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

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, Strate 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

[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]

What Have We Learned from

Table 1 – Eleven CII Differentiating Factors

Item	Factor	Item	Factor
1	Logistical Challenges	7	Inadequate Size, Skills,E, Seies

Table 2 – CII Sixteen Impact Factors

Item	Impact Factor
1	Inadequate Size, Skills, and Experience of Project Management Team
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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 a1 (p)2 -Oatjejec

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

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.

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

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.
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> Module layout and design had to consider centers of gravity and eccentric loading to insure the transporters, cranes and/or jacks were not overloaded.
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> 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.
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> 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.
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> 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.

What Have We Learned

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, 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 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 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 ed. ( )-10pi ,-2 (t)-2 (.002 Tc -0r (t)-2 (i)4 (nt)-2 (e)-6 (d))e)4 (.002 Tc -24 (a)-4 ()-16 ((e

What Have We Learned from

most importantly developed a relationship between the parties, and an understanding

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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

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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.

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 cause rth svar1or>n4 (al)-6 (r)3 (t)-2 (6-6 (r8()-1 (hope)4 (./-1 (o)-- (t)-1-)2.9 (r)3.1 6 (rt

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