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Is modularization right for your project?

One gasoil hydrotreater case history illustrates how $12.5 million was saved

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Modularization: certainly a subject that has been discussed at length but is sometimes not fully understood nor the benefits fully recognized. Modularization is not unlike nitroglycerin: In the right hands, it can be a very effective tool, decreasing cost and shortening schedules while minimizing risk. In the wrong hands, it can add complexity and chaos.

Modularization is seen in many industries—including home and building construction, ships and offshore platforms—and in orbit with the International Space Station. But is modularization right for your project? The bottom line is that no matter how attractive a modularized project may appear to be, it must provide a clear economic advantage over stick-built (or onsite) construction.

Potential value. In hydrocarbon processing, the goal of modularization can be stated this way: "To provide an economical solution for designing and constructing process plants that are to be built in a resource-limited, hostile or relatively expensive construction environment."

The main drivers for modularization may be apparent in that statement. Certainly, money is the heartbeat that drives modularization. So how can modularization save a project money? The following are a few of the items that contribute to modularization's cost benefits:

- **Labor cost.** This is a benefit if shop costs are less than the field labor cost. This is often the case, especially when the infrastructure required to support crews in the field is considered. The cost of tools, facilities, supervision, training, safety watch, hiring, testing, etc., impact the field much greater than in an established shop environment. In addition, many areas have bare labor rates that are higher than shops located in a more economical labor environment.
- **Productivity.** Shops tend to maintain standards procedures, QA and assembly-line techniques that add to the overall efficiency of the shop environment. In addition, many shops work in a covered and/or environmentally controlled environment. This eliminates the loss of productivity due to wind, rain, snow, flooding, lightning, etc.
- **Equipment.** With proper work scheduling and sequencing, modules can allow for shorter durations of large cranes and other equipment in the field.

The above main money drivers for modularization are important; however, several other benefits may be derived from modularization under the proper conditions.

- **Safety.** Shifting work into a controlled shop environment generally benefits the overall safety risks of a project. In addition, large vertical structures can be constructed in

FIG. 1 An 18-ft x 18-ft module leaves the fabrication shop in Texas bound for South Korea.

the horizontal by use of modularization. This limits the amount of vertical work at elevation and can decongest areas that, by their nature, possess a riskier work environment.

- **Reduction of peak work loads.** Modularization reduces the amount of direct and indirect field labor. This can be a reassuring factor in projects that are competing for resources with other projects or simply are limited in local resources. In addition, cost can be saved on expensive job camps or, in the case of offshore and desert work, the cost to transport workers, food, water, housing, medical needs, and recreation to the jobsite.
- **Schedule.** On projects that are hampered by a lengthy permitting process, modularization can effectively allow construction to begin months earlier in a shop environment. Once the permit is acquired, modules can be set much quicker than the time required for onsite fabrication and assembly.

Determining the suitability. How do we go forward? How can we determine if our project is a likely candidate for modularization? Before a decision is made, one must dig deep into the numbers. However, some checklist items can give you a fairly quick indication whether modularization may be a viable option. Ask the following questions:

- Is field labor productivity <80% of shop productivity?
- Is field labor cost >30% of shop labor cost?
- Is there a high probability of severe weather during the construction phase at site?
- Do field labor requirements put restrictions on where and who can fabricate modules?
- Do national or local content requirements restrict the amount of labor used for modularization? (Fig. 1)
- Do shipping limits allow module transportation?
- Does the mass flowrate (size) of the plant allow for modularization?
- Are site permits readily available?
- Is crane capacity available and economical?
- Is fabrication capacity available?
- How will modularization affect the schedule?
- Are equipment spacing requirements reasonable for modularization?

The sections that follow examine many of the issues that need to be addressed during a modular project, the estimated benefit from a modular approach and the actual benefits achieved on a project that was completed in 2005. This case study helps illustrate how to execute a successful modular project.

CASE STUDY: GASOIL HYDROTREATER

To identify the relative savings for modularization, a gasoil hydrotreater (GOHT) project located near the US Great Lakes area is analyzed. This project, which was designed to reduce the sulfur emissions level in gasoline, was awarded in August 2003 as a lump-sum turnkey engineering, procurement, fabrication and construction project. The project included 66 pieces of major equipment, over 57,160 linear feet of piping and 520 tons of structural steel. Overall mechanical completion was achieved in September 2005.

