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AP1000 Construction Schedule

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INTRODUCTION

Westinghouse performed this study as part of EPRI's interest in advancing the use of computer aided processes to reduce the cost of nuclear power plants. EPRI believed that if one could relate appropriate portions of an advanced light water reactor plant model to activities in its construction sequence, and this relationship could be portrayed visually, then optimization of the construction sequence could be developed as never before. By seeing a 3D representation of the plant at any point in its construction sequence, more informed decisions can be made on the feasibility or attractiveness of follow on or parallel steps in the sequence. The 3D representation of construction as a function of time (4D) could also increase the confidence of potential investors concerning the viability of the schedule and the plant's ultimate cost. This study performed by Westinghouse confirmed that it is useful to be able to visualize a plant's construction in 3D as a function of time in order to optimize the sequence of construction activities.

Construction costs of commercial nuclear generating plants must be reduced in order to expand the future use of nuclear energy. Two of the drivers of plant construction costs are the cost of financing during the construction duration (overall construction time) and the amount of skilled craft labor hours needed on site during construction ("in-hole activity sequencing"). The application of information technology (IT) was examined and has proven its potential to reduce the impact of both of these drivers.

The first construction cost driver is the length of time needed to complete plant construction. The construction schedule for AP600/1000 had been developed to reduce the overall duration of construction activities on site. These schedules have been developed using IT tools, such as Primavera. The durations of individual activities were reduced to reasonably aggressive values. The logic of sequencing these activities was not necessarily optimum. Therefore, it was beneficial to review these schedules with construction specialists using the visualization capabilities of a 4D-plant model.

The second cost driver of plant construction, the number of skilled craft labor hours needed on-site during construction, was also reduced by linking the construction schedule to the 3D plant model. The improved visualization will also benefit the project in the future by improving the training and preparedness of craft labor. Labor crews would know in advance what their roles are relative to the overall construction, and could visualize the finished project, the intermediate steps required and their sequences.

Westinghouse modeled the construction of AP600/1000 in 4D to show its viability, to improve its sequencing, to improve the plant design for constructibility and to reduce overall time and risk in the construction schedule. This 4D modeling is equally applicable to the AP1000. The design of AP1000 was constrained to be a duplicate of AP600 except where components required changes for the higher power level. As a result, the AP1000 schedule is the same as for AP600 with only the addition of one shield building concrete pour. There are no new critical path containment vessel module lifts or welds. The larger components used in AP1000 can be installed in the same sequence as those for AP600. Therefore, the mature, short construction schedule for AP600 (36 months from first basemat concrete to fuel load) is basically unchanged for the AP1000.

Westinghouse used their detailed 3D model of AP600/1000 in Intergraph's PDS and DesignReview software and their extensive Primavera schedule for this effort. Using portions of the plant model attached by software to activities in the schedule allow for a 4D simulation of the construction of AP600/1000. Westinghouse reviews were conducted for the entire sequence as each construction month was placed into 4D. These reviews resulted in refinement and correction of the construction sequence. Two additional formal reviews were conducted with construction project managers from Morrison-Knudsen. Monthly reviews with representatives from EPRI were also held.

Schedule Development

Westinghouse chose to use the Schedule Review accessory in the Design Review software available from Intergraph for this task. Schedule Review provides a method to attach 3D model files from Intergraph PDS or Bentley Microstation to activities identified in a Primavera schedule file.

Westinghouse had already developed an extensive, detailed model of the AP600 nuclear reactor plant. This model was developed over eight years, using input from a number of design participants from a variety of countries. Westinghouse also led the effort by Morrison-Knudsen (MK) to develop a construction schedule using Primavera for AP600 over the same period as the 3D-model development. MK used its construction experience and a detailed knowledge of the plant to create a detailed schedule for construction of the entire plant. This schedule was "logic" driven and included activities with industry standard durations. It is based upon a 50 hour, 5 day week and resulted in a 36 month duration from start of basemat concrete pour to the beginning of fuel load.

The overall 3D model of AP600/1000 is composed of individual elements connected to form model files. These files are connected to form the whole AP600/1000. Most of the model elements are standard units such as pipe lengths or fittings, structural steel pieces, valves and so forth. These elements are assembled into models of specific portions of the plant such as a module structure, a piping spool, a building structure and so on. These models are categorized in discipline areas: piping, cable tray, HVAC duct, equipment, steel structure and concrete. The models were developed system-by-system and area-by-area within the plant. The boundaries of the models were based upon the responsibility boundaries of the designer or on natural boundaries dictated by analysis. For construction simulation, these models of elements previously grouped on a system or building area basis had to be broken down into smaller models with boundaries based on construction tasks. For example, without changing the layout or data base information, piping models based upon analysis boundaries were divided into models based on installation boundaries. Concrete models based on complete structures were divided into models of individual pours.

