the above examples show, the digitised system can be fully utilised in atypical circumstances as well. (Mizohata, 2012)

### 3.5 Further Development of the System

Since its introduction in 2004, the system has improved the management of railway facilities and solved the problems caused by the traditional paper-based asset management system. Moreover, as railway company activities expand, usage of the system has also been developed in various ways.

For example, the system can be combined with other related data, such as topography and urban structures. By combining the system with the related information, it can be utilised for various purposes, such as disaster prevention planning, urban development planning, analysis of trading areas and leaflet design. As these examples show, besides ordinary asset management for railway facilities, the system can be applied for various purposes by combining its data with digital maps, and it is expected that system utilisation will further expand in the future. (Kobayashi, 2007)
As most of Japanese passenger railways own and manage infrastructure, compared with vertically separated railways, it is more advantageous to have close relationship between the infrastructure department and departments for train operation. The development of the system facilitated closer relationship between the concerned departments, and thus promoted the efficiency and safety of the railway operation furthermore.

In addition, Japanese railways have been active in promoting their affiliated businesses. The application of the system, such as utilization for market analysis and that for making leaflets, has contributed for the development of their affiliated businesses as well.

4. APPLICATION OF THE GPS TO RAILWAYS

4.1 Train Location Information System for Passengers

In addition to the GIS, the GPS too can be utilised to improve railway services and management. After developing the asset management system, JRC further developed a train positioning and passenger information systems utilising the GPS. As this system is relatively
simple and could be developed without much investment, it has already been introduced into some local lines. As a system configuration, the GPS is installed in a train’s driving cabin; thus, the train’s location can be detected. In some stations, displays have been set up for passengers. These displays reflect real-time train locations and other related information, such as delay time and arrival guidance.

![Diagram of a Train Positioning System Utilizing GPS](image)

**Figure 4. A Train Positioning System Utilizing GPS**

*Source: Authors’ revision of Kobayashi (2007)*

### 4.2 Portable Tablets for Drivers and Conductors

At the request of JR East, JRC also developed a portable information tablet system. JR East announced the introduction of this system in 2013, and currently, all drivers and conductors take a portable tablet with them when they board the trains. There are more than 7,000 tablets in circulation, and they are given to the drivers and conductors by managers before they board a train. As the tablet also includes the data of the related manuals, it is no longer necessary to carry bulky manuals on the train, nor does the company need to revise the paper-based manuals when their contents are updated. The necessary information can be transferred to the tablets, and particularly in unusual operational conditions, the conductors can provide passengers with the relevant updated information without taking much time as before. (JR East, 2015)

In addition, traditionally, the railway system could detect the location of the trains only by observing the range of the track circuits, and detecting the location more precisely was not possible. However, as the tablet is equipped with a GPS system, the detailed location of all trains can now be detected. This facilitates better train operation, particularly in extraordinary circumstances such as train delays. (Yamazaki, 2015)
4.3 PRANETS: An operation support system

Apart from train location service systems for passengers, the GPS was used when establishing an operation support system. In Japan, this system was first introduced in 2008 by JR Freight, and it improved driving reliability and freight transport management. This section outlines the new system and its advantages.

The new system is called ‘PRANETS (Positioning system for RAil NETwork and Safety operating)’. It utilises a GPS to detect the location of operating trains and consists of two sub-systems: 1) a train driving support system and 2) a container information system. An outline of each sub-system is presented below.

4.3.1 A train driving support system

The GPS is installed in the driver’s cabin so that the location of the trains can be detected. In addition, the cabin is also equipped with a display and speaker system to support the driver. The characteristics of the train’s driving support system are summarised below. (Shigeta & Fujimoto, 2009)

1) The system covers all trunk lines in Japan.
2) The information is updated every two minutes.
3) The speaker system alerts the driver regarding excess speed, cautions him to slow down, and indicates other operations that require attention.
4) The display provides varied useful information for driving the train, such as alerts, cautions to slow down, the train’s timetable, delay time and the condition of stations.

The data provided by the train driving support system include information useful for safe and reliable driving according to the specifications and conditions of the line. As the information must be updated based on the latest restrictions and related information, a manager in the train drivers’ depot transfers current data to a memory stick and gives it to the driver before each journey. The driver then inputs the digitised data in the system in the driver’s cabin.

