Interoperability Platform

i-models to Unlock the Value of Information Mobility

A Bentley White Paper

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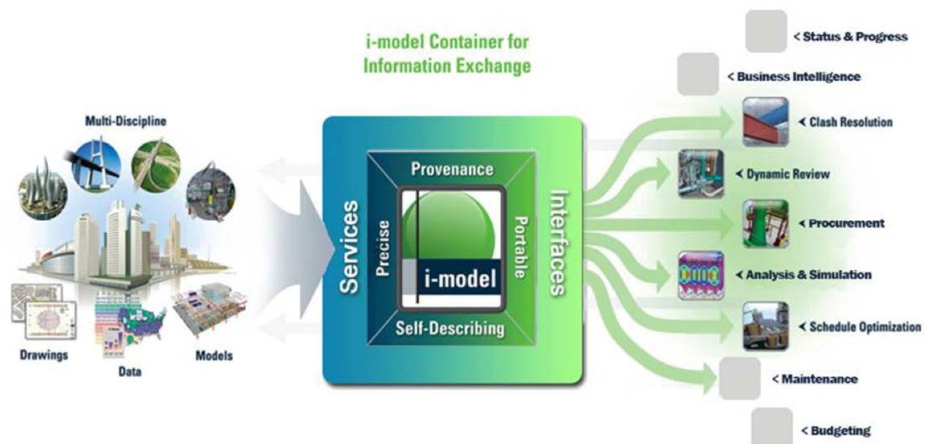
Executive Summary

In 2008, Bentley published an *Interoperability Platform whitepaper* that provides background information on the issues and challenges associated with the interoperability of information technology systems supporting the lifecycle of infrastructure assets. In particular, it focuses on the performance of the *projects* executed in support of infrastructure assets, including *design, construction*, and *commissioning* as well as the repeated projects to *expand, improve, retrofit*, and *rehabilitate* infrastructure assets. It also describes the rationale and elements of Bentley's strategy for implementing an *interoperability platform*.

In this paper, we begin with a brief summary and update of the issues surrounding interoperability and the key elements of Bentley's interoperability platform strategy, and then focus on the implementation of *i-models*. In short, *i-models are containers for the open exchange of infrastructure information.* They serve as the digital currency for the broad-based exchange and reuse of the information models associated with the lifecycle of infrastructure assets. i-models are fundamental to Bentley's overall interoperability strategy of enabling *information mobility*.



i-models are containers for the open exchange of infrastructure information. They are fundamental to Bentley's interoperability strategy of enabling information mobility across multidisciplinary project participants and lifecycle phases.

As described in the original whitepaper and summarized here, to satisfy the unique demands of infrastructure projects, Bentley's interoperability strategy is built around the concept of *federation*. To enable interoperability and information mobility across project phases and project disciplines, a federated environment must support:

- Operational independence
- Managerial independence
- Geographic distribution
- Incremental implementation
- Existing applications
- Adaptable information models

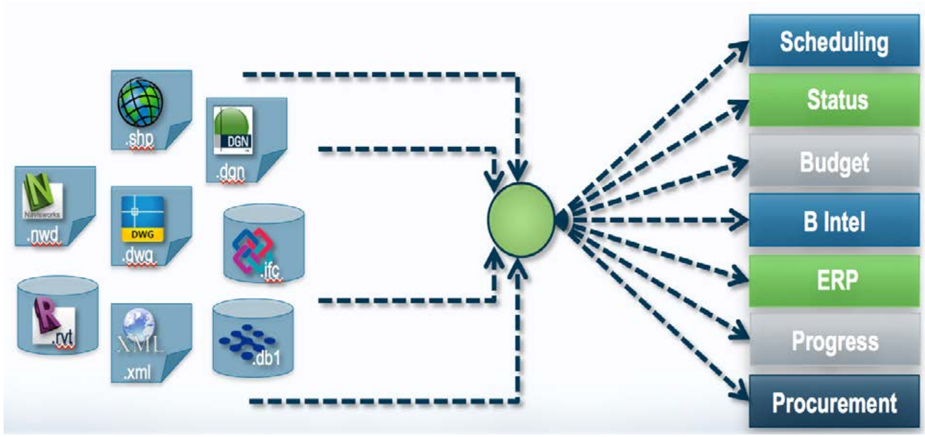
The i-model concept, along with its subsequent implementation and supporting services, is a fundamental enabler that allows users to reap the benefits of Bentley's federated interoperability strategy. In simple terms, an i-model contains all of the rich content associated with a project's information models. All of the content within an i-model is from a *known source*, of a *known scope*, of a *known state*, at a *known time*, intended for *known purposes*. As such, the i-model concept maps directly to the *necessary, widespread*, and *well-understood* concepts and processes for exchanging and distributing packages of information within the multi-organizational, multi-disciplinary, and multi-phase structure of infrastructure projects.