4D Schedule Review

In this project the AP600/1000 construction schedule was linked to the AP600/1000 3D model. The linkage was performed using the Intergraph suite of software products. The plant construction schedule and 3D model were studied to determine methods to link the elements in the model with the activities on the schedule. The granularity and level of detail was initially different, and one-to-one matchups for every item were not possible for all objects and all schedule activities. To address this issue, generic rules and procedures were developed to facilitate the linkup of objects. Also, work on both increasing the level of detail, where appropriate, and in combining objects, where appropriate, was performed.

The detailed linking of the AP600/1000 construction schedule to the 3D model was for nuclear island activities after start of basemat concrete. The nuclear island includes the containment and the auxiliary building (including shield building). Using the nuclear island is appropriate because its construction activities are on the critical path for the plant, start at the beginning of construction and involve complex operations. Moreover, this part of the plant is a comprehensive example to link schedule with model due to the complex shapes in the model of concrete in the containment vessel cradle, annulus and lower internal structure areas.

Nuclear island construction is representative of all the activities for constructing the rest of plant, including concrete and structural steel work, equipment placement, structural module placement, piping and equipment module placement, piping, raceway, and HVAC installation. This provided all of the level of complexity needed to adequately study and demonstrate the benefits of linking construction schedule to a 3D model.

Another aspect of this project was to determine and implement the appropriate level of detail. There was a point of diminishing returns, as increasing the level of detail required an increasing amount of effort, but produced a disproportionately smaller level of incremental benefits in construction visualization and proper construction review.

At the beginning of this virtual construction demonstration task, the construction schedule had over 5500 activities. Not all activities could be represented pictorially, so a screening process was conducted to identify which schedule activities were to be linked to AP600/1000 models. For example, tasks related to NRC interactions or to site preparation were screened out. In addition, detailed models of reinforcing steel had not been developed and depicting rebar models on composite construction views would obscure other activities. Most rebar installation activities were screened out and not linked to their schedule activities.

Once this screening process was complete, 3D models with revised boundaries were attached to their identified construction schedule activities. The process of attachment was different for different types of models. For concrete, Microstation 3D models are used instead of Intergraph PDS models. It is easier to create, manipulate, and detail the complex 3D concrete shapes in Microstation than in PDS Modeldraft/Frame Work.

At this early phase of the construction visualization program, concrete pour models required modification a number of times before an optimal pouring schedule was achieved. Employing Microstation models for concrete pours allowed for quicker implementation of changes between reviews. For example, when the construction schedule identifies an activity to pour concrete for a wall between two elevations, a 3D model was created of the concrete wall object consistent with that particular pour. The same concept applies to structural steel between elevations. Structural steel and concrete models had been created in PDS in order to perform structural, shielding and space analyses and thus the models encompassed multiple levels and multiple areas. These models serve well the engineering needs of analysis and space management of the completed plant, but do not provide the appropriate level of detail to support construction planning and work force training. Thus Microstation models satisfied the need for simplified concrete pour models.

For steel, piping, and equipment, 3D models from PDS were used. The models and component design data were extracted from the AP600/1000 PDS project models depository through the DesignReview session module. It is important that the linkage between PDS Project models and Schedule Review Project models are maintained so that changes that occur in PDS Project models are also replicated in the Schedule Review project.

Piping, raceway, and HVAC duct provided other examples of inconsistencies between the level of detail in the 3D model and the construction schedule. Piping is typically routed in the 3D model by system from nozzle to nozzle, nozzle to anchor, or anchor to anchor. The line number IDs on the piping are established based on the P&IDs. Rarely is the 3D model of piping created consistent with construction work packages and construction activities on the schedule. Significant effort was required to create 3D model objects that can be matched to the construction schedule. Existing 3D model objects must be segmented, and then recombined to form objects that can be matched to construction schedule activities. For these commodities, the overall plant PDS model remained unchanged, but the boundaries of individual object models were established.

For five critical rebar installation activities, "cartoon" models were created to represent the associated rebar. These "cartoons" appear to be a grid of bars of the proper overall dimensions. They are not representative of real rebar weights or densities. The representation of rebar preserves some visibility of the virtual construction model. The rebar was modeled to show that given sufficient time, meaningful representation for all rebar and perhaps formwork activities could be prepared.

As the project progressed and 3D models were attached to schedule activities, day by day screen simulations of the construction sequence for the nuclear island from construction start were reviewed by the Westinghouse team. These simulations were reviewed one additional construction month at a time, with schedule corrections being implemented between reviews. Then two reviews of the first nine construction months were conducted with the support of experienced construction managers from Morrison-Knudsen. All of the reviews resulted in an improved overall construction sequence, an improved plant design, confirmation that the construction sequence was reasonable, and added confidence that the AP600/1000 construction schedule could be achieved.