Freight trains often operate at night, which involves varied problems, such as the darkness that complicates driving conditions and drivers’ sleepiness. To a large extent, the display and speaker system has played an important role to avoid human errors and contributed to safe and more reliable train driving, particularly at night.
1. Outline of PRANETS

GPS Satellite

Detection of the Train Location

*Speed of the Train*

(A Message) Braking/Slowing Down

*Train Location*

(A Message) Exchange of AC/DC

*Timetable*

(A Message) Departure of the Train

2. Data Flow & Image of the Display

Data Inputting

Data about Timetable, Slowing Down, Limit of the Speed, etc.

Down Loading the Data into a Memory Stick

Safe Driving Supported by the System

Messages by sound and display

Display within a Station

Display with a Message

Figure 5. A Train Driving Support System of PRANETS
Source: Authors’ revision of Otsubo (2009)

4.3.2 A Container Information System

In PRANETS, the GPS is also utilised for detecting trains’ location. The data concerning train location detected by the GPS is transferred to JR Freight’s central system. This enables the company’s operation managers to observe the location of the trains on the line. As the data is updated every two minutes, train location can be detected with some precision.

The system can identify various conditions related to trains’ operation, such as 1) delay time of trains, 2) the location of trains and 3) other related information. The data of train operation for the previous three months is recorded in a database and can be utilised to follow the movement of the containers carried by the trains. (Shigeta, 2009)
The clients can also identify the movement of their containers by accessing the company’s website, which is supported by JR Freight’s information server. The system is useful for the clients especially in the case of train delays as the location of the containers can be easily identified through the website. Figure 6 shows an outline of the container information system.

![Figure 6. A Container Information System of PRANETS](image)

Source: Authors’ revision of JR Freight (2009)

5. UTILISATION FOR RAILWAYS WITH VERTICAL SEPARATION

5.1 Sharing the Data among Different Entities

Over the past few decades, railways in Japan and overseas have been reformed, and in many cases, vertical separation has been introduced. In the case of Japan, though six JR passenger companies and many other urban railways still maintain an integrated structure, vertical separation has become a desirable option when constructing new railway lines and when local railways are experiencing management-related difficulties. In the case of overseas railways, management systems in some countries have already been reformed and those in other countries are undergoing changes. Vertical separation has been introduced in the reform process in many cases. Thus, the number of vertically separated railways has increased, and this trend shows signs of continuing in the future. (Kurosaki, 2008)

In these cases, the infrastructure is owned by an entity that is separate from the railway operator. Though railway operations vary depending on the country, in Europe, the infrastructure is usually managed by the entity that owns the infrastructure; other entities...
operate the trains. In such cases, as railway operation is implemented by more than two entities, it is essential to share information concerning the assets among them. Hence, in such circumstances, the digitised asset management system can be effective for data sharing. In particular, it can enable the efficient management of a railway system with vertical separation.

5.2 Management of Complex Infrastructure Assets

Even post the introduction of vertical separation in Japan, a single operator operates railway systems, which differs from the European system of railway operation. Although the introduction of vertical separation in Japan’s railway sector also raises new issues, it is expected that the digitised asset management system can adeptly cope with these issues.

In many cases, the composition of railway facilities becomes complex in terms of railway operation. For example, in addition to ordinary maintenance work, the railway operator may invest in the infrastructure due to certain managerial decisions. Concerning the track structure, the operator might decide to replace the original ballast track with a slab track to reduce maintenance costs. In this case, the initial ballast track will be replaced by the slab track. If the original ballast track is a public sector asset and this investment is implemented by the private railways, the initial public assets are replaced by private assets. Accordingly, in the process of this railway operation, the asset structure and infrastructure ownership becomes complex. (Kurosaki, 2009)

Traditionally, railway operators managed fixed assets using paper-based drawings and ledgers. As fixed assets become more complex, however, managing these assets through traditional means also became complicated. The digitised asset management system became a more useful means for managing the complex infrastructure. Vertical separation is expected to be introduced further in Japan and overseas; consequently, digital asset management systems will become essential for managing complex assets and sharing information between the infrastructure owner and railway operators.

