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CIGRE US National Committee
2018 Grid of the Future Symposium

# AEP's Experience in Improving Overall Efficiency of Power Transmission Station Projects Using Integrated Design and Construction (IDC) Process and Prefabricated Construction

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## SUMMARY

In recent years, utility companies are undergoing rapid change and growth, resulting in an urgent need for a more efficient use of resources in design, construction, and operation and maintenance of their facilities. The necessity to improve the project delivery process has placed AEP Transmission and other progressive utility companies in a unique position to leverage the current experienced resources along with new tools and technologies in developing an intelligent 3D model of a station and the entire system to streamline processes and procedures not only in engineering, but also in construction, operation and maintenance groups. In addition, AEP Transmission is transforming its substation construction practices with an emphasis on prefabricated stations and components by leveraging innovative tools/technologies such as prefabricated bus, prefabricated foundations and smart 3D modeling. Prefabricated construction provides significant construction time and labor savings, while enhancing field safety due to less work being done on-site. This paper discusses how AEP is applying these emerging technologies to improve project execution, field safety and hence overall cost.

## KEYWORDS

Building Information Modeling (BIM), Integrated Design and Construction (IDC), Virtual Design and Construction (VDC), Ground Penetrating Radar (GPR), Terrestrial Scanning, Laser, Prefabricated Construction, 4D, 5D Modeling, Augmented Reality (AR), Design-Build, Design-Bid-Build, Engineer-Procure-Construct (EPC), Earned Value, Cash Flow, Prefabricated construction

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## INTRODUCTION

American Electric Power (AEP), one of the largest electric utilities in the U.S., is in the process of implementing the Integrated Design and Construction (IDC) process. AEP has over 4000 stations that are spread across an 11 state service territory. As a regulated public utility, it has fiduciary responsibility for cost prudency and control when it comes to the capital investments supported by rate payers.

The exponential growth in tools and technologies has brought new opportunities to improve current processes. One of the opportunities to gain the most from this process improvement is when the majority of projects involve rebuilding existing stations where build-in-the-clear is not an option without requiring multiple outages. As a result, there is a need to execute these projects in a more efficient manner.

Construction labor is the highest cost category for our projects and it has been trending up in recent years. To address these challenges, AEP utilized Building Information Modeling (BIM) on several pilot projects to improve cost efficiencies and further support construction safety in 2016.

## BACKGROUND

The importance of collaboration and coordination in project planning and design between engineering and construction resulted in choosing IDC for referencing to the BIM process for our industry. Major brownfield station projects were selected to pilot the new IDC process by using model-based design for collaboration among project stakeholders including project planning and construction team. These projects allowed AEP to identify several areas of improvement opportunities throughout project lifecycle management. The lessons learned from the initial set of pilot projects have been documented, analyzed, and incorporated for continuous improvement.

The selection of an intelligent 3D/4D modeling tool and its implementation is a major undertaking that needs to be rolled out in a coordinated manner initially for projects within the subject region. This effort can be expanded to the rest of the projects within the same region. Through these efforts the necessary standards can be developed. This phase of implementation is estimated to take 2-3 years. System wide implementation can proceed once the necessary standards, tools and resources trained in the new process are in place.

The plan in the interim is to refine and standardize the new process while maintaining the course in supporting the existing workflow. The long-term goal is to develop intelligent models of existing stations for future station construction, operation and maintenance. AEP has a large project portfolio with the majority involving improvements to existing stations. Given that some of the projects span multiple years, it is estimated that it will take anywhere from 5 to 10 years to complete the modeling effort for the entire system. The majority of these models will be created as part of the projects' scope of work.

## IMPLEMENTATION STRATEGY

It is important to note that before Standards can be created there is a need to gain enough knowledge from pilot projects to be able to identify what works best in the current environment. One idea is to focus IDC in a certain region of the company and have a team formed representing all stakeholders from Planning, Project Management, IT, Engineering, Operation, Construction, and Maintenance. This approach involves all aspects of IDC to be tested and clearly defined to minimize the amount of disruption while building a center of excellence for refining the process before standards can be developed.

