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A Bridge-centric Approach to Digital Delivery

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Abstract

The continuously evolving discipline of digital delivery is revolutionizing the way projects are delivered. Development of federated models provide views into the future of construction sites and completed projects, improving the way engineering teams, contractors, and asset owners coordinate and manage projects and bridge assets. The industry's increase in digital delivery capabilities and demands has caused disturbance to the traditional bridge design process. While construction drawings may still lag engineering design, digital bridge models are often developed before engineering has even begun, introducing new costs and uncertainties early in the project lifecycle. For projects of all sizes, management of these new costs and uncertainties requires detailed digital delivery strategy that must be developed through collaboration with key stakeholders. These stakeholders include asset owners, contractors, and internal design teams, including bridge engineers, each of whom brings individualized desires that drive a project's digital deliver. A strategic bridge-centric digital delivery must explore, understand, and address each of the stakeholder needs while prioritizing the key drivers of a bridge's engineering design into the digital delivery strategy. This approach optimizes the design process and timeline by increasing the bridge engineer's control of the design and digital model and reduces abortive work at intermediate deliverables, while still meeting the objectives of all stakeholders.

This presentation will discuss how bridge design teams can drive digital delivery processes while keeping bridge design and construction as the focal point. We will examine recent projects and highlight the changes occurring to design processes, coordination, and reviews, as well as provide suggested best practices.

Keywords: digital delivery, bridge modelling, workflow, risk management, client management

1. Introduction

Adoption of BIM (building information management) in the transport infrastructure space has added another tool for design consultants, constructors, and stakeholders to use in the pursuit of accelerated delivery, improved quality, and reduced cost. Such a tool represents a great innovation enabled by advancing technology. As such, it is becoming common for a project's digital delivery scope to include development of a single federated model, or a three-dimensional model incorporating design data from all relevant disciplines.

Successful inclusion of a federated model into a project’s scope requires a digital delivery plan that holistically captures the desired outcomes while granularly accounting for the effort, costs, and challenges that digital delivery adds to a project’s delivery. Developing this plan is the responsibility of project leaders from all involved parties, including design consultants, construction contractors, owners, and stakeholders.

Development of the plan must consider a variety of factors. First, each project party’s desired outcomes and planned uses for the federated model should be established. This enables the information exchanges required to fulfill those objectives to be determined, including considerations for level-of-development (LOD) requirements during the project life cycle. With these objectives and requirements in place, granular digital delivery plans at the discipline level can be developed.

A bridge-centric approach to digital delivery focuses on the unique aspects of bridge engineering and bridge design delivery. It seeks to maximise efficiency and to minimise risks of re-work primarily by utilising a timeline for development of the digital model that enables maximum engineering to be completed ahead of digital modelling.

Through coordinated efforts with all project disciplines, the contractor, owners, and stakeholders, a bridge-centric digital delivery plan also provides tailored levels of information exchange during design development and seeks to fulfill the objectives and interests of each party. Implementation of a bridge-centric plan requires upfront understanding and management of expectations for all parties. This ensures the digital delivery is not pressured to advance beyond its planned LOD early in design, yet still provides sufficient detail to meet objectives.

In summary, a bridge-centric digital delivery plan is one that puts the bridge design as a priority, while still respecting all stakeholders. It maintains the bridge engineer’s control of the design and plans digital development, while encouraging continued interdisciplinary design coordination throughout a project. This is all accomplished while minimising risk of re-work and catering to the objectives of project parties.

2. Design Development and Digital Delivery

For discussion, digital delivery refers to the development and use of 3D models for the development of infrastructure design. The models are provided with information attributes that can then be used for a variety of purposes. Current practice typically sees 3D bridge models developed both for incorporation to a project’s federated model and for use developing construction drawings for a bridge. This is a change from CAD based delivery, which saw bridge drafters assemble construction drawings using a collection of individually drafted 2D details.

Despite a shift towards digital delivery, the level of development for details on construction drawings remains largely unchanged. Concept design plan still represent approximate 15-30% design completion and indicate intended structural layout, sizing, and articulation. Preliminary design represents 50-60% design and should reflect the structure’s layout and articulation accurately, including the sections of each member. Finally, detailed design approaches 90% completion and includes reinforcement, bolt sizing, welds, and all other requisite detailing. Once final details are added and project parties are satisfied with the design, Issued for Construction drawings containing the fully completed design are prepared.

