# A Way to Improve the Safety of Highway Infrastructure Based on BIM and Digital Technology

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**Abstract.** With the rapid development of information technology and intelligent means, the construction and management of highway infrastructure are increasingly adopting digital and intelligent technologies. Building Information Modeling (BIM) and digital technology are crucial tools in modern engineering management. These technologies offer new ways to improve highway infrastructure safety. By applying the CMFs system to analyze highway safety data and identifying and coding basic highway safety information, combined with BIM technology, the effective application of the highway safety information coding system can not only significantly improve highway management efficiency, but also play an important role in accident handling, traffic flow optimization, and safety prediction, achieving safety assurance and data-driven management throughout the entire process of highway design, construction, and operation.

**Keywords:** Highway Infrastructure; Digital Technology; Crash Modification Factors; BIM; Highway Safety.

## 1. Introduction

With the increasing demand for modern transportation, highways, as an important artery of the national economy, have become a focus of social attention in terms of safety and reliability. The construction and maintenance of highway infrastructure not only involve engineering quality, but also directly affect traffic safety, economic benefits, and environmental protection. However, the traditional management mode of highway infrastructure faces many challenges, including information silos, lagging data updates, and low management efficiency, all of which may lead to the accumulation of hidden dangers and the occurrence of safety incidents. In recent years, the Chinese government has issued the "National Comprehensive Three dimensional Transportation Network Planning Outline" [1] and the "Action Plan for the Construction of New Infrastructure in the Transportation Field (2021-2025)" [2] issued by the Ministry of Transport, both of which have made the digitization of all elements and the full cycle of infrastructure construction goals and tasks. In terms of improving the level of intelligent highway services, requirements have been put forward for high-precision spatiotemporal information services such as precise positioning and lane level applications. At the same time, the planning outline once again clarifies that "building a high-precision transportation geographic information platform and accelerating the independent innovation and application of building information modeling technology in various fields" is a key task.

The integration of BIM and digital technology offers innovative solutions for enhancing highway infrastructure safety. BIM enables data sharing and collaboration across the entire project lifecycle, improving efficiency and precision in design, construction, operation, and maintenance. Digital technology optimizes real-time monitoring, data analysis, and fault warning capabilities. This article explores how BIM and digital technology improve highway safety, focusing on a highway information database for advanced technical support and practical guidance in highway management.

# 2. Methodology

## 2.1 BIM and Digitalization

With the development of information technology, BIM (Building Information Modeling) and digital technology have been widely applied in the field of highway construction, providing important support for improving the efficiency, quality, and safety of highway construction. In the process of highway construction, the application of BIM and digital technology is mainly reflected in the following aspects [3]:

BIM and digital technologies improve highway construction by enhancing design accuracy, optimizing management, ensuring quality control, and supporting asset management. They enable 3D modeling, real-time conflict detection, schedule optimization, resource allocation, safety management, and predictive maintenance throughout the project lifecycle.With the support of these infrastructure, BIM models can effectively integrate and manage large amounts of data, improve the efficiency, quality, and safety of highway construction [4], and provide long-term support for later operation and maintenance.

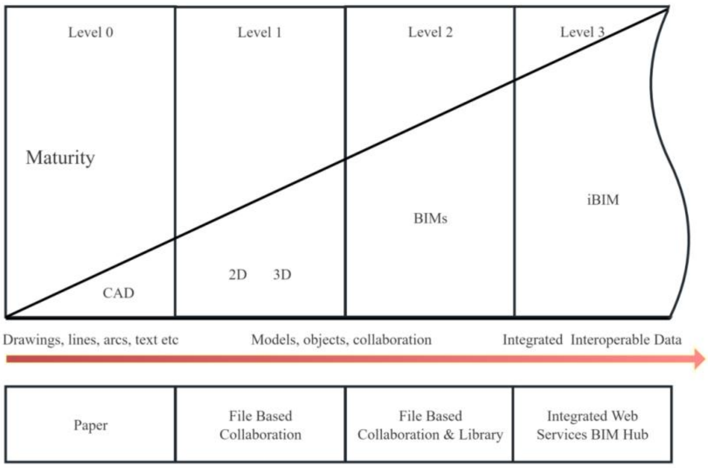


Fig. 1 BIM maturity model [5]

## 2.2 Basic Information Data Related to Highway Safety

When analyzing the safety of highways, the required data can be roughly divided into three types: classical data, natural driving data, and innovative technology data.