The transition for sharing a model based design with project stakeholders, especially construction teams, instead of 2D drawings will require several steps to gain sufficient hands-on experience. The first step in the process is creating an accurate existing condition model that can be easily leveraged in design for upfront scoping. There has been good progress in creating the standards for this initial step. However, the result of this initial step has to be delivered in a timely and user friendly manner in order to have a positive impact on a project. The augmented design will require an adequate system for data storage and viewing. As an example, the project designers have to be proficient in using the point cloud data collected through laser scanning of the site for brownfield modeling. In addition, there is a need for selecting proper software for streamlining the conversion/modeling process. The focus for becoming proficient with IDC has been on the priorities cited by BIM users in the area of project existing condition modeling, coordination, and collaborations as shown in Fig.1 and Fig.2.

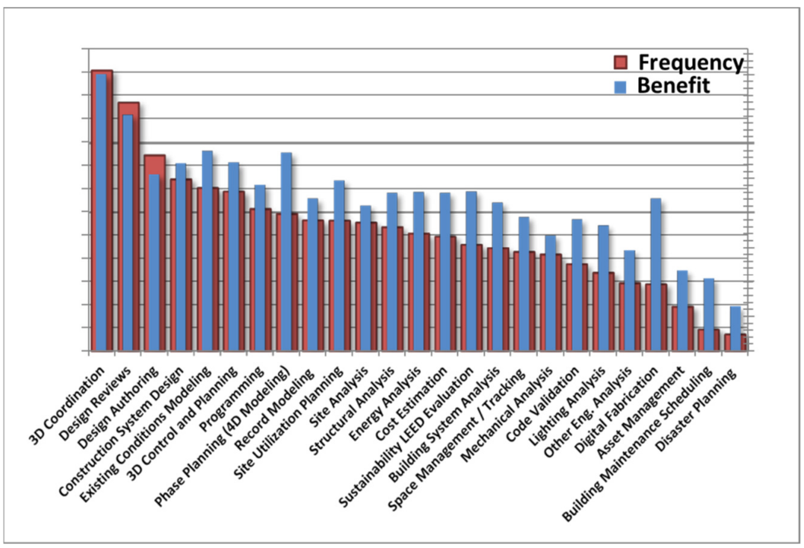


Fig. 1 - BIM Frequency and Perceived Benefit

Source: Penn State University survey of 25 BIM users

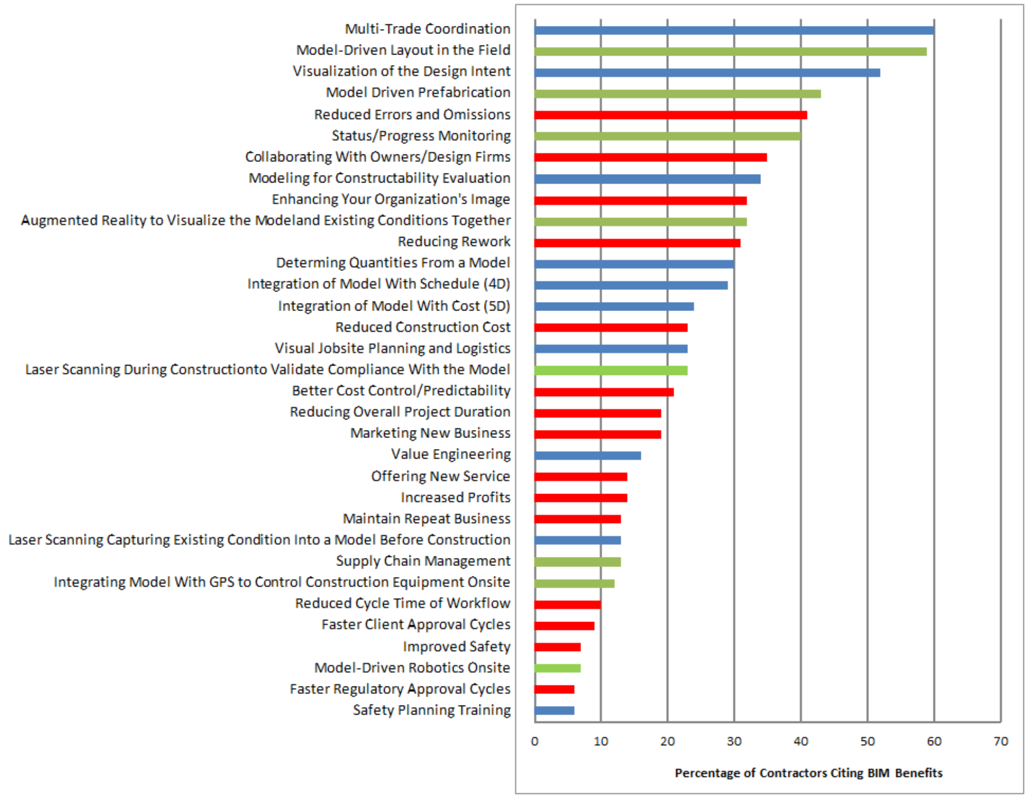


Fig. 2 - Percentage of contractors citing their top three BIM benefits in various aspects of their business operation
Red: Percentage of contractors citing their top three BIM benefits in various aspects of their business operation.
Blue: Percentage of contractors citing their top three usage of BIM during design/pre-construction phase.
Green: Percentage of contractors citing their top three usage of BIM during construction phase.

Source: McGraw Hill Construction, 2014

