From Design To Operation: Integrating Model-Based Processes Into Traditional Utility Design-Build Processes

A GTM Research Whitepaper

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CHAPTER 1

Executive Summary

The increasing complexity of the grid, along with the usual challenges of safety, resiliency, reliability, regulation and cost pressures, is driving change at utilities in the domains of transmission, primary distribution and secondary distribution. Over the last five years, utilities have focused on improving operations in order to enhance efficiency and address challenges presented by stagnating load growth, increasing distributed energy resources, and aging infrastructure. However, this focus has often overlooked or downplayed the needs of engineering teams working toward improving the efficiency and execution of current and future projects. For these teams, the ability to quickly evaluate the effects of changes to new and existing facilities is a vital component of optimizing material use, reducing construction or maintenance times, and ensuring effective communication and collaboration between teams and external stakeholders.

As the United States transmission and distribution grid continues to age, the cost-effective replacement of old equipment and integration of new technologies has become increasingly challenging. The American Society of Civil Engineers (ASCE), which performs ongoing assessments of the state of all U.S. infrastructure, claims that the transmission and distribution infrastructure is underfunded by $94 billion through 2020, despite billions in stimulus spending, $1.8 billion directed to rural co-ops through the Department of Agriculture, and billions in recently announced spending from investor-owned utilities. This pattern of underfunding, along with an ever-aging infrastructure and long-term legislative and regulatory difficulties with siting new facilities, led ASCE to give the American energy infrastructure a grade of D+ in its most recent assessment. To support American communities over the next decade and in the decades to come, utilities will have to finance, permit, design and construct new transmission lines, substations and distribution systems.

Utility companies must continually meet long-established customer expectations, including keeping the lights on and restoring power in a timely and efficient manner in outage situations. However, the increasingly dynamic nature of the grid is challenging the traditional day-to-day processes used to manage it, creating an increasing need for flexibility in both the physical and the IT infrastructure. This, in turn, has served to heighten the involvement of design and modeling teams in weekly operations. Teams of engineers and designers can provide additional insight into the temporal, monetary and physical effects of system changes to major substations and primary feeders, as well as of improvements to incorporate distributed generation, smart homes and buildings, and other innovative technology.

In a variety of other industries, building information modeling (BIM) has been used to address many issues in the design process, reducing prototyping costs, enabling on-the-fly design changes, and improving efficiency in materials, labor and scheduling. BIM enables users to more easily update traditional design standards, documentation procedures, data capture, and data-sharing policies. The adoption of BIM best practices can help address many of the problems associated with an increase in designer workload and the integration of new technologies through the creation of intelligent, computational 3-D models. In utility industry settings, BIM principles can improve planning, design, construction and handoff.

CHAPTER 2

Emerging Concerns

2.1 A Changing Workforce

The utility workforce continues to age as increasing numbers of designers, field crews and engineers near retirement. In all, approximately 50 percent of the utility workforce is set to retire in the next seven years. This collective loss of experiential and company-specific knowledge could be devastating for the efficiency of utility operations. As these employees retire, utility-specific knowledge will be lost, and the aggregate experience with and preference for legacy software will dissipate.

Increased automation and embedded rules-based design can help ease this workforce transition by decreasing the time needed to train new designers, as well as speeding data entry and reducing the number of design errors. In addition, the use of automated information transfer between systems reduces the potential for translation errors and increases designer efficiency. Improved analytical acuity helps both design and engineering teams properly size assets, accurately model power flows, and increase the efficiency of design processes using embedded rules-based design. It can also ensure that new hires adhere to individual utilities' design standards, further reducing the time required to complete the design process.

In addition to these tangible benefits, the use of more automated and advanced planning tools utilizing 3-D modeling will complement the training and expectations of recent engineering graduates, reducing training time and increasing the attractiveness of the industry to potential recruits.

2.2 Impending Infrastructure Replacement

According to The Brattle Group, the U.S. electric utility industry will have to spend between $1.5 trillion and $2 trillion between 2010 and 2030 to maintain electric service at current reliability standards. At a more granular level, significant investment will be required in states such as New York where 85% of all transmission lines were built prior to 1980. New York is not an isolated case. Utilities in California, Maryland, New Jersey, Ohio, and elsewhere are embarking on large infrastructure plans to replace aging lines and cables, substations, and line equipment. These projects will require significant design and project management work, the success of which will have a tremendous effect on local utility's bottom line for decades to come.

