What Have We Learned from Megaprojects?

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ABSTRACT

The construction project delivery environment has undergone dramatic changes due to Globalization and growth in both project size and complexity. In the past three decades we have seen the rise of the megaproject, large-scale, complex ventures that typically cost over a billion dollars; take many years to develop and construct; and involve multiple public and private stakeholders. Megaprojects are not just magnified versions of smaller projects. Megaprojects are a completely different breed of project in terms of their level of aspiration, lead times, complexity, and stakeholder involvement. Consequently, they are also a very different type of project to manage. As a result, these projects are taxing the ability of contractors to deliver these behemoths with a high standard of quality and safety, as well as on time and within budget. They are equally a challenge to the owners' level of sophistication in contract management, which exposes the project to increased risk for massive delays and cost overruns as well as numerous contractor claims. In addition, these projects often put a strain on the countries' infrastructure, which often do not have the capacity or resources that can deal with such massive logistics.

In this very risky area of management, best appears to be the exception and average practice a disaster. The question that must be asked is, "Isn't there a better way?" The panelists will address the significant challenges of megaprojects considering their unique characteristics and the lessons learned in their success and failure in meeting these challenges, and how they can bring about better results on future megaprojects. The Panel will explore the challenges of megaprojects considering: What are the characteristics of megaprojects? What are the impetuses that drive megaprojects? What are the performance factors that are leading to megaproject failures? What lessons have we learned? The presentation is intended to be interactive with the audience and, as we are addressing Lessons Learned, Risk and Disputes. Presenters will include a cross-section of owners, counsel, and consultants with extensive megaproject experience.

Can we learn from past mistakes, replicate successes or will we continue to fulfil the observation that: "Human beings, who are almost unique in having the ability to learn from experience of others, are also remarkable for their apparent disregard to do so."

INTRODUCTION

The growth in global population has placed immense pressure on already deteriorating infrastructure around the world. In response, spending on infrastructure worldwide is forecasted to grow exponentially. Price Waterhouse Coopers infrastructure spending outlook indicates global expenditure between 2014 and 2025 on infrastructure projects will be nearly US$78 trillion. The outlook states the annual rate of expenditure is expected to rise from US$4 trillion per year in 2014 to over US$9 trillion per year by 2025.[1] In a similar study, The McKinsey Global Institute forecasts global expenditure on infrastructure will reach US$57 trillion between 2013 and 2030.[2]

This level of expenditure will continue to place tremendous burdens not only on the construction industry but also the countries in which these investments will take place. Burdens these countries will face include: public sector budgets being taxed and more commercial debt, higher and more volatile resource costs, and the additional costs of mitigating environmental impacts. Much of this investment in these capital projects will be performed as "megaprojects."

Megaprojects often fail to achieve their objectives with significant increases in cost and time to complete. This has occurred even where the project delivery organization applied best practices. Edward Merrow, in "Industrial Megaprojects: Concepts, Strategies, and Practices for Success" citing the results of a 2010 study of more than 300 global megaprojects, revealed that 65 percent of these projects failed to meet their business objectives. In some industries the failure rate was higher.[3] Failure was not just due to cost overruns or delays, but in many cases a failure to deliver the expected product or production rate. The Ernst and Young ("EY") 2014 study of 365 oil and gas megaprojects found that of the 204 projects where cost data was available 64% were experiencing cost over runs; and, of the 242 projects where schedule data was available 73% were

[1] Price Waterhouse Coopers, LLC, "Capital project and infrastructure spending Outlook to 2025," 2014.
[2] The McKinsey Global Institute, "Infrastructure productivity: How to save $1 trillion a year," January 2013.
[3] Op. Cit. Merrow 2011.

experiencing schedule delays. EY reported the average cost overrun was over 50 percent for all projects.[4]

Considering the capital being spent, and forecast to be spent on infrastructure alone, along with the high probability of cost and schedule overruns on megaprojects, it behooves all stakeholders in this process to better understand why megaprojects are experiencing such cost and schedule overruns, and why they fail to meet their business objectives. If 65 percent of projects failed to meet their business objectives, this means that 35 percent did met most if not all their objectives. This begs the question, where do we look for answers, to determine:

- What factors had a negative impact on megaprojects?
- What factors had a positive impact on the success of megaprojects?
- What changes should be made to improve the success rate of megaprojects?

To find the answers do we study projects that fell short of their expectations, or those that met their objective? The answer is both.

First, we need to define terms. What is a megaproject? A review of available academic and industry literature reveals there is no uniform definition of the term "megaproject."   The US Federal Highway Administration (FHWA) defines a megaproject as:[5]

"Major infrastructure projects that cost more than $1 billion, or projects of a significant cost that attract a high level of public attention or political interest because of substantial direct and indirect impacts on the community, environment, and State budgets. "Mega" also connotes the skill level and attention required to manage the project successfully."

Generally, all parties agree megaprojects are large scale, complex ventures, that cost in excess of US$1 billion, take many years to develop and build, and may involve multiple public

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[4] Ernst and Young, Spotlight on Oil and Gas Megaproject, 2014 pp 4-5.
[5] Capka, J. R., "Megaprojects - They Are A Different Breed" Public Roads, Federal Highway Administration, Vol. 68 No. 1, July/August 2004.

and private stakeholders. This complexity includes impacts on the community, the local economy, technological development, and the environment of the region or country where the work will be performed. Megaprojects are also characterized by a significant number of interfaces, and interdependencies, some of which are strategic, which must be managed at a level above the project team. As with any definition there are exceptions,

The Construction Industry Institute ("CII") in a 2015 research project on the successful delivery of megaprojects further expanded the list of complexity factors to include one or more of the following: an increased number of stakeholders; a significant number of interfaces; a challenging project location; limitations on the availability of resources; unfamiliar technology; difficult regulatory constraints; extensive local infrastructure requirements; geographically dispersed teams; and, significant political, economic, environmental, or social influence.[6]

FACTORS INFLUENCING MEGAPROJECTS SUCCESS

CII offers an extensive list of factors which have been identified as contributing to a mega-project's success or failure. Following is a summary of the more frequently cited factors that may impact megaprojects:

- Underestimated project cost
- Order of magnitude cost estimates based on preliminary design
- Constantly escalating labor and material costs
- Inadequate front end planning
- Poor schedule practices
- Insufficient cost monitoring
- Scarce labor resources – both quality and availability
- Lack of competent management (owner and construction manager)

[6] Construction Industry Institute, "Research Team 315 Successful Delivery of Megaprojects, October 2015, p.

- Unique management issues
- Lack of adequate technical data
- Lack of commitment
- Poor communication
- Multiple design professional and construction management firms
- Failure to monitor performance
- Insufficient contractor competencies
- Lack of integrated processes
- Huge logistics problems
- Complex environmental issues
- Insufficient contract terms and conditions
- “Fast tracked’ design and construction schedules
- Misunderstood end user constraints
- Inadequate risk and liability assessments
- Lack of program oversight
- Stakeholder conflicts
- Ill-defined goals and objectives
- Remote locations

“Success” and “failure” are also subjective terms. The metrics most commonly used to measure the success of a megaproject are final cost vs original budget, and time to complete vs. original plan. However, success or failure must also consider the end users’ satisfaction.