As will be described in this paper, by building upon the principles of federation, i-models and their surrounding services can be introduced and add value at any point in the lifecycle of an infrastructure asset. Their use is not dependent upon specific workflows, information models, or software applications. They are not limited to any single phase of the asset lifecycle. This technology to support a federated approach to lifecycle interoperability is unique to Bentley and can provide significant value to all of the participants in a project enterprise.

Interoperability Challenge

Projects are the engines that drive an infrastructure asset's lifecycle. Through projects, infrastructure assets are created, expanded, improved, adapted to new technologies, modified for new purposes, and decommissioned. From an information technology perspective, every project faces significant challenges, driven by the characteristics of today's infrastructure projects:

- The multiple project participants and the project "supply chain" are brought together quickly, exist for a short time and are then disbanded. A project enterprise is always ***temporary***.
- New technology, new suppliers, and new requirements inevitably change the configuration of a project enterprise. Likewise, every infrastructure project is bound to "place," to a specific location on the earth, subject to local regulations, the local political and economic environment, local practices and methods, local suppliers, and the local workforce. It is unlikely that the exact project configuration of one project will appear in the next project. Hence, every project is ***unique***.
- The participants and stakeholders in a project will not be located in the same location. For 21st century projects of any size, the project participants are nearly always ***globally distributed***.
- In the multi-organizational, distributed, and highly parallel workflows of today's projects, no project participant could effectively execute its tasks if it were exposed to the constant "information churn" that takes place across the project every day. Information is communicated across disciplinary, organizational, and project phase boundaries -- not through constant database transactions -- but in discrete groupings of information in a specific state representing a specific scope of the project. Information is communicated across project boundaries in ***packages***.



The complexity and multiple, specialized formats of engineering information have long been a barrier to the complete and timely use of this rich information by critical project management, operations, and business applications. The implementation of i-models mobilizes this information for direct use by the broader distributed enterprise.

It is these characteristics that drive the information technology challenges that an organization faces as it moves from project to project. Significant among these challenges is adopting a strategy for *interoperability* and *information mobility* that enables an organization to survive and thrive in the dynamic environment of infrastructure projects.

If projects are the engines that drive an infrastructure asset's lifecycle, then information is the fuel. Projects succeed or fail based on how effectively information is created, shared, applied, and distributed. The obvious conclusion to draw is that today, information technology has a central role to play in the successful execution of infrastructure projects. The key to unlocking the full value of information technology is to solve the interoperability challenge.

The lack of interoperability also limits the opportunities for much needed innovation in the form of new work processes, new business models, new contractual models, new delivery mechanisms, and so on simply because it is too difficult or costly to opportunistically adapt our information technology systems new configurations. These lost opportunities may reflect the real cost of the lack of interoperability.

