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IFC Data Schema Extension for Railway Track Facility Management

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Abstract: Railway track facility management (FM) is an intricate and multifaceted discipline that necessitates precise data management and scheduling for ensuring the safety and efficiency of railway operations. Although the Industry Foundation Classes (IFC) version 4.3 has incorporated railway infrastructure into its data schema, it still falls short in catering to the specialized needs of track FM. This paper presents an exhaustive extension to the IFC schema, specifically designed to address the challenges and complexities inherent in railway track FM. A two-step approach was employed in the development of this extension. The initial phase involves the development of a Unified Modeling Language (UML)-based conceptual model, encapsulating four pivotal elements: "component" for track asset and condition identification, "action" for the related tasks during track FM, "resource" for required materials and equipment as well as involved actors, and "operation" for track operation information capturing. This conceptual model serves as an intricate blueprint, offering a comprehensive structure for various FM facets. Thus, the proposed IFC extension is developed and aligned consistently with the conceptual model, forming an integrated, interoperable data management framework that can be easily adapted into the openBIM environment. The efficacy and applicability of the proposed extension are substantiated through real-world case studies, thereby demonstrating its capability to significantly enhance data visualization, interoperability, and overall decision-making in railway track FM.

Key words: Railway Track; Facility Management (FM); Industry Foundation Classes (IFC).

1. INTRODUCTION

In the realm of railway infrastructure management, railway track facility management (FM) stands as a critical yet complex discipline, necessitating precise data management and FM activities scheduling to ensure the safety and efficiency of railway operations. The multifaceted nature of railway track FM encompasses a range of activities, from periodic inspections and physical maintenance of tracks to sophisticated data analysis for predictive maintenance [1]. The execution of these activities requires a delicate balance between operational efficiency and minimal service disruption, often constrained by limited maintenance windows [2].

One of the core challenges in railway track FM is the efficient integration and interpretation of diverse data sources. This complexity is not merely about aggregating real-time sensor data, manual inspection logs, and historical maintenance records, but also involves interpreting this information in a dynamic operational environment. These data sources create a multifaceted web of information that must be managed and analyzed to ensure optimal decision-making [3]. The complexity is further compounded by the dynamic nature of FM data, which continuously evolve due to factors such as changing track conditions, varying usage patterns, and ongoing maintenance activities. This evolving data landscape necessitates a robust and flexible information management method that can adapt to the fluid nature of railway operations, thereby underscoring the need for a more advanced data management schema [4]

Considering the unique characteristics of railway track FM, the concept of open building information modeling (openBIM) holds significant potential for enhancing this process. OpenBIM refers to a universal approach to the collaborative design, realization, and operation of buildings and infrastructure based on open standards and workflows [5]. Among these standards, the Industry Foundation Classes (IFC) plays a pivotal role. IFC, as a comprehensive data model, is developed to facilitate interoperability in the building and construction industry [6]. The latest version, IFC version 4.3, has notably advanced in incorporating railway infrastructure into its framework [7]. However, despite these advancements, IFC version 4.3 still exhibits notable limitations, particularly in the realm of railway track FM. It does not fully address the specialized needs and intricate granularity that are critical for effective FM data management in railway tracks. This gap is evident in the handling of detailed FM data, where the existing schema falls short in capturing the dynamic and intricate nature of railway track operations [8], [9]. Consequently, there is a pressing need for an extended and more tailored data schema. Such an extension would not only align with the principles of openBIM but also provide a more robust method for the railway track FM decision-support process, enabling better data management, analysis, and visualization to enhance operational efficiency and safety.

In response to this need, this paper proposes a novel extension to the IFC data schema, specifically designed to enhance data management in railway track FM. This extension is grounded in a conceptual model that encapsulates four key aspects: component, action, resource, and operation. The model's comprehensive structure is crucial for effectively capturing and organizing the diverse elements of railway track FM, thereby facilitating informed decision-making and efficient operations management. The practicality and effectiveness of this extended IFC schema are validated through real-world applications, as evidenced by case studies that demonstrate significant improvements in railway track FM. The case study aligns with other research demonstrating the potential of openBIM and IFC in managing existing railway infrastructure and enhancing data management and visualization [10].

