Development of an Ontology for Interoperability Between Lift Systems and Other Systems

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Abstract. This paper proposes an approach to the development of an ontology for interoperability between lift systems and other systems. It introduces the concept of an ontology and gives examples of the services and roles of service users, in the context of lift operation, which might benefit from interoperability. An analysis methodology is discussed, which elaborates the use case "stories" for the service users, leading to the identification of requirements for information exchanges necessary to achieve interoperability. The collective information requirements may then be formalised into the technical definition of the interoperability ontology, and some specific examples are given.

1 INTRODUCTION

This paper proposes an approach to the development of an ontology for interoperability between lift systems and other systems. With increasing sophistication of building services and the systems which deliver them, in both commercial and residential property, the requirement for transparent interoperability between those systems is becoming urgent. Lifts, individually and as coordinated groups, offer a rich and diverse contribution to such an ecosystem of integrated building services. The systems and services, which might interoperate with lifts, are diverse (e.g. environment control, people flow, energy management, materials delivery and refuse collection, cleaning, access security, maintenance, etc.), and standardisation is seen as key to realising the necessary level of interoperability.

A service may have unique requirements of the information domain of lift operation, while at the same time, also having requirements which overlap with other services. It is the combination of all foreseeable service requirements that best identifies the scope and nature of the types of information required to enable interoperability. This paper describes an approach whereby the requirements for the types of information elements, and modes by which they are accessed, are identified by analysing each use case as a textual description or "story". Each story is elaborated from the perspective of a specific service user. Some overview examples are presented, which demonstrate that whilst a simple representation of the current state of the lifts is important, there is also a need for more complex information structures to support the requirements of the varied roles of each of the types of user of any service.

2 WHAT IS INTEROPERABILITY?

Characteristic of a rapidly evolving concept, there are currently various definitions of interoperability. Frequently mentioned aspects [1, 2, 3, 4] include:

- *Diverse systems* talk to each other
- *Share information*
- Applications *securely* and *automatically* exchange data

- *Cross-domain interoperability* - multiple social, organisational, political, and legal entities working together for a common interest or information exchange, irrespective of geographical, political or organisational boundaries.
- *Syntactic interoperability* - common data formats and communication protocols
- *Semantic interoperability* -
    - automatically *interpret* the information exchanged *meaningfully* and *accurately* in order to produce useful results as *defined by the end users of both systems*.
    - both sides must refer to a common information exchange *reference model*.

The European Union is actively promoting interoperability through the Interoperable Europe Act 2024 [5], the European Interoperability Framework (specifically semantic interoperability) [4, 6(sec5.3)] and data sharing through the European Data Governance Act 2024 [7].

For the current purpose, we are interested in identifying the requirements for semantic and cross-domain interoperability, i.e. lifts with other building services and users. This is the prerequisite for subsequent, though no less important, determination of the requirements for syntactic interoperability. In other words, we must know *what* the information is, before deciding *how* best to exchange it, taking into consideration any constraints of the operating environment. The result of the semantic analysis, the "reference model", is referred to as an 'ontology'.

3 WHAT IS AN ONTOLOGY?

Again, various definitions are offered, including: "An ontology is a *formal description of knowledge* as a set of *concepts within a domain* and the *relationships* that hold *between them*. It ensures a common understanding of information and makes explicit domain assumptions, thus allowing organisations to make better sense of their data." [8]

Other definitions [9, 10] that are relevant to semantic interoperability include:

- *Formal Definition*: A formal, explicit specification of a shared conceptualisation of a domain.
- Key Elements:
    - *Concepts (Classes)*: Categories of things (e.g., *lift*, *call*, *door*, *trip*).
    - *Properties (Attributes)*: Characteristics of concepts (e.g., a Lift *hasRegisteredCalls*, a Door *is locked*, etc).
    - *Relationships*: How concepts relate (e.g., a lift *travels to* a floor).
- Benefit – it acts as a:
    - shared *vocabulary*, ensuring that when one system says "direction," another system understands precisely what that means, facilitating data exchange, and
    - the *grammar,* ensuring that relationships are used meaningfully, allowing automated reasoning (e.g. a call is *assigned to* a lift, or a lift is currently *moving* in a direction, while it is *committed* to travelling in the opposite direction).
- *Formal Description* – the specification is:
    - coded in language understood by machines/computers (typically OWL)
    - published as text and diagrams understood by humans