## IDC EXPERIENCE

This new process started in 2016 by teaming up with an engineering consultant and a construction firm who are leading the utility industry with BIM modeling experience. Initially, three pilot projects were selected across the AEP service territory to evaluate the perceived benefits of the IDC process. For the purpose of the study, two transmission and one distribution brownfield station projects with varying levels of complexity were selected. All of these projects were beyond the project planning phase using the current process known as Project Lifecycle Management Process (PLMP). The current process uses various gates to help identify project status and deliverables throughout the project lifecycle. These pilot projects did not have the opportunity to benefit from a model based design as a communication tool in the early stage of project planning – this was the first learned lesson from the pilot projects. The value of effective communication offered by using model based design can only be maximized if it is used for developing project scope, schedule and cost estimate prior to project funding authorization. Studies show the leading indicators used for measuring IDC project success is the reduction in the number of change orders which will be a focus as we move forward.

Progress is being made in three major areas related to integrated design for leveraging the 3D model beyond traditional design work. Focus has been on enhancing construction safety and efficiencies by utilizing the virtual 3D model to communicate the design intent to craft labor and improving constructability by using animation to verify working clearances and access for moving equipment in and out of a station.

Preliminary results indicate project scoping along with construction planning can be completed more efficiently. Fig. 3 and 4 depict examples of some deliverables to increase construction efficiency.