Using 2D drafting to prepare plans, the effort required to prepare the drawings at each gate has typically followed the percent of design completion. However, use of a 3D model for preparation of construction drawings can result in substantial up-front effort to develop a model suitable for extraction of details for construction drawings. Figure 1 below shows a relationship between level of effort required for digital delivery methods compared to 2D drafting. It also indicates an assumption that 2D drafting’s progression typically matches level of completion of engineering design.

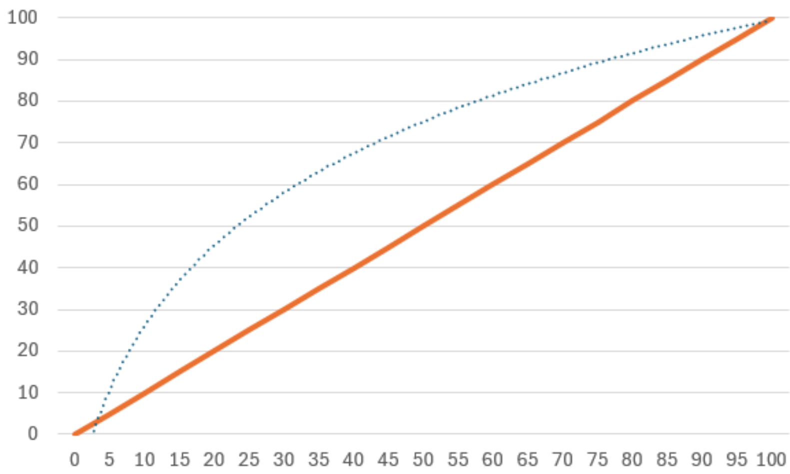

Figure 1: Level of modelling effort compared to level of completion of engineering design

This illustrates that the addition of a 3D bridge model as a project deliverable has created disruption in the traditional flow of bridge design delivery as it appears to require 3D modelling effort to exceed and pre-empt bridge engineering effort in the early stages of a project. If modelling progresses as suggested by the graph in Figure 1, this introduces additional risk of re-work compared to 2D delivery. This risk of rework can be visualized by the gap between the modelling level-of-effort and the engineering level of completion.

As Figure 2 shows, this gap is affected by not only the design of the bridge, but also by the development of design by other design disciplines and input from stakeholders.

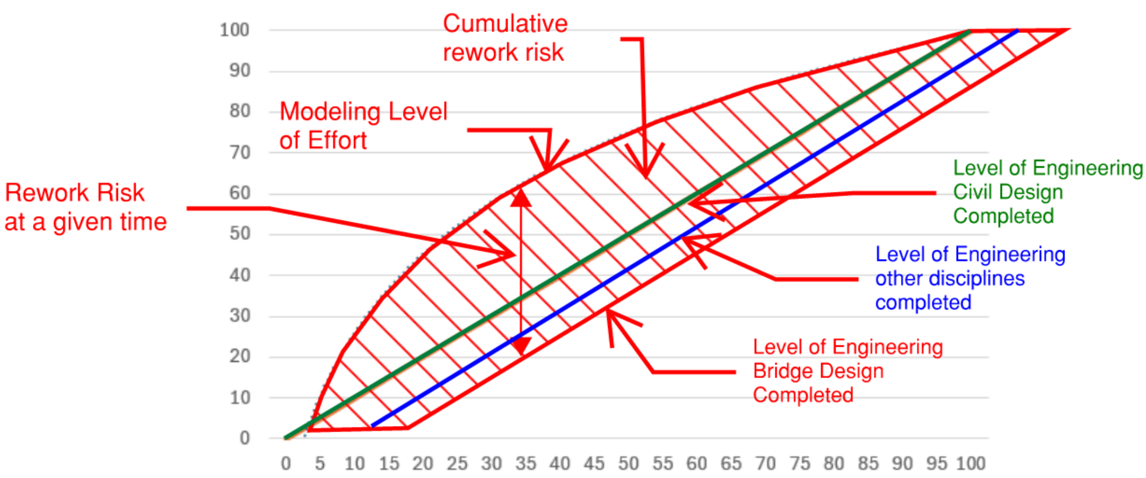

Figure 2: Rework risk

Each time that change is introduced, the bridge model reverses in level-of-completion. The non-linear relationship between modelling effort and design completion therefore results in a compounding increase in time to complete the project, as shown in Figure 3.