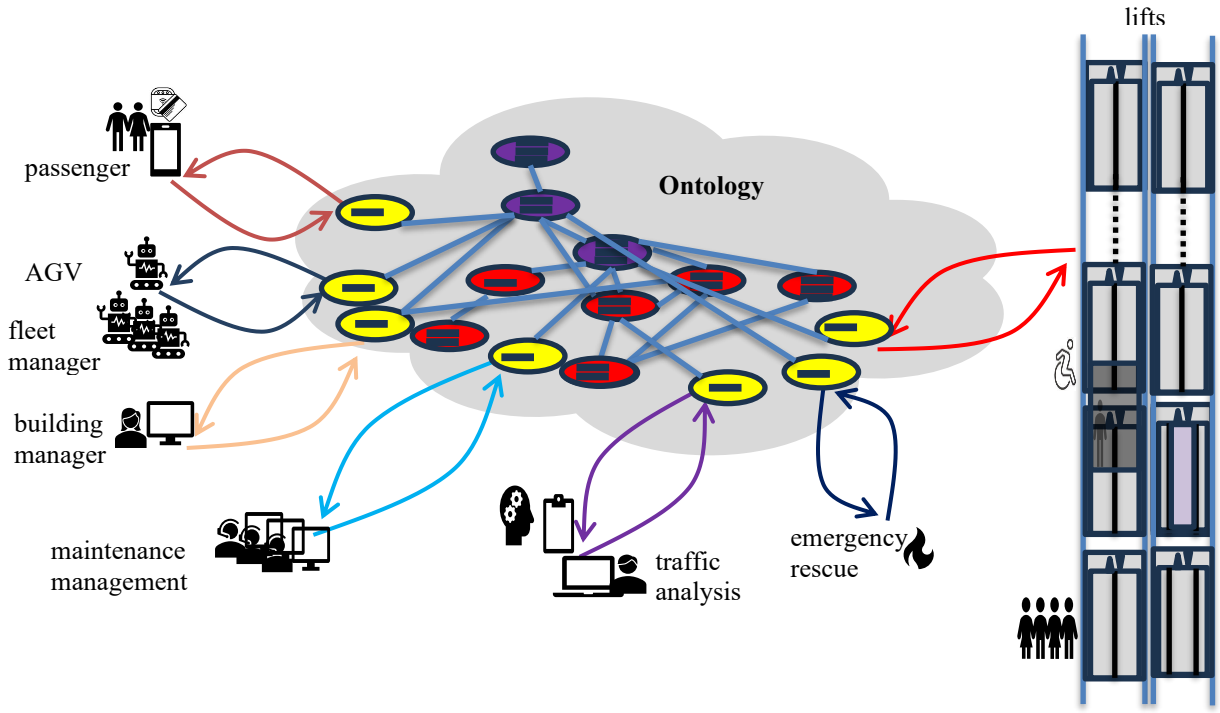


Figure 1 Ontology - supporting interoperability with lift systems

Figure 1 is a visual representation of how, in the lift domain, different types of user might interact (curved arrows) with elements of information (coloured ellipses), where the types of information and their relationships (straight lines) are defined by an ontology. The diagram is simplified for readability, and in reality, any user type will have multiple interactions with many types of information element. Note that no user interacts directly with the lifts or with any other user type.

Once the ontology is defined and published, it can be used to populate any number of information models with confidence that the information contained in each is consistent and interoperable.