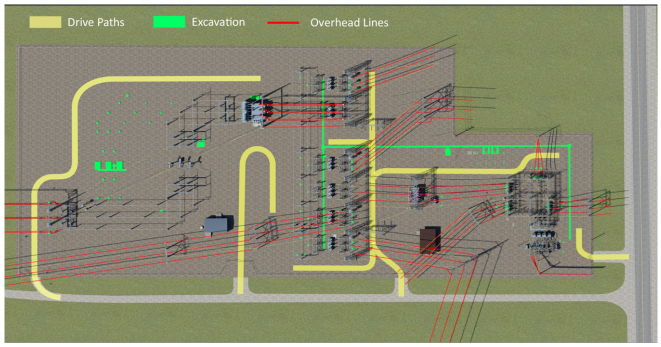

Fig. 3 - Routing of Hydrovac truck for excavating trenches and foundations

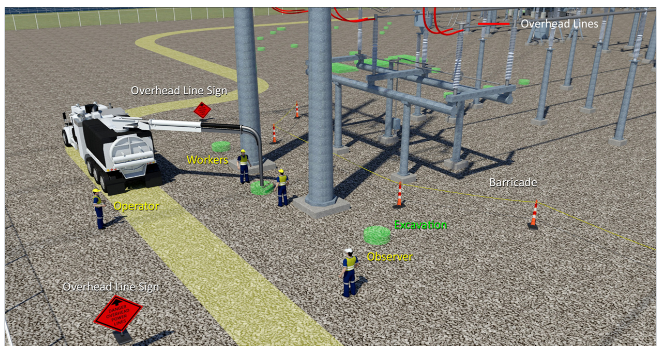

Fig. 4 - Verifying working clearances around energized equipment/buswork

## SINGLE SOURCE OF TRUTH

The plan is based on moving towards establishing a model based design as a single source or at least as single version of truth that can be leveraged as an improved communication tool for project collaboration and coordination through engineering, construction, operation, and maintenance. AEP Transmission's long-range goal is to be able to go paperless and have an accurate existing condition model of above and below grade of stations that can be used as a basis for initiating a new project. This approach along with geospatial referencing of stations will help in integrating station and T&D line assets. Overall project cost and schedule certainty is achieved as the use of the 3D model is leveraged by all project stakeholders with construction knowledge and experience in planning, design, procurement, and field operations.

The biggest benefit of implementing IDC comes from improving the current process in search of information during operation and maintenance of the system. Lack of information/conflicting information compiled throughout the life of an aging facility requires extensive effort in verification of the information. With the IDC approach, an accurate as-built model and BOM will be available upon project completion. Operation and maintenance folks will have for the first time an opportunity to use a model based design as a single source of truth for the life of an asset. A model based design, when used throughout the project lifecycle as a single source of truth, will improve the legacy processes by bringing tremendous efficiencies in effective use of resources.

The model based design provides the best means of communication and collaboration on a project during design and construction. Having accurate geospatial models of each of our stations as a single source of truth will serve as a building block for integration to other systems. This is achieved by using the existing condition modeling of above and below grade assets to lead the design of any major improvement work to existing stations. These steps will pave the road for a future of station design, construction, operation, and maintenance in which the model created initially by engineering will be leveraged throughout station lifecycle from inception to retirement of the facility. By taking the first step in building the necessary platform for adding mobility, AR/VR, and automation to our work processes, it will be possible to bring greater efficiency throughout the station lifecycle in the near future.

The use of 3D modeling and engaging station construction and transmission operation in upfront engineering for design and constructability review will facilitate detailed design and construction. This improved project planning process would lead to mitigating construction issues that result in delays and loss of productivity. Planning the work and working the plan is not just a cliché when it comes to brownfield projects which may include a large portion of the capital budget. Planning and scheduling all the work activities requiring material and labor resources could include verification of existing condition, demolition of existing facilities, temporary work, major equipment delivery and installation, material delivery in support of outage schedule, and staging the needed construction equipment.

## TIMING IS EVERYTHING

As explained above, timing is highly important especially to realize the full benefits of IDC projects. The most effective time for being able to impact cost of a project is in the very early stage of the project lifecycle as shown in Fig. 6. Decisions made for a project with full knowledge of existing condition modeling (as-built 3D model of the station) will facilitate not only conceptual planning and feasibility studies, but also improves the quality of project scope by harnessing the power of 3D visualization/collaborating with project stakeholders.

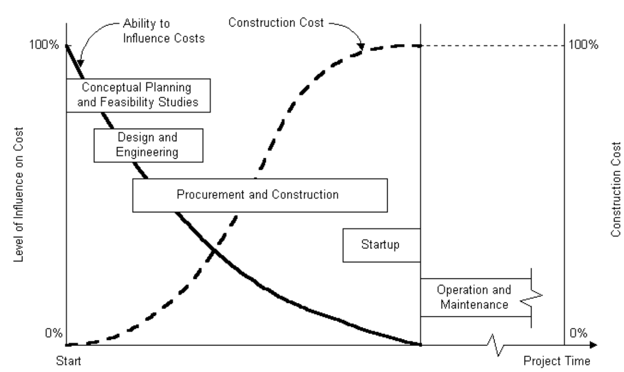


Fig. 5 – Ability to influence cost during project life cycle

Source: PMBOk

It is easy to underestimate the value of visualization by having a 3D model early during the facility study and project scoping phase. We learned from our early pilot projects that IDC is not a silver bullet answer to improve field constructability and hence further reduce project cost and delays, if we don't start early. To be successful, we need to facilitate existing condition modeling at project planning and collaborate with project stakeholders by using a 3D model for leading the design from the facility study to project planning and development.