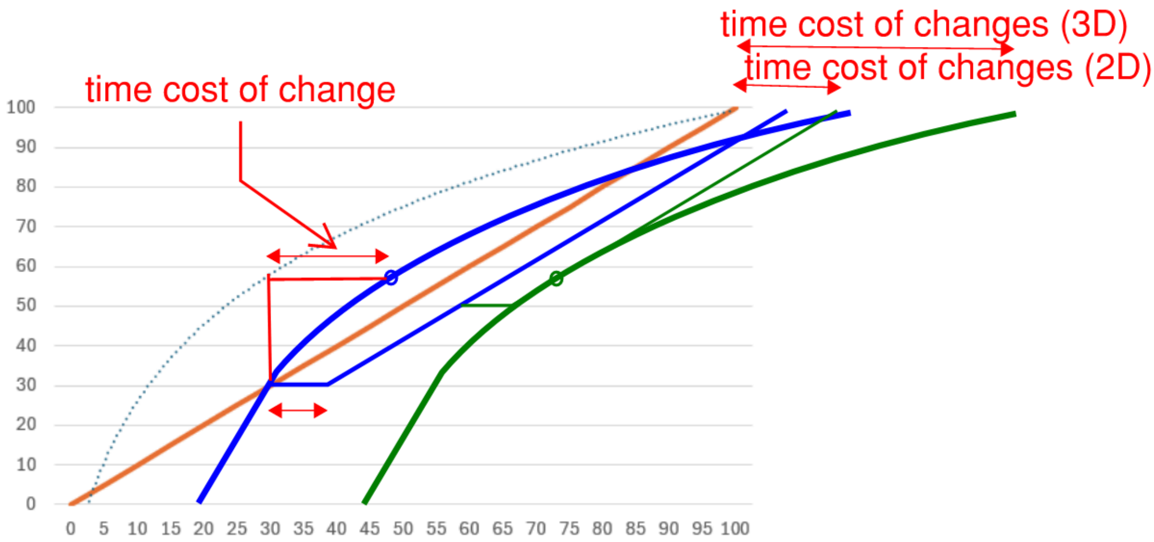

Figure 3: Time cost of change

Taking an approach to digital delivery that is not bridge-centric blindly charges towards a bridge model that is 100% completed while discounting the numerous unknows that existing during design development. This approach maximises risk of re-work.

Instead, a bridge-centric approach limits modelling to what is confidently known about a bridge's design and limits the resulting 3D modelling as much as possible. It also seeks to strategically employ tools such as parametric modelling to efficiently create models and mitigate the costs of re-work when required. While it is likely impossible to eliminate modelling with some uncertainty, the digital delivery plan will have identified the unknowns so that modelling level-of-accuracy does not over-reach and is understood. In this approach, gaps may appear in the structural model, especially during the early stages of development. However, a bridge-centric digital delivery plan is in place has planned for such gaps, giving interested parties confidence that they can wait on the development of the model.

Construction plans with an incomplete model

Paramount to the bridge-centric digital delivery plan is a clear expectation of the information and level of detail that will be provided at each deliverable stage. Prior to project commencement, the project owner, the design delivery team, and any relevant stakeholders must review and agree to the plan.

Engagement with the project owner will likely require a detailed communication of potential reduction of details provided at early deliverable gates. This reduction of detail may be seen as non-compliant with typical requirements and will require an open-minded owner to accept an alternative approach. However, through collaborative planning, project teams can establish delivery plans that both meet expectations and digital delivery efficiency goals.