The significance of this study lies in its potential to revolutionize railway track FM by leveraging advanced data management capabilities. By extending the IFC schema, the study aims to provide a unified and consistent framework for FM data, enhancing visualization, interoperability, and overall decision-making in railway operations [11].

The structure of this paper is organized as follows: Section 2 delves into the development of the conceptual model and the corresponding IFC extension, detailing their components and integration. Section 3 presents real-world case studies to validate the effectiveness of the proposed IFC extension in railway track FM. Finally, Section 4 discusses the broader implications of our findings and concludes with insights into future research directions in this domain.

2. Conceptual Model Development and IFC Extension

In addressing the need for enhanced railway track FM through openBIM, our study introduces a specialized extension to the IFC data schema. This initiative comprised a two-phase approach. The first phase entailed the creation of a conceptual model designed to structurally represent the varied aspects of railway track FM, providing a comprehensive blueprint for data integration and management. Building upon this foundation, the second phase involved the strategic expansion of the IFC data schema. This expansion was guided by the buildingSMART guidelines, ensuring alignment with global standards and the unique requirements of railway track FM. Through this approach, our research aims to elevate the capabilities of railway track FM, particularly in data management and operational efficiency, by offering an IFC schema more aligned with the specific needs of this sector.

2.1. Conceptual Model Development

The conceptual model's development began with a thorough analysis of the information exchange requirements for railway track FM. This analysis drew upon insights from semi-structured interviews with domain experts, case studies, and a comprehensive review of relevant literature and technical standards. Our findings pinpointed significant gaps in the current IFC schema, especially in its representation of the diverse data spectrum generated during the FM stage. The literature review emphasized the need for an integrated, digital FM framework to replace traditional, paper-based methods.

After the information exchange requirements were determined, the Unified Modeling Language (UML)-based conceptual model were developed to structuralize the data model. We selected UML to capture the data types and structure due to its ability in representing complex systems, which provides a visualization of the track FM domain's nature and interdependencies [12].

In the proposed conceptual model, four main aspects were considered: component, action, resource, and operation (CARO). The component aspect details the infrastructure elements of railway tracks, including structural components and geometric details. It classifies these elements into categories such as rail element, track element, and track bed element, providing a granular view of the track infrastructure for precise evaluation and targeted maintenance. Moreover, the action aspect categorizes FM activities into practical execution (element classes) and documentation (record classes), ensuring the comprehensive tracking and historical accounting of FM operations. The resource aspect focuses on defining the equipment, personnel, and scheduling resources essential for FM, highlighting the importance of effective resource management in maintenance schedules and personnel allocation. Finally, the operation aspect addresses the broader operational context; this aspect integrates external and procedural information influencing FM decision-making and strategic planning, like environmental conditions and train traffic data.

Thus, the CARO model provides a robust structure that not only meets the current FM requirements but is also adaptable to future changes. It serves as the foundation for the proposed extension of the IFC data schema, ensuring that the model is comprehensive, relevant, and capable of enhancing railway track FM.

