General Information Model and Its Application for Rock Excavation in Underground Work Sites

Esa Viljamaa[a], Irina Peltomaa[b] & Annemari Kaaranka[c]

[a] *VTT Technical Research Centre of Finland, P.O. Box 1100 90571 Oulu Finland*
[b] *VTT Technical Research Centre of Finland, P.O. Box 3, 92101 Raahe Finland*
[c] *University of Oulu, Department of Mechanical Engineering, Erkki Koiso-Kanttilankatu 3, FI-90570 Oulu Finland*

E-mail: esa.viljamaa@vtt.fi, irina.peltomaa@vtt.fi, annemari.kaaranka@oulu.fi

Abstract

In the underground mining and tunnelling rock excavation processes, there is plethora of different machine, tool and information system providers involved and practically no general information model covering the complete process. The competition in the field is getting more intense and all the actors should intensify their operations. The information management and integration of different information systems' data is among the most interesting enablers for such a better operational efficiency. The main goal of the research was to develop flexible methods for better application interoperability and information management for the underground rock excavation processes. The research used a literature survey, a commercial systems survey, professional interviews and worksite observations in order to develop a new general information model for rock excavation and define a toolchain for the exploitation of the developed model. In this research, the information model for underground rock excavation actions was developed applying applicable parts of existing standards and software tools. The main information model can be extended by using separately designed sub-models. In addition to information model also a toolchain of how to practically do the model development and information integration, has been described. These actions will enhance information management and application interoperability in the rock excavation processes and enable more efficient information exploitation leading potentially to better controlled processes, more efficient work phases and cost savings.

Keywords -
Information Model, Information Management, Data Integration, IFC, IREDES, Rock Excavation

1 Introduction

Like in many other industries, the underground mining and tunnelling operations are facing more global and more severe competition than earlier. This means that all the operations must be intensified and made more cost-effective to meet new challenges. Also the common demand for less polluting and safer processes is pressing system and process developers and managers globally.

In order to intensify processes, more accurate and more extensive information about the processes is needed. The days when a company could thrive with stand-alone systems for different enterprise functions are over. Enterprise systems focused on different functions in a company may never become one, but they must share information to assure success. [1] In the underground mining and tunnelling operations, there may be tens or hundreds of different sources of information that are potentially useful from the process control and management point of view. This information should be brought to the disposal of the process management either as an individual data sources or rather as integrated information. Better methods for converting the raw data into integrated and useful information for both a product and a process control through the complete value chain are essential for development of mines [2]. There are few commercial solutions in the market to integrate information in the tunnelling operations, but those solutions remain to be vendor specific, closed and covering only some narrow sub-fields of needed total view for information. Information management solution must ensure that the right people and the right processes have the right information and the right resources at the right time [1].

In this research, the general information flow and information system integration were improved by means of the developed application interoperability concept consisting of a new information model and a defined toolchain for information integration concerning the model. The model was based on industry standard from the building construction field that was combined with de-facto rock excavation communication method along with other necessary parts. The model is mainly targeting the improved process management and decision making support among other benefits. This paper discusses mainly how the model was developed and its applicability will be tested later on in a real-life in real environment with a developed pilot system. The results of the research are potentially applicable within advanced mining and tunnelling worksites with proper process data collection systems and production control software. A practical functionality of results of the research will be validated in subsequent comparative research phase.

2 Methods

The information model and the toolchain developed in the research were based on information collected from a literature survey, worksite visits and personnel interviews involved to work in tunnelling and underground mining operations.

2.1 State-of-the-Art

For the underground mining and tunnelling operations there are several commercial solutions, however these solutions are concentrated on certain functions or are tightly vendor specific. Interoperable and overall information management solution for whole chain of underground mining and tunnelling operations doesn't exist.