2.3 Incorporating Smart Grid Into Design

Factors such as smart grid technologies, communications networks, the increased penetration of distributed generation, electric vehicles, large inductive loads, and storage are changing the capabilities required for the design and maintenance of substations and the distribution grid. Many of these updates will require minimal effort, but designing for the integration of digital relays, new substation devices such as storage systems, an increasingly large number of intelligent electronic devices, and grid-edge devices can require significant redesign of feeders and networked lines and cables. To enable these emerging technologies, distributed energy resources, and infrastructure improvements, design software will have to meet new requirements, including:

- Enabling what-if modeling to minimize the costs of redesigning substations, feeders, and circuits to enable two-way power flows when required
- Enhancing the ability to view and collaborate via a five-dimensional model that acts as a single point of truth regarding utility infrastructure, such as a substation, to improve coordination and scheduling

2.4 Improving Event Response

A utility's ability to effectively restore power during a widespread reliability event is becoming increasingly important as customers, politicians, and regulators become more engaged with and aware of issues of resiliency and preparedness. Major storms in the Northeast U.S. over the last few years have driven awareness of the state of preparedness for large-scale outage events. Coordination and information-sharing between utility systems, personnel and outside stakeholders have been made more difficult by an inadequate network model and lack of enterprise integration. Widespread access to detailed design documentation on specific equipment and substations can improve field operations by enabling faster and more accurate ordering of replacement equipment.

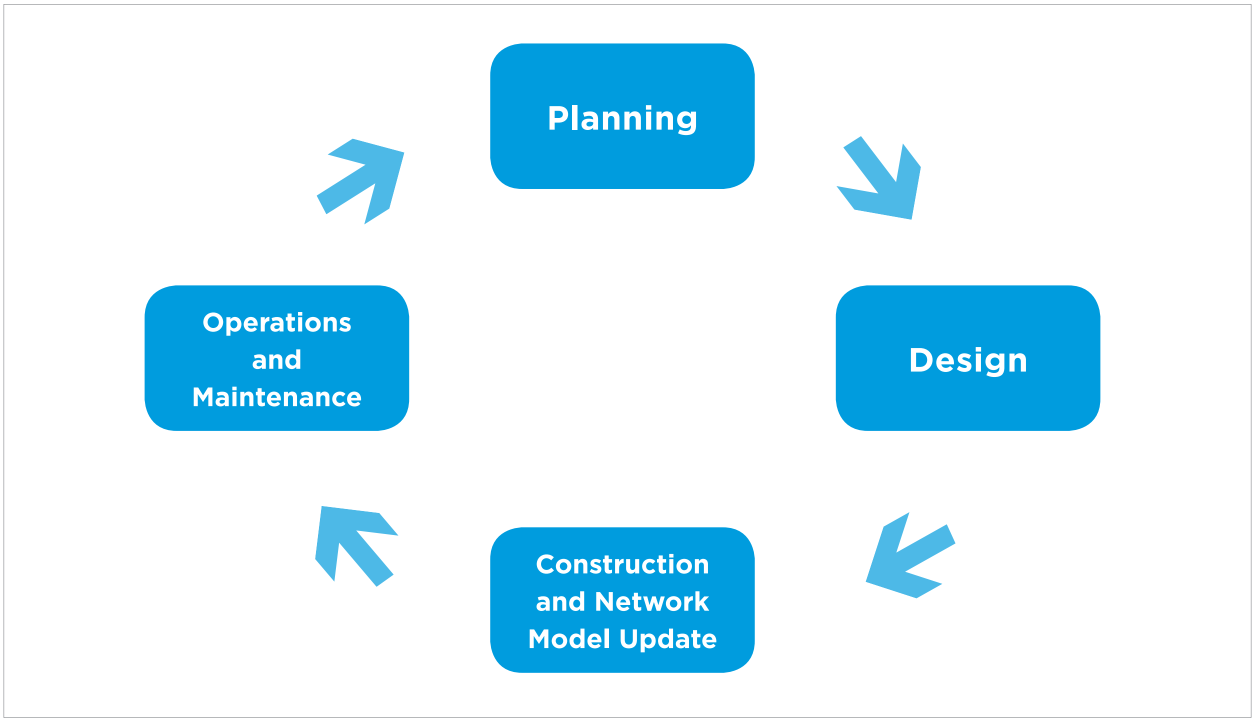
In a major event, these minor process improvements can provide significant benefits. Events such as Hurricane Sandy and the nor'easter that followed it overwhelmed many utilities' and design teams' business processes. In the aftermath of Hurricane Sandy, PSE&G coordinated upwards of 4,000 utility employees, rebuilt 1,282 overhead and underground distribution circuits, and replaced or repaired 1,022 transformers. Of the utility's 291 substations, 96 were affected, and 29 were impacted by the storm surge. In an event of this scale, field crews, operators, and dispatchers need access to a wide variety of scheduling, facility and equipment information. A single network model can help support restoration activities, but to fully leverage data and back office capabilities, utilities must end dependence on manual and disconnected back-office processes and records that slow design, recovery and data maintenance during and after major events.

