Analysis and Improvement of Megaprojects Performance

Authored by

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ABSTRACT
Megaprojects are large, complex, and expensive projects that often result in undesired outcomes with enormous cost overruns and time extensions. Megaprojects have been studied in many academic areas such as public planning, urban decision making, and economic analysis areas. They have been analyzed as complex hard to finance projects with economic gain and social impact. Limited research has been done in the construction industry to investigate megaprojects and to improve their performance. This research defines megaprojects in their construction management context. It analyzes their characteristics that cause time and cost overruns. Finally, it attempts to improve megaproject poor performance by presenting a set of work practices that were applied on different megaprojects.

KEYWORDS: megaprojects, size & complexity, performance, integration

I. INTRODUCTION
Megaprojects are unique construction projects known for their complexity, vast size, expensive cost, and long time frame compared to conventional construction projects. The size and complexity are reflected by a price tag that exceeds one billion dollar and by a time frame that may exceed the five year limit. Megaprojects are known for their poor performance in terms of cost and time where the cost overrun could exceed initial project cost and the time extension would extend for years. There are numerous examples of megaprojects that were built and performed poorly. The most famous project is the Channel Tunnel which cost 2.6 billion pounds in 1985 and led to 80% cost overrun (Flyvbjerg et al. 2003). One of the most expensive highway projects in the U.S. is the Boston artery “Big Dig” project, where an elevated highway was replaced with an underground tunnel. The project was estimated in 1985 to cost $2.8 billion but was completed with over $14.6 billion (Reina et al. 2002). In addition, there are different specialized megaprojects such as power plants. Nuclear power plants are the most expensive to build and lead to enormous cost overruns. The cost overruns of nuclear power plants built between years 1966 to 1977 averaged to 200% (Energy Information Administration, 1986). Given their infamous reputation, megaprojects have attracted researchers’ attention from different academic areas. They have been studied from many points of views especially the public planning, urban decision making, economic analysis, and social impact point of views. Unfortunately, limited research has been done in the construction industry to investigate megaproject’s characteristics and poor managerial performance. In addition, no practical means were developed to improve their performance in order to meet time and cost constraints.

This paper progresses in a series of steps that start with clearly defining megaprojects according to size and complexity. It continues by analyzing megaprojects’ characteristics and the corresponding managerial challenges that cause poor project performance. It progresses by presenting a theoretical approach to improve megaproject performance through adequate system integration. Finally, it presents the theory’s corresponding work practices by identifying existing

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work practices that were employed in megaprojects and contributed to the improvement of project performance in terms of cost and time.

II. DEFINITION OF A MEGAPROJECT

Up till now there is no exact definition of a megaproject. Moreover, there is no definite understanding of what differentiates it from any other large or complex project. The only common agreement among practitioners and researchers is the concept of a large scale project with a price tag in excess of one billion dollar (Fiori et al. 2005), that frequently leads to cost overruns (Flyvbjerg et al. 2003). In this paper megaprojects are defined in their construction management context according to project size and project complexity. The first part of this section presents previous definitions provided in the literature. The second part defines project size and complexity for the purpose of defining and differentiating megaprojects. Finally in the third part, a System Diagram is developed to clearly differentiate projects based on their size and complexity, hence clearly defining megaprojects.

A. Literature Definitions of a Megaproject

There are numerous definitions of megaprojects throughout the construction literature. However, the majority of definitions provided place megaprojects not in their construction management context but in a wider public planning and economy context. For instance, megaprojects are defined as significant undertakings characterized by multi-organizations seeking success on different objectives subject to socio–political impacts (Ruuska et al. 2009). Other definitions consider megaprojects as projects that have a strikingly poor performance in terms of economy, environment, and public support. Also, they lead to cost overruns and lower-than-predicted revenues that hinder economic growth instead of advancing it (Flyvbjerg, et al. 2003). The Federal High Way Administration (FAHWA) defines megaprojects as: “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 interests because of substantial direct and indirect impacts on the community, environment, and state budgets”. Megaprojects should be defined in their construction management context that is projects with activities, resources, budgets and deadlines. Capka (2004) defines megaprojects as expensive projects that require the management of numerous, concurrent, and complex activities while maintaining tough schedules and tight budgets. More elaborate definitions describe megaprojects as large scale complex projects that often fail to meet costs estimations, time schedules, and anticipated project outcomes. Other definitions describe megaprojects as projects that contain a large element of technological innovation associated with high risk and characterized by conflict, uncertainty, and poor cooperation between partners (Marrewijk et al. 2008).