Commercial solutions for underground mine planning include Dassault Systèmes GEOVIA's Surpac [3], CAE's CAE Studio 5D Planner [4], and Mintec Inc.'s MineSight [5]. Commercial solutions for tunnel construction site planning include Trimble's Business Center HCE [6], Tekla's Tekla Civil [7], and Vianova Systems's Novapoint [8]. Integration and accessing to planning information is usually possible through common file formats.

In academia, the application interoperability research in underground mining and tunnelling fields is not executed widely. However the need for improved information integration and management in mines is noted in the research [2][9]. Compared to underground mining operations the interoperability research is more advanced in the field of AEC/FM (architecture, engineering, construction and facilities management). [10] have reviewed wireless web services enabling technologies, [11] have made an extensive review from data and application integration research in construction domain, and [12] have conducted a comprehensive review on system integration technologies in AEC/FM. In the following, few information management studies from AEC/FM field are introduced.

[13] present domain taxonomy for highway construction. The taxonomy is based on Industry Foundation Classes (IFC) and several other classification systems. It uses seven major domains to classify construction concepts: Process, Product, Project, Actor, Resource, Technical Topics, and Systems. The taxonomy was used to develop an ontology for the construction domain including semantic relationships and axioms. The major ontological model is process-oriented and can be summarized as follows: Construction knowledge is encapsulated in several overlapping Systems, where a set of Actors use a set of Resources to produce a set of Products following certain Processes that are part of a Project according to boundary conditions and within the confines of the work environment (Technical Topics). [13] The operation of the developed domain ontology was evaluated during a e-COGNOS project [14] as a part of a web based knowledge management software, which connected various systems using a Web Service technology. The development of the ontology architecture was continued by adding more knowledge levels (application knowledge, user knowledge) to domain ontology [15].

[16] present more general level domain ontology called Infrastructure and Construction PROcess Ontology (IC-PRO-Onto) for infrastructure and construction domain. IC-PRO-Onto captures the most fundamental concepts in the domain in a structured, extendable, and flexible format. It uses five concepts to represent things: Entity, Constraint, Attribute, Modality, and Family. An Entity is a Project, Action, Actor, Product, Resource, or Mechanisms. Concepts were structured into hierarchal taxonomies using sub-sumption and aggregation relationships. The taxonomical classification of concepts supports multi-perspective viewing of the same process through Process Modality Views including Core Processes, Management Processes, Knowledge Integration Processes, and Support Processes. [16]

[17] present AEC-domain specific ontology merger Onto-Integrator. Existing ontology mergers could not fully address requirements set by AEC domain, which is multidisciplinary and has several stakeholders. Onto-Integrator uses semantic similarity comparison and relational concept analysis (RCA) for merging ontology taxonomies and relations, and knowledge base integration for axiom merging. The merging approach uses a heuristic. [17]

[18] have developed an IFC based ontology, which purpose is information retrieval from an IFC model. The

ontology source is IFC2x3 version and the ontology format is Web Ontology Language (OWL) 2 DL. The ontology consists of two parts Basic and Extended Ontology. The Basic Ontology includes those ontology components that are derived from the IFC specification directly. Extended Ontology is the ontology components that are not originally included in the IFC specifications but are added according to the requirement of the system. These components facilitate the information retrieval when the inputted query includes terminologies that are not readily available in the IFC specifications. [18]

[19] introduce semantic web services based approach to enable interoperability between Computer-Aided Design (CAD) and Geographical Information System (GIS). The approach consists of three modules: Task Interpretation, Web Service Matching, and Web Service Composition. The implementation of these modules requires development in for example algorithms and Quality of Service parameters. [19]

[20] propose a method for intensifying road construction process management. Method utilizes resent advances in communication and machine control systems, and the development of information management technologies. The prototype implementation called Dynamic Site Control Center (DSCC) enhances the information acquisition during road construction process. DSCC integrates information from different companies' information systems participating to road construction process. In ontology-based integration process DSCC combines and refines the information gained and visualizes it for users. DSCC ontology forms from sub-ontologies, corresponding sub-processes of infrastructure building process. DSCC improves the process management's situation awareness and provides platform independent access and visualization tool for process data. [21][22][20]

In the following two central data exchange formats are introduced more closely as they are central background formats in our information model development.