Every organization within the infrastructure industries – small to large – faces these interoperability issues at some level. How do we share information among the multitude of application systems across functional boundaries, across organizations, and across the lifecycle? Can the manner in which we deliver information to other participants in the project enterprise add value to our services and products? How do we create and capitalize on new opportunities to leverage information technology and the vast amounts of project information to our collective advantage? How do we capture the knowledge and best practices for project execution so that it can be adapted and reused from project to project? In the section that follows we will describe Bentley's strategy and supporting technology to address the issue of interoperability and thereby answer these important questions.

Interoperability Strategy

Multiple approaches are applied addressing the interoperability challenge across the spectrum between point to point interfaces, industry data standards, and a single "centralized database." While these approaches can provide value within a limited scope, none of these alone are adequate to address the broader interoperability requirements that span the entire project enterprise and the infrastructure asset lifecycle. Here we'll describe Bentley's strategy for an "interoperability platform" aimed at transcending the limitations of these approaches. The objective of this strategy is to provide the *flexibility, scalability, transparency*, and *economy* demanded by actual infrastructure projects and eliminate the constraints imposed by the other approaches.

A Federated Approach

It's natural for our rational minds to conclude that if we know the requirements, we can build the system. Putting aside the non-trivial issues associated with "building the system," this seemingly obvious conclusion overlooks an important fact – given the dynamics, uniqueness, and limited timeframe of each individual infrastructure project, we can *never* know *all* the requirements of a *future* project. So the issue is not one of becoming infallible predictors of the future or capturing every requirement from every point of view in a single place. Rather, it's one of determining how we implement an interoperability strategy that enables us to navigate and thrive in a constantly changing world with constantly changing requirements.

To overcome the limitations of the "point-to-point" and "centralized database" approaches when applied to infrastructure projects, Bentley has adopted a "federated" approach. Federating project information is <u>not</u> the same as "merging" all project information, as in the case of the centralized database approach.

In a federated approach, multiple heterogeneous applications and information sources from multiple software providers are loosely coupled for the purpose of:

- Sharing information between applications,
- Handing over and reusing information across organizational and project phase boundaries,
- Aggregating information into multiple consolidated "views" of the project information that are tailored to the requirements of key project participants.

Under this scenario, each application maintains its autonomy but is able to participate in an open, flexible, and interoperable project environment.

Requirements for a Federated Project Environment

Successfully meeting the interoperability challenge requires a federated environment that exhibits the following qualities:

Supports operational independence

Each application (or sub-system of applications) within a federated environment is able to operate and provide value in its own right independent of the specific configuration of the project systems. This is a key element in supporting the flexibility and scalability required by infrastructure projects.

Supports managerial independence

Hand-in-hand with operational independence is managerial independence. Given the multitude of groups and organizations involved in infrastructure projects, a mix that can also vary over time during a single project, the success of a federated environment is not dependent on how the individual applications and sub-systems are acquired and who operates them.

Enables geographic distribution

A critical requirement is the ability to support the increasingly distributed – often globally distributed – nature of infrastructure projects. This means a federated project environment must function across multiple communication infrastructures, accommodating whatever communication infrastructure exists in the multiple localities.

> "Whatever may be the plays on words and the acrobatics of logic, to understand is, above all, to unify. The mind's deepest desire, even in its most elaborate operations, parallels man's unconscious feeling in the face of his universe: it is an insistence upon familiarity, an appetite for clarity."
>
> – Albert Camus, 1955

Allows for incremental implementation

In an environment of changing requirements and unknowable future requirements, where we don't know everything "up front," it is an absolute necessity that the federated environment enables and supports incremental, evolutionary implementation. Experience and new best practices will continue to inform the configuration and capabilities of our project systems, even during a project. A federated project environment will make it possible to continue to improve project execution and enable the required scalability and flexibility needed for infrastructure projects.

Embraces existing applications

A federated project environment allows existing applications to connect to the interoperable environment with minimum impact on existing application. The federated framework provides configurable connectors for popular industry applications and industry standard information formats, as well as a robust software toolkit for streamlining the implementation of custom or unique connectors. In all cases – unlike the point-to-point approach – only a <u>single</u> connection to the federated environment is required.