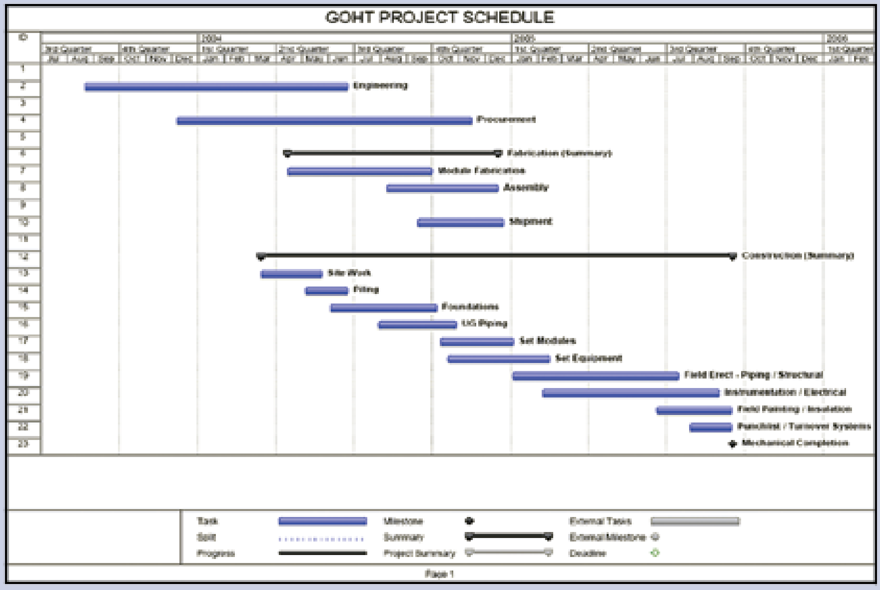


FIG. 2 Schedule for a gasoil hydrotreater project shows that coordination between disciplines is critical.

In addition to the fast-track, 25-month schedule, the project faced several challenges. As with most industrial plant projects, performing work in the field posed a significant cost risk. The site had limited laydown areas for fabrication and material storage. Labor issues also created a cost risk. Most of the area's available labor was not qualified for work in a refinery environment, meaning that a large portion of the labor force would have to be imported from other union labor pools, which were heavily weighted for the manufacturing environment. A third issue was the weather: frigid temperatures could affect field productivity and hinder transportation. During the winter season—usually from late November through March—a 35% load restriction is imposed on all road transportation in that area.

As a solution to all of these challenges, the project team turned to modularization. The GOHT unit was divided into 48 modules, in addition to other ship loose, field-installed equipment and materials. These included process modules (17), piperack modules (25) and stair tower modules (6).

Getting started. Before design begins on a modular project, one must decide how large to make the modules. Obviously, larger modules allow greater flexibility in the quantity, size and spacing for equipment, pipe and other material. However, larger modules present more challenges in fabrication, shipping and erection. To make the right decision, it is prudent to look at the shipping limitations. The modules for this project were to be constructed in Texas and shipped to an area near the Great Lakes. Each state—from Texas to the jobsite—has limits on truckable load size and weight (Table 1).

The traffic survey indicated that 15 ft × 15 ft × 100-ft modules could be shipped by truck. It was also determined that if the modules were shipped by barge, another foot could be added to the height and width: allowing for a 16 ft × 16 ft module. This may seem insignificant; however, in modular construction, 1 ft can make a big difference.

During the engineering phase of a modular project, special consideration is required in the plant arrangement and layout. The end user's specifications and spacing requirements were incorporated into the design. Access and maintainability had to be designed into each module. In addition, constructability reviews were conducted to ensure that construction concerns were met and that the scheduled sequence of module fabrication matched the preferred erection sequence in the field.