For example, a design team may decide that at concept design (30% design) and preliminary design (50% design), the digital bridge model will include the main superstructure and substructure elements only. Finer elements such as the bridge articulation elements (bearings, restraint pins, etc.) are deemed unreasonable to model at such early stages. This decision may be made because of existing unknowns such as unknown soil parameters, or simply a lack of design development to properly size the elements. In this scenario, the bridge-centric delivery plan will either decide to generate drawings that include the un-modelled elements using 2D drafting or to produce drawings with the elements missing. The latter option will be selected if the digital delivery plan requires all drawings to be cut from the model and therefore avoids 2D drafting.

Either choice brings complications. The first will deliver to the client a more “normal” set of drawings, with all of the bridge elements normally shown on construction drawings. Considering the LOD, there is no guarantee that the sizes and configuration is accurate, but the plans will “look right.” However, the 2D drafting required to compensate for the unmodelled elements is abortive work solely completed to satisfy existing expectations.

The second plan would deliver drawings with obvious “errors.” Without bearings, the superstructure would appear to be floating. Without restraint pins or blocks, design requirements for lateral restraint are clearly not met. It is therefore incumbent upon the design delivery team and owner to collaboratively answer the question, “Is it important for this detail to be shown at 30% design (or 50% design)?” Potentially that answer is “no,” in which case the parties can agree upon a means of communicating the missing information such as using callouts, notes, or the design report.

This example illustrates the granularity of planning and coordination that is needed in a bridge-centric digital delivery approach. Keeping such fine details in mind, bridge design delivery team can then shape its plan for developing the bridge digital model and incorporating it into a project’s federated model.

3. Federated Model Objectives

Early in the project lifecycle, skilled modelers can develop federated models that deliver conceptual renderings of completed infrastructure projects far before ground is broken. As design develops and a project eventually moves to construction and completion, the federated model evolves from conceptual renderings to data-rich and spatially accurate representation of the completed works. It incorporates design data from each engineering discipline involved in a project and becomes a significant coordination undertaking on even the smallest of projects.

These models provide fantastic opportunity for each of the project parties (consultant, contractor, or stakeholder) to better visualise the final project outcome. Benefits of this visualisation include easier identification of challenges that may occur during design and construction, and identification of improvements for the end use. Eventually, amongst other benefits, the model can be used as a quality check for site surveyors and as baseline for asset management by project owners.

As project teams develop their digital delivery plans, development of the bridge-centric plan must consider the desired use-case of each project party at each delivery gate. The plan should seek to meet all objectives in a way that is practical for development of the bridge delivery model.

This following section provide examples of the objectives that each project party may have for a project’s federated model.

Project design team

The design team generally consists of a collection of design consultants across the engineering disciplines of a project. The team may also include members of the future construction team and representatives from the project’s owner. Throughout design development, the design team assembles the federated model using digital information from each discipline. The model may start with the establishment of existing conditions including roads, utilities, buildings, and natural elements such as waterways and vegetation. The design team then incorporates their designs into the model, constantly updating it as design develops. Eventually, the model represents the expected finished project.

Throughout the design development, the design team may typically review the bridge model for the following purposes, amongst others:

- Geometric consistency or clashes with the adjoining roadway
- Horizontal and vertical clearances to the bridge structure, including from planned or existing infrastructure
- Incorporation of the bridge design to hydraulic analysis

- Geospatial location of foundations for geotechnical exploration or analysis
- Space-proofing around existing and future utilities
- Constructability evaluation
- Tracking of design quantities.

Coordination of the bridge design with other disciplines is critical for project success. However, certain bridge engineering design details, especially for internal elements such as reinforcement, are likely not important to other disciplines. As such, the bridge-centric digital delivery plan should seek to only provide information that will be relevant cross-discipline coordination consistently throughout design development. Once other engineering disciplines have locked down their designs, the remainder of the modelling can be completed.

Project construction team

Depending on the delivery model, the project's construction team may or may not be involved in the development of the federated model. In the case of a traditional design-bid-build delivery, the construction team may receive the complete project federated model, including all digital bridge models, at the kickoff to tender. In a design-and-construct delivery, representatives from the construction team are likely interacting with the federated model throughout design and using it to kick-start procurement and develop construction strategies.

Common uses of a digital bridge model, as part of a project federated model, by the construction team are:

- Clash detection
- Constructability evaluation and planning
- Tracking of design quantities
- Procurement for sub-contractors
- Procurement of fabrication
- Temporary works design
- Site survey quality control.