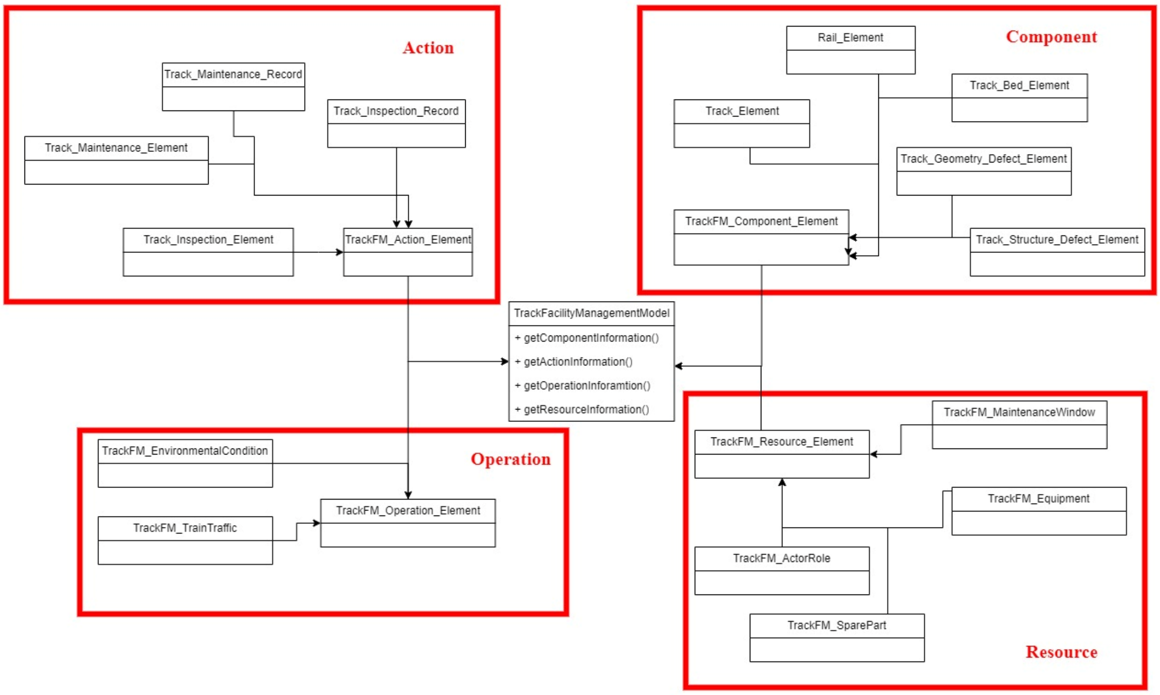

Figure 1. Structure of conceptual CARO model

2.2. IFC Extension

After proposing the conceptual CARO model, we delved into the extension of the IFC data schema—a key initiative tailored for enhancing railway track FM. This extension, informed by the CARO model, integrates existing IFC entities and introduces new elements to meet the specific requirements of railway track FM.

Initially, we embarked on a comprehensive review of the existing IFC schema, particularly focusing on the railway domain schema which is first proposed in IFC 4.3. This review, based on the latest IFC 4.3.2.0 (IFC4X3_ADD2) release [6], was instrumental in identifying reusable entities and property sets. It aimed to minimize additional workload while ensuring the seamless integration with the current IFC framework.

The review highlighted several railway domain entities that align with the component aspect of the CARO model. As shown in Table 1, these entities, including IfcRail, IfcTrackElement, and IfcRailway, form the foundation for representing static elements of railway track infrastructure within the IFC schema. IfcRail is an entity to for describing rail information, which is a predominately linear built element that has a special section profile. The other track elements, such as sleepers and fasteners, and other components are expressed by IfcTrackElement. Moreover, the spatial information is represented by IfcRailway. This alignment not only demonstrates the feasibility of integrating FM-focused data, but also sets the stage for further extensions.

Table 1. Reused entities in IFC Rail Domain Schema

CARO class	IFC entity
Rail_Element	IfcRail
Track_Element	IfcTrackElement
Track_Geometry	IfcRailway

Following this, we proceeded to extend the IFC schema, aligning it with the CARO model's broader structure. This step involved the development of new entities and property sets, ensuring that the dynamic and operational data essential for comprehensive FM are accurately represented. Figure 2 shows the relationship between the CARO model and its connection between current and extended IFC data schemas. The existing IFC entities were mapped onto the CARO model, forming the basis for subsequent extensions. This alignment helped identify areas where the IFC schema needed augmentation to fully capture the complexities of railway track FM.