### 2.2.1 Classical data

Classic data typically includes the following five main categories [6]:

Accident information, including the time, location, nature, causes, and vehicle types involved, is crucial for safety research and road safety analysis. Road condition data, such as geometric parameters, surface conditions, signs, slopes, and turning radii, significantly impact vehicle stability and driver safety. Traffic flow data, including volume, speed, and density, helps identify potential bottlenecks, congested areas, and high-risk zones for accidents. Additional information, like climate changes (precipitation, snow, haze) and road condition alterations (e.g., waterlogging, landslides), as well as construction activities, can also affect safety. Other safety-related data includes driver behavior, vehicle conditions (e.g., brake failures, tire wear), and other factors influencing road safety. These data form the foundation for highway safety assessments, supporting hazard analysis and the development of improvement measures.

### 2.2.2 Natural driving data

Natural driving data refers to driving data collected by installing sensors on vehicles in an environment without external interference. These data can provide information on driving behavior in real environments, helping to study driver behavior patterns, vehicle reactions, and the impact of road conditions on driving.

2.2.3 Innovative technology data

Innovative technologies refer to those that can significantly change the way consumers, industries, or businesses operate. Taking smartphones as an example, as a disruptive technology, they can provide a large amount of driving related data, such as the driver's location information, the specific time and location of sending text messages while driving, vehicle speed, etc. These pieces of information have important value for safety analysis.

## 2.3 Correlation Analysis of Highway Safety Information Based on CMFs System

In order to effectively improve the safety of expressway, it is particularly important to use scientific evaluation system to analyze the effect of various safety measures. In this context, The Crash Modification Factors (CMFs) system is used to analyze correlations in highway safety data. system provides a quantitative and systematic analysis method for traffic safety management [7]. By introducing CMFs system, we can more accurately evaluate the impact of different safety improvement measures on the frequency and severity of traffic accidents, and provide data support and theoretical basis for improving the safety of highways.

Through the analysis of CMFs data elements, this paper further improves the basic safety information database of expressway. In the Highway Safety Manual (HSM) [8], the characteristic elements of CMFs are divided into five categories: Road section characteristics, intersection characteristics, grade separation characteristics, special facilities and geometric characteristics, and road network characteristics. In view of the fact that China's expressways usually do not set up grade intersections, and the characteristics of the road network are mainly for urban roads, this paper ignores the features of grade intersections and road network. According to the existing standards and specifications and the actual situation of China's expressways, this paper screened out the safety information elements in line with the current situation of China's expressways, and constructed the highway safety information identification system.

Table 1. CMFs road cross section information elements

| Feature Element | Data Type | Accident Types | Severity | Traffic Volume Correlation |
|---|---|---|---|---|
| Lane Width | Numerical | Single-vehicle Run-off, Multi-vehicle Rear-end, Same-direction Side-swipe | All severities | Correlated |
| Shoulder Width | Numerical | Single-vehicle Run-off, Multi-vehicle Rear-end, Same-direction Side-swipe | All severities | Correlated |
| Raised Central Divider | Numerical | All types | All severities | Not correlated |
| Central Divider Width | Numerical | All types | Casualty | Not correlated |
| Roadside Slope | Numerical | Single-vehicle Run-off | All severities | Not correlated |
| Roadside Guardrail Stiffness | Discrete | Vehicle Run-off | All severities | Not correlated |
| Roadside Crash Barrier Installed | Boolean | Single-vehicle Collision | All severities | Not correlated |