CHAPTER 3

The Design-Build Lifecycle

The traditional design-build cycle consists of four broad steps: planning, design, construction, and operation and maintenance. This cycle is the foundation upon which the grid is built; as requirements change, equipment is damaged, or new technologies are integrated onto the grid, the cycle begins again. For large projects, this process engages a variety of stakeholders inside and outside the utility for approvals, analysis, and reviews.

Figure 3-1: Asset Lifecycle



Source: GTM Research

For many utilities, much of this process is still organized around two-dimensional designs, which rely on manual data entry to communicate requirements between disparate systems, technical paper network models for storage and manually enforced utility standards. The data from these processes is typically siloed into various databases, retained in hard-copy documents, or ensconced in construction or field crew "tribal knowledge." When systems are rarely altered, siloed operation and data capture and storage is not problematic. However, factors such as more active grid management, restoration work following major weather events, and continued efforts to reduce operational costs are making design change more iterative, increasing the need for quick access to data both from various enterprise systems and the field.

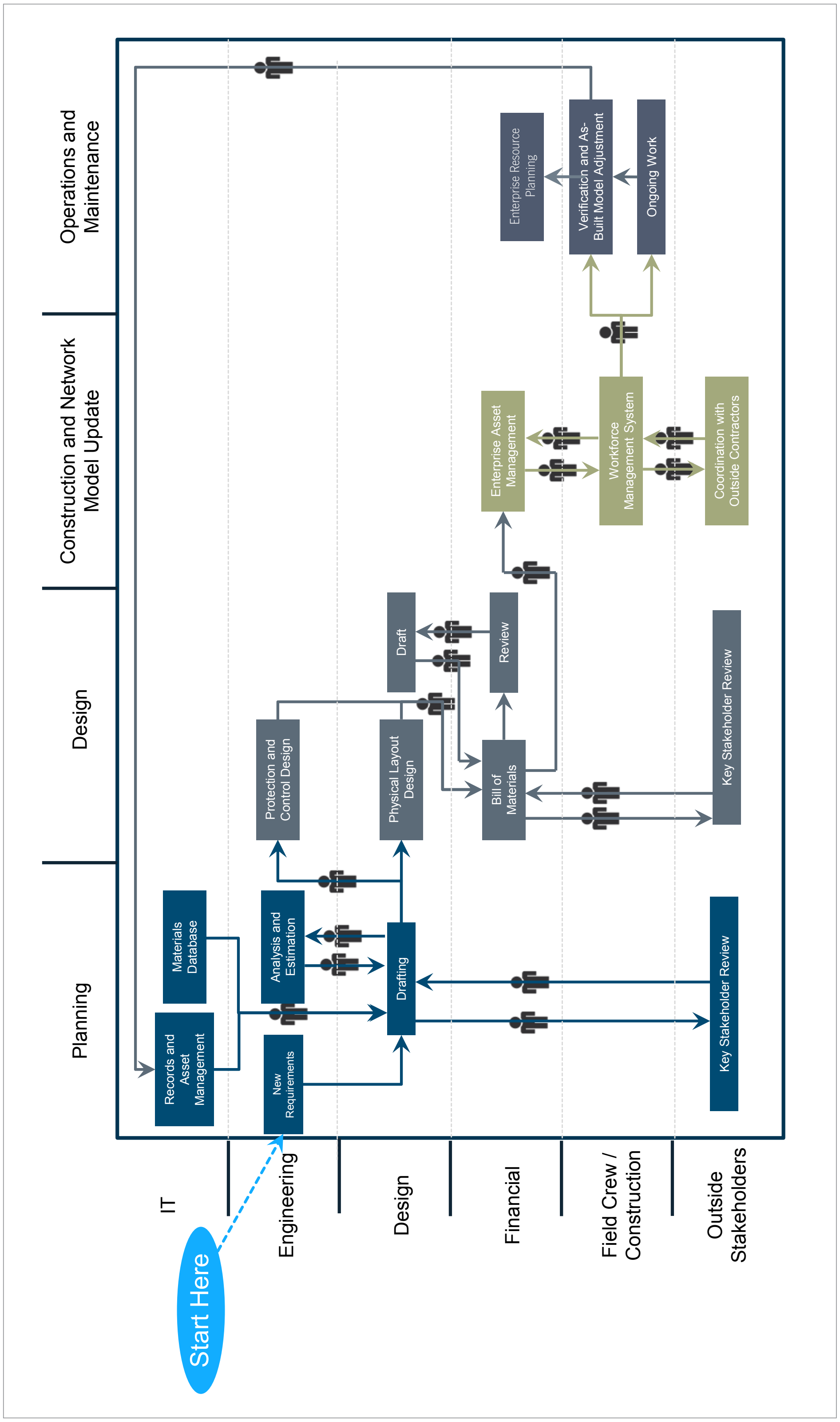
CHAPTER 4

The Traditional Design-Build Process

Legacy systems and business processes strongly influence the success of large capital projects such as the construction of substations. The planning process for these projects requires the expenditure of time and political capital, weeks or months of design, a barrage of applications for approval, significant monetary investment, and months of construction time. Traditional business processes rely on specialized design policies, as well as requiring physical or digital storage of two-dimensional models.

Traditionally, the foundation of this process consists of a collection of models that record landscaping, civil and environmental site design, equipment layout, engineering, and protection and control data onto two-dimensional paper or digital maps. To create these models, designers and engineers manually share limited information to create separate initial mockups, as well as independently updating various application-specific models following revisions to the design. These independent models must be subjected to rigorous manual quality assurance and quality control processes to spot translation errors, ensure a correct bill of materials, and address discrepancies. These lengthy checks create delays and add significant labor costs to a project. Years after completion, these designs form the foundational data used to plan network upgrades. The absence of an integrated model often slows these data-gathering efforts, forcing utilities to seek the help of various contractors to investigate and verify the as-operated system topology, increasing costs and slowing project completion.

Figure 4-2: Example Substation Design-Build Process



Source: GTM Research

Figure 4-3: The Design-Build Cycle

STEP	STAGE	PROCESS	EXPLANATION
1	Planning	Gather Requirements	Large capital projects begin with the identification of the need for additional capacity, increased redundancy, or additional resiliency.