2.1.1 IFC

Industry Foundation Classes (IFC) is a schema developed to define an extensible set of consistent data representations of building information for exchange between AEC software applications. It is a neutral exchange format, which was designed as an extensible "framework model". That is, its developers intended it to provide broad, general definitions of objects and data from which more detailed and task-specific models supporting particular exchanges could be defined. It covers all building information supporting full lifecycle from planning and design to maintenance. [23] However, [24] state that the formal standards on Building Information Modelling (BIM), such as the IFCs are complex and have not had the resources for rapid development and promotion that their potential deserved. In addition IFC has been weakened by varied non-consistent implementations [23]. Therefore it may take some time for this approach to be widely adopted [25].

Nevertheless IFC has become an international standard for data exchange and integration within the building construction industries. While IFC is able to represent a wide range of building design, engineering, and production information, the range of possible information to be exchanged in the AEC industry is huge. The IFC coverage increases with every release and addresses limitations, in response to user and developer needs. The latest version IFC 4 has about 800 entities (data objects), 358 property sets, and 121 data types. While these numbers indicate the complexity of IFC, they also reflect the semantic richness of building information, addressing multiple different systems, reflecting the needs of different applications, ranging from energy analysis and cost estimation to material tracking and scheduling. [23]

From system architecture perspective the IFC consists of four conceptual layers: Resource, Core, Interoperability, and Domain Layers. [26] The bottom layers define base reusable constructs which are generic for all types of products. The base entities are then composed to define commonly used objects in AEC, termed Shared Objects in interoperability layer. At the top level are the domain-specific extensions, which deal with different specific entities needed for a particular use. [23] .

All IFC models provide a common general building spatial structure for the layout and accessing of building elements. It organizes all object information into the hierarchy of Project-Site-Building-Building-Storey-Space. Each higher-level spatial structure is an aggregation of lower-level ones, plus any elements that span the lower-level classes. All application-defined objects, when translated to an IFC model, are composed of the relevant object type and associated geometry, relations, and properties. In addition to objects that make up a building, IFC also includes process objects for representing the activities used to construct a building, analysis geometry that is often abstracted from the building geometry, and analysis input and result properties. [23]

Model views are another level of specification, above the IFC schema. Model View Definitions (MVDs) identify what should be expected for an exchange to be effective. MVDs specify exactly what information should be exchanged, and in what form and structure the IFC entities are to be used. Defining MVDs requires principle decisions and workarounds because the IFC itself does not address a number of semantic issues comprehensively. Two sets of semantics are at the core of any successful model exchange. One of which is the user or application functional semantics defining the information that must be exchanged and the other being the representational semantics available in IFC or other data modelling schema representing the user intentions. [27]

2.1.2 IREDES

The need for effective exchange of process information was driven force for standardization initiative called International Rock Excavation Data Exchange Standard (IREDES) [28]. The objective of IREDES is to define a "common electronic language" for easy and standardized data exchange between mining machines and corporate IT systems. [29] IREDES is based on eXtensible Markup Language (XML) technology and uses XML schema to define the formats of the machine generated files. Thus, the produced data report is understandable for both humans and machines. [30] XML structure supports object oriented software design and data encapsulation. Furthermore all major databases provide standard XML import and export features. [29]

IREDES architecture consists of three different levels: IREDES Base, Application Profile, and Equipment Profile. The IREDES Base level covers all data which objects in other levels require. The Application Profile level contains all information specific for one application purpose (e.g. Planning Data, or Production Quality Log). This is information which may be used independently from a specific type of equipment. The Equipment Profile level adds detailed, equipment specific information to each Application Profile applicable for the specific equipment type. The first available Equipment Profiles cover the Drill Rigs and LHD's/Trucks as transport. [29]