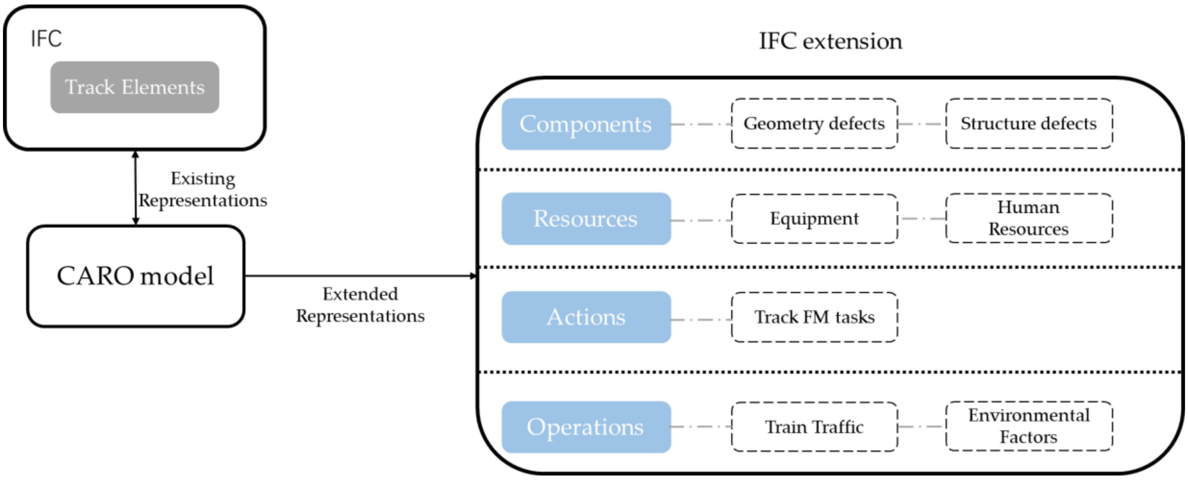

Figure 2. Concept of the CARO model and its connection between current and extended IFC

To address the requirements and gaps in track FM, new entities and property sets were developed. The newly added entities were designed to represent elements in track FM domain. Detailed information on each entity is expressed by property sets. Tables 2 and 3 show samples of extended entities and property sets.

Table 2. Sample of hierarchy and description of the extended entities

Main Entities	Sub Entities	Description
IfcTrackFMComponentElement	IfcTrackStructureDefect	An entity to describe the track structure and components defects, including defect component, defect type, location and severity
	IfcTrackGeometryDefect	An entity to describe the track geometry defects, including defect type(e.g., twist, alignment level, longitudinal level deviation, gauge deviation, location and severity
IfcTrackFMActionElement	IfcTrackInspection	An entity to describe inspection activities in track FM.

Table 3. Sample of the extended property sets

Property Sets	Name	Property Type	Data Type	Description
Pset_TrackGeometryDefect	DeviationValue	IfcPropertySingleValue	IFCReal	Indicates the value of geometry deviation.
	AssessmentCondition	IfcPropertySingleValue	IfcLabel	Describes the level of defect based on technical standard

	DefectLocation	IfcPropertySingleValue	IfcText	Indicates the location of defect
	AssessmentDate	IfcPropertySingleValue	IfcDate	Date on which the overall condition is assessed

After the extended entities and property sets were determined, we aligned the final version of the extension with the conceptual CARO model to maintain the consistency of the structure. Figure 3 shows the main structure of the proposed IFC extension. Corresponding to the conceptual CARO model, the extended IFC has four main aspects: component, action, operation, and resource. The proposed IFC extension marks a significant step in bridging the gap between the existing IFC schema and the specific needs of railway track FM. It enables the more effective representation and management of FM data, thereby contributing to improved maintenance strategies, operational efficiency, and overall safety in railway track FM.