Schedule. As is evidenced by the schedule in Fig. 2, coordination between engineering, procurement, fabrication and construction is critical. During a three-month period of this project, all four of these activities were happening contemporaneously. Limited laydown area at the site and the desire not to double-handle large equipment and modules meant that module fabrication in the shop, shipping from the shop to the dock, barging to the dock near the site and offloading at the site had to be planned with great detail. It also required excellent communication between the groups.

A further complication was the project and design team's decision to barge most of the modules. This required that the modules reach the site before the end of December. Slipping the shipment for any reason posed the risk of modules being stranded in transit due to shipping lanes being closed to ice or severe weather.

Fortunately, communication between the groups was excellent and the modules arrived in time and in the proper sequence for construction to minimize handling of the equipment and modules.

Shipping. Transporting modules across the country requires the talents of an experienced shipping and traffic coordinator. Even though some shipping restrictions are easy to define, as in Table 1, many municipalities, counties, townships, etc., have their own rules that can change with the seasons.

In some areas, load size and weight limits can be reduced by as much as 50% during winter months. Other areas will restrict or prohibit large loads due to holidays, local celebrations, chili cook-offs or conventions of, say, the Third Order of Royal Antelope. During the case study, the modules left a Texas fabrication facility by truck to the US Gulf Coast. From there, they were barged up the Mississippi River, then through several smaller waterways, to the Great Lakes, and then off-loaded at a port where the modules were trucked to the final destination.

One might surmise that if you can truck a module, you should be able to barge a module. This is not always the case. Fig. 3 shows a load that used a special barge that could be partially flooded to clear a bridge crossing the Des Plaines River. Had this minor detail been overlooked, the shipment never would have made it to the site on time. With a great deal of planning, effort and communication, construction received the modules in time to complete the project on schedule.

As the schedule in Fig. 2 illustrates, modularization decreased the field work hours and allowed module fabrication and assembly to occur in parallel with field foundation and underground piping

FIG. 3 Special barge can be partially flooded to allow bridge clearance.

TABLE 1. Overland shipping limits in the US

State	Length, ft	Width, ft	Height, ft	Gross weight, lb
Alabama	150	16	16	180,000
Arizona	120	14	16	250,000
Arkansas	100	14	14	120,000
California	120	14	16	220,000
Colorado	130	17	16	228,000
Connecticut	120	15	16	250,000
Delaware	120	15	15	250,000
Florida	150	16	16	250,000
Georgia	100	14	14	120,000
Idaho	110	16	15′6″	200,000
Illinois	145	14′6″	15	250,000
Indiana	110	16	15	250,000
Iowa	120	18	16	250,000
Kansas	126	16′6″	16	250,000
Kentucky	110	16	15	250,000
Louisiana	125	18	16	250,000
Maine	125	16	16	250,000
Maryland	100	15′11	15′11	220,000
Massachusetts	115	14	14	240,000
Michigan	150	16	15	230,000
Minnesota	95	14′6″	14	250,000
Mississippi	100	14	14	120,000
Missouri	100	14	14	120,000
Montana	110	18	17	240,000
Nebraska	120	14	15′6″	212,000
Nevada	105	17	16	240,000
New Hampshire	120	15	16	250,000
New Jersey	120	18	16	220,000
New Mexico	120	14	16	250,000
New York	120	14	14	160,000
North Carolina	100	14	14	120,000
North Dakota	120	14′6″	15′6″	150,000
Ohio	100	14	14′10″	120,000
Oklahoma	100	16	16	212,000
Oregon	105	14	16	220,000
Pennsylvania	120	16	15′6″	201,000
Rhode Island	90	14	13′6″	120,000
South Carolina	125	16	14	250,000
South Dakota	120	14′6″	15′6″	150,000
Tennessee	120	16	15	250,000
Texas	125	20	18′11″	252,000
Utah	125	15	16′6″	250,000
Vermont	100	15	14	150,000
Virginia	150	14	15	150,000
Washington	150	14	16	200,000
West Virginia	150	16	15	212,000
Wisconsin	150	16	16	250,000
Wyoming	110	18	17	252,000