The first three pilot projects are currently under construction with projected service dates in 2019. The combined numbers of scheduled outages for these three projects are approximately 20 which highlight the overall complexity and the need for planning the work. The 4D model is extensively used in daily/weekly project planning to support the work plan. Planning the work by using the inherent capability of virtual construction offered through 4D modeling has provided the necessary flexibility to quickly rework the plan when there are changes to the scheduled outages due to system conditions.

In an effort to expand our collective experience with the IDC process, we are identifying additional projects to add to the IDC list. We intend to apply some of the key lessons learned as listed below in our new projects:

1. Identify potential IDC candidates that are in early project development phase
2. Develop existing condition modeling using terrestrial laser scanning and GPR
3. Secure agreement for appropriate project delivery and contracting
4. Implement the use of an intelligent modeling tool to lead the design
5. Increase awareness among transmission contractors of the new requirements in using 3D/4D modeling for improving cost efficiencies and enhancing construction safety

## NEW IDC PROCESS

It is important to note that before IDC standards can be created, enough knowledge must be gained from pilot projects to be able to identify the most suitable candidates within the electric utility industry. The change management aspect of IDC is addressed by limiting the number of pilot projects thus minimizing the impact of the new process on the rest of the project portfolio. Additional pilot projects have been identified by focusing on the complexity and site conditions of the brownfield projects involving multiple outages. This selective approach provides a better chance for more benefit and an opportunity for refining the process before it is rolled out to production. The shift of more engineering studies, constructability review, and design work to the beginning of the process will need to be taken into consideration when planning a project. Subsequent changes to the scope of work are needed for construction contractors to work closely with the engineering consultant to provide regular updating of the 3D and 4D models throughout the construction phase and delivery of the as-built model and BOM upon project completion. These changes and any other lessons learned will be applied to the new set of pilot projects.

This is mainly achieved by advancing data collection of the legacy design and as-is information and making it available for upfront project scoping. The intent is to make all engineering decisions impacting overall project cost and schedule based on accurate as-is information before starting detailed design. The current process for developing detailed scope and estimate relies on the accuracy of existing as-built drawings and collaboration for planning a new project using Issued for Review (IFR) drawings.

With any new initiative, there is a need to have a process for measuring how effective/useful the new process is in meeting the original expectations. The success of the new process is not necessarily measured by the number of projects or amount of money spent, but by its effectiveness in reducing total cost-of-ownership and improving the customer experience in construction, operation and maintenance of the transmission assets.

## EXISTING CONDITION MODELING

One of the key aspects of IDC is to start a project with correct and complete existing condition data. This is mainly achieved by advancing data collection of the legacy design and as-is information and making it available for project scoping. Laser scanning of stations and 3D modeling can be shared virtually among a number of different project stakeholders for project scope development, outage planning, construction sequencing, site utilization planning, prefabrication, and record modeling.

The preplanning effort supported by existing condition modeling of above and below grade assets continues on a select number of projects to prevent costly interferences with existing facilities. Having accurate as-built information is crucial for avoiding rework in major modifications of existing stations. Hydro excavation is a current standard practice in brownfield projects that accounts for 10 to 15% of the total labor cost. By utilizing below grade as-built modeling, the use of hydro excavation can be significantly reduced to increase savings. Currently, the station engineering group is leveraging the existing condition modeling in design of over 40 station projects in an effort to improve construction efficiencies.