2	Planning	Gather Conditions Data	Following identification, designers are tasked with creating a draft for further review. The designer begins a project by acquiring project requirements and gathering information on existing conditions. Paper drawings of the existing infrastructure will often be scanned and built off of for brownfield substations. In addition to paper drawings, survey crews are often deployed to the site to verify site information.
3	Planning	Initial Design Work	Some preliminary design work may be completed in order to develop equipment and labor costs and timeline estimates for the project.
4	Planning	Initial Engineering	Electrical engineers and the substation designers will work together to create rough estimates that follow required standards for equipment, sizing, compatibility, and clearance, among other parameters. At this stage, long-lead-time parts are identified and sourced.
5	Planning	Key Stakeholder Review	Before completion, rough design ideas are often shared with key stakeholders for review and approval. These stakeholders may include local government officials, community organizations, homeowners and/or residents. Typically, utilities present these outside stakeholders with non-contextual, two-dimensional project visualizations and simplified timelines. Stakeholder comments and requirements may lead to significant redesign work in an iterative process.
6	Design	Technical Draft	Once initial designs are approved, engineering completes the electrical relay protection and control design and chooses equipment, allowing designers to finalize the physical layout and complete the design. Quality assurance and quality control reviews occur throughout this process, occupying the time of skilled designers and engineers and slowing project completion.
7	Design	Quality Assurance and Control	When finalized, equipment choices from the design are used to manually create a bill of materials in a separate application. Counting and listing hundreds or thousands of parts down to the level of individual nuts, bolts and cross arms occupies designers for a great deal of time.
8	Design	Review, Redraft, and Recreate Bill of Materials	During constructability reviews, complications can arise that require redesign, forcing designers to make adjustments manually and restart the quality control process. This includes adjusting the bill of materials, recounting the parts, and sending the design for final equipment evaluation.
9	Design	Project Handoff	The final bill of materials is then entered into an EAM/ERP system, as well as the work management system, in preparation for the construction phase.
10	C&NMU	Ordering	Materials are ordered and received, and field crews begin work. Any data entry errors not caught by this stage can lead to over- or under-ordering, thus increasing waste and reducing workforce efficiency.
11	C&NMU	Construction Tracking	Construction crews use two-dimensional design models to guide construction, verify delivery of bill of materials, and determine when as-built modifications are required.
12	O&M	Completion and Logging	When construction is complete, as-built modifications are manually added to drafted model, the work order is closed out, and the paper record of the design is verified as complete and stored via paper in a physical system model repository.