The Panama Canal Expansion, for example, was placed in operation on June 26, 2016 two years later than planned. The 2006 estimated cost for the project was $5.25 billion, excluding interest. The original budget could increase by as much as 70% as the Panama Canal Authority (“ACP”) is currently enmeshed in a US$3.6 billion conflict with its two prime contractors; Spain’s Sacyr and Italy’s Salini Impreglio.

While some question the ACP's revenue projections, the ACP predicts the volume of cargo transiting the canal will grow by an average of 3% per year, doubling the 2005 tonnage by 2025. By 2021 the ACP expects the canal expansion will generate US$2.1 billion per year in added revenue. As a result, the ACP expects to recover its investment costs in less than 10 years.[7]

The benefits of the Panama Canal Expansion extend beyond Panama. As a result of the expansion U.S. East Coast and Gulf Coast ports are currently planning major port facility upgrades to handle the expected increase in traffic. The American Association of Port Authorities ("AAPA") estimates US$155 billion will be spent on port related freight and passenger infrastructure between 2016 and 2020. This represents more than a threefold increase over the US$46 billion figure from the 2012–2016 survey.[8]

If the forecasted expenditure of up to US$9 trillion per year can be expected on global infrastructure projects, can we afford cost growth of fifty percent, or higher? Therefore, what must be done to rein in uncontrolled costs and delay?

One criticism of the success factors cited in the relevant literature is the lack of an assessment of the priority of the success factors. The CII research addresses this omission.

CII's research included a literature review, surveys, project personnel interviews and case studies of 20 megaprojects; 12 of which were complete and 8 were still ongoing. The interviews were designed to gain information that would accomplish the following objectives:

- Verify the differences in occurrence and performance influence level of the impact of various factors on megaprojects and "large projects".
- Identify the frequency of the impact factors and their performance impacts on megaprojects.
- Identify impact factors that are more likely to occur on and affect megaprojects.

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[7] 19. Panama Canal Authority, Annual Report 2017, http://www.acp.gob.pa/eng/general/reporte-anual/2017-AnnualReport.pdf

[8] American Association of Port Authorities, "2016–2020 Port Planned Infrastructure Investment Survey," 2016.

- Identify the most impactful factors on megaproject performance (in terms of cost, schedule, and business objectives).

Not surprisingly, the results of the interviews reinforced the findings of the literature reviews. Based on the cumulative findings from the literature review and the interviews the CII team created a list of 100 factors that had been reported as affecting megaproject performance. Following further review and analyses the list of 100 factors was narrowed down to 34 primary factors. Using the 34 factors the research team solicited surveys on "large projects" (defined as projects with approved budgets between US$100 and US$750 million) and megaprojects (defined as projects with approved budgets over US$1 billion).

After the literature review, interviews, and their survey, the research team identified the factors which were more unique to megaprojects. Consideration was given to factors that had a significantly higher occurrence or performance impact. The result of this analysis identified 11 factors with a statistically greater occurrence or performance impact on megaprojects. The following Table 1 are these eleven differentiating factors.[9] The purpose was to identify those factors that reflect the unique complexities of megaprojects and thus must be more thoroughly addressed in the planning and execution of a megaproject.

[9] Op. Cit. CII, Table 2, p. 17.

Table 1 – Eleven CII Differentiating Factors

Item	Factor	Item	Factor
1	Logistical Challenges	7	Inadequate Size, Skills, and Experience of Project Management Team
2	Jurisdictional Complexities	8	Business Approach Differences across Stakeholders
3	Unavailability of Qualified Craft Workers	9	Limited Capable Contractors
4	Unplanned Changes in Key Personnel	10	Cultural Differences across Stakeholders
5	Multi-location Challenges	11	Underperforming Contractor or Key Subcontractor
6	Optimism Bias		

CII's survey questionnaire asked the respondents to identify the five factors that most impacted cost, schedule, and business performance. The results were ranked and scored with the result that 16 factors made up 80% of the total impact scoring. Of these 7 of the 11 differentiating factors were among the factors with the most impact on megaprojects. Table 2 below lists the sixteen factors the CII research team identified as having the most impact on megaprojects.[10] They are listed in the order of the percentage of occurrence and impact as determined in the CII research.

[10] Op. Cit. CII, Table 3, p. 19.

Table 2 – CII Sixteen Impact Factors

Item	Impact Factor
1	Inadequate Size, Skills, and Experience of Project Management Team
2	Underperforming Contractor or Key Subcontractor
3	Optimism Bias
4	Unavailability of Qualified Craft Workers
5	Logistical Challenges
6	Unexpected Materials and/or Equipment Delays
7	Regulatory and Environmental Delays
8	Limited Capable Contractors
9	Lack of Execution Input to Front End Planning
10	Jurisdictional Complexities
11	Ineffective Stakeholder Communication
12	Inadequate Integrated Schedule
13	Baseline Schedule Acceleration
14	Misalignment within Partner Organization
15	Inadequate Front End Planning Resources
16	Lack of Execution Plan Alignment

A thorough assessment of these 16 factors and development of correction actions to behaviors, organization, planning and execution are critical to address the recent trends and improve project performance.

Note the two leading impact factors in Table 2 are the two lead players on every project, the Project Management Team and the Contractor. It is human nature to place blame on external factors, however the CII's research suggests the leading causes for megaproject failures are internal. This is consistent with the authors' experience.

Qualified project management talent is one of the more significant challenges facing the construction industry today. To address this problem owners and contractors need to invest heavily to attract and retain talent. Unfortunately, this is not a problem that can be overcome in the short term. The solution is not just in graduating more engineers, it is also recognizing leadership and developing and promoting qualified personnel to positions of leadership and management. While many contractors already develop and promote from within, too few owners and construction management firms do. Construction is about people, and the skills needed to manage megaprojects are not typically acquired in the university curriculum.

On too many projects we have heard the owner comment, when problems start to arise, that the contractor promised to staff the project with his "A" team, but in the owner's opinion he got the "D" team. On the other side imagine the observations of the contractor regarding the owner or construction management team. We are reminded of the warnings that are displayed on TV when a dangerous stunt is being show, "do not try this at home." Based on the performance history of megaprojects, owners and contractors should not undertake projects for which they are not qualified.

This leads to impact factor number three, optimism bias. In the literature this factor is amended to add the phrase, "strategic misrepresentation." Optimism bias and strategic misrepresentation refers to the project manager's decision making process that results in an underestimation of costs and an overestimation of benefits. This behavior is often the result of a sense of ownership project managers assume for the project and deliberately overestimating benefits and underestimating costs, time, and risk to increase the likelihood "their project" gains approval and funding. Optimism bias and strategic misrepresentation are two of Flyvbjerg and

Cantarelli's central arguments and, in case of a megaproject the escalation of commitment is too often a cause for cost and schedule overruns.[11]

The first three impact factors in Table 2 alone account for over 26% of the cumulative impacts reported in the CII research. Collectively these 16 factors may now provide a more focused effort in planning future megaprojects to improve project performance.