5.3 Reliable Train Operation with GPS Application

When trains are operated by accessing the infrastructure of a different entity, a driver will travel longer distances than he would in vertically integrated railways. In the case of Japan, the Japanese National Railways are separated into six passenger integrated companies and a single vertically separated freight company, JR Freight. As each passenger company operates its trains only within its own network, the drivers are familiar with the conditions of the infrastructure, such as the tracks, safety facilities and other assets. In contrast, the drivers of JR Freight travel all over Japan’s network and have to drive on a network owned by different entities.

As this comparison shows, train drivers in a vertically separated railway in general travel longer distances accessing other railways’ tracks. Thus, normally it is more difficult for drivers in a vertically separated railway to familiarise themselves with the conditions of the infrastructure, such as the alignment and location of the signalling poles. Thus, as a PRANETS’ example shows, an operation support system incorporating a GPS contributes to safe and reliable train driving from the drivers’ viewpoints.
GPS application is also useful for railways with vertical separation from the technical viewpoint. When trains are operated by a vertically separated structure, where the infrastructure is owned and managed by an entity different from operators, it is more difficult to promote close data exchange between the separated entities. For example, though the train locations are detected by track circuits, they are owned by an infrastructure manager. Using the GPS, the vertically separated train operators are able to detect where their trains are without relying on the information provided through the track circuits. In addition, when the length of the track circuits is long, a GPS can detect the train location more precisely than the traditional system utilizing the track circuits.

As shown by PRANETS, a GPS facilitates precise detection of train locations; it also contributed to the development of a driving support system for the railway sector. Though drivers have to be very careful regarding the various restrictions related to train operations, such as train speed when navigating curves in tracks and track engineering work, a train driving support system that is developed through the application of the GPS can support drivers and help them properly manage their trains. As JR Freight has developed PRANETS, the application of the GPS is useful for safe and reliable train driving, especially for vertically separated railways.

Figure 7. Comparison of Train Driving Between Vertically Integrated and Separated Railways
Source: Authors
1. **Train Detection without GPS**

- Operator A
- Operator B
- Infrastructure Manager

Only an infrastructure manager can detect the location of trains by its track circuit.

2. **Train Detection with GPS**

- Operator A
- Train detection by GPS
- Operator B
- Infrastructure Manager

Train operators also can detect their location. By using GPS, they can detect the location with precision.

![Diagram](image)

**Figure 8.** Train Detection by GPS for Vertically Separated Railways

Source: Authors

### 6. CONCLUSION

Digitising the railway asset information has various advantages. The experience of the Japanese railway sector shows that the digitised asset management system facilitated the efficient maintenance and management of railway assets. The integrated management database has created a seamless flow of data not only for engineering projects but also among different sections and organisations. In addition, as digitised data can be integrated with other digital data, such as three-dimensional information, the system can be utilised for various purposes and applied to various fields. Thus, the system has certainly contributed to the efficient operation and management of railway companies and has also been applied to critical uses, such as recovery operations subsequent to a disaster.

Despite the inherent difficulties in digitising large-scale alignment plans and allocating coordinate representations to a number of railway facilities, the digitisation process was made possible by linking each facility’s data to the kilometrage of the line. This link has made it feasible to practically establish a digitised asset management system for the railway sector. Currently, the digitised railway asset management system is utilised quite commonly in the Japanese railway sector; further, it is expected that a similar system can be applied to the asset management of other network industries such as roads, as the asset data of their infrastructure can be linked to their network’s kilometrage.

This study also shows that applying the GPS is also effective for the safe operation of railways. For example, JR Freight developed an operation support system, PRANETS. This is a train driving support system with a speaker and display system that cautions drivers regarding railway safety factors, such as speed and curves on the track. The varied information provided by this system contributes to safe and reliable train operation.

The digitised asset management system and GPS application is especially effective for vertically separated railways, which the infrastructure owner and railway operators are different. This is because 1) the information on the railway infrastructure must be shared among the different entities, 2) the system is useful for managing complex infrastructure and 3) the system is useful for drivers who have to drive longer distances on other entities’ tracks.
Vertical separation is already common in overseas railways and is expected to be increasingly implemented in Japan’s railway sector. This study shows that the employing the digitised asset management system and GPS application would be advantageous in the future in both overseas and Japanese railways.

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