Source: GTM Research

4.1 Inefficiencies in the Traditional Design Process

The traditional design and construction process leaves many opportunities for process improvement that utilities can leverage to increase the efficiency of designers, planning engineers and field crews. Increased efficiency can also reduce costs, improve model accuracy, design quality, and knowledge transfer; decrease the time required to train new utility personnel; and ameliorate operational difficulties often encountered while working with other utilities, as well as with outside consultants and contractors.

In planning, design and construction processes, there are a variety of bottlenecks that can extend project timelines and reduce the return on investment of the existing IT infrastructure. These bottlenecks require excessive numbers of labor-hours to alleviate. There are many opportunities to utilize open, standardized and integrated tools to enable improvement of these potential snags.

Figure 4-4: Opportunities for Improvement in the Design-Build Process

PROBLEM	SOLUTION
Errors and time lost in translation between design and engineering analysis	Direct integration of design and engineering programs or embedding engineering calculation capabilities in design software
Lack of connection between utility equipment library and design programs	Connection and digitization of utility materials databases with design software based on smart objects
Time-consuming acquisition of system data for design projects	Direct or enterprise service bus integration with GIS system to put geographic modeling data at the fingertips of designers and engineers
Reliance on old and inaccurate as-builts for existing condition data for brownfield projects	LiDAR and photogrammetry can be used to gather existing condition data for aggregation in intelligent modeling systems.
Difficulty tracking and ensuring accurate bills of material	Connecting design and engineering software, materials databases, and ERP systems reduces translation errors and waste by connecting procurement from design to purchasing.
Updating vendor equipment libraries when products are upgraded and new products are introduced	Utilize digital smart objects libraries that include engineering, physical and pricing parameters that can be updated by manufacturers
Long design backlogs	Increasing the speed of design work without sacrificing quality calls for standardization of design and improved tools. Standardization can be realized with the creation of a digital equipment library and the integration of utility-specific design standards. Improved tools can visualize in three dimensions and represent the environment around the construction site, increasing productivity and outside stakeholder buy-in.
Difficulty demonstrating plans to stakeholders	The creation of three-dimensional models incorporating environmental aspects of a site and providing the ability to create fly-throughs improves stakeholder awareness and reduces the likelihood of late-stage adjustments to a project.
Time-consuming constructability reviews	The use of five-dimensional design software enhances a designer's ability to dynamically alter designs and/or to simplify and improve the efficiency of a design, drastically improving cost efficiency.

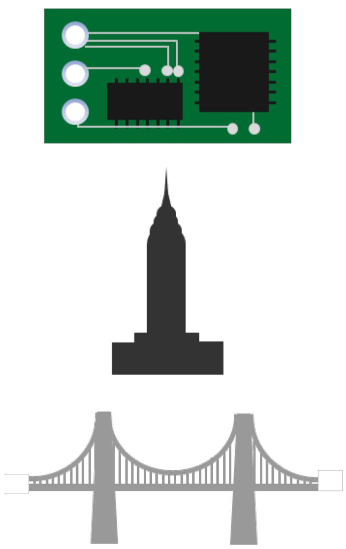
Source: GTM Research

CHAPTER 5

Building Information Modeling

Building information modeling (BIM) is a design process that incorporates functional and physical characteristics into a three-, four- or five-dimensional model. BIM practices have led to significant cost and time savings over traditional design practices in a variety of technology and asset-intensive industries by enabling rapid prototyping and on-the-fly adjustment and evaluation of the physical, technical, monetary, and temporal aspects of equipment and system models.

Figure 5-1: Building Information Modeling in Other Sectors



Manufacturing

- Faster decision-making, reducing the number of physical prototypes required
- 3D modeling enabled digital prototyping
- On-the-fly performance analysis of a model

Buildings and Architecture

- Cloud-based iterative design allows optimization of design
- Improve design and construction coordination and collaboration between stakeholders on large building projects leading to millions saved on large projects
- Wind load analysis, computational fluid dynamics and other simulations help to reduce materials and construction costs

Civil Infrastructure

- Win work and get to yes faster on proposed projects with 3D modeling and visualization of existing conditions
- Speed stakeholder understanding and approvals with conceptual models of preliminary designs
- Improve design and construction collaboration between stakeholders on transportation, land, water, or utility projects

Source: GTM Research

BIM allows designers to use predetermined or generated models to integrate and generate a single set of plans for use in design, engineering, construction, maintenance and upgrades for a particular project. The purpose of this intelligent model-based process is to empower all project stakeholders to make better-informed decisions and respond quickly to the needs of the project with accurate, accessible, and actionable information throughout the project lifecycle.