Applying these 16 factors to a current megaproject, for which the author has firsthand knowledge, factors 1, 2, 4, 5, and 12 demonstratively impacted that project.

Item #1 - Inadequate Size, Skills, and Experience of Project Management Team

The senior project management positions were staffed with individuals who had the requisite engineering, construction and project management skills for the project, however it was the next level where the personnel lacked the commercial, construction, and project management skills to deal with the day-to-day challenges they had to face. In many cases these managers, or package leads, were rarely located at or near the physical construction. The individual at the work face had limited authority and had to refer questions back to the package leads. It was also rare to find a manager who had a working knowledge of the contracts he or she was assigned to manage.

In addition, there was a serious lack of project controls, schedule and cost engineers to support each functional entity. There was also a lack of recognition of the role these individuals play in the management of any project, and certainly a megaproject. Schedule review meetings with the contractors were rare.

Item #2- Underperforming Contractor or Key Subcontractor

The most significant impact has been the failure to perform on the part of three prime contractors. The options to deal with these problems were limited. With two of the prime contractors their deficiencies were addressed early and actions taken to mitigate the impacts. The

[11] Cantarelli, C. & Flyvbjerg, B., "Megaprojects' Cost Performance and Lock-In: Problems and Solutions," Hugo Priemus and Bert van Wee, eds., International Handbook on Megaprojects, 2013.

contractors were both welling to work with the owner to address their deficiencies which they did. The overall evaluation of the situation was that with the contractor's cooperation, help was preferable to termination.

The problems with the third prime contractor continue. Fortunately, the work is being completed and due to float in the project schedule the schedule impacts are minimal. Changes to the work have been approved, but the contractor is currently assuming its cost overruns.

Item # 4 Unavailability of Qualified Craft Workers

Adequate skilled craft labor has been a continuing problem, and labor productivity has rarely exceeded 65% across the board. Part of the poor productivity is due to the project location and climate, but an equal share rests with the prime contractors' failure to plan and direct the work. Productivity studies on the project have identified the leading causes for the poor productivity. The two leading causes are excessive travel time for craft from the work face to their break areas, excessive break times, and early departures from the work fronts. The corrections to these behavioral problems should be relatively straight forward. However, the prime contractors appear to lack the will to address these practices. The contractors' deficiencies are compound by a lack of cooperation from the craft foremen and general foremen to discipline their crews

The leadership on the project management team is skilled. Many of the key positions have had experience on other megaprojects, however the lack of functional procedures has diminished the benefits of that experience. Another problem is that the owner's organization is new and formed solely for this project, thus these individuals have not worked together previously resulting in a loss of valuable time to develop a cohesive team.

Item # 5 - Logistical Challenges

The project location experienced severe winter conditions that eliminated effective construction from December through March. There was no rail service, limited air service, road transportation that was long, and in the spring thaw loads were restricted. Ocean barge and ship service was available but again excluded during the winter months. In spite of these conditions, material and equipment deliveries were not delayed.

Labor was on a work rotation and was typically able to fly in and out on either charter or commercial flights. Weather could delay arrivals and departures, although this was more of an inconvenience than a severe impact to the project. The onsite camp and local facilities provided adequate accommodations for craft and management personnel. As harsh as conditions were, the work force was well acquainted with these conditions.

Item # 12 - Inadequate Integrated Schedule

The single greatest weakness has been in project controls. The project has lacked, from the beginning, sufficient qualified planners to evaluate and approve baseline schedules, schedule updates and monitor the contractor performance. There has been little effort to enforce project scheduling requirements. As a result, baseline schedules were submitted late, and in almost every instance well short of project or industry standards. It took a year to receive an acceptable baseline schedule from one prime contractor, at which time their work was over a year late. It took another three months to get the contractor to accurately update the schedule to provide a realistic date for completion of key milestones. It took up to two years in that instance to convince the owner's project manager of the need to consider the schedule in evaluating to solutions to problems as they arose and to compel the contractor to address their schedule deficiencies. While the project has not regained all the time lost, it will start operation only a year later than the original seven-year plan. Some of that time is excusable.

The change management process on the project is well defined, and proactively manages changes, as well as administering the change order process. Changes are typically identified early and their need proven before the contractor is issued a change request, and/or authorized to proceed. Likewise, the management of project costs and the forecast cost to complete are well defined and controlled.

Invoicing and payment procedures are also well defined. Payments are typically made within thirty days of receipt of an approved invoice which first goes through a certification process to approve the work performed and accepted and the amounts to be invoiced are accurate. This certification process is not dissimilar to the "pencil mark-up" most of us have experienced during our careers. No invoice could be paid unless there were available funds allocated to that contract or purchase order to pay the amount due.

Having identified the critical impact factors on megaprojects the following case study allows for an examination of how some of these factors impacted an actual project and the mitigations strategies adopted to successfully minimized the impacts to this project. This project was in all aspects a success, in terms of cost, schedule, quality, safety and owner satisfaction.

CASE STUDY: THE SAUDI ARABIAN PETROCHEMICAL PROJECT

The project was constructed for the Saudi Petrochemical Company ("SADAF"), a joint venture of Saudi Basic Industries Corporation ("SABIC") and a division of the Shell Oil Company. SADAF awarded the project to Fluor Technical Services (Flour") in 1977, at an estimated cost of US$2.3 Billion. Preliminary development and planning for the project began in 1977 however in 1978 the project was put on hold. SADAF did not fully release the project for engineering and construction until July 1980. By April 1, 1985 all processing plants were on line two to seven months ahead of schedule. The most significant feature of the project was the adoption of modular construction to fabricate each of the process plants. Modularization accounted for almost 40 percent of the total project work on what was then, and may still be today, the largest modular construction project in the world.

Fluor originally planned and estimated the project based on conventional ("stick built") construction methods, but shortly after award Fluor made the decision to consider the advantages modular construction. Five factors influenced this decision:

1. Fluor had previously studied the application of modular construction on Middle East projects. These studies demonstrated the potential benefits in cost, schedule and reduction in jobsite manpower that could be realized.
2. Labor Resources: Due to other ongoing projects in Saudi Arabia it was likely that a sufficiently large, qualified labor force might not be available for this project.
3. Several shipyards made presentations to Fluor and the owner touting the benefits of their shipyards for modular construction. Perhaps even more significant was the reduced demand on the shipyards, and as a result they were looking for alternative markets to fill their capacity.
4. The site location of Al-Jubail was well suited for modular construction.
5. The Saudi Arabian Government and SABIC supported the modular concept, and were willing to provide the unloading facilities, roads and other infrastructure developments required to support the movement of modules from ships to the jobsite.

In August of 1980, a request for proposal for module fabrication was issued; two contracts were awarded in July of 1981; the construction kick offs meetings were held in September 1981, and the contracts signed in November 1981.

Fabrication began in January 1982 and the first voyage departed Japan for Saudi Arabia in August 1982. Over a two-and-a-half-year period, 219 modules were designed in the United States, constructed in two shipyards in Japan, transported on 30 ocean shipments over 6,000 miles to Saudi Arabia, off loaded, transported inland to the Industrial City of Al-Jubail, and set on foundations within millimeters of their intended location. In December 1983, the utility plant was completed and in April 1984 the Ethylene Plant was completed. One year later, on April 1, 1985, all six process plants were in production.