Schedule Improvements

The real power and benefit of using this 4D-schedule review technique was being able to view the entire construction sequence as a function of time in a visual and integrated way. Using the technique, the design and construction team could view each construction day's progress from any angle and distance. This allows a critical review in three dimensions of the real constraints, or lack thereof, on the next activity planned. This provided Westinghouse with the opportunity to maximize the sequencing of parallel paths of activities which, when started early in construction, provide schedule savings throughout the entire 36 month schedule. As a result, non-interfering parallel paths were established early in the construction sequence that reduced the overall duration of the AP600/1000 schedule several months out of the original 36. Additionally, there is increased confidence that the remaining sequence is reasonable. These results were brought about by the application of a variety of schedule changes that were suggested during group reviews of the 4D portrayal of the sequence.

It is important to remember that the construction critical path for AP600/1000 runs through containment and its internal structures and equipment. It is also important to erect the auxiliary building and install its equipment in a timely manner so that it does not become the critical path. Significant effort was expended to modify the construction sequence to expedite auxiliary building erection. Throughout the sequence review and revision process, only logic was revised. Except for a few obvious errors, no durations for individual activities were changed. Near the end of this program, experienced construction managers from MK joined Westinghouse to evaluate if the AP600/1000 Construction plan was still reasonable. They provided additional suggestions for schedule improvement while ensuring that the schedule remained achievable.

The balance of this section provides descriptions of anecdotal schedule reductions that were implemented during the course of this program. The real, overall reduction in schedule and increase in confidence resulted from the integrated application of this 4D visualization technique over the entire duration of this program.

There were a number of improper sequences that would have been hard or impossible to detect from a simple listing of the construction activities. For example, a situation where equipment was scheduled to be installed after the required access was eliminated is difficult to detect from a list and easy to see with a 4D simulation. In addition, the order in which large modules are installed relative to surrounding concrete pours was refined during the review process. It is hard to visualize all boundaries of a large, outfitted, complicated module without seeing it and its surroundings as a function of time in 3D on a computer screen. Sequencing of adjacent and connecting structures, equipment, modules, piping and ductwork is simplified if the large module boundaries can be seen. Using the techniques of this program allowed us to refine and detail the interfaces of the large (over 900 tons) module CA-20 that makes up most of the fuel building. The sequencing of effecting these interfaces was created using this 4D technique.

An example illustrating the power of this technique is the 4D review of the simulation of the containment vessel bottom head installation. While reviewing this sequence, someone asked why does it take so long between head installation and pouring of the first in-vessel concrete. The answer was that the lowest in-containment rebar was placed after the lower head was positioned on its pedestal. Since this activity was on the critical path, shortening it or moving it off the critical path would be beneficial. Putting this lowest rebar into the containment vessel bottom head before the head was landed on the pedestal could be done. The resultant assembly weight did not exceed the Lampson construction crane capacity. An additional benefit of installing the rebar before bottom head placement is that the installation can be done in the assembly area where access and support services should be better. The result of this single logic or sequence change removed weeks from the critical path schedule.

Another example of using the 4D simulation to investigate sequence inefficiencies concerns painting in the auxiliary building. The original construction sequence had general painting activities for entire areas scheduled after sufficient cure time for the last concrete pour in that area and before the first equipment or module placement in that area. This was followed by installation of makeup pieces, then the ceiling/floor above the area in question and so forth. This resulted in a longer than necessary erection sequence. Using the 4D-construction simulation technique, we were able to tailor more definitive painting activities to selected concrete activities to allow earlier installation of modules and equipment. In some cases, with the aid of the MK construction experts, we were able to identify those modules and pieces of equipment that could be installed before painting the concrete. This allowed for overall acceleration of the entire auxiliary building construction sequence.

Similar revisions were done within containment. We first split bulk concrete pour activities into those for the west (around and under the in-containment refueling water storage tank (IRWST) and refueling canal) and those for the east (around and under passive core cooling (PXS) and chemical and volume control system (CVS) pits). The structure and concrete placement activities for the east side of containment were then split into north and south activities. This allowed the northeast activities to be performed independently of those in the west or southeast. As a result, concrete placements in the southeast did not have to wait for equipment placement in the northeast and vice versa. These parallel sequences were over a month shorter than the combined series sequence. It is felt that the 4D technique not only was instrumental in suggesting this placement technique, it provided the means to create a sequence with maximum efficiency and confidence.

From these and many more detailed sequence logic changes brought about by being able to visualize the overall construction sequence, the overall critical path was reduced over 15% without changing any activity duration estimates.