4 INFORMATION MODEL

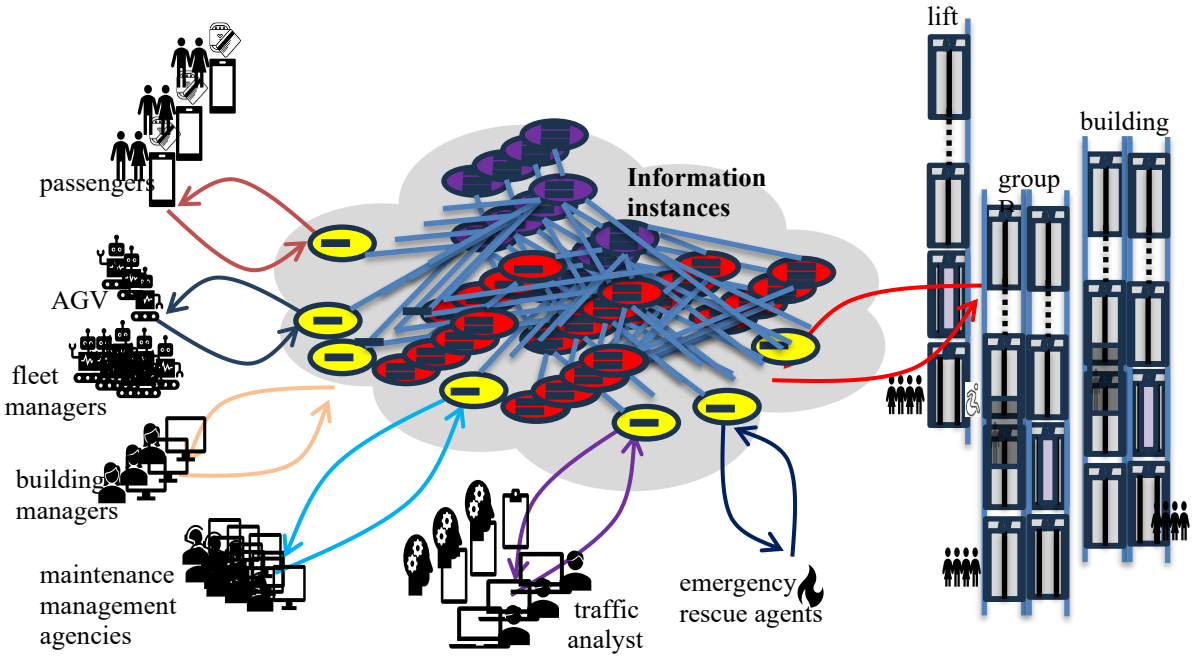


Figure 2 Information model – holds many individual instances of information as defined by an ontology

The ontology for lift interoperability describes the nature of the information of the domain – its concepts, structure and meaning – as a reference model. In the domain of lift operation, the types of entities and their interrelationships are expected to be stable, consistent and well-defined (i.e. standardised). In this case, an information model, which is distinct from the ontology that defines it, is the appropriate means both for holding instances of that information and for publishing it to support interoperability with other domains. The individual instances of the information itself – entities (e.g. the current state of each of the N lifts in Building X) – are held in an information model [11], using the datatypes and relationships that are defined by the ontology.

4.1 Information is accessed via nodes

To be able to address a specific individual instance within the information model, for example, to query the current state of a particular lift, or the state of one of its sub-components, key entity types are defined as nodes. Each instance of any node will have a unique identifier. The combined node address and identifier is referred to as a "resource identifier" [12]. A possible example might be[1]:

```
L4.NorthWing.CentralHospital@acommunity.health.uk/Door?DoorID=Rear
```

The resource identifier allows a precise logical identification of a specific element of instance information (i.e. the current state of the Rear doors of lift L4). However, using this

[1] NB While the resource identifier points to a unique resource, there may be more than one resource identifier pointing to the same unique resource. This simplifies the management of the resource (lift) by various agents/enterprises that may have different formats for cataloguing resources (e.g. following a change of service contract or a business take-over).

representation, the physical location where the information is held is neither explicit nor relevant. For this reason, the information model is represented in Figure 2 as existing within a cloud, isolated from its sources and users.

4.2 Information sources other than lift control equipment

The primary source of information for populating the information model of the lift interoperability ontology is obviously the lift(s). However, the analysis of requirements may identify dependencies on elements of information that, while they are specific to the domain of lift operation, are nonetheless not directly available from regular lift equipment and/or attached devices. For example:

- Static information: floor designations, travel times between floors, etc.
  This class of shortfall may be overcome with the introduction of:
  - manual input of data at the time of installation/configuration.
  - self-learning algorithms based on duration and direction of travel and stops made.
- Dynamic information: demand profiles, immediate contextual pre-history of a fault, door operation cycles whilst stationary, etc.
  This class of shortfall may be overcome with the introduction of:
  - additional software to provide "sensor fusion" [13], that combines and processes data collected from a number of physical sources and devices to provide more complex and richer elements of abstract information.
  - software to undertake logging and trend analysis.

The SAREF SmartLift [14(Sec 5.1)] technical specification, while not covering as broad a scope as discussed in this paper, includes assignment of a variety of different responsibilities amongst defined architectural elements, which comprise the Smart Lift System. These architectural elements can augment the lift control equipment to overcome such shortfalls.