This nearly Herculean effort was accomplished safely, without incident or damage to the modules, within budget, and ahead of schedule. As a direct result of modularization, the project realized significant cost and schedule savings well in excess of expectations.

This success was built on a foundation of detailed planning and thorough execution, and was even more remarkable because it was achieved in spite of significant cultural differences, language barriers, and geographical hurdles. These challenges were met and conquered, and the lessons learned are as applicable today as they were then.

The module yard ("Mod yard") story is as much about the men and women who built this project as the pipe and steel they designed, fabricated and erected. Faced with uncommon challenges, they rose to meet those challenges through commitment, teamwork, patience, and communication. Their efforts were a true testimony to Ronald Regan's famous quotation, "There is no limit to the amount of good you can do if you don't care who gets the credit."

Although there are many aspects of the mod yard story that could be discussed, this case study will only focus on two major features; planning and execution. Planning will address the evaluation of the modularization concept and the modularization plan. Project execution will look at the challenges facing the project team, how those challenges were met and ultimately turned into opportunities for success.

The extent of modularization included the Ethylene, EB/Styrene, Crude Industrial Ethanol ("CIE"), utilities, offsite plant, and Chlorine-Ethylene Dichloride plants. The 219 modules fabricated had a combined weight of over 78,000 metric tons ("MT"). More than 4.6 million man-hours were expended in the mod yards and involved over 50 subcontractors.

With the jobsite in Al-Jubail, Saudi Arabia, the engineering design offices in Massachusetts and California, the project management team in Irvine, California and the mod yards in Japan, the project was truly global.

Planning can never be overestimated on any project and this project was no exception. Effective, detailed planning was crucial to the ultimate ability to schedule the work, monitor progress, and maintain the shipping schedule. While extensive planning was a prerequisite to commencing the work, it was also a constant feature of the project.

Modularization Evaluation and Study

The first step in the planning effort was the evaluation of modularization. The modular evaluation posed the following questions:

- Was it feasible?
- What portions of the project could be modularized?
- Where could the modularization work be done?
- How would the modules be transported to site?
- How would the modules be off loaded and set in place?
- What completion work would be required at the Jobsite?

The end result of this evaluation was the decision to maximize modularization. While the typical benefit of modular construction is a savings in project costs, that is not always the primary consideration, nor should it be. Reduction in the duration of the project schedule and earlier on stream production dates were also considerations. In addition, improved quality, reduced infrastructure impact, and a reduction in project risk were critical factors in the evaluation.

Once the decision was made to explore modular construction, the modularization study set about to identify the principal concerns, benefits, and any drawbacks it imposed:

- Fluor and the process design contractors jointly evaluated the design differences in plant design between modular and conventional construction and the impacts they had on operation, safety, maintenance, and constructability. The design evaluation concluded that modular construction would have minimal impact on any of these factors.
- Total manpower requirements were thoroughly evaluated. This was based in part on updated project cost estimates and better definition of the project scope. These studies confirmed that significant savings in total manpower, and sharp reductions in peak manpower could be achieved. This would significantly reduce the infrastructure requirements at the Jobsite to support a larger labor force.

- Constructability reviews indicated the potential for early plant completion and improvements in on stream production dates.
- A review of existing drawings, data, and site surveys confirmed that the site was suitable for modular construction and would pose no impediments to large scale modularization.
- Site visits to shipyards in Japan, Europe and the United States confirmed capacities and capabilities for large scale module construction were readily available.
- All this was good news, but if the modules could not be successfully transported to the jobsite, and set with the degree of accuracy required, the overall modular alternative would be for naught.
- Detailed studies of modular transportation including ocean transport, loading and off-loading, transportation to the jobsite, and final placement was performed. From this study an overall module transportation plan was developed.

The modularization study concluded that the advantages of modular construction over "stick built" construction would result in shifting up to 50% of the total field man hours out of Saudi Arabia; a reduction in project costs of up to 10%; and, a reduction in project duration.

An important decision reached in the modularization study dealt with the module setting method and the preference to use a single butt weld between modules vs. the use of "pup" pieces. This decision would impact not only design and quality control, but the selection of the module transportation and setting methodologies.

Module Transportation

Module transportation was a critical factor influencing not only the decision to proceed with modularization, but also the extent to which the project would be modularized. The modular transportation plan considered all the transportation and handling conditions; module land transportation; module ocean transportation; module setting; and, haul roads, dockage and storage areas.

Several options for land transportation were considered, ultimately the most suitable was deemed to be a self-propelled unit, either crawler or rubber tired. After the preferred transporter system was selected, bids were solicited for haulage at the jobsite and the Mod yards.

Consistent with their prior evaluation of multiple options for land transportation, Fluor considered several configurations for ocean transportation including; tug and barge; self-propelled barges; and heavily lift or Ro-Ro type ships. Each of the bidders was required to develop stowage plans, a transit plan stating the number of ships/barges required, the number of voyages and a cost proposal on a voyage or time charter basis. The proposals were giving a weighted evaluation which considered cost; acceleration forces of the vessel or barges to be used; safety; and, capacity to carry other cargo to the jobsite. Larger ships offered greater safety and stability over barge and tug operations in part due to their speed, maneuverability and lack of the need for a tow line. In addition, Ro-Ro vessels offered improved loading characteristics that improved turnaround time.

The final link in the transportation of the modules from mod yard to jobsite was the modular jacking system for setting and positioning the modules into their final location. While large capacity jacking systems were available, the module setting criteria required that the jack not only have an electro-mechanical system for the raising and lowering of the modules but also a hydraulic system for horizontal positioning. As the jacks were a prototype design, testing of the jacks under load conditions and preparation of the operational procedures had to be developed prior to acceptance and shipment of the jacks to the jobsite. Early planning anticipated that setting the modules could take up to two days after arrival at the jobsite. In practice, the use of the jacks became almost a routine operation, and modules were typically set within hours after their arrival at the Jobsite.

Initial surveys of the commercial port facilities at Al-Jubail indicated they could not accommodate the unique rail extension system on the Dock Express vessels. Of equal concern was the condition of the haul route from the commercial port to the jobsite. The condition of this route was deemed to pose unacceptable risks to the modular transportation. As a result, new offloading facilities nearer the jobsite and a new haul road were constructed. These included the required vertical and horizontal clearances required for the largest modules.

Module Fabrication Yards

Following initial surveys conducted early in the project planning period, proposals for module fabrication were solicited on a worldwide basis. One option available to the bidders was to construct all the modules in a single yard. All but one of the bidders declined to bid on the total package due to the large number of modules involved, the total tonnage of material, and the estimated manpower requirements.

The mod yard bid documents were subjected to the same detailed planning as the work which they encompassed. The project schedule necessitated that the mod yard contracts be awarded early in the design stage, in fact the contracts included a statement that "…design was less than 5% complete at the time of award." Accordingly, the pricing structure of the contracts reflected this condition using three separate pricing structures:

1. A lump sum amount covered the rental cost of the shipyard, staff, and equipment for the contract period of two and a half years;
2. Unit prices to price the value of each module based on Issued for Construction ("IFC") drawings; and,
3. Unit rates were provided to price the cost of changed work, and other work where measurement was done on units of input versus units of output.