Particularly in the design-and-construct environment, careful coordination between the design and construction teams must occur to develop the digital delivery plan for the bridges. A thorough understanding of the model's intended use by the design team will then inform how much information is included in the digital model throughout the design development.

Project owner

Owners play a pivotal role in the digital delivery of a project. Key contributions made by owners include initial scoping of digital delivery requirements and collaboration with project's digital delivery teams to establish information exchange requirements. To effectively do so, owners should be clear on how they intend to utilise digital models in the near- and long-term. Clear articulation of their intended uses in their scoping requirements and interactions with digital delivery teams allows for delivery plans to be crafted around the owner's objectives.

For example, if the owner intends to use a federated model to consistently generate renderings for a public information campaign, they may ask for certain aspects of a model to be developed early in a project's delivery.

Or, if the model's primary use is to serve as a baseline reference for long-term maintenance, the owner's scope may have enhanced requirements around the provision of metadata in a bridge. However, a digital delivery team may suggest to the owner that provision of metadata (i.e. reinforcement quantities, material types, etc.) is not necessary to provide until the final design submission considering it cannot be used until constructed.

An owner may even wish to specify that the federated model be the official construction documentation, thus avoiding construction plans all together. Such a decision would drastically shape the approach to digital delivery.

In any case, it is crucial that early agreement and planning is in place between project owners and digital delivery teams. Further, the plan must be adhered to by all parties to avoid common pitfalls and inefficiencies such as duplication of information and unnecessary additional information exchange gates.

Federated model uses by project owners include:

- Public information campaigns
- Project planning
- Stakeholder communication
- Project reviews
- Asset management.

Efficient development of digital delivery plans can hinge on the clarity of the owner's expectations. Owners should understand their objectives around requiring digital deliverables. If they are not clear in scope documents, project teams should collaborate early with the owner to attain such clarity and craft the digital delivery plan around the owner's objectives.

Project stakeholders

Stakeholders may have minimal input to the requirements for and development of a project's digital delivery plan. However, project teams and owners should consider how to use the federated model for stakeholder engagement.

Community members are often interested in how a project will visually affect their town and property, and how the finished project will affect their daily routine. Projects often include interruptions to usual traffic patterns and access. The digital models allow for such views into the future and have potential to positively influence the public's perception of a project.

Likewise, federated models can be used to coordinate with owners of adjacent existing assets. Where a bridge crosses a railroad, for example, a project can use the model to illustrate the bridges configuration to the rail owner, show clearances to the rail and associated services, and demonstrate feasibility of construction. The enhanced visualisation of federated models compared to traditional construction drawings brings great potential to improve stakeholder collaboration.

4. Proposing level of development at deliverable gates

The bridge-centric digital delivery plan has been established above as one that maximises efficiency by minimising re-work risk and caters to the federated model use-objectives of project parties. With these principles as a focus, the LOD of the model at each deliverable gate can be decided. Determining this early in the project lifecycle is critical to ensure that the information exchanges meet all project party expectations.

It is common practice to define the LOD for each design gate that be applied across projects. Table 1 below presents LOD definitions according to bimforum 2020.

Table 1: Level of development descriptions

LOD	Description of requirements
100	● The model element may be graphically represented in the model with a symbol or other generic representation but does not satisfy the requirements for LOD 200. ● Information related to the model element can be derived from other elements ● Any information derived from the LOD 100 element must be considered approximate

200	• The model element is graphically represented in the model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. • Non-graphic information may also be attached to the model element • Any information derived from LOD 200 elements must be considered approximate
300	• The model element is graphically represented in the model as a specific system, object, or assembly accurate in terms of quantity, size, shape, location, and orientation • Non-graphic information may also be attached to the model element • The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to the non-modelled information such as notes or dimension callouts. • The project origin is defined, and the element is located accurately with respect to the project origin.
350	• Satisfies LOD 300 plus the model element interfaces with other building systems.
400	• The model element is graphically represented in the model as a specific system, object, or assembly accurate in terms of quantity, size, shape, location, and orientation • Non-graphic information may also be attached to the model element • Element is modelled at sufficient detail and accuracy for fabrication of the represented component.
500	• The model is a field verified representation accurate in terms of size, shape, location, quantity, and orientation • Non-graphic information may also be attached to the model element

Table 2 shows an example how these LOD definitions may be applied to a typical bridge abutment. A few aspects of the plan in Table 2 are notable. First, the LOD prescribed for each element is relatively consistent and generic, meaning it does not consider the LOD's correspondence to level of engineering design completion for each element. Second, LOD 300 is required for all elements from Preliminary Design to IFC. This plan therefore requires modelling to be essentially completed for the elements tabulated at Preliminary Design, which generally may correspond to 50% completion of engineering design of the bridge.