Table 2. CMFs road alignment information elements

| Feature Element | Data Type | Accident Types | Severity | Traffic Volume Correlation |
|---|---|---|---|---|
| Horizontal Curve Radius | Numerical | All types | All severities | Not correlated |
| Horizontal Curve Superelevation | Numerical | | | Not correlated |
| Longitudinal Slope | Numerical | | | Not correlated |
| Transition Curve Length | Numerical | | | Not correlated |

Table 3. CMFs marking information elements

| Feature Element | Data Type | Accident Types | Severity | Traffic Volume Correlation |
|---|---|---|---|---|
| Install Delineators | Boolean | All types | All severities | Not correlated |
| Install Standard Edge Line | Boolean | All types | | Not correlated |
| Install Widened Edge Line | Boolean | All types | | Not correlated |
| Install Permanent Road Signs | Boolean | All types at Night | | Not correlated |

| | | | | |
|---|---|---|---|---|
| Install Speed Limit Signs | Boolean | All types | | Not correlated |
| Install Variable Incident Warning Signs Ahead | Boolean | All types | | Not correlated |
| Install Variable Queue Warning Signs Ahead | Boolean | Rear-end Collisions | | Not correlated |
| Install Variable Speed Warning Signs | Boolean | All types | | Not correlated |

Table 4. CMFs weather and lighting elements

| Feature Element | Data Type | Accident Types | Severity | Traffic Volume Correlation |
|---|---|---|---|---|
| Install Highway Lighting Facilities | Boolean | All types at Night | All severities | Not correlated |
| Install Variable Weather Information Warning Signs | Boolean | All types | | Not correlated |
| Increase Winter Maintenance Readiness Level | Boolean | All types | | Not correlated |

Table 5. CMFs interchange information elements

| Feature Element | Data Type | Accident Types | Severity | Traffic Volume Correlation |
|---|---|---|---|---|
| Highway Overpass on Intersecting Road | Boolean | All types | All severities | Not correlated |
| Type of Grade-separated Intersection | Discrete | All types | | Correlated |
| Acceleration/Deceleration Lane Length | Numerical | All types | | Correlated |
| Spacing Between Grade-separated Intersections | Numerical | All types | | Correlated |
| Install Right-in/Right-out Ramp | Boolean | All types | | Not correlated |
| Ramp Horizontal Curve Radius | Numerical | All types | | Correlated |
| Ramp Lane Width | Numerical | All types | | Correlated |
| Length of Weaving Area Between Adjacent Exits/Entrances | Numerical | All types | | Correlated |
| Install Collector-Distributor Road | Boolean | All types | | Correlated |

## 3. Data Collection and Organization

### 3.1 Data Collection

To ensure the accuracy and comprehensiveness of the expressway safety information database, this paper employs four methods to collect safety-related data. First, the traffic management department provides data through Excel tables that record accident details such as time, weather, location, and severity, along with supplementary descriptions in Word reports. Second, road design documents, including electronic drawings, design specifications, and parameter tables, are essential for understanding road geometry and operational characteristics. Third, real-time road condition and meteorological data, such as precipitation and visibility, are gathered from online platforms. Finally, site survey photos and videos are used to verify and update existing data, documenting changes in alignment and the condition of safety facilities like guardrails and traffic signs. These diverse data sources form the core of the highway safety database, offering a comprehensive reflection of road design and operation while providing valuable support for subsequent safety analysis.

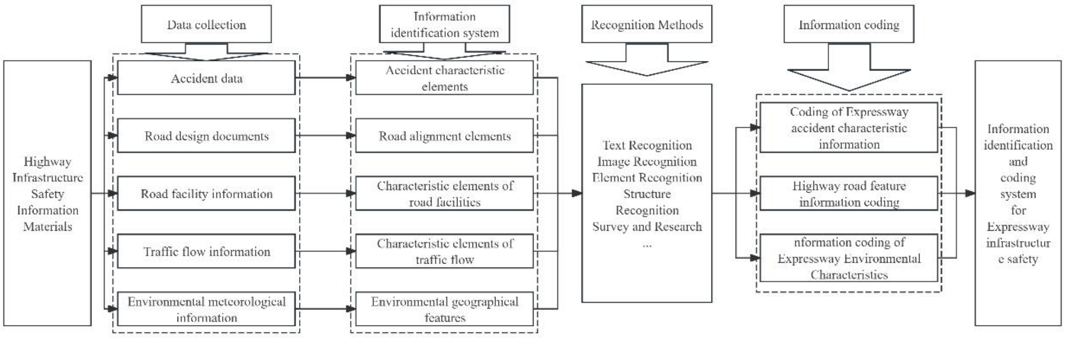


Fig. 2 Information identification and coding system for Expressway infrastructure safety