Enables adaptable information models

A federated environment allows the information models used to be extended and modified without requiring subsequent modifications to each of the applications and their connections to be modified. Interoperability strategies dependent on specific information models that are "baked in" to the source code of project applications place a significant constraint on the needed flexibility to support an incremental and scalable implementation.

The characteristics of a federated project environment outlined here are necessary for any significant system expected to provide value within the context of the uncompromising dynamics and far flung distribution of infrastructure projects. The benefits of a federated approach are not dependent upon using only software applications from

Bentley and equally can accommodate software applications from multiple vendors. A federated approach also makes it possible to introduce new applications and new information sources at any point in the project lifecycle.

Beyond enabling an interoperable project environment to achieve actual project interoperations, the interoperability platform described here provides the capability to create true information technology *solutions* – solutions for specific types of infrastructure assets and solutions for specific lifecycle phases of those infrastructure assets. The adaptable information models, along with the rules for managing, transforming, and delivering project information, represent critical *solution knowledge* that can be reused and adapted for future projects. Leveraging the inherent flexibility of the interoperability platform described here allows these solutions to be quickly adapted to the unique realities of each individual project.

Interoperability Platform: i-models

Bentley's interoperability platform is not a single product or technology. Rather, it's a collection of products and technology that users can deploy and configure to implement a federated, interoperable environment for their project in order to realize the benefits of information mobility. A fundamental element of the interoperability platform is *i-models*. The i-model concepts and implementation are driven by the requirements of a federated environment that can accommodate the characteristics of today's infrastructure projects – i.e., the *temporary* and *unique* nature of every project, project participants that are *globally distributed*, and the exchange of *packages* of information across project boundaries. The following section describes the motivation, characteristics, and supporting software infrastructure for i-models.

In simple terms, an i-model is a digital container for the rich project content associated with project information models. All of the content within an i-model is from a known source, of a known scope, of a known state, at a known time, intended for known purposes. As such, the i-model concept maps directly to the *necessary, widespread,* and *well-understood* concepts and processes for exchanging and releasing information within the multi-organizational, multidisciplinary structure of infrastructure projects, such as work packages, milestone deliveries, issued for construction deliverables, and so on.

An i-model stores and exposes project content at multiple levels of abstraction. At the file level, this includes artifacts such as documents, images, database tables, drawings, models, and so on, including business properties, multimedia objects, and relationships. To fully satisfy the requirements of a federated project environment, i-models are intended to support *all* types of project information including:

- Business properties and tabular data
- 3D geometry (surfaces, solids, point clouds)
- 2D graphics (vector, text, raster)
- Documents
- References and links to other project and enterprise information

The utility of i-models is not limited to a single domain, application area, or lifecycle phase. They are equally applicable, for example, in the operational phase of an asset's lifecycle as they are during design and construction. From the Bentley perspective, i-models are applicable to all product lines and all solution areas. From the broader project perspective, i-models are intended to be applied to workflows that incorporate software applications from multiple software vendors, including applications developed by users themselves, across the lifecycle of infrastructure assets.

i-model Characteristics

In order to support the requirements of a federated environment and enable information mobility, i-models have the following characteristics:

Self-describing

To be a broadly applicable container for exchanging project information, the contents of an i-model are completely comprehensible without requiring specific application logic from the authoring application – in other words, it is *self-describing*. To achieve this, the properties, graphics, geometry,and so on created by the authoring application are normalized to a consistent and complete form within the i-model. This allows consumers of i-models to interact with them using the same methods and tools, regardless of the specific authoring application that created the content, regardless of the provider of the authoring application.

In order to have general applicability, an i-model does not dictate a specific information model (schema) for its content. An i-model can support any schema defined by the authoring application. In order to be self-describing, an i-model includes the schema definitions within the i-model, along with its project contents.

An i-model can also support external references and links that are represented in standard, well-understood mechanisms, such as URL's, reference files, etc. that can, likewise, be resolved without requiring any application logic from the authoring application.