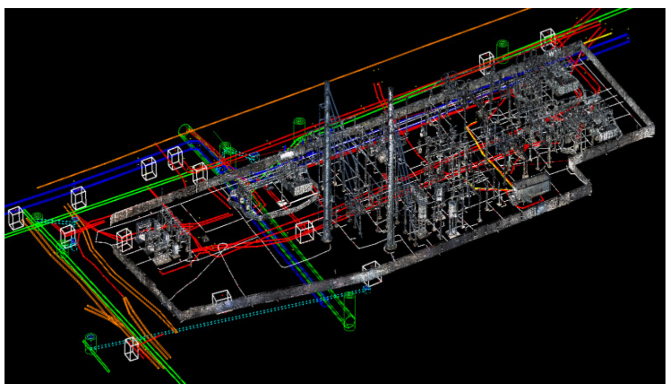

Fig. 6 - Existing Condition Model of above and below grade of a 138kV station

Through the earlier pilot projects, it was realized there is a need for establishing survey-quality models of our stations. By acquiring existing condition models of existing stations via terrestrial laser scanning, imagery, and high-resolution three-dimensional (3D) geospatial data, AEP has found a clear solution to effectively manage and rebuild its vital assets. The existing condition models have provided the means for communication and collaboration between stakeholders to precisely illustrate where legacy facilities are missing and/or are inaccurate. Having accurate as-built documentation before the start of a new project is essential in eliminating rework and construction delays. Changes to the work plan during construction have a large impact on the overall budget and schedule of a project and increases the risk of safety incidents. The ripple effect of construction interruptions and loss of productivity is greater when the majority of construction projects involve working in existing brownfield stations.

## PREFABRICATED CONSTRUCTION

With the advancement of transportation technologies and availability of large-scale equipment to handle large shipments, there is an ever growing demand for prefabricated construction in many different fields. Prefabricated construction is the concept to complete and assemble large segments of the physical assets in a controlled environment and ship the final product to the site. However, to be able to prefabricate large segments that will eventually fit together at the station site, accurate 3D modeling of the assets must be created and utilized. Being able to utilize model-based design for prefabrication of stations can streamline the design process by reducing rework. This certainly is one area that directly benefits ongoing projects by reducing onsite construction labor. By moving the fabrication and assembly of the station to a controlled environment, onsite construction time is reduced, the quality is improved and a positive impact is made to construction safety. AEP first started to utilize this concept with Drop-In Control Modules (DICM), which are the completed control house units transported to the substations. With the successful implementation of the DICM, the concept was expanded to include distribution size assets and bus work in the stations, which was piloted in 2015 involving a 12kV distribution bay. By focusing on prefabrication and factory assembly of the 12kV distribution structure, it has been possible to fast-track a project by paralleling the prefabrication with site development thus reducing the overall construction time. This construction method has been expanded to the 138kV lonesome breaker and breaker-and-a-half stations. This effort will help to create the necessary specification to expand the pool of prefabrication vendors. The goal is to reduce on-site construction time of distribution bays from two to three weeks to two days after foundations are installed.

Fig. 7 – Prefabricated 12kV Distribution Bay

Along with prefabricated above grade assets, AEP has started to utilize prefabricated foundations (PFF). The types of PFF used are precast concrete foundations and driven steel piles which replace cast-in-place slab foundations and drilled piers. Similarly, PFF reduces the overall cost and length of construction while improving the quality of the installed foundations. With all of these advantages, there exist some limitations with the implementation of the PFF, such as rocky soils for the driven piles or limited handling area at site for the larger precast slabs. These limitations have to be considered during the scoping stage of the project to guarantee a successful utilization of prefabricated options.

Fig. 8 – Installation of a driven steel pile with vibratory hammer

## CONSTRUCTION MONITORING

Construction progress reporting and automatic change detection through photogrammetry data collection and augmented reality is also piloted. This process was completed using 3D modeling and Unmanned Aerial Systems (UAS). The initial step provided an augmented visualization of a CAD model and existing condition model that would require manual detection of the changes. The next phase of the pilot project is more challenging and will address automatic change detection and recognition. The main takeaway from this pilot project is that we need to improve the accuracy of XYZ coordinates of the data collection by ¼ ft. in order to be able to use it in the change recognition process. This final phase is being pursued through three separate efforts by 1) a survey/LIDAR consultant, 2) internal AEP research, and 3) an academic research group. The outcomes will enable AEP to improve the project cost control process by automating project progress reporting and cash flow projections. Figs. 9-11 show examples of the construction monitoring process.