4.3 Information model is distributed

The semantic interoperability ontology deliberately does not specify the location(s) where different elements of the information model are stored and maintained. Indeed, different types of information (or even different instances of the same type) may be held in physically distant locations. As indicated in Figure 2 – information conforming to the ontology reference model is best considered simply as a cloud. This allows great flexibility for a designer to choose devices and connections, from multiple suppliers, which are best suited to the available network, processing and storage infrastructure resources. Infrastructure technologies are rapidly evolving so that the restrictions that apply today may become irrelevant in one or two years, thus emphasising the importance for the ontology of its independence from infrastructure.

5 SUMMARY OF TERMINOLOGY

To summarise:

- The "semantic interoperability information exchange reference model" is defined in an ontology.
- Reference model (ontology) describes the nature of the information. It is standard and common to all lifts.

- An information model holds the current state (and logs) of the information for each individual lift and group of lifts.
- The ontology does not define the physical source of any type of information, nor where information is held. The information in the model should be considered in abstract terms, simply as a cloud.
- Independent decisions about network topology, data rates and storage capacities, etc., can be made to suit individual circumstances.

6 HOW TO DEVELOP AN ONTOLOGY FOR INTEROPERABILITY BETWEEN LIFT SYSTEMS AND OTHER SYSTEMS

The primary objective of interoperability is to make information available from a domain to users (humans and systems) in other domains that could benefit from it. This highlights the importance of the *user perspective* when gathering and analysing requirements for an ontology to support interoperability. In the following sections, a methodology is discussed for developing an ontology for lifts, which places the user perspective as the starting point.

Various methodologies are well documented, including [15, 16, 17] for capturing and analysing requirements of software systems, and specifically for the development of ontologies [18, 19], which can be summarised as:

1. Determine the domain and scope of the ontology –
   This is summarised in the Services and Roles lists in section 6.1.
2. Consider reusing existing ontologies –
   Section 6.2 discusses the contributions from existing work.
3. Enumerate important terms in the ontology to identify –
   Classes, relationships, properties, and rules governing permitted values. This is achieved by documenting requirements as use case "stories" (see section 6.3), followed by requirements analysis (see section 6.4).

6.1 Scope of services and user roles

Figure 1 shows generic examples of use, with implied roles and services. These must now be refined and catalogued. The following lists are typical of the services and user roles that might require interoperation with lifts. These are taken from the following references: CIBSE Guide D 2025 [20], SmartM2M [21]; Requirements & Feasibility study for Smart Lifts in IoT [22] and Singapore Standards standard for robot interface, TR93:2021 [23]. It is important to consider, as a separate use case, the interactions of each role with one or more services. This approach helps to ensure that specific requirements are not overlooked. However, although the listed services and roles represent a wide range of examples, it should remain easy to add further use cases, as required.

- *Services*: Status monitoring and management; Dynamic display of lift operation; External call registration; Pre-emptive/Predictive maintenance; Floor/Location-specific information delivery; Secure access control; Traffic analysis; Investigation of reported abnormal behaviour; etc.
- *Roles*: Standard passenger; Passenger with special privileges and/or accessibility requirements; Robot; Service technician (on-site/remote); Maintenance company;

Building manager; Building owner; Emergency service/Evacuation officer; Lift traffic design consultant; Accident investigator; etc.

6.2 Re-use of existing ontologies and schema

- *SAREF SmartLift* [21, 24] – considers requirements of different user roles and identifies different functional elements of an overall lift system. However, the scope of the information is not broad enough (for example, call registration and assignment are not covered), nor is there a deep enough level of detail of properties (for example, the logical operation of a lift travelling between floors).
- *Standard Elevator Information Schema* [25] – is a comprehensive and structured definition of the information types likely to be required, but as the name indicates, it is a schema and not an ontology. Therefore, it will be necessary to enhance certain aspects (e.g. the relationship between events and the functions of a lift to which they relate) to support the services and user roles.
- *Other standards* [26, 27, 28] – are useful references. However, while offering varying levels of syntactic interoperability, these do not provide the level of semantic interoperability necessary to support the target ontology.

6.3 Document information requirements by use case story

For each service and each type of user (role) of that service, a use case is developed, which includes a use case description or “story” [16]. This is a stepwise textual walk-through of the significant interactions (which can also be presented as a sequence diagram –Figure 3 Sequence diagram example – Call registration and service from external application Figure 3) between the user and the lift(s), with particular emphasis on the information required to be exchanged at each step. In this case, the detailed operation of the user interface (i.e. the presentation) is not significant, but rather the information content of the exchange must be clearly described (e.g. a lift is assigned).