Provenance

All i-models include information about its origin and history, known as its provenance. The provenance enables consumers of an i-model to know exactly where the information came from. The i-model provenance specifies the source, date, state, scope, and purpose for the information contained in the i-model. If the source content is managed within a content management system, such as Bentley's ProjectWise, the metadata from the content management system is also included. Provenance at both the file and component levels can be accommodated. Transformations applied to the content (e.g., mapping to new schemas, filtering objects, aggregation, decomposition, relating, etc.) after being published from source content are recorded in the provenance and result in a new i-model. The provenance can support the aggregation of transformations applied to an i-model, thus providing a complete history of the i-model from its original creation from the source content to the consumer of the i-model.

Security

To be a reliable container for exchanging project information, an i-model is secure. To support this, an i-model is always read-only. This is required since any change to an i-model invalidates its provenance. For a change to be valid, it must result in a new i-model and with a corresponding new provenance. Additional security can be applied to i-models through standard digital rights and digital signature technology.

Precision

The geometric and graphical content within an i-model is geometrically precise. The geometric representations are not approximations of geometry elements, such as 3D solids. Rather, the geometric elements can include the same representations and precision of the application that originally created the geometry.

Perhaps more importantly, the objects contained in an i-model can include the precise geospatial location, even for objects that include no geometry or graphics. While many applications for consuming i-models can operate with geometric approximation, such as faceted surfaces, the precise geospatial location of a component within the context of the project is nearly always critically important.

Openness

Finally, to be usable across the infrastructure communities at large, an i-model is open. While the documentation of the precise file format is available, this is insufficient for i-models to be directly usable by project participants on a broad basis. From a practical point of view, the key to openness is not formats, but the available *interfaces* and *services* described in the following section. Bentley currently supports two formats for i-models: one based on the .dgn format and the other based on the SQLite format. However, this is largely transparent to end users and developers as consistent interfaces are used, independent of the persistence format of the i-model.

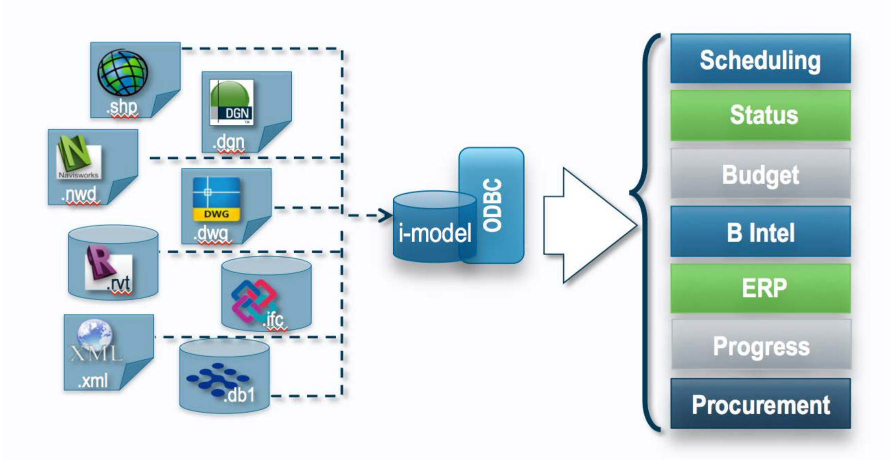
i-model Interfaces and Services

To increase the usability – and thus the openness – of i-models, Bentley provides a wide range of tools for i-models and an i-model ecosystem for the various constituents within the infrastructure communities. These include:

Interfaces

Bentley provides a number of interfaces to i-models to users and third parties, including:

- Free viewers for interactively viewing the rich 2D and 3D graphics and querying associated business properties – These enable any infrastructure user to view and query any i-model.
- A free ODBC driver for i-models – The driver exposes all the business properties contained in an i-model to any ODBC-enabled application, which includes Microsoft Office applications such as Excel, MS Access, Visual Basic, database tools, reporting tools, and so on.