Intelligent models have several attributes that can simplify design processes, improve worker efficiency and speed utility business processes.

Figure 5-2: Characteristics of BIM Models

CHARACTERISTIC	DESCRIPTION
Smart Models	BIM models contain descriptive and operational parameters such as manufacturer, model no., size, cost, and weight, as well as capacity, fault tolerance, and a host of other equipment-specific parameters.
Containment	BIM models incorporate containment principles to ensure equipment units remain connected. For example, a load tap changer, the transformer to which it is attached, and the required concrete platform are linked together into a single element comprising all three components during the design process, while still maintaining the integrity and accessibility of the data and specifications for each piece.
Connectivity	The incorporation of enhanced connectivity ensures that conductors are connected to grid equipment and vice versa. Enhanced connectivity awareness can allow designers to complete wiring diagrams more rapidly.
Parametric	The parametric nature of this type of model enables the models to change as the design iterations change. These changes flow from the visible layout of the model or models to the attributes and finally to the bill of materials.

Source: GTM Research

The combination of these properties allows a design and engineering application to more easily evaluate various equipment configurations on the fly. Expanded to a group of assets, a model-based system can be visualized in a 3-D environment that contains the visible characteristics of the asset being designed such as a power pole, transformer, or circuit. For utilities, the combination of models can create intelligent three-dimensional views of entire substations, networks or other large capital assets such as a generation facility.

Furthermore, the model can be used to communicate and collaborate from preliminary design to constructability reviews. This single point of truth allows utilities to go beyond pure visualization to find clashes and design or operational issues, thus allowing the proper scheduling of the construction for the project based on the appropriate order of the work, as well as materials and resource availability. BIM-based design can provide a foundation to increase project clarity, improve information continuity, and boost business agility with advanced technology for intelligent-model based design, visualization, simulation and coordination.

5.1 Five-Factor Dynamic Analysis

Five-dimensional analysis enables designers to model not only the three-dimensional physical layout of a design, but also the costs and construction time associated with the overall project, as well as minor alterations made along the way. The addition of real-time engineering validation with cost and temporal estimates enhances utilities' ability to examine various possible configurations, keeping costs to a minimum while ensuring reliable service and accounting for physical and environmental impediments. Visualization and rules engines enhance designers' and engineers' ability to identify physical clashes and problems with designs. Additionally, by providing cost and temporal estimates, design software can enhance project planning to reduce costs and speed construction by coordinating scheduling, materials delivery and tracking. These attributes can then be extended to maintenance activities to improve system visibility, coordinate maintenance scheduling and materials delivery, and extend network model data and 3-D visualization into the field.