Construction management definitions describe the megaprojects broadly. These definitions could apply to any construction project that may lack megaproject’s characteristics. In other words, the definitions do not clearly define megaprojects and differentiate them from other projects.

B. Definition of Size and Complexity

Project size and complexity are defined for the purpose of differentiating projects with varied sizes and dissimilar complexity levels. The size of a system is defined by the number of items found in the system such as activities, work groups, or designs etc. Complexity is harder to explain. There are dozens of complexity concepts, definitions, and models one could obtain from
the management theory resources and construction management literature. The meaning of project complexity is wide and open to many interpretations. In other words, the meaning of complexity is subjective and it is in the eyes of the beholder (Stocks et al. 1985). In this research, complexity is defined according to 2 dimensions; the number of interrelated parts, and the interrelatedness of these parts (Baccarini, 1996).

Every system is defined according to a size and a degree of complexity. Complexity is determined by the number of different elements in the system and the interrelatedness of these elements; size is determined by the quantity of similar items per element. Accordingly, a Project Diagram is developed to define and differentiate projects based on size and complexity dimensions. The complexity dimension is defined by two aspects, differentiation i.e. total number of dissimilar elements (shown in different geometrical shapes) in the system, and interdependence among these elements (shown in the number of arrows).

![Project Diagram](image)

**Figure 1: Size-Complexity Project Diagram**

1. **Project Size**

Project size could be explained by a multitude of aspects. In this paper, the most basic size aspects considered are the constructed area and the time frame needed to build the project. The constructed area and the construction time frame are indications of the quantity of items per element used in the project such as labor, equipment, work groups, and material used.

2. **Project Complexity**

There is a multitude of aspects that could explain complexity. However, the most basic aspects to describe project complexity in the construction management context are the design complexity and managerial complexity.

- **Design Complexity**

Design complexity is determined by design differentiation and design interdependence.

**Design Differentiation:** It is explained by two aspects. The first aspect is the number of different steps taken to achieve the final product. For instance, a civil engineering design of a simple road would be composed of a limited number of steps. Whereas a tunnel design that includes many geotechnical, structural, environmental, and safety elements would be composed of plentiful steps. The second aspect of design differentiation is the number of different engineering specializations included in the design. For instance, designing a complex power plant would
require civil, electrical, and mechanical engineers in contrast to designing a simple road that would require a limited number of specializations.

**Design Interdependence:** It is explained by the interrelatedness of different design elements. The elements could be different design steps that may be highly related or independent. In addition, interdependence could be explained by the relation between different engineering specializations. For instance, electrical and mechanical trades are more interdependent in industrial plants that include motor control centers, than in simple buildings that include simple electrical lighting and simple piping and ventilating systems.

- **Organizational Complexity**

In the construction management context, organizational complexity is illustrated by the managerial and operational complexity. In other words it is the complexity of integrating work crews and coordinating dissimilar engineering trades.

**Organizational Differentiation:** It is explained by the number of different entities to be managed. The entities could be different work groups and different engineering trades. As the project increases in size, more work groups are added contributing to more organizational differentiation. Also, as the project increases in complexity (namely design complexity), more specializations are added contributing to more organizational differentiation.

**Organizational Interdependence:** It is explained by the interrelatedness of different entities’ works. Different projects have different organizational interdependence depending on the nature of the works and the design complexity. Thus, different projects require varied efforts of integration and coordination among work groups. For instance, physically integrated electromechanical works found in electric rooms need more coordination efforts than physically distant electrical and mechanical works.

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**C. Definition of Megaproject Based on Size and Complexity**

Theoretically, a megaproject is not different than any other construction project. It includes numerous parallel activities, limited resources, tight schedules, and multiple decision making parties. Therefore, a megaproject is defined in comparison with other projects according to size and complexity. The Project Diagram is further developed to set a clear differentiation among different categories of projects.