Table 2: Typical bridge LOD requirements for digital delivery

	Design Development				
Element	Concept Design	Preliminary Design	Detailed Design	Issued for Construction	As Built
Bridge Pier					
Headstock	200	300	300	300	500
Sidewalls	200	300	300	300	500
Lateral Restraint	200	300	300	300	500

Bearing	200	300	300	300	500
Columns	200	300	300	300	500
Pile Cap	200	300	300	300	500
Piles	200	300	300	300	500

An alternative LOD requirement table is provided in Table 3. This table fits the bridge-centric approach, meaning that it delays more stringent modelling LOD requirements until bridge design is nearly complete. Further, this also allows for further progression of other activities that have potential to change the bridge pier. Such activities include design development of other disciplines such as civil, hydraulic, and geotechnical, constructability reviews, and stakeholder input.

A key feature of the LOD requirements provided in Table 3 is a column noting how information about each of the elements will be provided at design gates with LOD less than LOD 300. Development of such a plan with collaboration from all project parties ensures that adequate LOD is provided at each critical stage of the bridge design development.

Table 3: Bridge-centric approach to LOD requirements for digital delivery

	Design Development					Information Exchange Plan for less than LOD 300
Element	CD	PD	DD	IFC	As Built	
Bridge Pier						
Headstock	200	200	300	300	500	Sizing shall be called out in drawings and provided in the design report. Relevant clearances shall be drawn
Sidewalls	200	200	200	300	500	Indicative sizes shall be called out
Lateral Restraint	200	200	200	300	500	Indicative sizes and any fixity provided shall be called out and noted in the design report
Bearings	100	200	200	300	500	LOD 100: Bearings may be shown or omitted. Intended articulation or fixity shall be noted in the drawings and design report. LOD200: Bearings may be shown at expected dimensions and indicatively. Intended articulation or fixity shall be noted in the drawings and design report.
Columns	200	200	300	300	500	Sizing shall be called out in drawings and provided in the design report. Relevant clearances shall be drawn
Pile Cap	200	200	300	300	500	Sizing shall be called out in drawings and provided in the design report. Relevant clearances shall be drawn
Piles	200	200	300	300	500	Sizing shall be called out in drawings and provided in the design report. Lengths shall be modelled indicatively until founding level is established. Estimated toe level shall be called out in drawings or provided in tables. Relevant clearances shall be drawn

The difference between these two tables demonstrates the refined level of planning that is needed to craft a bridge-centric digital delivery. At each design gate, the LOD must be established including provision of how each element may be detailed or noted.

5. Bridge model development

As discussed above, the bridge-centric approach to digital delivery minimises the gap between the effort that is expended modelling and the level of engineering design that has been completed. Being bridge-centric, the plan focuses on developing the bridge model to enable coordination with other parties while allowing the bridge engineers to complete the structural design.

The bridge modelling workflow is somewhat fluid and is constantly improved as technologies develop. Current industry software includes useful tools for developing bridge digital models using automation with relatively little effort by utilising scripts to layout bridge elements. Digital delivery teams should utilise these tools to generate models at the agreed upon LOD for each level. Again, the LOD for each element should be planned for each design gate with due consideration given to the risk of re-work associated with the level of design progression.

Concept Design (30% design) LOD Plan

The concept design plan often represents the initial submission of bridge design plans to the owner and contractor, as applicable. It also may be the first official exchange of the digital bridge model.