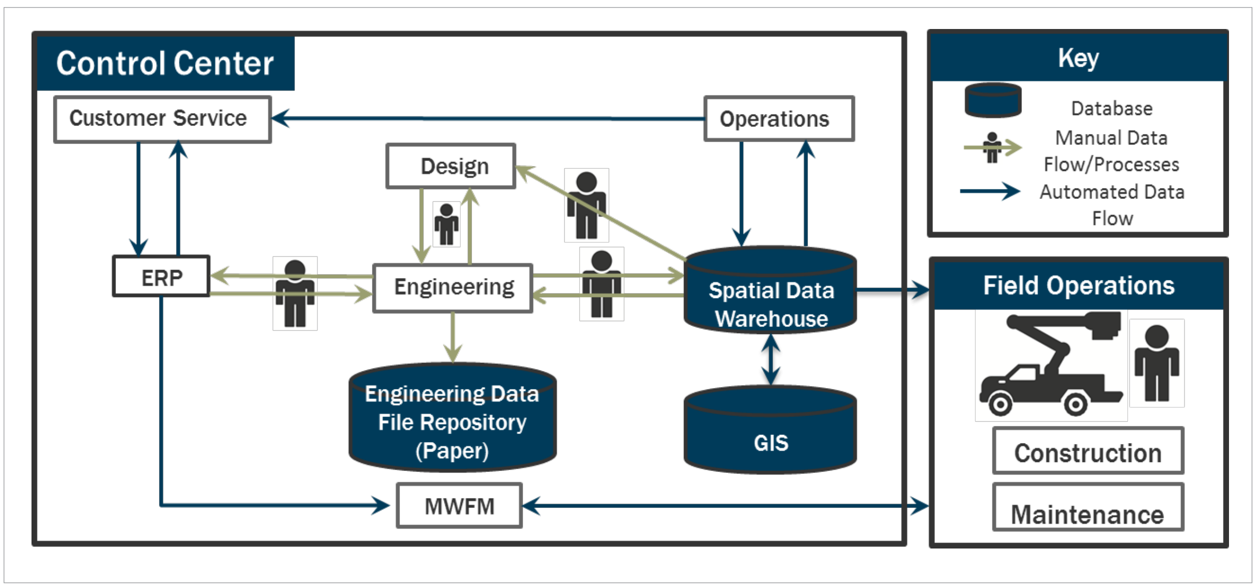
5.2 Increased Buy-In

Three-dimensional modeling can incorporate environmental features such as nearby trees, homes, commercial buildings and infrastructure. This ability to contextualize large substations and other construction projects improves outside stakeholders' ability to evaluate the impact of a project on the surrounding environment. In addition, the ability to walk stakeholders through the construction process temporally allows utilities to provide valuable information to outside entities, contextualizing current progress, upcoming work, and the final design in three dimensions. This capability is most valuable in the early stages of a project as a means of helping to achieve buy-in from multiple internal and external stakeholders. Achieving more accurate designs earlier in the process can help keep a project on time and on budget by minimizing the likelihood of significant design changes in final stages of the design review process or even during construction.

5.3 Systems Integration

BIM models with component assemblies that are standardized and automated not only speed utility processes, but can also significantly reduce mistakes and enhance the quality of data underlying operational utility processes when supported by targeted systems integration.

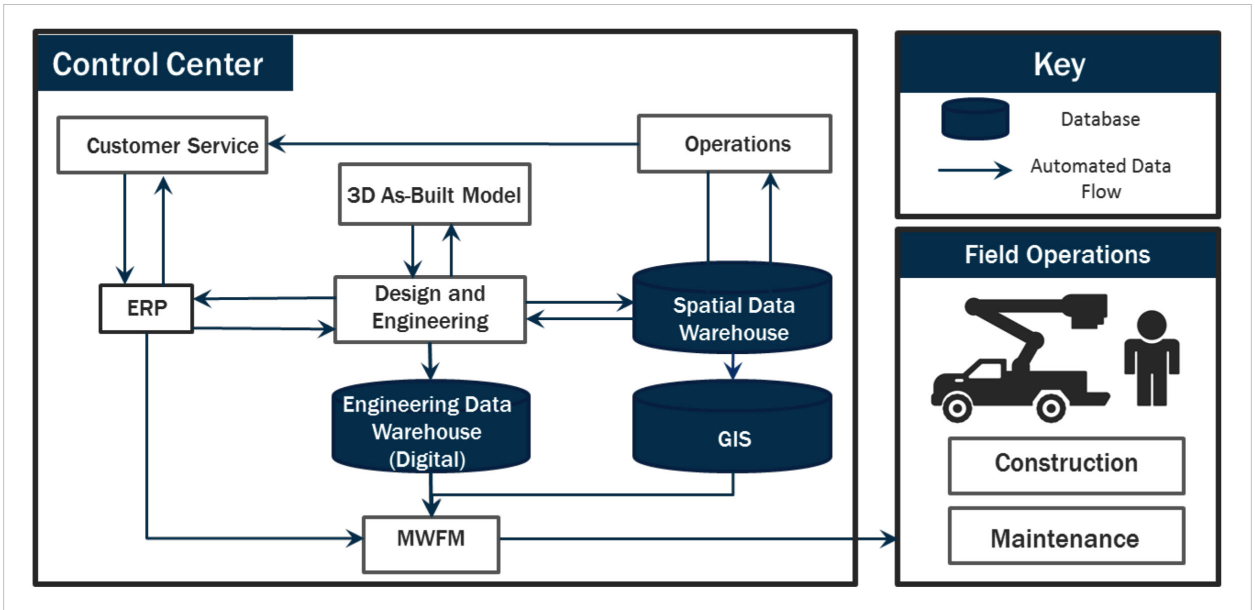
Figure 5-3: Traditional Utility Design Process Operations



Source: GTM Research

By integrating directly or through a service bus, utilities can reduce the quantity and extent of data-entry tasks required of designers in the initial design phases. Utilizing a three-dimensional model also allows designers to better investigate the unique physical characteristics of a site, including foliage, flood stage, and geology. Coupled with real-time bill of materials generation and cost estimation, utilities are now able to examine various options much more rapidly, allowing for more educated decision-making and risk-taking regarding site preparation.