The Diagram’s size axis is composed of the constructed area and time frame. The complexity axis is composed of two aspects. The first aspect is the design complexity that ranges from simple design to complex and difficult design. Simple design corresponds to a limited number of design steps and specializations. Complex and difficult design corresponds to a large number of design steps and design specializations. It also corresponds to a high degree of interdependence among different design steps and among different engineering specializations. The second aspect is the organizational complexity that ranges from simple execution to complex execution. Simple execution corresponds to a small number of work groups with limited interdependence among
them. Complex execution corresponds to numerous groups with substantial interdependence among them. The following project categories could be allocated using the diagram:

- **Small and non-complex projects (Small Projects - SP)**
  Small non-complex projects are described to have a small constructed area and a relatively short construction time frame. They are simple to design and build. They neither require complex designs nor complex managerial organizations to have a successful project performance. Several projects could fit this category such as simple roads, houses, and small residential buildings.

- **Large and non-complex projects (Large Projects - LP)**
  Large-scale projects have a large constructed area and a relatively long construction time frame. They neither require complex designs nor the services of many engineering trades. However, they require a complex organization to integrate numerous work groups and to manage limited as well as plenty resources. Several simple yet large projects could fit this category for instance long roads, highways, bridges, and airport runways.

- **Small and Complex (Complex Projects - CP)**
  Complex projects have a relatively small constructed area as compared to large projects such as highways. The time scale would vary among different projects. They encompass complex designs since numerous specializations are required. They require complex management, integration, and coordination of different engineering trades. Examples of such projects are complex hospitals, hotels, and other specialized projects.

- **Large and Complex (Mega Projects - MP)**
  As their name signifies, large scale complex projects have a large constructed area and a long time frame. They encompass complex and challenging designs since numerous design steps and specializations are required. They require complex management, integration, and coordination of different work groups. Furthermore, they require the integration of different engineering trades within each work group. They require complex resource management given the limited labor resources and enormous material quantities. Examples of such projects are power plants, large industrial plants, airports, and large transportation such as metro-railway tunnels.

![Figure 2: Developed Project Diagram](image)

According to the Project Diagram, megaprojects are defined as large scale projects that have a long time frame and are characterized by a complex difficult design and complex organization. Their size and design complexity necessitate a complex managerial structure in order to manage and integrate different work groups, engineering specializations, and limited resources.
III. MEGAPROJECT PROBLEMS AND THEIR CAUSES

The recent decades have seen numerous well-known infrastructure megaprojects that expanded the engineering limits and brought economic development and progress worldwide. Nevertheless, these projects were accompanied by overwhelming problems. Megaprojects throughout the world have had a calamitous history of cost overruns where the difference between the actual and estimated cost was often fifty to a hundred percent (Flyvbjerg et al. 2003). In the United States, large scale projects have similar problems. According to a study done by the US Department of Transportation that covered ten US rail transit projects, the total capital cost overrun of these projects was sixty one percent (US Department of Transportation, 1990).

Throughout the construction management literature, different case studies and researches have determined several megaproject problems and the causes of these problems. This paper attempts to explain megaproject poor performance by means of size and complexity. The increase in size and complexity impose enormous project management difficulties that the management team is incapable to handle leading to inefficient performance in terms of cost and time.

A. Literature Problems and their Causes

Megaproject’s poor results could be contributed to a variety of reasons. Several different researchers have determined different causes of poor performance. According to Flyvbjerg (2003), the causes of poor performance are:

- Lack of realism in initial cost estimates
- Underestimation of the length and cost of the delays
- Contingencies are too low
- Changes in specifications and designs are not adequately taken into account
- Underestimated changes in currencies exchange rates
- Underestimated geological risk
- Undervalued quantity and price changes
- Underestimated expropriation costs and safety and environmental demands
- High risk as a result of technological innovation that is translated into cost increase

The Construction Industry Institute CII summarizes the general reasons of large scale project problems in the following areas: Front end planning, design, procurement, startup phase, human resources issues, organization structure, project processes, and project control (CII 1987).

Throughout the construction management literature, numerous case studies have been conducted to determine the causes of the poor performance. The causes of poor performance are summed up in the following list:

Planning Phase Causes of Poor Performance:

- Incomplete design especially with innovative designs
- Incomplete execution requirements
- Non-realistic planning in terms of cost and time (compressed schedule and competitive low prices)
- Underestimation of the project’s complexity (optimism in ability to manage such complexity)
Underestimation of the size and material requirements (optimism in ability to supply and manage resources with such size)
Under evaluated risks (low contingencies for technical, operational, and business risks)
Difficult long term planning that doesn’t solve uncertainty issues in the long run
In-efficient governmental procedures and regulations, environmental and other time consuming effects