Concept design is generally meant to capture the form and function of the structure. It is meant to show the type of superstructure and substructure, anticipated dimensions, and intended articulation. At this point, engineering level of completion is low, meaning likelihood of changes is near its highest and the modelling LOD should be kept to a minimum. As shown in Table 2, major elements should be modelled using expected dimensions and will likely be set out relative to vertical and horizontal control lines. Minor elements such as bearings, lateral restraint blocks, conduits, junctions, should be modelled with limited detail or excluded from the model completely.

These concept design models can be produced relatively quickly and easily using the following steps:

- Civil alignment control lines are exported to provide specific data exports to input into tools such as Dynamo. Automation scripts can then be run create bridge elements such as bridge deck, DWS, concrete barriers/kerbs and relieving slabs.
- Manually set out the substructure centerlines using positioning parameters provided by the engineering team. This establishes span lengths and enables positioning of the headstocks
- Manually position girders and headstocks using the generated finished surface levels and estimated superstructure and substructure dimensions provided by the engineer. In some cases, girders may not be modelled but are instead represented by a constant superstructure depth
- Attach piles to the underside of the headstocks. Position pile toes at approximate or arbitrary depths depending on level of geotechnical design information available.

At this stage the model is at an adequate level to produce concept drawings. Likewise, the model can now be introduced into the federated model to begin coordination to the wider project team considering the primary structural elements have achieved LOD200. Enough detail is included to enable reviews of the bridge for interfaces with adjacent infrastructure including roadways, rail corridors, utilities, and waterways.

It is appropriate, however, to keep the level of bridge modelling effort minimised at concept design, particularly in a design-and-construct (D&C) environment that likely sees the engineering level of completion of other disciplines at a similar level. Detailed modelling of elements such as girders and bearings is not beneficial, as the structural design has not developed enough to warrant such things being modelled. Instead, these items should be identified using the agreed upon action plan proposed in the project's LOD requirements (refer Table 3 above).

Depending on the contract type, formal review of the concept design plans may include a comparison against tender design. Owners may be seeking to resolve comments provided in the tender period and contractors could be comparing quantities and performing constructability and value engineering reviews. The LOD should consider these factors when deciding what is included in the concept design model.

It is unlikely that owners or contractors would be utilising the concept design plans for procurement of construction or fabrication, and therefore these potential uses of the model can be ignored.

Preliminary Design (50% design)

Progression of engineering design from concept to preliminary design is generally accompanied by additional confidence in the engineering design. Not only will the structural engineering be progressed, but other disciplines will have progressed or finalised their designs. Further, stakeholders will have had opportunities to provide input. These factors all can contribute to a reduction in the overall risk of rework associated with further developing the bridge digital model.

At preliminary design, progression of the engineering design for primary structural elements (girders, piers, piles, etc.) will have likely progressed beyond 50% complete and engineering design will have progressed substantially on elements like bridge barriers, bearings, articulation fixity, and joints. However, it is unlikely that design on any of these elements is finalised. Further, factors outside the bridge design still may pose a risk.

The delivery team must evaluate whether the value gained from further LOD in the digital model is worth the associated cost investment and risk of rework. As suggested in Table 3, it may be advantageous to provide minimal additional bridge modelling at this stage, particularly if the general form of the structure is unchanged.

A bridge-centric digital workflow should consider the following modelling activities at preliminary design, which generally allows the full bridge model to reach LOD200.

- Refresh exported civil control line data and related automated elements, as required.
- Update sizing of any primary members. This will typically require minimal effort and requires only updates of parameter of existing elements
- Add girders if not completed at concept design. Update dimensions to suit LOD200.
- Elements such as bearings can be added using automated scripts.
- Other elements such as restraint bolts, junction boxes, conduit, etc. should be considered optional for addition to the model and treated in accordance with the agreed LOD plan.

Again, software tools enable relatively easy additional of such elements to the bridge model. However, this does not automatically justify the effort required to implement such items, particularly if alternative and less-costly means for providing the information are possible.

Detailed Design (85% design)

Delivery of detailed design plans for a bridge structure requires full structural detailing to be provided including sizes of all elements, connections, and structural reinforcing. It is typically the last information exchange before the design team may seek approval to proceed to construction documentation. Therefore, this gate should be accompanied by a near-complete engineering design of not only the bridge, but also all interfacing disciplines.