Figure 5-4: Integrated Utility Design Process Architecture



Source: GTM Research

Redesigning utility back-office systems to simplify data architectures, integrate advances in enterprise asset management and enterprise resource planning (EAM/ERP) systems, as well as three-dimensional modeling systems, can significantly reduce design time, increase the effectiveness of field construction, restoration and maintenance crews, and reduce the time required to design and integrate advanced smart grid technologies. Integration of these systems can tie together business processes across functional areas, increasing access to data and coordination during the planning, design, construction, and operations and maintenance processes. Wider enterprise access to EAM/ERP systems and a utility's engineering data warehouse can provide the information necessary for a utility to create a more complete as-built model with access to operational and asset characteristic data, increasing data homogeneity and accuracy; improving designer, field crew and maintenance intelligence; coordinating data sharing within and outside of the corporate LAN; and providing an updatable three-dimensional network model of a utility's grid for network operations software suites.

5.4 BIM for Utilities

Planning and design processes are at the heart of any utility project or proposal. Following lengthy concept and approval processes, designers operate as digital first movers and project coordinators, creating and honing the initial plans for brownfield or greenfield projects – whether they are large, multidisciplinary generation, substation or transmission projects, or smaller distribution or renewable generation projects. BIM allows designers to work in three dimensions and add critical factors like time, money and carbon values to a project. The project can exist as a single model, enabling each team involved to complete their part and pass the model along for other teams to check against their standards (such as safe working conditions, security or constructability reviews). As manufacturers continue to migrate to 3-D product modeling, third-party libraries can be leveraged to speed construction and reduce the time required for custom product alteration. Improved visualization, collaboration, and estimation tools are allowing core design platforms to be a single point of truth for design, engineering, and constructability for suppliers, construction crews, outside contractors, field crews and operators. Via features such as access to more intelligent models from the manufacturing ecosystem and the ability to manage cost and time more accurately, BIM is transforming the design and construction of infrastructure projects. This transformation is enabling more accurate, accessible, and actionable insight throughout a project's execution and lifecycle, leading to direct cost savings and improved construction efficiencies.

CHAPTER 6

Conclusion

Design is a central application in the utility IT infrastructure. When combined with 3-D, 4-D, and 5-D modeling, customized utility design standards, and integrated enterprise processes, the use of design-build and asset management business process software and workflows can greatly improve workforce efficiency both inside and outside the control center.

BIM can enable a variety of benefits for utilities through cost savings, data reuse, improved workforce efficiency, and more productive collaboration with outside stakeholders and suppliers.

- 3-D visualization eases stakeholder education efforts by enabling active engagement and providing film-quality fly-throughs of current design drafts.
- Once a design is approved, material and quantity take-offs can be applied using the model, simulating the physical construction process and thus eliminating the potential for errors and clashes.
- Once an asset is installed, the model can be used as a precise, accurate record of what is installed, where it is, and who installed it. This data can be used as a foundation for predictive maintenance and training of operational crews.
- Many long-term benefits have yet to be fully realized, but the ease of collaboration between supply chain personnel, designers, and external stakeholders and other utilities will have wider impacts, improving industry efficiency into the next century.
- Using laser scanning and intelligent algorithms, it is possible to reverse-engineer models of existing assets, making it possible to create highly accurate, 21st-century models of 50-year-old installations.
- With focused integration, redesigned business processes, and advanced technologies such as building information modeling (BIM), utilities can improve planning, design and construction, as well as operational efficiency.

As in other industries, the BIM process provides utilities with a decision-making aid to optimize the safety, cost-effectiveness, and construction scheduling of both specific projects and the system as a whole. This aids not only in construction, but also in operation, where the intelligent model can be utilized by asset managers to help maintain the grid and IT systems.

In addition to incorporating improved design processes, enhanced visualization and collaboration tools, as well as accurate engineering design data management processes, BIM establishes up-to-date as-built models that can be used to support operational systems such as geographic information systems and distribution management systems. In the near future, increasing pressure to improve project cost performance, bolster stakeholder acceptance, and reduce risk while simultaneously increasing safety, reliability, and resiliency will continue to increase the benefits of incorporating BIM workflows as configuration changes become more frequent.

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