**Execution Phase Causes of Poor Performance:**
- Variations and mistakes due to inadequate planning, incomplete execution requirements, and ambiguous design documents
- Poor project culture leading to productivity loss
- Parties’ adversarial relationships and disputes
- Inadequate project organization that is insufficient for the size and complexity of the project
- Poor communication and team work
- In-efficient owner decision making structure caused by governmental intervention, paralyzed public/private inadequate partnership operation
- Poor coordination and integration of work crews; inexperienced personnel in critical positions

Several causes of poor performance obtained from the literature review – i.e. underestimation of size and complexity, non-realistic planning, inadequate project organization, inefficient structure, and poor integration – highlight the fact that the conventional management practices are insufficient to handle megaprojects’ characteristics. The following section analyzes how megaproject’s characteristics impose managerial challenges that are difficult to handle leading to poor performance in terms of cost and time.

### B. Megaproject Characteristics & their Management Challenges

In megaprojects, the workforce is composed of numerous work groups that operate in parallel due to the large size and complexity. With a single work entity, the managerial duties are limited to the daily duties such as cost control, time control, progress reporting, communication, correspondence, and workflow direction. The operational level would be consumed with daily workforce activities in order to stick with the project milestones. However, with multiple work entities, the managerial duties would differ substantially. Management has to conduct the daily duties with each of the work groups independently. Furthermore, management has additional duties in order to organize and integrate a complex web of systems over an enormous construction site. It has to manage and integrate work flow, schedule, and resources among all working groups. Consequently, the management team would be overwhelmed by the number of interactions needed to manage all these elements leading to a bottleneck at the management level and an inactivity of work crews at the operation level.

The following is a description of the management difficulties imposed by the characteristics and the corresponding managerial problems

The increase in size would impose:
- An increase in the number of work groups to be managed leading to a multiplication of the daily efforts to follow up with each of the work groups
• Work coordination and managerial efforts to integrate the work flow and schedule of the work groups
• Increased coordination efforts among different work groups
• Labor workforce management among different work groups
• Material and equipment management efforts among different work groups

The increase in complexity namely design complexity would impose:
• Management efforts between subgroups or engineering specializations within each group. The subgroup management efforts would be rigorous since the works should be coordinated and integrated according to time and space constraints
• Technical and functional support which would add to the managerial efforts required to handle a complicated design. The support required is summarized by quality control, quality assurance, means and methods, and design support

The increase in size and complexity is often underestimated by construction practitioners and is usually countered by an increase in resources (equipment, labor) and an increase of the number of working hours. The inability of conventional work practices to handle the increase in managerial load would lead to:
• Unutilized working teams because of the large number to be integrated
• Slow progress and mistakes in uncoordinated operations because of the complicated sequence of activities and operations that demand coordination
• Unavailability of resources because of the large load of material to be managed
• Mismanagement of finite resources such as the labor workforce
• Improper coordination that would lead to the inactivity of some engineering trades and time consuming error corrections.

IV. MEGAPROJECT PERFORMANCE IMPROVEMENT

Megaproject managerial performance could be improved by modifying the work practices in order to handle megaprojects characteristics. Several previous attempts have been provided by researchers in order to improve performance. However, the techniques provided were general and were not tested on a construction site. This section presents a theoretical approach on how to
improve megaproject performance through adequate system integration. Furthermore, it presents the theory’s corresponding practical work practices to be applied on the construction site.

A. Literature Performance Improvement

Construction management literature has provided limited methods of how to improve performance on large complex projects. Nevertheless, the literature provides numerous studies about critical success factors that contribute to project performance improvement. The Critical Success Factors CSFs are general guidelines of what might contribute to the project success. For instance, some important critical success factors are effective project planning and control, sufficient resources, detailed written contract, and clear defined goals … (Toor et al. 2007). According to different studies by different researchers, the CSFs may vary in importance and in number. Though useful, the critical success factors only answer the question of what to do instead of how to do. In other words, they only provide guidelines and goals not methods and practices of how to achieve the goals.

There are several researches that did provide an insight on how to improve performance on large projects. Platje (1993) provided that classical planning and management is not suitable for megaprojects and can result in a bureaucratic, inflexible, and powerless organization. Thus, the solution would be to delegate responsibilities to the lowest possible levels of the organization and to improve the communication between departments and head project managers. This would lead to an open, flexible, and creative organization that is suitable for large projects. Other researchers provided different organizational alternatives for large projects that would aid the managers in meeting the challenge of effective project organization. The organizational alternatives are determined by the situational analysis of goals, external influence, design and work technology, and project phase (Tatum et al. 1986). Nevertheless, these organizational alternatives haven’t been tested or evaluated by construction practitioners.