[30] presents the idea of IREDES On-line which purpose is to setup an industry standard to enable volatile data to be transferred via network reliably such that the machine current status is visible to authenticated users. Volatile data includes real time data and current status information as these types of data vary rapidly over time. IREDES On-line suggests two alternative ways for communication: direct or infrastructure communication. In direct or peer-to-peer communication end user connects to machine using IP address, and machine acts as a server responding to client requests. In infrastructure communication the communication between machine and end user is done via server. This is more efficient method as machine's calculation resources are limited and software is purpose specific. In infrastructure communication there is possibility to send more complex requests to server, for example ask for history information of the machine. [30]

2.2 Personnel Surveys and Observations

Part of the information needed for the developed information model and its application were gathered from personnel surveys from two different Finnish worksites. Other worksite was a tunnel construction site from a Helsinki subway expansion project and other was from an underground hard rock mining site. Although a final product of those separate work sites are different (ore and a subway tunnel), the production processes in the rock excavation phases are quite similar. Due to the worksite similarity, the replies to inquiry were processed as they were all from a single site. Part of the information was collected by interviewing personnel from different levels of responsibility from production planning staff and work supervisors to the machine operators as well as maintenance and measurements personnel. Rest of the individual data was collected by paper inquiries.

Questions in the interviews and the inquiries were about the current good and bad practises, bottlenecks and improvement suggestions related to information flow in general and also special ones related to assignment of the specific staff member in the question. Most of the interviews were done while a current interviewee was actually doing his duty making it also possible to do actual worksite observation and notes based on communication between different actors in the process.

The technology level of those two work sites involved varied between modern production control systems and all-covering production Wi-Fi to the paper based reporting method and analogue walkie-talkie communication system. There were 23 persons interviewed and 76 replies to inquiry.

Table 1 depicts a job type share of employees that answered the inquiry.

Table 1. Share of different job types in the inquiry.

Job Type	Number	%
Management	1	1
Production planning and system engineers	12	16
Measurements staff	2	3
Work supervision	8	11
Maintenance and equipping staff	20	26
Machine operators etc.	28	37
3rd party contract supervision	1	1
Safety personnel	4	5
Sum	**76**	**100**

3 Results

The resulting model and the data integration toolchain were based on the literature survey of the academia and the commercial systems as well as professional interviews and inquiries.

3.1 Information Model

Based on the literature survey and the professional interviews and inquiries, there were multiple requirements gathered related to developed information model. The requirements included topics from model general requirements to single data fragments from process to be included to the model structure.

First, there were multiple requirement suggestions received from interviewees related to detailed information fragments of different sub-topics in underground tunnelling process. Depending the position of an interviewee there were many different perspectives brought up. Different work planning and process follow-up terms like project, task and assignment with related performance parameters like cost, time, a sequence and such were considered important for the model. Also sub-process and machine specific topics like drilling, blasting and hauling machine use, process and maintenance related parameters were supposed to be included to the model.

The system designers and State-of-the-Art research pointed out quite obvious requirements for the model; the model should be modular and extensible in order to guarantee its updateability. Also it was supposed to be semantic in nature for application design that can distribute intelligence of the system also to the model side.

The core of the developed information model consists of selected components from IFC4 and IREDES definitions. Since the main goal of the research was to develop tools for an improved information flow to the tunnelling operations, only applicable parts were selected. From the IFC4 definition, Core schemas with Resource schemas were applied with Construction Management Domain schema. These schemas were then extended using the tunnelling process specific information gathered from the IREDES definition, professional interviews and the SoA research. The extension was named as TunnelBuildingDomain. Since IREDES is mainly an information exchange format that may be getting more common in the future, the activity definition in the developed information model is mapped to IREDES working sequence for later compatibility. The developed model does not cover the physical tunnel model, but physical models can be added to the main model using mechanisms provided by IFC relationship connectors. The model structure and the basis are depicted in Figure 1.