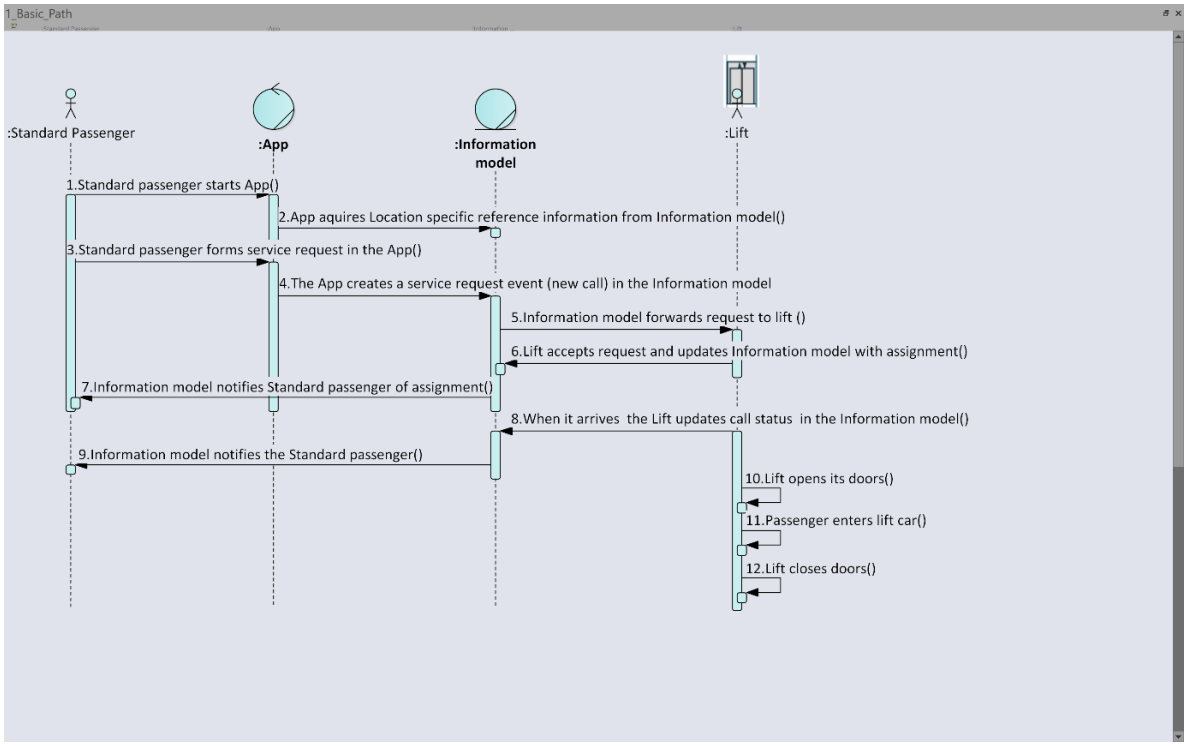


Figure 3 Sequence diagram example – Call registration and service from external application

The resulting use case story allows a thorough analysis of the information requirements, and each use case may contribute some new aspect that needs to be supported. It is a tool for deriving an ontology that is fit for purpose. At the same time, it helps to avoid duplication of, and contention with, other domains by supporting an analysis that highlights those aspects that are specific to the domain of lift operation.

6.4 Analyse information requirements

Once all the use case stories have been outlined, a more detailed and technically formal analysis may be conducted, this time to collect all the concepts of an ontology from the collection of use cases. The analysis results in an identification of the components of the ontology:

- *Resource* – how to find a specific information item (e.g. a specific lift in a group in a building/location)
- *Classes* – lift information is complex and often compounded of several properties which may themselves also comprise a number of properties, e.g. call, demand profile, fault event. As the analysis of requirements proceeds, a catalogue of these complex classes can be compiled. A careful definition of classes is essential for defining a robust and efficient ontology.
- *Property types* – simple data types which are nonetheless specific to the lift operation will also be identified, e.g. floor, direction, operating mode.
- *Relationships* – generally abstract, e.g. a lift serves a set of floors (or landings).

For the identified resources, the ontology will support the following access modes:

- *Query* – what is the current value of an information element (e.g. committed direction of a lift, load on the upper deck, etc)? Usually, a query language is supported, allowing the

resulting information set to be filtered, focused, and possibly ordered according to query-specific criteria.