The strategies and guidelines provided by the literature are broad, well known, and applicable to all construction projects. However, these techniques are general and do not provide a practical work plan for construction practitioners. Therefore, more tangible and practical methods should be researched. In addition, the methods and work practices should be tested on a construction project to determine their affect on the performance outcome.

B. System Integration and Work Practices

A construction project is analyzed as a large and complex system composed of different interrelated elements i.e. workgroups. The work groups should be sufficiently integrated to provide better performance.

In this research, system integration is defined as a process to bring together inputs, different elements, and outputs to improve project performance. The inputs are project design, project schedule, and resource supply systems such as labor, equipment, and material. The elements are the different work groups, management levels, and engineering trades that should be integrated according to the design, common works, and schedule. The output is the workflow of groups that impacts future activities of different groups in terms of schedule or design changes. Therefore, system integration is explained according to two different aspects i.e. production integration and functional integration. Each of these integration aspects would be necessary to offset the poor performance caused by the megaproject characteristics. Accordingly, as the project size increases, there would be more need for production integration; and as the project complexity increases, there would be more need for functional integration.
1. Production Integration

Production integration is the integration of all systems that contribute to the construction process. As size increases, there is more need for production integration in order to make the construction process more streamlined and efficient. It includes the integration of teams’ work flow, teams’ schedules, material supply, labor supply, and the construction activities. Furthermore, it includes the integration of different managerial levels in order to make the procedural and decision making processes more efficient and less disruptive to the construction process. The production integration could be achieved through the application of the following work practices and Innovative tools:

- Streamlined site organizational structure
- Centralized networking systems among different work groups
- Material supply chain
- Resource management of labor and equipment

2. Functional Integration

Functional integration is the integration of different functional groups. The functional groups are groups that have different specializations or who have different functions throughout the construction process. It includes the integration of different functional work teams; the integration of the workflow among different specializations according to a sequence and time constraints; and the physical integration of the works according to space constraints. The functional integration could be achieved through the application of the following work practices and Innovative tools:

- Integrated organizational structure among different functional groups (specializations)
- Centralized networking systems among different specialization groups
- Visualization and other computer aided technologies (3D-4D technologies)
- Design constructability and easiness of execution

V. MEGAPROJECT CASE STUDIES

Several case studies were conducted to retrieve the work practices applied on large scale construction sites. The work practices researched were the practices that improved production and functional integration such as planning and design, site management organization, top management organization, and modular work practices. The targeted projects were projects that belonged to the megaproject category. In other words the projects were characterized by large size, design complexity, and execution complexity. The information retrieved was from previous construction management literature, managerial technical reports, engineering technical reports, and management books that analyzed different aspects of the projects. The following is a brief description of the projects researched:

1. I-595 Port Everglades Expressway

The expressway is 13.4 mile long and includes three major 4-level interchanges with I-95, I-75, a US Route, and Florida Turnpike (Over 300 lane miles of road that required 15 million CY of embankment). The total cost of the project including the design, utility relocations, construction, inspection, and owner’s administrative costs was estimated at 1.2 billion Dollars (1990). The
construction time was in excess of 7 years. The project was composed of 20 separate construction-contract segments designed by eight different consultants.

2. *The Denver Airport Megaproject*

The Denver International Airport is one of the largest airports in the world. It was initially planned to cost 2.5 billion dollars in 1990, but that figure grew to a 5.3 billion dollars in 1995. The airport was built on a 53 square mile construction site and was composed of 2 terminals, 3 airside concourses, 6 runways, 88 air carrier gates, and 32 commuter gates. The concourses were connected to the terminals through a 6,200 ft long tunnel system. The design team was composed of 61 designers of different specializations. Furthermore, there were 134 construction contracts and about 2000 subcontracts agreed to by the airport officials.

3. *Boston's Central Artery/Tunnel Project*

The Boston Artery/Tunnel is the largest and most expensive public works project ever taken in the United States. It is a 7.8 mile system of bridges and underground highways and ramps. It includes the world’s widest cable-stayed bridge and a deep underwater connection. It imposed several engineering challenges. The construction site was a dense urban area so traffic was to be kept flowing. The soil was to be stabilized to ensure minimal damages to existing structures.