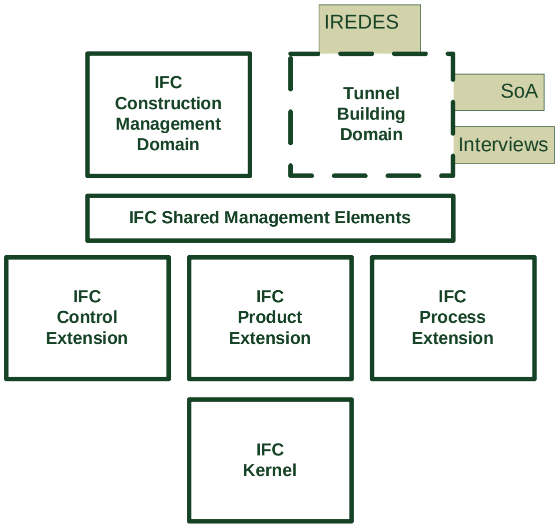

Figure 1. The basis and the structure of the developed model.

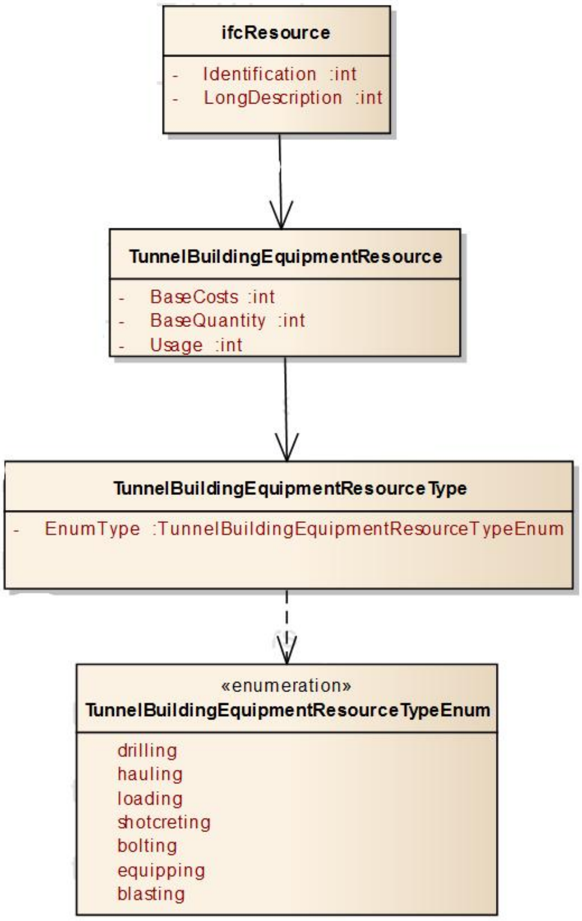

Figure 2. Snippet from the model class hierarchy.

The information model and its components were composed to a class hierarchy following the example of the original IFC4 model. An example snippet from the model can be seen in **Error! Reference source not found.**, where TunnelBuildingDomain sub-classes are inherited from the ifcResource class. The model was modelled following the principles of Unified Modelling Language (UML) Domain Model extension. This model type is so called Domain Model that can be later on grounded to a physical model e.g. Structured Query Language (SQL) database scripts etc.

3.2 The Model Application

A prerequisite for the application interoperability is usage of a common information model. In addition, there are also multiple other actions that may be done to enable successful multi-actor data share. This chapter explains briefly how the model can be developed and deployed in practise.

First, the main information model must be modelled using some appropriate enterprise architect software tool. It may be done using UML Domain Model tool that also supports different relationships between entities. The domain model may then be derived to a physical model that includes database tables and their relations.

Secondly, an essential data may be then brought to database tables. E.g. any ETL (Extract, Translate, Load) tool may be used in order to upload and convert data from data sources to the database and to the model. The important data is then easily accessed from the database over enterprise service bus (ESB) solution or other communication solution. Figure 3 shows an explanatory development and application of the presented information model.