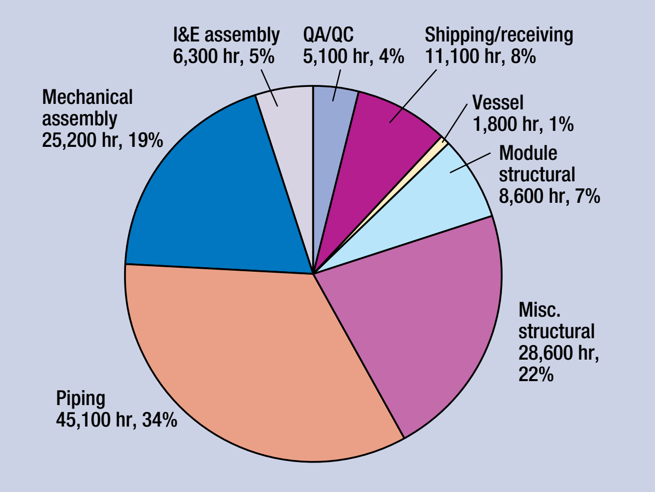


FIG. 4 Actual shop work hour breakdown for gasoil hydrotreater project.

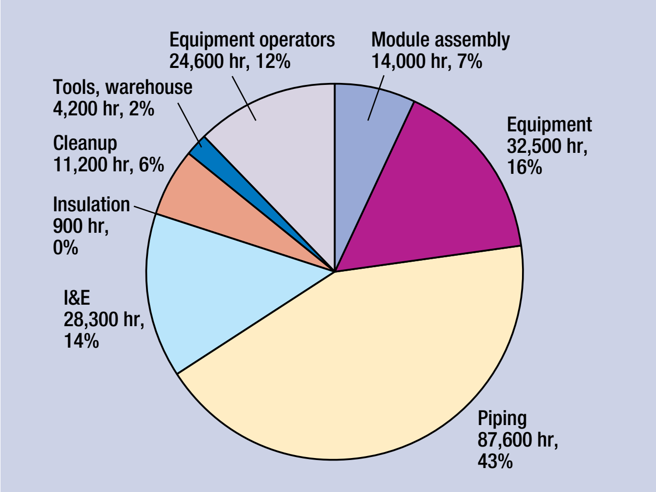


FIG. 5 Actual field work hour breakdown for the gasoil hydrotreater project.

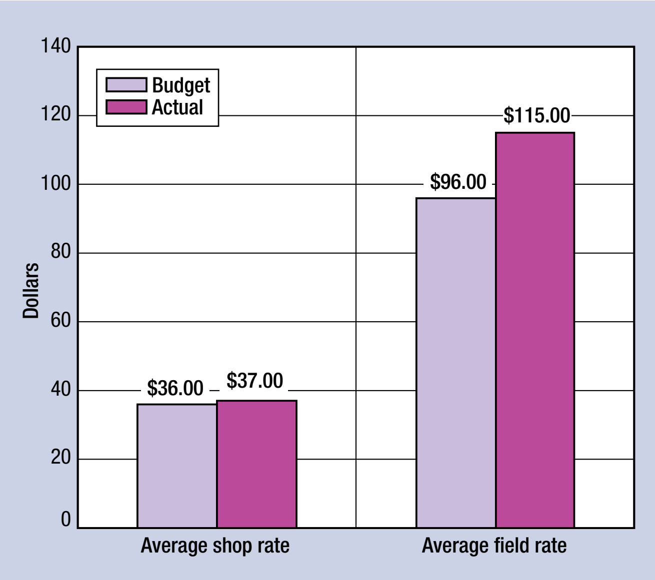


FIG. 6 Labor rate comparison for the project.