The services integral to implementing i-models normalize and unify information from complex and disparate sources. The i-model interfaces enable the direct and immediate consumption of this valuable information by standard, business-oriented applications.

- In addition, the ODBC interface can be configured to provide multiple "views" of the i-model component properties optimized for a specific end use. This is particularly useful when the i-model contains information with a highly normalized schema, such as those associated with complex design applications or industry standards such as IFC or ISO 15926.
- All Bentley design applications include services to publish, display, and query i-models.
- A growing number of i-model publishing capabilities provided by Bentley for non-Bentley applications.
- Software developer kits (SDKs), provided by Bentley through the Bentley Developer Network, to allow users, third parties, and Bentley competitors to publish i-models from non-Bentley applications, as well as to consume all of the content contained within an i-model (e.g., business properties, graphics, geometry, raster, etc.).

These interfaces are typically available either as inherent features of existing Bentley products or freely available as iWare applications.

Services

Bentley also provides services that can be configured to meet the needs of a specific project, to enhance and extract the value contained within i-models, including:

- A set of user-configurable processing services to enable the tailoring of the information contained in an i-model to support specific project workflows – Known as *Transformation Services*, these include a broad range of capabilities for manipulating i-models, such as:
  - » *Map an i-model to a new schema that is most appropriate for a specific project task* – A simple example is a design review incorporating models from multiple design applications from multiple software vendors. Inevitably, the

design applications from each vendor will have unique schemas, even within the same discipline. This makes it extremely difficult to do queries across all of the i-models. By mapping all the i-models to the same schema it is possible to perform queries much more easily.

» *Filter i-model objects* – The consumer of an i-model may wish to work with only a subset of the content within a set of i-models. Filtering makes it possible to generate an i-model from an existing set of models that includes only the objects satisfying a query defined by the user. For example, a user receiving an i-model for an entire building might want to work only with the curtain walls.

» *Relate the contents of multiple i-models* – When interacting with i-models, it is often useful to have direct access to associated information, for example cost, status, specifications, etc. This service provides the ability to relate objects from one i-model to another i-model based on rules associated with the project.

» *Augment object properties with content from external sources* – In addition to retrieving information from related content by traversing relationships, it is often desirable to query an i-model based on the related content. The properties of objects in an i-model can be "augmented" through a Transformation Service. For example, an i-model, including design content, can be augmented with construction content, making it possible, for example, to have a query return only those objects whose construction is "installed."

> "Thus the creative act is an effort to give enduring shape or pattern and meaning to perpetual-seeming flux of ongoing experience."
>
> – Albert Murray, 1977

- The Transformation Services rely heavily on schema definitions. Bentley provides a component, the *Bentley Class Editor*, that enables users to directly create, edit, and manage the schemas used within a i-model transformation process.

  Transformation Services can be applied individually or, using tools provided by Bentley, a sequence of transformations can be interactively scripted and executed. As in the case of i-model interfaces, the services described here are freely available from Bentley.

What i-models are not

Given the fundamental importance of i-models within Bentley's interoperability platform, it is important to point out a few key points regarding i-models:

i-models are not substitutes for industry standards

An i-model can contain information in industry standard forms, such as IFC or ISO15926. The industry standard would be defined via the i-model schema. In this sense, the i-model is a secure container for transporting and delivering industry-standard content that also includes the provenance of the content.

Standard deliverable formats, such as PDF, and the degree of richness and complexity they support, can be published from i-models. There are cases in which an i-model may be regarded as a deliverable, but this is not its primary purpose. Through Bentley's PDF publishing tools, i-models containing 3D model data can be embedded in PDF files and viewed with Adobe Reader using a plug-in freely available from Bentley.