- *Event* – notification that the current value of an information element has just changed, e.g. doors now fully opened, fault event, etc. This will be time-stamped with the instant that the change occurred. Usually, an "observer" "subscribes" to a type of event to be notified each time that event occurs.
- *Request* – update the existing value (e.g. door open request) or create a new one (e.g. register a new landing call).

Additionally, the ontology will support:

- *Discovery* – publish the classes of resource information that are supported by this ontology. This can be used to identify the version and coverage offered by a specific instance of the ontology.

7 EXAMPLES OF SIGNIFICANT OUTCOMES OF ANALYSIS

In this section, some examples of more significant concepts are given, which identify dependencies on information that might not be obvious from the title of the use case alone.

- A passenger registering a call, having been identified and authorised by the access control system, should only be presented with the choice of destination floors which they are authorised to access. A similar list will be required of floors served by each of the lifts to which the call might subsequently be assigned. This indicates that a list of floors (defined as "*floorset*") is a useful type of information element. The list is ordered by increasing relative height above the lowest floor, so that the building can be presented to passengers in a meaningful manner.
- Notification of exceptional behaviour to a service technician is more useful if the notification includes the *event context*. For example, if the exception occurs during travel, then the events that occurred during the trip leading up to the exceptional event provide valuable context. This indicates that in addition to the position and speed of the car at the time of the exception during travel, a *trip* (origin and destination floors, car load on departure) is a useful type of information element. This example highlights that in exceptional circumstances, which by their nature cannot be predicted, the detailed logging of events and status can be of significant value, whereas in normal operation this level of detail would simply represent a costly burden.
- The previous example of the benefits of associating an event with its context highlights the advantages, from the perspective of a user/system that is external to the lift information domain, of a combined view of the elements of information of a lift (current state and associated events), in terms of the *functionality offered*.
  Key functions (there may be others) are:
  - *Passenger access function* - Enable passenger access to the lift car (usually to operate the opening and closing of the doors). This is a cyclic function which starts and ends with a closed/locked state. Final context of an instance of the passenger access cycle includes timings of opening, closing and dwell operations, number of reversals, load on arrival, minimum load, and load on departure.

  - *Travel function* – Manage the safe standard movement of the lift from an origin floor to a destination floor. Again, this is a cyclic function, beginning and ending when the car is stationary at floor level.
  - *Service request function* – The acceptance of requests to travel (directional and destination landing calls, car calls, and parking calls). This function is not cyclic - it starts with a new call request and finishes when the call is no longer active (e.g. for a destination landing call, when the passenger is delivered to their requested destination floor).
- A *travel plan* for a lift – the sequence in which floors (landings) will be serviced by the lift – would be useful for an emergency responder during building evacuation.
- A *demand profile,* which is a statistical summary of demand over a period, per sample period as averages and other statistics, per floor and direction (or origin-destination pair if known), is needed when undertaking a traffic survey.

8 CONCLUSION

This paper gives an overview of the many aspects of analysing the requirements of an ontology which supports the interoperability of lift systems with other systems. Starting with a discussion of the objectives of interoperability and what is meant by an ontology, the paper presents these concepts in the specific context of the domain of lift operation.

A use case-based methodology for capturing requirements and their subsequent analysis is then discussed, and examples of important concepts are given, which are specific to the domain. This approach emphasises the user perspective, the essential quality for interoperability. It provides a stepwise analysis of the users' requirements for information. It also highlights elements of the required information model that may not be readily available from standard lift equipment, with the aim of prompting a discussion of how such requirements might be supported.

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BIOGRAPHICAL DETAILS



Jonathan Beebe has more than 40 years' experience in bringing software design and information modelling technologies into the domain of lift system control and monitoring. Throughout his career, Jonathan has maintained an active interest in research, resulting in the publication of the Standard Elevator Information Schema (SEIS) in 2003. Jonathan's research includes designs for a Global Dispatcher Interface (GDI), based entirely on the SEIS. He is currently developing an ontology to enable semantic interoperability between lift systems and smart buildings and cities, in which vertical transportation systems play a fundamental role.

AUTHOR'S NOTE

This paper is the result of independent thought and research spanning more than 25 years. At the time of writing, the author is actively contributing to the working group of the International Organization for Standardization (ISO), representing the British Standards Institution (BSI), on Approved Work Item: *ISO/AWI TS 8100-11, Lifts for the transport of persons and goods. Part 11: Interoperability between lift and other systems*.

The author confirms that this paper is original work and is neither published on behalf of nor endorsed by either ISO or BSI.