4. *Nuclear Power Plants*

Power plants in are in general very large in scale. According to the Department of Energy nuclear power plant assessment (2005), a resource loaded schedule is estimated to be a five-year schedule with site preparation taking 12 to 18 months, construction (first concrete to fuel loading) taking 36 to 42 months, and commissioning and testing taking 6 to 12 months. The project complexity is so great that the number of contractors and suppliers who can undergo such projects is limited. According to the Department of Energy nuclear power plant assessment (2005), constructing a nuclear power plant needs highly-skilled and highly-valued qualified construction workers and specialized workers such as boilermakers, pipefitters, electricians, and ironworkers.

**VI. WORK PRACTICES APPLIED**

Different work practices applied would improve the project performance since each work practice would contribute to the production and functional integration of the project. The work practices retrieved from the case studies:

**A. Site Management Organization**

The choice of site organization would determine the level of production integration and functional integration of the project. The management organizations retrieved are well known by construction practitioners and in the construction literature. However, more elaboration is done to give an insight on how the organization was tailored to adapt to the project’s characteristics. In other words, it answers the following questions:

- How was the work divided among different groups and different managerial levels?
- What responsibilities were retained by different groups to keep the workflow smooth and undisrupted?
1. Area Management

The area management organization is well suited for large scale projects where a single team cannot handle the large size. It was applied on the I-595 expressway and Boston artery tunnel where the projects were divided into separate manageable sectors.

In this organization, the works are divided among two management levels to ensure fast response: the global management team and the area management teams. The global project management team retains the global responsibilities of the project and the area management teams retain the duties and responsibilities in their areas. The area management system is decentralized to respond to decisions, variations, problems, and unanticipated conditions as fast as possible.

The global management team is responsible of major construction items, global issues, and overall project controls. In other words it is responsible for control cost, schedule control, global project coordination, long lead items, approval of major changes, claims management, and other issues that extend in more than one area. The global management team is positioned to ensure the resource supply of all groups and adequate integration of works among different groups. In order to conduct these duties, the global project management team is composed of senior project directors, project managers, and senior construction engineers.

The area managers are responsible for the administration of all contracts in their designated areas. In addition, they are responsible for coordinating their work with each other and with other areas throughout the site. Accordingly, the lower level or field managers would have direct responsibilities on their project portions i.e. total control of the construction process and decision making authority. In order to conduct these duties, area management positions demand experienced people with capabilities and experience in cost engineering, planning, scheduling, contract administration, IT knowledge, and technical knowledge. It is usually composed of a manager, support staff, number of resident engineers, field engineers, and quality assurance inspection teams.

![Figure 4: Area Management](image)

Functional integration could be achieved using this management organization. The area management staff would be changed according to the specialization needed as the project progresses from phase to phase. For instance, in the Denver Airport project site management responsibilities shifted from one area manager to another as the works changed i.e. site preparation area manager changed to paving area manager.
2. Area Management with Technical Support

This type of organization is well suited for large scale complex projects. It was applied on the Denver Airport megaproject. As the project technical complexity increases, area management teams are incapable to perform all engineering activities and functions in their designated areas. In addition, the global management team would be incapable to follow up with the overwhelming technical and the managerial processes. Therefore, more functional integration is needed giving rise to the technical support group.

The support group functions vary depending on the needs of the area management teams. Its functions could be technical (engineering), managerial, or even legal. The technical staff assists area managers in their duties and reports to the global project management team. In many cases the area managers would report to the support staff in engineering or technical issues. The support staff is usually composed of experienced senior level support managers that include specialists in management, safety, security, quality assurance, construction engineering, and contract administration. Furthermore, the staff would develop program wide policies and procedures and would ensure their implementation.

![Figure 5: Area Management with Technical Support](image)

3. Area Management with Functional Distribution

This type of organization is well suited for very complex large projects such as power plants. Projects as such have a design that is complicated to construct where the services of many engineering specializations are needed. This management scheme is similar to the area management. However, all engineering trades are placed in each work group to ensure maximal functional integration among different specializations.

The hierarchy starts with the project management team on top and subordinated by area managers. Each area manager acts as a project manager in his area and is subordinated by engineers with different specializations. Each engineer is subordinated by his own project superintendents, foremen, and laborers. The engineers are responsible for the technical and managerial aspects of the project and report to the project manager. The work group specializations could be modified according to the complexity of each area or the phase of the project.