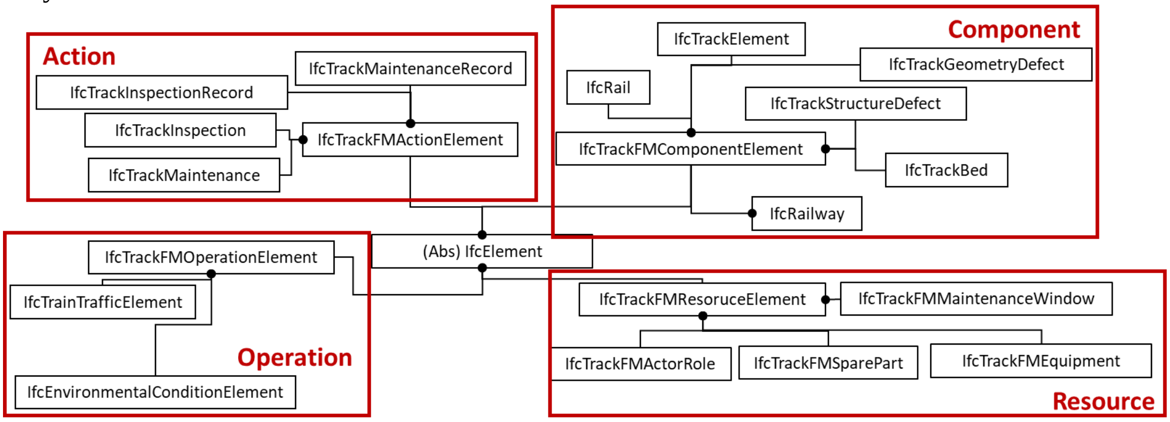

Figure 3. EXPRESS-G diagram of the proposed IFC extension

3. Case Study and Validation

After proposing an extension to the IFC schema, a case study was executed to assess the feasibility and practicality of this enhancement for railway track FM. This case study applied the extended IFC schema to a section of an operational railway, thereby offering a realistic context to evaluate the schema's utility within the complexities of a real-world FM scenario.

The selected case model incorporated a wide array of FM-relevant data, encapsulating both detailed component specifications and defect data. Table 4 displays the essential attributes of the chosen case model.

Table 4. Basic information of selected case model

Attribute	Description
Railway Type	General Speed Railway
Operation Speed	160 km/h
Type of Track-bed	Ballast Track

The methodological approach to the case study was structured as followed. Initially, the track model was exported into the IFC format. FM data were then retrieved from the existing database. These data were then integrated into the IFC-based track model. The final step involved the visualization of this information using an IFC viewer.