Existing applications do not need to be rewritten

As a container for exchanging, delivering, and handing over project content, the i-model exists outside the bounds of a single application. Existing applications simply need to publish and/or possibly consume i-models as dictated by specific interoperability requirements. For those applications without this inherent capability, this can be implemented through one of the several SDK tools readily available from Bentley as described above.

i-models are not a substitute for existing tightly integrated product suites.

i-models are primarily targeted at achieving interoperability across application, organizational, and lifecycle boundaries. They are not intended to support multiuser transactions against their contents. Bentley and many other vendors provide tightly integrated product suites aimed primarily at a workgroup level. Bentley's approach to enabling more tightly integrated work groups that include applications from multiple software vendors is a concept know as Cross-Discipline Coordination Service.

Implementing i-models

The desktop tools for creating, viewing, querying, and transforming i-models are freely available from Bentley on the ***iWare Apps for Information Mobility*** page of Bentley's website. These include:

- Plug-ins for third-party applications, such as Revit, to publish i-models from design content
- Bentley View to view and query i-models
- Tools that allow users to publish i-models in a format optimized for viewing on an iPad; the iPad viewing apps are available for free in the Apple app store
- Transformation Services for transforming i-models in a variety of ways, many of which were described under the "Services" section above – The Transformation Services are completely configurable by a user to accommodate the workflows, requirements, and information models for a specific project.
- An ODBC interface to easily access the business properties within an i-model. This interface exposes all the business properties, geometric properties, and provenance contained in an i-model to any ODBC-enabled application, which includes Microsoft Office applications such as Excel, MS Access, Visual Basic, database tools, reporting tools, and most business oriented applications. The ODBC interface also incorporates the i-model "view" capability described above.
- Bentley Class Editor component for creating and adapting the schemas for the information models used for a specific project

In addition, virtually all Bentley applications can publish and consume i-models, including those applications based on Autodesk's AutoCAD. An increasing number of third-party software providers support i-models within their applications. Third parties and end users can enable their applications to support i-models through the Software Development Kit (SDK) available through the ***Bentley Developer Network.***

Ultimately, all of the services associated with i-models – creation, transformation, publishing – will be available through the *i-model Composition Server.* This will provide i-model services, deployed on a server or via cloud services, that enable batch processing, workflow automation, and distributed access to the i-model services. The *i-model Composition Server* will become a component of Bentley's emerging online services capability for Bentley users known as *Bentley CONNECT*.

Summary

An i-model is a container for the open exchange of infrastructure information. It can be considered the "currency" for distributing and exchanging project content within a federated project environment. There are many interoperability "pain points" within user workflows that can be addressed and alleviated by i-models and their supporting infrastructure.

Project conditions are in constant flux – new technology, new project types, new business opportunities. The flexibility enabled by i-models and, more broadly, a federated environment make it possible for a project to adapt in "real-time" to the inevitable unplanned and unexpected events arising during the project. This flexibility also dramatically improves scalability. The ability to configure familiar and productive tools for small projects, large projects, and diverse projects can be a significant advantage. This flexibility also enables greater resilience for the project as there is no "single point of failure" or reliance on one single technology or one single software vendor.

The broad-based implementation of i-models and associated services enables the ability to create multiple aggregated "views" into the project information, thereby providing much greater visibility into the project and how it is performing. These capabilities enable users to make better-informed decisions, to react more effectively to crises and unexpected events, and to explore a broader range of alternatives in project decision-making. In the end, these capabilities make it possible to be much more effective at managing risk.

Bentley's interoperability platform can be a strategic component of any infrastructure project by creating an interoperable project environment and enabling true interoperations among the diverse software applications applied to the project. It delivers the flexibility, scalability, and robustness demanded by today's infrastructure projects. It acknowledges the fact that every project is unique – a special case. It is the key to *navigating* and *thriving* in a dynamic industry with ever-evolving requirements and opportunities arising as we collectively continue to create, operate, and sustain the world's infrastructure. i-models are a fundamental building block of Bentley's interoperability platform and a key to unlocking the value of information mobility.