This type of organization ensures substantial integration of different specializations within each group. However, it does not ensure sufficient integration of specializations among different area work groups.
4. Area-Functional Matrix Organization

This type of organization is well suited for complex and large projects where the coordination of specializations among different areas is substantial.

In this management organization, each work group has to report to an area manager and functional managers. The area manager would manage the works done in each area, whereas each functional manager would manage the works of each specialization throughout the project. This type of organization would ensure substantial integration of different specializations within each group. Furthermore, it would ensure sufficient coordination of specializations among different area work groups.

The two dimensional hierarchy starts with the project management team subordinated by two groups: the area managers, and the functional managers. The two groups are subordinated by the area work groups. Each area work group would include all engineering trades and would report to both area manager and functional managers. The functional managers (engineers) would be responsible for the technical aspects of the project. The area managers would be responsible for the managerial aspects.

Reporting to multiple superiors could be troublesome and inefficient. However, procedures could be established to streamline the works and make the managerial process more efficient. A similar form of hierarchy worked well on the I-595 expressway where the roles and responsibilities were delineated between the bosses to avoid conflicts and management inefficiencies.
B. Top Management Organization

The choice of top management organization would determine the level of integration of different project parties. Furthermore, top management organization affects the production integration since it influences decision making procedures and change procedures. The top management structure is not simple since many public and private authorities would act as the owner. Furthermore, many parties such as consultants would be employed to act as project managers and as owner representatives.

In the classical owner-contractor organization, all decision making processes pass through the owner or owner’s representative. In the case of projects that demand a great deal of managerial intervention, the owner-contractor decision making procedure would be slow and disruptive to the construction process. Therefore, different organizations should be applied on megaprojects to be able cope with their managerial demands. The following is a summary of the top management organizations applied on different megaprojects and had different outcomes.

1. Independent Project Organization

The independent project organization (IPO) was applied at the Boston Tunnel/Artery project. The decision making team was an integrated organization formed of the owner i.e. Massachusetts Turnpike Authority (MTA) and a management consultant i.e. Bechtel-Parsons Brinckerhoff (B/PB) under the direction of the owner. For instance, the best qualified person available for a particular managerial position was selected regardless of which organization he came from. The IPO structure was formed to improve integration through encouraging better communication between the parties and producing more efficient decision making. Unfortunately, the IPO structure did not resemble the usual owner-consultant relationship by which the two parties operate independently. No clear lines of responsibility and accountability were presented. This led to numerous problems, conflicts, and legal claims between different parties.

2. Matrix Organization

As applied in the I-595 expressway, the organization was based on a matrix approach. The roles and responsibilities were delineated between the owner and project manager to avoid conflicts and management inefficiencies. The work load was divided by which the owner retained technical, engineering, and administrative responsibilities. The project manager retained project management issues (cost, work packaging, production planning and scheduling) and other business related and integrative decisions. This form of organization performed well although there was not considerable integration between the project manager and owner/consultant.

C. Planning and Design

Several advanced planning steps are necessary to better prepare the construction team adapt to megaprojects’ complexity and project size. Therefore, planning is not confined to the classical scheduling and planning steps. Many items such as the design, long lead items, project schedule, and procurement schedule should have better preparations.

The following is a list of advanced steps and recommendations of work practices applied on different megaprojects that enhanced project integration and led to better project performance.
1. Project Planning and Scheduling

Project planning and scheduling work practices could be applied to improve the work teams’ coordination (production integration):

- In the I-595 project, a task force composed of the owner and the management consultant was introduced at early planning stages to develop the scope and the work plan. At this stage all individual projects or work packages of the main project were planned. Furthermore, the organizational structure was introduced before construction started where roles and responsibilities were assigned to different managers in both organizations.
- The field team was familiar with the project one year ahead of commencement. Furthermore, the construction schedule was set based on the input of all participants where maximum flexibility was given for contractors to set their schedules.
- The schedule should be relaxed as much as possible. Compressing the project schedule to finish early and to limit the turnover of experienced construction managers would lead to acceleration costs, haste approval of change requests, and schedule modifications.