The contracts included provisions for adjustments to the unit prices, for variations in estimated quantities, and piping complexity factors. Because of the level of design at the time of award, over 50% of all unit prices in the Contracts were changed or new unit prices were added. In addition, to the unit price changes, rework was a serious risk to both cost and schedule. Prior to the start of erection, Fluor and the contractors developed rework procedures including pricing models. To better understand the scale of the rework issue, at the IHI Mod yard alone there were over 2,600 items of rework.

Despite this volume of change the Mod yard work was completed on time and without any disputes or claims, a testimony to the successful management processes implemented on the Project.

Integrated Construction Plan

The second step, and fundamental to the entire program, was the preparation of an overall integrated construction plan to coordinate the delivery of the modules with the non-modular construction work. The primary factors considered in the development of the plan were setting sequence, module design criteria, Mod yard capacity, engineering, and procurement.

Module Setting Order

The initial consideration in determining the project's critical path was the module setting order. The process to determine this sequence was a study in "reverse order scheduling." Ideally, the modules would be shipped in the sequence and placed on the ship in accordance with the setting sequence requirements. These requirements were dictated by site access, restrictions imposed by non-modular construction activities, and engineering and procurement constraints on long lead items.

Based on the proposed setting order, engineering and procurement constraints for long lead items, and factored durations for module fabrication, a detailed project schedule was prepared. Generally, the planned duration for equipment modules was assumed to be 10 or 11 months from receipt of IFC drawings to complete fabrication, assembly and testing. The duration for pipe way modules was 8 months. The required dates for each module were identified on a master reference sheet which literally became the project's "holy grail." The plan focused all project activities on meeting the shipping dates for each of the 30 voyages. So, in reality, 30 mini-projects were being managed. There was very little flexibility to the plan and it required the total commitment of all parties. Slippage was a luxury none could afford.

The plan was flexible enough to tolerate some adjustments. Due to the constraints of ship space, stability, and sea force criteria, it was necessary to ship some modules out of sequence. This necessitated creation of a storage area at the jobsite. Temporary storage introduced new considerations such as access roads, and temporary foundations to support the modules.

Module Design Criteria

Modular transportation and setting plans were far reaching. Critical to both considerations was the module design criteria itself. First was the development of a uniform set of principles and criteria for modularizing the design of the process plants. The following is a sampling of the guidance provided:

- Modular transportation and handling capacities limited the modular weight and dimensions.
- Module layout and design had to consider centers of gravity and eccentric loading to insure the transporters, cranes and/or jacks were not overloaded.
- Modules were design to withstand all conditions of handling, wind loads and acceleration forces caused by the ships motion in all sea conditions. To satisfy this condition, the acceleration curves were developed to govern the design and had to be verified by an independent naval architect. Det Norske Veritas ("DNV") of Norway was selected to perform this review.
- The ship stowage plans considered the estimated weight and center of gravity of the module and fixed the orientation based on those factors. Structural framing and equipment was designed for the calculated forces for the modules orientation on the ship. The module design assumed the worst case conditions if the stowage plans were not known at the time design commenced.
- Design guidelines addressed piping systems fully contained within the module envelope and interconnecting systems. Self-contained systems were to be completed to the maximum extent possible including all in line components, insulation, coatings and testing.

- Extreme accuracy was required for piping installation to permit a single weld for piping connections between modules. To meet this condition, pipe terminations had to be erected to within three (3) mm in all three axes.

The design criteria were important to project, but a new and increasingly important aspect of the design was the impact of design changes. Changes in modular weight had to be carefully monitored during design and construction as changes could impact stowage plans, ship stability, and draft limitations. Module weight was carefully monitored during construction, and upon completion the module weight and center of gravity were physically confirmed.

Mod Yard Capacity

The IHI and NKK's fabrication capacities dictated which plants to build in which shipyard, which also had a direct impact on the duration of fabrication. While the initial idea had been to build all the modules at one facility, following a detailed risk assessment, the decision was confirmed to build in two yards.

One of the significant features of IHI's Chita shipyard was the two 450MT Goliath Gantry cranes. These cranes were in constant use during the mod yard project and led to some ingenious construction methods. These cranes facilitated IHI's block construction method which was, in effect, to modularize the modules. IHI partially assembled pieces of equipment modules which were then brought together at another location for final assembly. Block construction was highly productive on the large complex equipment modules with respect to material control and handling, reduction in scaffolding, coating, insulation and fireproofing, small tool utilization, quality, and safety.

Project Execution

Once the modular plan was developed, effective control of the plan was necessary to insure proper execution. Typical with almost every project, execution was the most visible point of conflict, literally and figuratively, between East and West. While each project has its own set of unique conditions and challenges, this project introduced some unique conditions not often seen on more typical projects:

- The cultural differences, not just between Americans, Japanese and Saudi Arabians, but also the corporate cultures of the different prime players.
- Language differences, Fluor's mod yard staff spoke very little Japanese, while the Japanese, spoke excellent, but technically limited English.
- Project geography was an ever present challenge in terms of logistics and timing; timing, not only in transit times, but also the different time zones and the ability to communicate.
- The decision to modularize the plant.
- Recognizing that effective communication was essential to success, several important rules of communication were laid down early on. While these rules may have seemed onerous initially, they shortly became a routine part of the everyday discourse, and any oversight was immediately corrected by any member of the project team.
- Mutual respect was imperative. While Fluor was the managing contractor, they were also "guests" in Japan. The Mod yard staff lived with the working community, developing relationships. Relationships with contractor personnel were encouraged. These included golf outings, league softball, weddings, and other social events. In the nearly three years there were only two incidents that would mar an otherwise exemplary period of social citizenship.
- Project correspondence was limited to a single subject; if the subject of a letter was deemed to be sensitive, a draft of the letter was prepared and reviewed with the contractor.
- Confirmation was immediately sought for any direction or instruction. It was important that directions and instructions were clearly and accurately conveyed and equally understood.

- Fluor never said "No" to the Contractor without qualification, thus, leaving the door open for submission of additional supporting documentation. In all instances this worked well since the contractor knew when they needed to substantiate their position or drop the matter.
- Words are powerful and they have different meanings for various people. An offense can come about even when the genus of the word or phrase is not intentionally prejudicial. As a check to insure correspondence would not cause offense the construction and contract managers in each mod yard were the only two individuals who could sign correspondence to the contractor, and they both signed each letter.
- Every action had an agreed upon action date. Failure to fulfill an action on the agreed date was not an option.
- Sharing of a common goal. Attention was focused on 100% completion of each module, load out and shipment. This goal was shared equally with the mod yard contractors. With the project goals clearly defined, mutual success was a necessity, and everyone worked together to ensure that they were each successful.