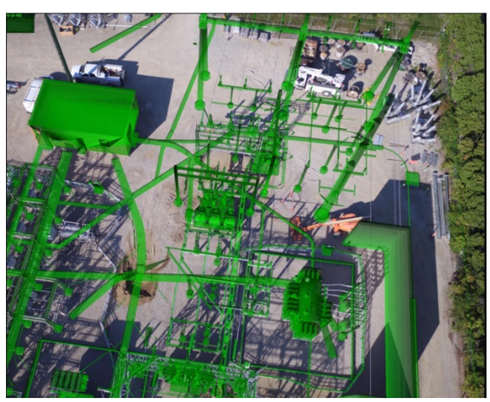
Fig. 9 - Augmented reality of construction work at a 138kV station

Fig. 10 - Orthographic image of construction work at a 138kV station

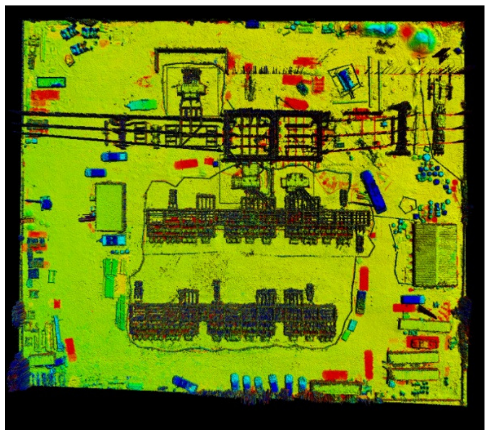

Fig. 11 - Change Detection of construction work at a 138kV station

## TARGET PRICING

Another advantage of the IDC process is cost and schedule certainty of a project. This is possible by establishing a target price with collaboration with construction contractor during pre-award process. Upfront engineering using modular design standards for creating 3D modeling of the project is a necessary part to achieve this goal. Virtual design and construction of a project will lead the detailed design and construction. The plan is to leverage existing experienced staff to conduct a thorough preplanning of projects based on the upfront engineering studies, modeling and constructability review when it has the most impact in influencing project cost and schedule. This approach provides the framework for establishing a good foundation for awarding an IDC project using design-build process. Ideally the same construction contractor will follow through the construction, if there is an agreement on pricing. An alternate approach is also being considered utilizing a competitive bidding process.

Completing existing condition modeling, soil studies, environmental assessment, 30 to 60% of physical design including station one-line, layout plan, grading plan, and foundation plan along with 4D modeling will significantly help cost and schedule certainty of projects. This approach requires a phased project funding to allow for completing the necessary upfront engineering studies and modeling which will help in preparing a workable plan by defining the majority of unknowns. It is expected that construction cost would be lowered by 10% when project risk is mitigated through IDC by enhancing the project planning process in advance of contract award.