Very complex and large scale projects demand several advanced planning steps. According to the Department of Energy nuclear power plant assessment (2005), the following steps are recommended:

- The construction schedule should be prepared to the maximum possible extent.
- The procurement schedule should be discussed with the suppliers and contractors to ensure the availability of required material at the appropriate time. Furthermore, according to the CII Project Definition Rating, each vendor should develop a resource-based schedule duration and information so that the main contractor could integrate different schedules and produce a final optimized one.
- Long Lead Items should not be left to be finalized during the construction project which would cause delays in case the items are not delivered in time.
- The project team should prepare for changes and mistake corrections by adequate staffing of response teams for problem resolution.

2. Design

Advanced work practices should be applied to improve the design completeness and constructability. In other words, to improve the project functional integration:

- In complex projects, the design should be complete to the maximum practical amount. According to the Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs, the design should be complete and all regulatory issues are fully resolved before construction commences. At the Denver Airport project, the design-build approach was used where the airport was planned to have future additions and the design was planned to accommodate these additions. Unfortunately, this approach did not save time nor cost because numerous changes were added. The additions caused a ripple effect of changes throughout the project including the previously designed systems.
- People with extensive experience in the construction of such projects should be used to design the project.
- Backup systems should be designed where new innovative technologies are tried.
The utilities, project officials, material suppliers, component suppliers should ensure and approve quality assurance/quality control programs ahead of the project commencement date so that all standards and procedures are followed before misinterpretations and nonconforming works are in place. Furthermore, regulatory issues should be resolved before the commencement of the project.

D. Modular Work Practices

Modular work practices are used in complex and large scale project where different parts of the project (modules) would be fabricated in parallel while site construction works are progressing. After the module fabrication is over the modules are installed on the construction site using cranes and work crews that would link different modules. Modular work practices are popular in military ship yards, industrial plants, and power plants. Modular work practices are necessary for complex large scale projects since they improve the project performance:

- They improve functional integration since they incorporate different engineering trades in each module. The construction would be in a planned and systematic way following a certain sequence that takes into consideration time constraints for trades, space constraints for equipment and components, and project deadlines.
- They improve production integration. Production would be much easier because there would be less congestion (less interference) in the construction site, less crew inactivity, and a lower number of interactions needed at the management level (less management bottlenecks).
- Construction production would be faster since it is possible to produce multiple parallel modules while the site works are progressing. Parallel assembly helps reduce the risk of overall project delay. In a parallel assembly, the delay caused by a single module being manufactured does not necessarily slow down the overall project as in serial construction activities since parallel activities are accompanied by float.
- Construction of works in a shop is much faster than construction of the same works on site. According to a study done by Bechtel Corporation on fabrication facilities in the United States, The U.S. shipbuilders claim that 1 job hour fabrication in a shop (dedicated factory) would take 3 job hours in an onsite temporary facility (site shop) and 8 job hours if done in-place (construction site) using tradition construction techniques.
- The use of modular work practices improves quality, standardizes the works, and optimizes them. Furthermore, they make the testing and commissioning process easier since each module could be tested for all the systems before installation.

In order to apply the modular work practices, project officials should have the design, construction, and manufacturing capabilities:

- The use of 3D Computer Aided Engineering technologies that could support module design. Furthermore, the firm should follow advanced steps in the design. For instance the modules structure should be able to support itself, support the final product building, and have a center of gravity for the ease of lifting. The electromechanical equipment should be designed and placed for future ease of access and maintenance. Furthermore, pipes and cables should be designed and placed for ease of connection with other modules.
• The use of very heavy cranes, large transportation vehicles, and open top installation technology to move and install modules with ease.
• The use of RFID and supply chain database for tracking and managing module components, labor, and other material and equipment.
• The use of advanced construction technologies such as cable splicing, cable rollers, cable lubricant, pipe bending technologies, and programmed robotic welding to connect different modules swiftly with ease.

VII. CONCLUSION
Megaprojects are defined in their construction management context as large scale projects characterized by a complex difficult design and complex organization. Megaprojects’ characteristics cause significant project management difficulties that lead to poor performance. Adequate system integration should be applied in order to improve project performance through the application of the correct work practices. Several work practices that were used in previous megaprojects are presented and analyzed in order to help construction practitioners improve megaproject time and cost performance. However, more research and analysis is needed to clearly assess the effectiveness of each of the work practices when applied on different types of projects. Furthermore, the methods and work practices should be evaluated by construction practitioners who have applied these methods to determine their affect on outcome, project cost, and project time frame.

REFERENCES