A fundamental rule of project management states that "anticipation and prevention are keys to overcoming problems." Before the first design drawings were issued, the project staff took a proactive approach to managing the mod yard work. Fluor management knew change was inevitable, that materials would be late, and delays would occur. Fluor also understood that the changes that could be encountered on this Project would be a challenge to the Japanese shipyards that typically dealt with 100% complete designs. Therefore, a series of working meetings were conducted at the mod yards and in Irvine between the project staff and the mod yard Contractors to develop project procedures for all facets of the work. These procedures were not window dressing, but working documents that would define the means and methods of project tasks such as; scheduling, modular pricing, invoicing, progress reporting, quality assurance, shop drawing submittals, reviews and approvals, and changes.

In many ways, the challenges the project team faced were the catalysts for the success ultimately achieved. The challenges demanded the best, and if success is a measure of doing one's best, working together the teams all did "our best."

Location

The project geography offered both advantages and disadvantages. The mod yards were 8,000 miles from Irvine, California, with an 11-hour time differential; plus, a day and 6,000 miles from the jobsite with a 9-hour time differential. While this prevented real time communication, problems could be transmitted via telex at the end of the work day at the mod yard, and the next morning an answer would be available.

Often decisions had to be reached with little or no time to reach out for consultation with others. Out of necessity, clear delegations of authority had been made to the mod yard staff. In consultation with SADAF's resident manager, the mod yard managers were authorized to take appropriate action on most matters; provided that, the action was consistent with the requirements of the module data sheet and project plan.

To address design questions, each of the process design engineers provided an engineer at each mod yard who was empowered to respond to design questions and when required would obtain the answer from their design office in the United States.

Shipping and transit time were a constant concern and sea conditions could have an impact on either an outgoing or return voyage. The average voyage between Japan and the jobsite was planned for 21 days; however, the average ended up slightly more than 23 days. The shipping schedule was extremely tight and the time lost on the transit side could only be recovered through improvements to the load out and off-loading durations. In the end, the final shipment left Japan on July 2, 1984, only five days later than had been planned nearly three years earlier.

The project design was pre-CAD and there was no ability to transfer drawings electronically as is done today. The distances between the mod yards and the design offices increased the turnaround time for shop drawing submittals and receipt of design revisions. The turnaround times were factored into the original schedules; however, the wait could be frustrating. Once Fluor and the design contractors had achieved a level of confidence in the quality of the mod yard contractors' shop drawings, approvals were transmitted by telex, with the marked up drawing to follow. This approach was not without its risks, but the mod yard contractors' accepted their responsibilities to build the modules to the tolerances required, and they did.

When a situation arose at the jobsite that could not be resolved from a distance, Fluor and the process contractors dispatched "flying squads" of subject matter experts to the mod yards to work through a problem.

Schedule Management

The initial consideration in developing the project master schedule was the modular setting order. The process used to determine this sequence was a study in "reverse order scheduling." Once that order was set, the focus of schedule management was on the shipping date and those dates were sacrosanct. As previously stated, the project was, in reality, thirty mini-projects, each with its own completion date, requirements for completion, inspection, documentation, and acceptance of the work.

The initial planning was reviewed with each of the mod yards against their known capacities and rates of production. Following this initial review, a detailed project schedule was developed to integrate the required dates for engineering, material take offs, procurement, equipment deliveries, fabrication, assembly, testing, load out, transit durations, offloading, and setting.

The mod yard contracts called for two levels of schedules: an A Level and a B level schedule. Both were manually drafted Gantt Charts. The project used Apple IIe computers to manage a great many aspects of the project. Primavera was still a few years off, and they did not have access to mainframe CPM scheduling programs. The A Level schedule was a Summary Level schedule for all modules in each mod yard summarized by process plant with each voyage as its major milestones. The B Level schedule was an individual schedule for each module showing the start and completion for each construction activity.

The Japanese took pride in achieving high levels of productivity. It was more than just pride; it was clearly recognized as key to their profitability. Their emphasis on productivity was evident in the main fabrication building where production figures for each crew were displayed on a large display board for all to see. This status board motivated competition amongst the crews to improve. Productivity was not just production for production's sake, quality and safety were equally important; the job had to be done right the first time, injuries and rework to correct errors were lost time and lost production.

A second measure of progress and forecast of potential shortfalls was accomplished by monitoring manpower and labor hours. Resources requirements based on the mod yard's historical production rates were developed for each activity for each module and rolled up and totaled for each month for each mod yard. If actual manpower levels fell below forecast, it was an early indication of potential progress shortfalls. When indicated, resources would be added or overtime scheduled to regain schedule.

Typically, the schedule engineers measured progress in each account each month for each module for each plant. When a work unit was completed, it was counted for progress. Each work unit was weighted, each account was weighted, each module was weighted, and finally each plant was weighted. Consequently, measurement of units of work completed during a progress payment period could be translated directly to progress in an account on a module as well as by account for each plant and the total project.

Shipping Schedules

The focus was on the shipping schedule since the arrival of the Dock Express ship was a significant milestone. Each mod yard scheduled module completion for at least one week prior to the planned shipping date.

Load out planning by the mod yard and contractor staffs and between the two mod yards was almost continuous. As a result of this continual planning, the shipping schedule was able to be modified several times to reduce transportation costs, improve mod yard schedules, and facilitate reception in Saudi Arabia.

The owner's general manager monitored key decisions effecting the shipping plans and schedule and implemented only upon agreement amongst the parties regarding the cost impacts of each such change.

Weekly Progress Meeting

The weekly progress review with the mod yard contractor was critical to management in the mod yards. The weekly meetings were attended by each department of the mod yard and the contractor's staff. A standard agenda for these meetings was developed early on and followed throughout the duration of the mod yard Contracts. Minutes of the meetings were carefully recorded. Meeting discipline was rigidly enforced and each person attending was responsible to be prepared to discuss his or her action items. During the meeting, the status of each module was reviewed:

- Piping and structural units fabricated and installed were reported;
- Productivity reviewed and resource allocation versus plan was discussed;
- Material requirements and engineering status were thoroughly reviewed; and
- Changes, costs and quality issues were reported at the weekly meetings.

These meetings served as a vehicle for exposing issues and identifying a need for closer coordination. When required, special meetings were called to resolve specific issues. The weekly meetings proved to be an excellent vehicle to approach potential problem solving, since concerns could be identified, discussed, and satisfied. Because of the focus on communication, these meetings were one more way in which a rapport was developed among the mod yard staff, contractor and Owner.

Monthly and Quarter Progress Review

Monthly Progress meetings were held in each mod yard, to review contract and work status, and quarterly these were held at the mod yard contractors' Tokyo corporate offices. The monthly and quarterly production meetings were carefully rehearsed with visual aids and reports thoroughly reviewed. These meetings were designed not to identify problems, but to demonstrate management attention to identified issues, and solutions to insure cost, schedule, and quality goals were achieved.

The quarterly meetings involved participants from the United States, Saudi Arabia, the mod yards, and the contractors' corporate executives. The quarterly meetings in Tokyo were not without some cost due to the number of attendees; however, they were vitally important to the overall communications process of the project. A key to success on the project was communication. To deal with the cultural and language differences "informal" communications played a major role in developing relationships and trust.