Design Improvements

Using this 4D visualization technique allowed for viewing the design from new perspectives. This new view allowed Westinghouse to see opportunities where the design could be enhanced or corrected. Since AP600 has received its Design Certification from the USNRC, actual design changes were confined to those that implemented true design corrections. However, if this technique is used for a plant design before design certification, plant improvements can be recognized and incorporated throughout. In some cases for AP600/1000 where the design detail is not explicitly covered by the Design Certification, this visual construction technique allowed for design improvements and will continue to show new opportunities as detail design progresses. Examples of design corrections, improvements and detailing are discussed below.

When viewing the entire auxiliary building basemat in 3D superimposed on the embedded drain piping layout, we discovered that the two elevator pits did not have drains. This oversight was obvious using the 4D-visualization technique studied in this program, but was overlooked using standard design review methods. The elevator pits could be drained using portable pumps or some other water extraction method, but it would be preferable for them to drain by gravity with permanently installed piping and equipment. As a result a design change was processed to add permanent drain capability to the elevator pits.

Similarly, when viewing the installation steps related to anchoring the bottom of the large CA-20 fuel building structural module, it was noted that access for the required welding was very limited. In addition, the duration for anchoring was long. As a result, an alternate design was developed that provides equivalent anchoring capability without welding. Access requirements were eliminated and the duration for this activity was reduced by weeks.

Throughout the design Westinghouse revised the location of field welds. In general, piping models in PDS were developed early in the design process. As a result, field weld locations were established before module detailing was complete, or even started, in some cases. Using the 4D virtual construction technique, we could better understand where piping module, assembly, spool and makeup piece boundaries should be. As we progressed through the construction sequence, field weld and PDS file boundaries were moved to establish an optimum piping installation sequence. Using this integrated simulation tool we ensured that the design, as reflected in PDS, was always consistent with the construction plan for piping.

AP600/1000 uses a number of large structural modules to accelerate the overall construction sequence by allowing parallel construction activities. These large modules are prefabricated in a suitable factory or on site assembly area and then installed into the plant. Detailed design of the structural connections between these modules and the surrounding building structure required significant engineering. Two of these large modules, CA-01 and CA-20, have to structurally interface with a number of walls and floors. Not only did the connection details have to be structurally adequate; they had to be accessible and configured in such away that their installation fit within the overall construction sequence. Using the 4D virtual construction technique allowed us to see the configuration of these large structural modules in a way that provided connection detail design that is structurally adequate without being on the critical path.

Associated with establishing piping installation boundaries is the establishment of outfitting limits for modules. The AP600/1000 construction sequence is based upon using a maximum of preassembled and outfitted modules, structural, as well as, mechanical. The modules will be installed with outfitting, painting and testing as complete as possible. They will also be installed in a configuration that allows for safe and stable lifting and handling. Seeing outfitted module boundaries in 4D with their surroundings in the building allowed us to refine the location of those boundaries. In some cases, piping modules were redefined to have some portions installed with structural modules and other portions installed alone. In other cases, modules were combined or split to enhance the installation sequence overall. These refinements would not have been possible using more conventional techniques.

Conclusion

Although linking the plant construction schedule to the 3D model is only one area in which plant construction could benefit from the application of IT; it is an area that has yielded substantial benefits. The current state-of-the-art in IT supports continued development in this area. Westinghouse has used commercially available software products to link the two information bases of 3D models and construction schedule to produce tangible results in the short term.

With the extensive AP600/1000 3D PDS design model graphics linked to its detailed Primavera construction schedule, better construction reviews were performed than could be performed with other techniques. The benefits of this better method for construction schedule reviews are:

- development of improved construction sequencing to reduce overall time
- verification of accurate and achievable schedules

- elimination of problems before they are encountered in the field
- generation of more investor confidence in the ability to achieve schedule predictions
- broader understanding of construction issues by the project team

This project has verified that developing a 4D representation of plant construction and using it to review and optimize the construction sequence is very useful. Three benefits are immediately apparent. First, the on screen representation allows for better understanding of the plant configuration at any point in the sequence. It is much easier to view the integration of construction steps on the screen than it is to assemble the plant in one's mind. Given that the partially constructed plant can be "seen", it is now easier to develop an optimum logic for proceeding through the rest of construction. Second, the technique allows for investigating options. It allows for comparing one sequence against another. This again helps in optimizing the overall sequence. Third, it is easier to understand how activities overlap in time. Viewing them in a distinctive color in a plant construction simulation is more obvious than reading and remembering the overlaps from several pages of a schedule software printout.

The utility of the technique can be proven by the results gained for AP600/1000. As a result of this study of the first 9 months of AP600/1000 construction, the initial 36 month critical path was reduced by over 4 months. For AP600/1000, each day during construction costs over $70,000 in non-construction overheads, leases, taxes, insurance, interest and the like. Thus any reduction of critical path duration results in significant savings. This technique can and should be used by any construction project with a sufficiently detailed 3D model.