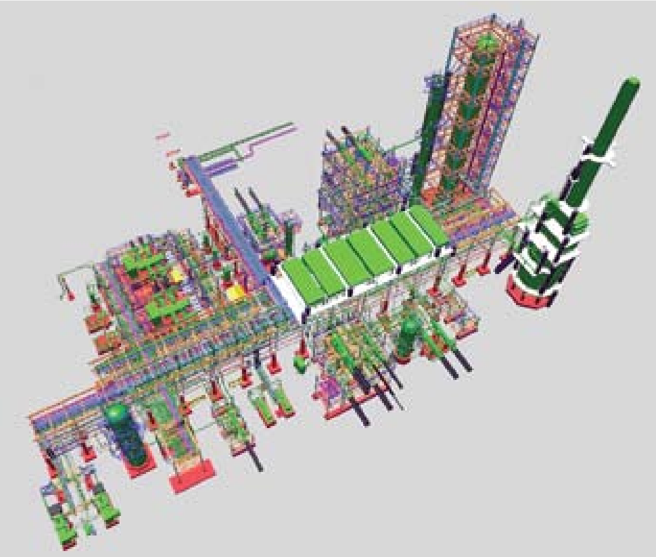


FIG. 7 The gasoil hydrotreater design consists of 17 process, 25 piperack and 6 stair tower modules.

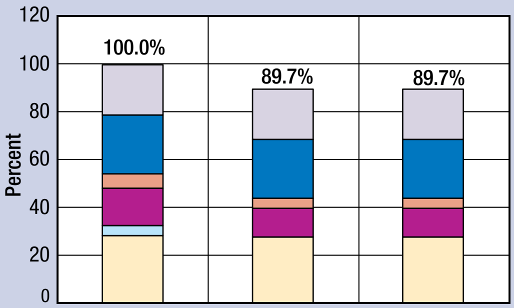
installations. Modularization enabled the project team to transfer high-cost, high-risk field work to a manufacturing facility. In the shop, modules could be assembled in a controlled environment using experienced, proven labor resources. Overall, the GOHT project resulted in 131,800 shop work hours and 203,300 field work hours. Fig. 4 illustrates the breakdown of actual shop work hours.

A total of 56% of the hours included prefabrication of piping and ship-loose structural steel. Module structural steel fabrication represented 7% of the work hours, while assembly of module piping, instrument and electrical components represented 24% of the work hours. Fig. 5 illustrates the breakdown of the actual field work hours, where module setting and alignment represented 7% of the work hours.

Cost-savings analysis. While it is obvious that modularization transferred work hours from a field environment to a shop environment, did it really save money when compared to the traditional stick-built approach? To understand the following analysis, several of the numbers and assumptions need to be clarified.

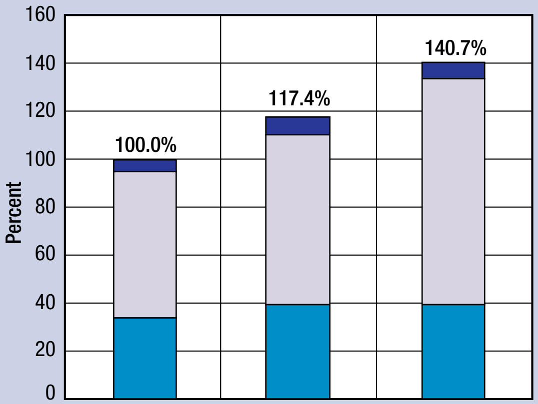
The first area of comparison is labor cost, both what was budgeted and actual. Fig. 6 shows the labor rate comparison for the GOHT project. For the shop, the rate is loaded to include indirect labor costs such as supervision and shop management. Likewise, the field rate is considered loaded to include field indirect labor costs such as supervision, management and field engineering. In both cases, actual labor cost was higher than the budget. However, actual shop labor rate was within 3% of budget while actual field labor rate was 20% over the estimated budget. This difference is mainly attributable to higher costs related to importing labor into the field and overtime.

A second comparison is labor productivity. At the time of the GOHT project, the fabrication facility had productivity numbers similar to US Gulf Coast productivity (pre-Hurricane Katrina). Likewise, field construction in the Great Lakes area was considered 0.50 of Gulf Coast productivity. So, every hour spent in the shop represented