Engineering Management

Engineering management focused on two major aspects of engineering; first the required drawing dates for each module; and second, with the necessity to meet a fixed shipping date, an emphasis was placed on minimizing drawing revisions. Recognizing that revisions are inevitable, processes were put in place to "manage change." Several steps were taken to manage these revisions:

- The process contractors were required to notify Fluor's mod yard staff of any design revisions that were required two months or more after the required IFC dates. These design changes were then reviewed with the mod yard contractor, and work plans modified accordingly.
- Changes three months or less before a module shipping date were reviewed with the mod yard contractor prior to being issued and a determination was made whether it could be done in the mod yard or designated as field work and accomplished at the jobsite after the modules were delivered. More often than not, the mod yard contractors undertook to perform these changes.
- An engineering team from each of the mod yard contractors met with their design counterparts in the United States to review design philosophies and methods, which

most importantly developed a relationship between the parties, and an understanding of what conditions were driving changes. The understanding of the conditions driving changes permitted the mod yards to implement better procedures to control and implement changes and track and report the effects of the change.

The interface between the process engineers and the mod yard contractors was initiated from the mod yards. It became clear early in the program that the process plant engineers needed to have a better understanding of how the mod yard contractors approached and performed their work. This was also true for the mod yard contractors.

The preparation of an interface summary was another tool that was unique to modular construction. These were prepared for each module and listed design/construction conditions unique to the module, such as special scheduling or shipping requirements for material or equipment, and erection conditions that required a special planning sequence. These interface summaries allowed the jobsite and the mod yards to better plan and sequence their work.

The mod yard contractors were also required to prepare module completion documentation ten days prior to the completion of each module. These packages included as-built drawings material lists, testing results, and the like. These completion packages were sent to the Jobsite so they could plan their work.

Material Management

The mod yard contractors were responsible for purchasing structural, piping, and electrical and instrumentation bulk materials, while Fluor was responsible for all equipment, valves, and tagged instruments. Material coordination in the mod yards was a necessity to insure timely delivery of Fluor provided equipment and material. Material management allowed for two added benefits that were not foreseen in the original planning. The project teams were able to use spare capacity of each of the 30 voyages to ship material and equipment sourced in Japan to the jobsite in Saudi Arabia thus saving on the commercial shipping costs, but also facilitating importation and customs clearance into Saudi Arabia. As surplus material was accumulated at the mod yards, jobsite requirements were queried and when required, surplus material was shipped to the site. At the completion of the mod yard work, all surplus material had been identified, and either shipped to the jobsite or sold.

Change Management

Management of changed work was perhaps one of the most significant management accomplishments at the mod yards. As noted earlier, when the mod yard contracts were awarded, design was in an early stage of completion, in fact the bid documents and contracts advised the contractors that design would be less than 5% complete at the time of contract signing. Design revisions were inevitable and there were a substantial number of revisions issued.

The procedure for managing engineering design revisions was just the first in a series of procedures for dealing with changes the mod yard would develop. Agreements for procedures related to quantity measurement for unit price work and invoicing for unit price work were reached with the mod yard contractors prior to the construction kick-off meetings, and were consistent between both mod yards. The mod yards recognized that changes would also result from Requests for Information ("RFIs"); rework resulting from interferences and conflicts in design; and, the need to monitor work priced under the cost reimbursable provisions of their contracts. These procedures were developed independently with each mod yard contractor.

Rework was seen as having several unique factors that transcended the typical pricing concerns. Rework could generate scrap or reusable material which could impact unit pricing for which strict accountability was required. Rework also had quality concerns related to material identification and dimensional tolerances if the rework was associated with interconnecting piping. Each of the mod yard contractors was required to draft a rework procedure which was then reviewed and approved. Rework procedures proved to be very dynamic and with mutual concurrence were constantly being refined, updated, and improved. There were a number of guidelines developed for rework that were common for both mod yards:

At the outset, the rework procedures generated considerable paperwork and required substantial staff resources. Initially weekly meetings were held to review rework items and agree on entitlement and cost. Over the life of the job, process simplification and contractor and mod yard staff "education" resulted in a smooth process that reduced paper and minimized the resources required, such that routine changes were routinely resolved with face to face meetings required for only the very complex or contentious issues. By May 1984 when all rework at IHI had been identified, over 2,600 rework changes had been identified and resolved.

The ratio of the cost of extra work performed to unit price work at IHI was less than three percent (3%), a reflection of the considerable care exercised by the mod yard staff in controlling field changes and the willing cooperation of the contractor. The procedures developed to control rework resulted in a high level of confidence between the parties. More importantly the resulting documentation of each action served to prevent claims from arising from one of the more traditional sources --field changed work. The total cost of changed work was well within expected and acceptable ranges

Cost reimbursable work introduced some unique challenges for all parties. This work included all pressure testing and non-destructive testing of piping, electrical and instrumentation; bracing and special protection of piping, electrical and mechanical equipment for shipping; receiving, handling storage and preparation for shipment all owner furnished materials ("OFM"); stress relieving; assembly of air cooled heat exchangers, fired heaters and furnaces; and engineering costs.

The Japanese construction industry was not generally familiar with cost reimbursable contracting methods. For example, Japanese companies then did not use invoices from vendors with whom they have enjoyed a continuing association. Thus, the paid invoice, as normally used in the United States to validate payment, was not available. As a substitute, the contractor's material delivery slip reflection receipt and direction to make payment was used in lieu of the invoice. Knowledge gained by the contractors regarding cost reimbursable commercial terms and by the mod yard staffs in understanding Japanese industrial practices greatly facilitated the provision of suitable documentation to validate cost reimbursable work. The contractors responded promptly to all requests for documentation and audits of their systems demonstrated their accuracy and efficiency.

Finally, a word about claims: there were none! Claims prevention planning was part and parcel of the module planning and integrated planning at the start of the project. Most of the obvious sources of potential claims were identified and practices put in place to identify and resolve issues early. The following is a sample of some of the conditions considered in this planning process:

- Late issue of IFC drawings or late revisions would impact cost and schedule;
- The module shipping schedule did not permit approving additional time to the contractors. Transferring work to be completed at the jobsite would defeat the benefits of modularization. Consequently, schedules were maintained or compressed, sometimes at cost;
- Rework was required during fabrication and assembly to accommodate late revisions, changes and misfits resulting from design errors;
- Owner Furnished Material (OFM)was required on a specified timetable, which was not always met despite extraordinary efforts to expedite engineering and procurement;
- Unit prices would change substantially and estimated unit price earnings changed also. The contracts provided formulas for variations in estimated quantities (“VEQs”) and piping complexity factors (“CF”), however in some instances the variations exceeded the formula limits;
- Issuance of RFIs; and,
- Owner directed changes.

Some of the processes adopted to support claims prevention included setting aside time at each weekly meeting to review current project status and identify any potential claims. Issues that were identified, by either party, were discussed in separate meetings. Procedures were prepared to close out each portion of the Contract as completion of a plant occurred, thus CF and VEQ calculations were addressed promptly and resolved. Progressive close out of each contract, by plant, fostered mutual confidence between the parties.