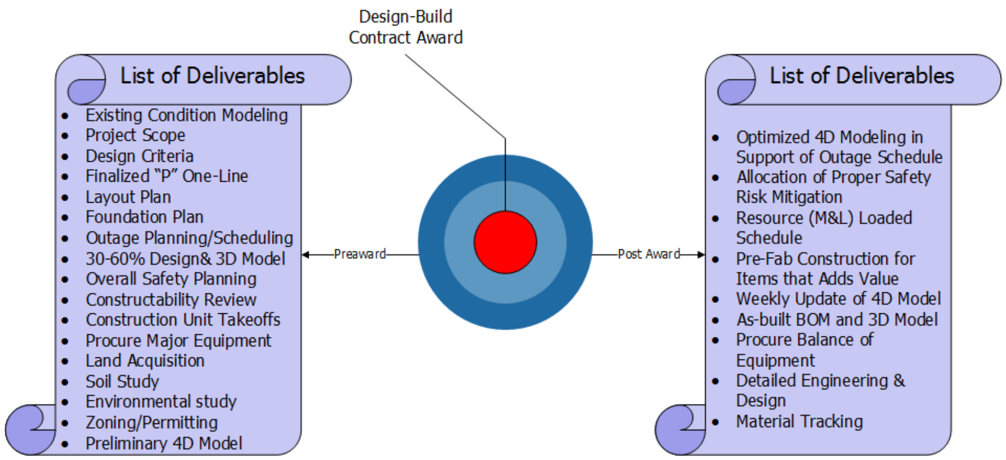


Fig. 12 - Target pricing and deliverables for pre-award and post award

## INTELLIGENT TOOL

There is an ongoing effort in implementing an intelligent design tool where all the pertinent information related to manufacturer drawings, warranty information, test reports, instruction manual, and applicable standards can be accessed through the model. The process of selecting a suite of software and hardware necessary to process and manage the large set of data is currently underway. It will take a couple of years before it is ready for full implementation. As with any new IT systems, the configuration, testing, training, and change management will take a lot of planning and transition time to accomplish a successful implementation.

## IDC ROAD MAP

Developing a balanced approach to IDC based on the continuous service improvement triangle consisting of technology, process, and people is essential to insure all three components are aligned for successful implementation of IDC. All stakeholders throughout project lifecycle from project initiation to retirement must develop a shared vision and believe that such a collaborative geospatial model based design is the future and we need a plan to get there.

To succeed, a roadmap which is based on realistic goals and milestones was created by taking into account the speed in which various aspects of the project delivery can converge together. This high level plan has to be adjusted as the process, tools and technology for power industry evolve. However, this cannot stop us from benefiting from some of the key elements of IDC that doesn't require an intelligent 3D model.

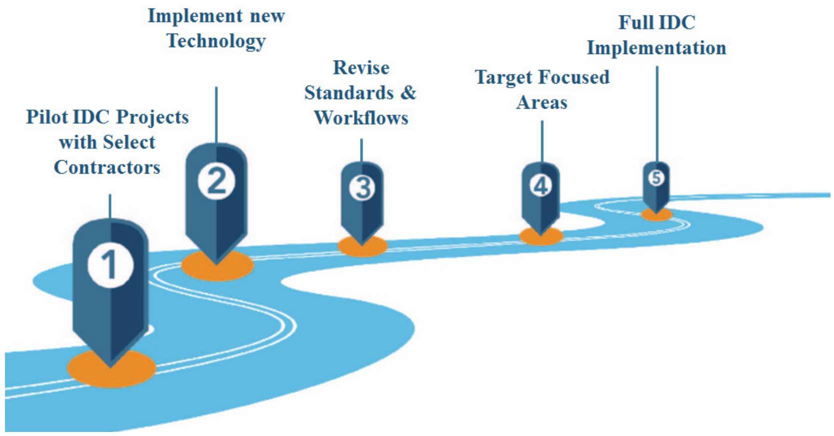


Fig. 13 – High-level IDC roadmap

One of the key aspects of IDC is to start a project with the correct and complete existing conditions data. This is mainly achieved by advancing data collection of the legacy design and as-is information and making it available for upfront project scoping. Laser scanning of stations and 3D modeling can be shared virtually among a number of different project stakeholders for project scope development, outage planning, construction sequencing, site utilization planning, prefabrication, and record modeling.

## CONCLUSION

It is realized this is a long journey and there is a need to start where this approach has the most impact on accomplishing IDC's prime objectives given existing constraints. Ultimately, advancing upfront engineering studies and modeling of the existing stations, similar to the commercial building design approach, before detailed design starts is needed to avoid unforeseen rework and their associated cost overruns and project delays for major brownfield projects.

The 3D/4D modeling has become very useful in reviewing and sharing design concepts with all project stakeholders to streamline the design review process by leveraging subject matter experts with constructability and operational experience. Experience has shown that there are substantial efficiency gains using this technology during the proof of concept design period with experienced staff from various disciplines who can contribute through collaboration using virtual design and construction offered by the data driven models.

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