4 Discussion

In this research, the application interoperability of underground rock excavation processes intensification was enabled by developing a common information model and by defining a practical way to exploit the resulted information model.

The research developed an information model and its application description that were based on literature survey, professional inquiry and interviews and worksite observation periods.

The developed model was based in IFC4 and IREDES standard definitions. Currently there is no holistic standard information model available for underground rock excavation processes, but IFC4 have been used as a basis in few other information model researches [13]. However, in this research, the developed model was realized without utilization of semantic web standard languages like Resource Description Framework (RDF) or OWL. In addition to the model development, also the short description how the model could be applied was presented.

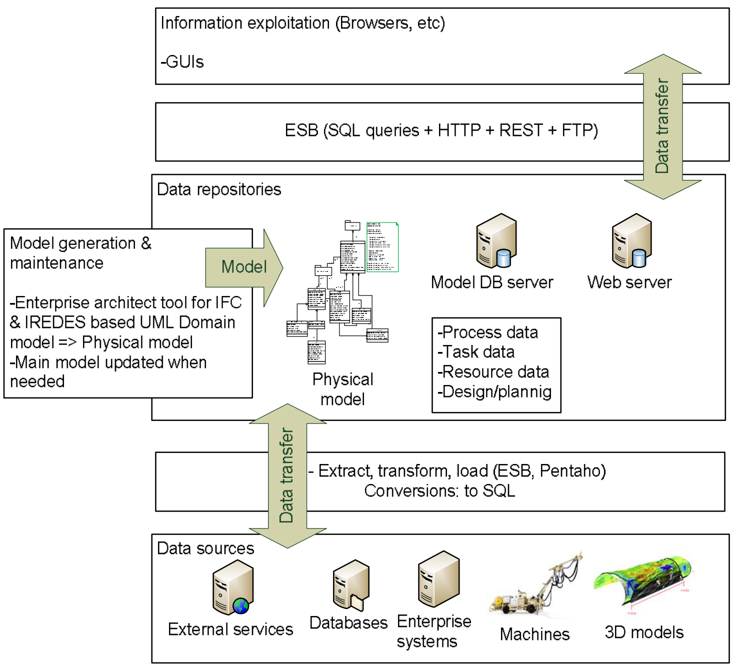

Figure 3. Model development and application practises.

There are several benefits while using the developed model; it is derived from standards or de-facto technologies meaning that a part of it has been reviewed in long run by experts from the different fields. IFC is still developing and maybe in some day there will also be an extension of a tunnelling physical model on it.

The developed model has been realized using UML which enables that the domain model can be read in and updated in multiple software. Also it is easy to derive a physical model automatically out of the domain model, in order to quicken the deployment. Due to the nature of IFC4, the model should be very easily extended and added to upper models.

Of course, there are also disadvantages in the developed model. Information models are always difficult to get standardized. The developed model is not modelled using "pure" semantic technologies meaning that some of the advantages of semantic web cannot be used. E.g. the model cannot be automatically aligned or mapped to other models using those highly advanced semantic linking technologies. Also it should be noted that the inquiry was only concerning two Finnish companies. There may be different requirements for models used in other work cultures with different technology readiness levels and practises.

There are many potential steps for further research work in the field of the application interoperability of underground rock excavation. First, the model and its applicability in practise should be tested in comparative tests in real-life environment including model realization and actual use as a basis for the application interoperability. In addition to the applicability, also its potential financial benefits should be researched. Also the information integration features of the model should be increased by modelling the wholeness with real semantic methods in order to enable automated mapping or aligning of other models to it. Also, the possibility to add real IFC-like tunnel physical model to main model should be developed.

5 Acknowledgements

This research was conducted in a research project called "Flexible Optimization of Underground Mine Production" that was mainly funded by Finnish Funding Agency for Innovation, TEKES. Also the contribution of co-funding companies is highly appreciated.

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