### 3.2 Identification and Coding of Expressway Infrastructure Safety Information

The basic safety information of an expressway encompasses various aspects, including road structure, traffic facilities, road conditions, and the external environment. Identifying elements such as pavement type, number of lanes, section length, and pavement condition is crucial for assessing the road's safety status and forming the basis for emergency and traffic optimization plans. Traffic facilities, including signs, lights, surveillance cameras, and flow monitoring equipment, play a vital role in ensuring safety and facilitating traffic management. Accurately identifying and positioning these facilities helps detect failures promptly, optimize flow, and improve management efficiency. Additionally, real-time data on road conditions, such as traffic flow, weather, and accident occurrences, are essential for addressing sudden changes like traffic bottlenecks, accidents, or adverse weather. This information allows for swift responses and adjustments to traffic management plans, ultimately enhancing safety.

### 3.3 Coding Method of Expressway Safety Information

In the process of highway safety management, in order to manage all kinds of safety information efficiently and accurately, unified coding rules must be adopted to transform the collected information into structured data [9]. These codes can ensure the standardization and efficiency of information, and enable relevant departments to obtain accurate road information in the shortest time.

Road and facility coding is based on road section attributes and the types/functions of traffic facilities. Numeric and alphabetic codes are commonly used, such as numbering expressway sections based on mileage and characteristics (e.g., lane type, toll stations). Traffic facilities like speed limit signs, cameras, and alarms are assigned unique identifiers for efficient identification and maintenance.

Emergencies such as traffic accidents, natural disasters, or equipment failures also require coding. Accident type, location, involved facilities, and causes are recorded and classified, allowing quick response from accident handlers to locate and address issues.

Road condition and environmental data, including weather and traffic flow, need encoding for quick processing. For example, weather conditions (sunny, rainy, etc.) can be coded so the system can send real-time alerts to drivers, advising actions like slowing down or taking detours.

### 3.4 Application of Highway Safety Information Coding System in BIM

Combined with building information model (BIM) technology, the effective application of highway safety information coding system can not only significantly improve the efficiency of highway management [10], but also play an important role in accident handling, traffic flow optimization and safety prediction. It can further improve the accuracy and intelligent level of the system, and realize the safety guarantee and data-driven management of the whole process of highway from design, construction to operation.

BIM technology enhances highway safety through real-time monitoring, traffic flow management, and safety prediction. In the event of a traffic accident, the real-time positioning function, integrated with the coding system, accurately locates the incident and aligns it with key elements in the BIM model, such as road facilities and emergency zones. This allows management to assess accident details, optimize emergency responses, and minimize traffic disruptions. For traffic flow monitoring, BIM integrates real-time data with road geometry to facilitate automatic signal adjustments, lane optimization, and bottleneck prediction, helping reduce congestion and accidents. Additionally, combining BIM with a security information coding system supports big data analysis and safety prediction by creating a "digital twin" model. This model integrates multi-dimensional data to identify potential hazards, predict high-risk areas, and enable early warnings and proactive traffic control adjustments, ultimately reducing accident risks.

## 4. Conclusion

In this study, Through the analysis of basic information data related to expressway safety and the correlation analysis of safety factors based on CMFs data system, this paper clarifies the structural levels of basic information related to expressway safety, and explores the information elements that meet the conditions of domestic expressway roads and have strong correlation with safety accidents. It also identifies and codes the basic information of highway safety, and summarizes a way to improve the safety of highway infrastructure based on BIM and digitization.

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