While this means that risk of re-work in the modelling space should be low, potential risks should still be evaluated by the digital delivery team. This should be completed in close coordination with the engineering team and other project parties who may be aware of outstanding risks such as pending stakeholder approvals.

Presuming that risks of re-work are mitigated or deemed low enough to proceed to LOD300 modelling or greater, the following steps can be executed, which represent the majority of the effort required in the bridge modelling development:

- Refresh exported civil control line data and related automated elements, as required.
- Update sizing and positioning of any primary members, as required.
- Add outstanding structural and ancillary elements such as bearings, restraint bolts or blocks, formed holes, expansion joints, cover plates, abutment protection, balustrades, junction boxes, conduit, and cast-in hardware. Automated scripts may be used to ease these modelling processes
- Inclusion of steel reinforcement in concrete elements is generally not suggested at this time as current processes demonstrate that the effort required exceeds the benefit to the client.
    - Modeling of typical high conflict areas could be considered at this point as they may affect construction phasing and/or construction joints, potentially element sizing, overall constructability.
    - Standard elements utilizing standardized detailing could follow afterwards as those elements typically wouldn’t offer much benefit.

Detailed design may also represent of level of completion where contractors begin to procure fabrication, or owners may begin procuring construction tenders. Therefore, it must be agreed upon in the LOD plan whether LOD 300 or LOD 400 is required at detailed design. The LOD may vary between elements.

As the model is now nearing completion, provision of metadata in the detailed design stage may be considered. Unless required for a specific time-dependent purpose, it is recommended that such data be added to the model at a later stage.

Issued for Construction (100% design) and beyond

Progressing from detailed design to the issued for construction drawings should require minimal modelling updates. It is likely that 2D drafting work may be required, but no major changes can be expected.

Therefore, the digital delivery effort at this stage typically includes addition of metadata or tagging of elements, along with preparation of the final information exchange for the bridge package.

Once site works begin, it is likely that the contractor will utilise the model for numerous purposes including surveyors checking set out information, understanding site conditions such as existing utilities or other infrastructure, and confirming construction staging. These are all possible using the provided LOD 300 or LOD 400 model.

Upon completion of construction, any revisions that have occured can be documented on drawings and updated in the model to establish the LOD 500 model. Inclusions in the LOD500 model should be discussed and agreed upon with the bridge owner prior to commencement of the project. This ensures that the bridge model fulfills the requirements of the owner’s model use objectives.

6. Conclusion

Digital delivery of bridges is becoming common place in today's industry. Development of the bridge model typically accompanies a traditional set of construction drawings and therefore represents an additional or alternative effort required to complete the required construction drawings. The current state of practice sees the model development and design development running in parallel with essentially two independent sets of data. The nature of this is essentially the root cause of the rework.

As mentioned in the paper, bridge design generally lags the other disciplines, such as the roadway design which provides horizontal and vertical alignments and typical sections. At concept design, very little, if any, bridge design calculations have occurred. This is why the common digital workflow, which rapidly progresses modelling, must be challenged.

Modelling data and engineering data, when produced simultaneously, essentially creates two data sets. However, if the digital delivery plan maintains close agreement between model LOD and engineering LOD, we can essentially remove an unnecessary data set, which is the "at-risk" modelling data that is not yet confirmed by engineering design. Initial models can be created with data extracts to obtain required parameters for concept designs. As engineering progressing, this data can be pushed into the digital model at appropriate times, when risk of re-work reduces. The finest details are then added near completion of engineering design to complete the fully detailed model.

The proposed bridge-centric digital delivery plan caters to the bridge team by delaying detailed bridge modelling until the engineering has been completed. Simultaneously, steps are put in place to satisfy contractual delivery requirements and cater to the use-objectives that project parties have for the bridge model and project federated model.

All project parties must contribute to and agree upon the bridge delivery plan, which includes required levels of development at each design gate. Through careful coordination, the objectives of each party can be incorporated into the digital plan and met using both targeting modelling efforts and other means of exchanging the required information such as drafting callouts or reports.

By implementing the ideals of the bridge-centric digital delivery plan, expensive modelling re-work risks associated with design development are mitigated and bridge engineers are better placed to drive the completion of the bridge digital model.

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