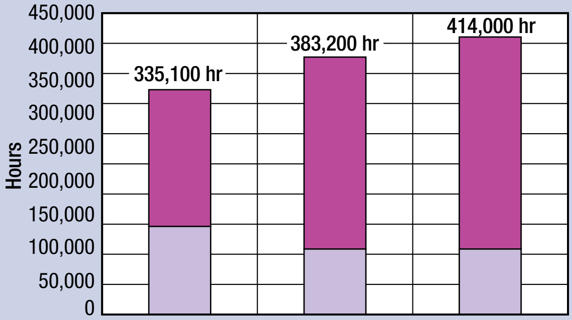
	Modular	Stick built (budget field productivity and labor rate)	Stick built (actual field productivity and labor rate)
▭ Equipment	21.1%	21.1%	21.1%
■ Engineering	24.9%	24.6%	24.6%
▭ Freight	5.7%	4.2%	4.2%
■ Shop labor	16.0%	11.9%	11.9%
▭ Subcontractor (insulation/ fireproofing)	4.2%	0.0%	0.0%
▭ Bulk materials	28.1%	27.9%	27.9%

FIG. 8 The project's FOB cost breakdown, modular vs stick-built comparison.



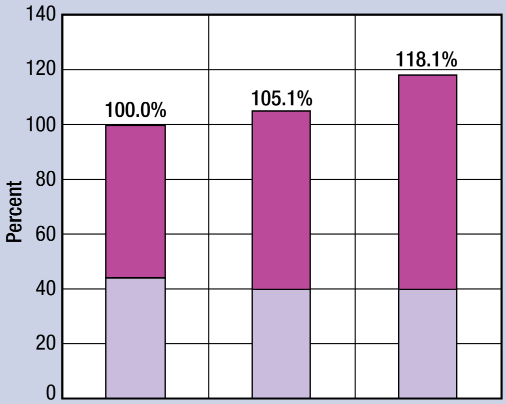
	Modular	Stick built (budget field productivity and labor rate)	Stick built (actual field productivity and labor rate)
■ Indirect/temp facilities	5.4%	7.0%	7.0%
▭ Field labor w/staff	60.9%	71.4%	94.7%
■ Field subcontract	33.7%	39.0%	39.0%

FIG. 9 Field construction cost breakdown in modular vs stick-built approach.



	Modular	Stick built (budget productivity)	Stick built (actual productivity)
■ Field work hr	203,300	285,200	316,000
▭ Shop work hr	131,800	98,000	98,000

FIG. 10 Field and shop work hours in modular vs stick-built construction.



	Modular	Stick built (budget field productivity and labor rate)	Stick built (actual field productivity and labor rate)
■ Construction total	55.7%	65.4%	78.4%
▭ FOB total	44.3%	39.7%	39.7%

FIG. 11 Total cost comparison for the gasoil hydrotreater project.

2 hr spent in the field performing the same task. That formed the budget or baseline productivity. However, the actual shop and field productivities were 1.05 and 0.78, respectively. In actuality, every hour spent in the shop facility represented 2.56 hr spent in the field doing the same task.

A third consideration is structural steel design and fabrication. On this project, piping and structural steel components are modeled in a 3-D environment (Fig. 7). This allows the owner to obtain a visual representation of the project before it is built. In analyzing the stick-built option, the project team determined that the module structural design represented a 17% increase in weight relative to stick built. This amounted to a 174,000-lb structural steel savings for the stick-built option. Stick-built material savings was assumed to be $0.35/lb, while shop savings was determined by applying a 17%-reduction to the module steel fabrication work hours.

A fourth consideration is shop versus field assembly hours. For the stick-built case, mechanical, instrument and electrical assembly hours (31,500) were deleted from the shop and transferred to the field, using the 0.50 budget productivity adjustment and 0.39 for the actual productivity adjustment. This resulted in a field budget increase of 63,000 work hours and an actual increase of 80,769 work hours. The same adjustment had to be applied for the field erection of the previous module structural steel. This increased the field budget by 31,044 work hours and an actual increase of 39,800 work hours.

A fifth consideration is insulation and fireproofing subcontract cost. For module fabrication, insulation and fireproofing can be installed prior to shipment. For stick built, this work has to be performed in the field. To account for this cost increase, a 2.5 multiplier was applied to the labor portion of these subcontracts. No change was made to the material portion.