Claims can be prevented by gaining the contractor's confidence and demonstrating the intent to be reasonable in approaching commercial issues on a timely and equitable basis. The Japanese took responsibility and accountability very seriously. Saving face often was more important than the bottom line. That concept was foreign to Americans; however, the project team came to the point where they understood the value and importance of responsibility, and as a result earned a level of trust and respect which was an important ingredient in negotiating solutions to the more sensitive issues.

Lessons Learned

For thirty-four years John Wooden was the very successful head basketball coach at the University of California, Los Angeles ("UCLA"). His teams won more championships than any other school, including 10 National Collegiate Athletic Association ("NCAA") Championships, of which seven were in a row. Coach Wooden preached the importance of fundamentals and balance, and constantly drilled his players on the fundamentals of the game. Just as the fundamentals of basketball are important to success on the basketball court, the fundamentals of project management are the keys to success on the "construction court."

The success of the Saudi Petrochemical Project was rooted in those fundamentals. The following list is a sample of these lessons learned.

- The project organization, experienced personnel and commitment were key to the Project's success. This covered the full spectrum of the project from the Project Directorate in Irvine, the mod yard staffs, the engineering offices, the jobsite at Jubail, and the mod yard contractors.
- Planning is critical from the beginning to the end of the Project. "Plan your work and work your plan" is the basis of good project management. Schedule time to review the plan on a regular basis and update the plan as required.

- Be proactive and develop processes and procedures to manage issues as soon as they are identified and before they become “project problems”. Be flexible and modify the processes as the work progresses and improvements are indicated.
- Clearly define project goals and requirements for schedule, cost, quality, and safety. Identify and quantify production, resources, and cost; report and manage each one.
- Manage change, don’t just administer the change order process.
- Timeliness in making decisions is an essential factor in preventing conflict from escalating into disputes. Resolve the issue before it becomes a problem.
- Construction is a communications process, so make sure all parties clearly understand the topic being discussed. Don’t assume anything. Remember communication includes listening. Everything should be in writing and transmitted in a timely manner. Correspondence should be focused and limited to a single subject. Be careful what you say and how you say it. You want the other party to read and understand what is being said without taking offense. Don’t say “no” without qualification.
- Encourage teamwork and build the team; take the time to build relationships of trust and respect.
- The one single factor that ensured the success of the Project was the planning which was embodied in the original Module Plan. Five key structural elements either expressed or implied in that plan were crucial to that success:
    1. Leadership: Leadership is always critical to the success of any project, and not only leadership at the top, but at all levels. In addition, it is imperative that the leadership is coordinated and committed. Commitment, not mere acceptance, is a prerequisite for success. One cannot say too much about the leadership and commitment of the men and women on the Saudi Petrochemical Project, the process engineers, Fluor’s project management, the mod yard staff, and mod yard contractors’ personnel.
    2. Clear definition of goals: The focus of the module contractors and the mod yard staff was to ship 100% completed modules on the scheduled shipping date.

Design, procurement, fabrication, and testing were planned and scheduled to achieve this goal. No decision was made without considering shipping dates, so when a problem arose, the first question asked was how this might impact the shipping date.

3. Sustain the plan: The plan and project schedule established a pace that required the mod yard staff to be proactive instead of reactive in determining the course of events. The advantages of proactive management should be self-evident, but are too often ignored. A reactive posture over time decreases options, increases costs, lowers morale, and reduces the probability of achieving success.
4. Flexibility: While the schedule imposed rigidity in time, the plan encouraged flexibility in development and implementation of actions that would enhance the plan and insure success. The policies and procedures that flowed from the plan and evolved over time were a testimony to the flexibility and capability of the mod yard staff and the contractors.
5. Focus: Despite the geographic impediments, the project was able to concentrate resources where and when needed to support the plan. At the owner's insistence, the mod yard staffs were limited in size. There was a clear delegation of authority down to each level of responsibility, and that responsibility coupled with accountability encouraged communication, direction, and execution.

CONCLUSION

The critical impact factors and accumulation of a library of lessons learned from completed and active projects can, and should, be used by project teams to identify particular factors that may impact their project and help the project team to manage or mitigate the impacts for each factor in the front end planning and execution phases of their megaproject.

Following are some key mitigation actions projects should consider to mitigate critical impact factors:

- Construction is a communications process from the RFP, through IFC drawings and specifications, RFIs, meetings, change requests, and verbal direction from the foreman to the crafts. Ineffective communication can undermine a project very quickly. Communication needs to be assessed constantly to look for the tone, gaps, and breakdowns to ensure communications are heard and responded to. Communication is not only important internally, but also externally to address public and political objections to the project. This outreach needs to be proactive and address issues as they arise in a proactive manner.
- Build relationships of trust among all stakeholders. Megaprojects tend to last a long time and the relationships you have on such a project may consume a greater portion of one's professional life. These relationships of trust should extend vertically as well as horizontally through all levels of the project.
- The management team needs to be staffed with qualified individuals at all levels with a clear understanding of their roles, responsibilities and authorities. Considering the long duration of megaprojects senior management needs to develop plans to address attrition of personnel. Training and mentoring programs are key to the development of future project managers.
- Effective front end planning is critical to the success of any project and especially megaprojects. The project team needs to clearly define the technical data, business/commercial data, site data, and execution data required prior to commencing with the plan. The project team also needs to be sensitive to optimism bias and develop auditable trails and cold eyes review to ensure the planning is realistic. Front end planning should identify high risk conditions, and methods to address those issues when and if they arise.
- Develop execution plans and contracting strategies that address self-performed work and contracted work. The contract plan should, at a minimum, address contractor pre-qualification, request for proposals, scopes of work, pricing structure, schedule, owner issued material and information. On too many projects contract packages are tendered,

evaluated and awarded late, yet with the expectation that the contractor can still meet the original schedules. Avoid “innovative” commercial contracts that someone believes will save money. They usually don’t, and often there are insufficient personnel to manage these commercial nightmares.

- When required, consider training programs for craft labor. Increasing their skills will improve efficiency, quality, and safety with a positive impact on cost and time. In the same vein be prepared to assist local inexperienced contractors in planning, safety, quality, and execution.

Current forecasts say the annual rate of construction expenditure is expected to rise from US$4 trillion per year in 2014 to over US$9 trillion per year by 2025. Most of this will be spent on megaprojects. Juxtaposed to this looming reality is the fact that presently over 65 percent of megaprojects are experiencing significant cost overrun and delays. On top of this are the demands these projects will make on over-taxed labor resources and qualified project management personnel.

The results could be the deferral of much needed infrastructure work that has already been delayed for too long, cancellation of projects due to the lack of resources, capital, management, craft labor, or engineering, or owners and contractors struggling to find ways to complete projects with massive cost overruns and delays. Clearly, mistakes have been made and more projects have experienced cost overruns and delays than any of us would want, but there is hope as many are completed successfully.

We have before us the lessons learned from past projects combined with research that demonstrates the root causes for the poor project performance that seems to be the rule rather than the exception. These lessons and project research point to ways to improve project delivery. If the suggested corrective actions are implemented, we may be able to avoid a future littered with the casualties of failed projects. Proactive planning is essential for preventing or mitigating these all too likely scenarios, for if we fail to plan we are planning to fail. So are we going to learn from the experience of others, or disregard the lessons learned and struggle on?

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