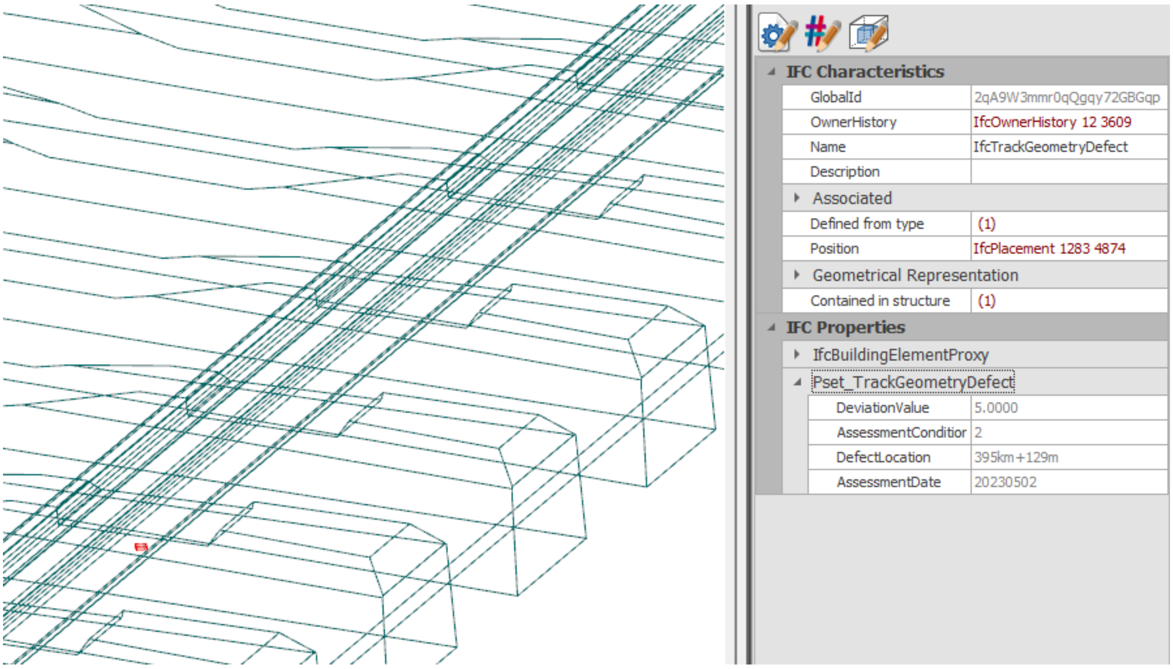

Figure 4. Integration of FM information into track model

Figure 4 illustrates the successful integration of track FM data into the model. The provided screenshot is indicative of how track geometry defect information is presented. The data appears correctly under the entity *IfcTrackGeometryDefect*, with detailed attributes captured in *Pset_TrackGeometryDefect*, which includes deviation value, assessment condition, defect location, and assessment date. The location of the geometry defect is also rendered within the 3D track model for visual context.

Furthermore, information on the IFC entity was delineated in the EXPRESS format to elucidate the structural composition of the entity. As depicted in Listing 1, the proposed IFC extension rigorously articulates FM data in a structured format that aligns with the current IFC schema, ensuring consistency and coherence.

```
ENTITY IfcTrackGeometryDefect;
  SUBTYPE OF (IfcTrackFMComponentElement);
     PredefinedType : OPTIONAL IfcTrackGeometryDefectTypeEnum;
  Properties : Pset_TrackGeometryDefect;
END_ENTITY;
TYPE IfcTrackGeometryDefectTypeEnum = ENUMERATION OF
  (TWIST, LEVEL, LONGITUDINAL_LEVEL, ALIGNMENT_LEVEL, GAUGE);
END_TYPE;
ENTITY Pset_TrackGeometryDefect;
 DeviationValue : IfcReal;
 DefectSeverity : IfcLabel;
 DefectLocation : IfcText;
 AssessmentDate : IfcDate;
END_ENTITY;
```

Listing 1. Extract of the IFC schema extension in EXPRESS format for IfcTrackGeometryDefect

4. Discussion and Conclusion

As we culminate our exploration into the extension of the IFC schema tailored for railway track FM, it becomes crucial to weigh the advancements against the inherent challenges brought forth by this extension.

The proposed IFC extension primarily advances the field of railway track FM by offering a more nuanced and detailed framework. First, it enhances the data representation capabilities, enabling a comprehensive understanding of railway infrastructure that is pivotal for informed decision-making. Furthermore, the extension significantly improves interoperability within the BIM ecosystem, ensuring the seamless integration with various systems and tools [13]. This integration is particularly crucial for fostering a cohesive and efficient FM process. Moreover, by facilitating predictive maintenance strategies, the extension can lead to a reduction in downtime and an enhancement in safety measures, marking a significant stride in railway track FM [14].

However, these advancements do not come without challenges. Integrating the extended schema into existing systems may pose challenges due to its specific and detailed nature [15]. In addition, the comprehensive data management required by the extended schema could potentially lead to increased overhead, necessitating more resources for efficient data handling [16]. Furthermore, the widespread adoption of this extended schema hinges on its acceptance by industry stakeholders, which may be a gradual process, requiring training and standardization efforts [17].

In conclusion, the extension of the IFC data schema for railway track FM represents a vital step forward in infrastructure management, addressing critical gaps in the current IFC schema and providing a more tailored framework for railway track FM. Although it brings significant advantages in terms of data representation and predictive maintenance, it also presents challenges in terms of integration complexity and data management overhead. Nevertheless, the extended IFC schema holds great potential for transforming railway track FM, contributing to more efficient, accurate, and predictive FM operations. Future research and development in this domain will be crucial, particularly in terms of refining the schema, implementing strategies, and evaluating the schema's impact in real-world scenarios.

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