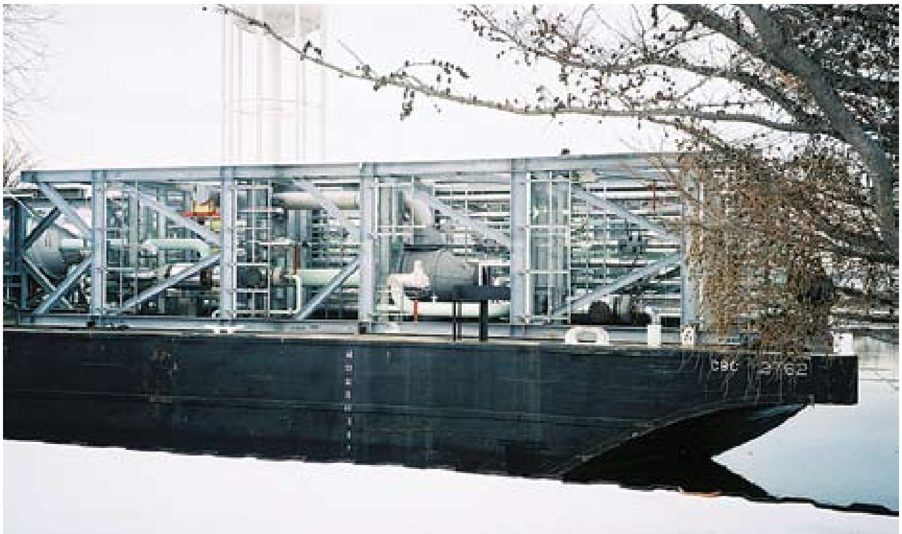


FIG. 12 Gasoil hydrotreater modules on barge.

A sixth consideration relates to schedule extension and field indirect cost. It was estimated that the field construction would have been extended by 10 to 12 weeks if the project was totally stick built. However, since loaded field labor rates were used in the analysis, as previously noted, no additional indirect labor costs were added. However, a 30% increase was applied to field indirect material and temporary facilities.

A seventh consideration relates to foundation design and installation cost. It was estimated that the stick-built construction would have added 68 foundation piles, at an estimated cost of $132,000. Modular construction allows the loads to be distributed more, thus decreasing the number of piles needed for the foundations.

A final consideration relates to transportation and crane cost. It was estimated that 30% of the actual cost of module shipment would be required to ship the modularized components minus the modular steel that would be unnecessary for stick-built construction. This resulted in a $471,000 decrease in the FOB cost. In addition, the entire crane cost for setting the modules in the field was deleted ($499,000). It was assumed that the other cranes already on site could be used for setting the new stick-built components.

Crunching the numbers. Using the previous considerations, a calculation of the potential GOHT stick-built cost for both the budget and actual labor rates and productivity was performed. Figs. 8–10 illustrate the results of that analysis.

Fig. 8 illustrates the expected cost increases for a modular project. Engineering, freight, shop and sub labor, and bulk materials (mostly steel) are all more costly than in a totally stick-built project. Fig. 9 illustrates the expected and actual savings in construction cost realized by using modular construction. Fig. 10 compares the total construction and assembly hours of the actual project to the projected construction hours at the estimated and actual field productivity.

The total cost comparison is illustrated in Fig. 11. For the estimated case, a stick-built design was calculated to be a 5.1%-increase in cost relative to modularization. FOB cost decreased by 4.6%, but field-construction cost increased by 9.7%. On the GOHT project, this amounted to an estimated $3.5-million savings for modularization.

The actual cost analysis was even more convincing. Due to higher labor costs and lower productivities, the stick-built design was calculated to be an 18.1%-increase in cost relative to modularization. FOB cost decreased by the same 4.6%, but field construction increased by 22.7%. For the GOHT project, this amounted to a $12.5-million savings for modularization. More importantly, by choosing modularization in the beginning of the project, the project team avoided the risk of a potential budget overrun of $9 million.

Overview. This case study illustrates the potential savings achieved on an approximately $70-million project. Even when labor and productivity differentials are not as extreme, modularization can prove positive to the bottom line. In many cases, as in the case study, it minimizes the risk of increased project cost due to volatility in labor resources, weather, rates and productivity.

With proper planning and teamwork, modularization can pave the road to a successful project. **HP**

ACKNOWLEDGMENT

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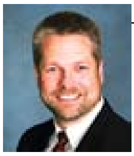

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