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What can we learn from the Hoover Dam project that influenced modern project management?

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Abstract

The Hoover Dam was completed two years ahead of schedule and under budget despite political, economical, technical, and organizational obstacles. Previous literature regarding the Hoover Dam project focused primarily on the aspects of design, engineering, and construction, with minimal analysis or discussions on project and program management techniques unique to this undertaking. This paper examines project and program management practices applied to the building of the Hoover Dam, and discusses how these factors contributed to the establishment and evolution of modern project management principles, tools, and techniques. A historical review of the Hoover Dam project reveals that the project team implemented a number of innovative strategies and practices that are comparable to critical success factors for today's megaprojects to overcome monumental project challenges and obstacles. This paper conveys the organizational and managerial best practices and presents lessons learned associated with the planning and construction of the Hoover Dam project.

Keywords: Hoover Dam; Infrastructure; Project management; History; Mega project; Lessons learned

1. Introduction

1.1. Background

The Hoover Dam is one of the greatest engineering and construction projects of the 20th Century. President Hoover, a former mining engineer, promoted the dam as part of federal efforts to combat the Great Depression and tame the infertile West. Completed in 1936 as one of the largest infrastructure projects ever built in the United States, the Hoover Dam was completed two years ahead of schedule and under budget despite political, economical, technical, and organizational obstacles (Starr, 1993). The construction of the Hoover Dam is well documented however, the literature to date regarding the Hoover Dam focuses primarily on the engineering aspects associated with design and construction, with minimal discussion on project and program management techniques, and how these factors contributed to the establishment and evolution of modern project management practices.

The history of the Hoover Dam from a project management's perspective is critical because it ushered in the framework of planning and managing government megaprojects, initiated innovative relationships between the government and various stakeholders, and introduced a host of social and managerial solutions (e.g., infrastructure and health management, project accounting strategies) for the workers and engineers that are nominal in today's project management practices (Flyvbjerg et al., 2003; Miller and Lessard, 2001; Morris and Hough, 1987). Modern projects and programs often utilize similar ingenuity and creativity deployed on the Hoover Dam without referencing or adequate consideration to their origins. Examining the organizational and managerial best practices and lessons learned associated with the planning and construction of the Hoover

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Dam will create common ground for academics and practitioners, and contribute to the project management body of knowledge.

This paper explores project and program management techniques unique to this undertaking, and how these factors contributed to the establishment and evolution of modern project management practices. The study examines economical, technical, organizational, and government obstacles, issues and challenges of the project along with its successful outcomes, followed by summarizing project management-related practices exercised by the project team for overcoming identified issues and challenges.

1.2. Research methodology

The primary research approach we employed was exploratory in nature by collecting reports, books, articles, and other related historical archives that captured various aspects of the Hoover Dam project. ABI/Inform, Civil Engineering Database, as well as national archives website were used to identify all relevant documents. Based on the collected materials, we were able to extract historical information that contains economical, political, managerial, and social aspects and environments related to the Hoover Dam. In fact, we were able to find many engineering and construction methods and techniques that were used for the project but, very little information related to project management principles or techniques were adopted. Due to the fact that the Hoover Dam project was completed more than 75 years ago and the documentation was scarce and limited, we acknowledge that the information that we used for this research is incomplete, however, content analysis was used to categorize historical information by project phase as well as document challenges and innovative management approaches that resulted in the successful completion of the Hoover Dam project. In the end, we document valuable insights and lessons learned that align with modern project management practices and principles.

2. History of the Hoover Dam project by project phases

2.1. Background

The Boulder Canyon Project, including the Imperial Dam, Hoover Dam, and the American Canal, commissioned by the Bureau of Reclamation, required 165 million dollars to finance, a total of 21,000 men and 4,400,000 cubic yards of concrete (Hoover, 2011). Initially used as a commerce route for transporting supplies to the Black Canyon area, the Colorado River was used for irrigation purposes that, despite the legislative difficulties in 1890s, was pursued by various land promotion companies and materialized by building a canal to irrigate part of the Imperial Valley in 1901. Operational problems of this canal, such as lack of an appropriate system for controlling the high flow of water in the river caused by torrential rains as well as the rapid rise of heavy silting disturbing the normal stream of the water in the canal, convinced the local and federal officials that there was an essential need for a stronger flood control program. In the Fall–Davis report of 1922, the Reclamation Service, which then was a part of the Interior Department, brought the necessity of constructing a dam on the Colorado River to the attention of Congress and other interested parties. The report was accompanied by an abundance of technical information supporting the recommendations.

2.2. Conceptual phase

Preliminary designs were prepared from over a period of ten years, so the successive designs reflected some of the developments in design techniques during the 1920s. The recommendation made by the Reclamation Service was then followed by a course of action including the following (Dunar and McBride, 1993).

- Agreeing on the amount of water to be apportioned to the seven Basin states affected by the project included Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. The agreement signed by six of these seven states (Arizona signed in 1944) in November 1922 is known as the Colorado River Compact.
- Studying the eight candidates' locations initially proposed for the location of the dam with respect to the geological and topographical features of each alternative, water and silt storage capacity of the reservoir, location of the site in relation to a railroad, and the market for hydroelectric power. After eliminating six of the alternate locations and by further analysis of the remaining two candidates being Black Canyon and Boulder Canyon, the final location was determined to be in Black Canyon, the current location of the Hoover Dam. The Interior Secretary and Congress received the report favorably at the end of this stage.
- Specifying the reimbursement methodology the federal government would receive for funding the project. This became a key feature of the Hoover Dam's enabling legislation that created and executed contracts for the sale of the hydroelectric power generated over a fifty-year period at the rate determined by the Interior Secretary.
- Undertaking comprehensive preliminary engineering of the dam, including study of the various dam types and load analysis of the selected type by the Bureau of Reclamation (formerly Reclamation Service) with the help of University of Colorado in Boulder and under supervision of a board of consulting engineers that had been appointed by Congress in 1928 to monitor the design effort and approve the final design.
- Agreeing on dividing generated electricity equitably among competing bidders. After 7 months of study and analysis, the interior secretary decided to divide the proposed electricity generated at the dam between the Metropolitan Water District (36%), City of Los Angeles (13%), Southern California Edison Company (9%), and States of Nevada and Arizona (18% each). The total value of contracts was higher than $327 million.

Finally, in December 1928 and after 4 years of study and review, the fourth version of the Boulder Canyon Project Act, which consisted of rough plans, cost estimates and two hundred pages of supportive information about the Hoover Dam, was

introduced to the floor of both houses of Congress and then passed by Senate. In June 1929, President Herbert Hoover signed the Boulder Canyon Project Act. Afterward, in July 1930 and by approval of the requested funding, the interior secretary ordered the Bureau of Reclamation to commence the final engineering and construction phases of the project.

2.3. Planning, execution, and construction phase

For the Bureau of Reclamation to receive approval of the Boulder Canyon Project Act, preliminary design related activities had to be conducted concurrent to the conceptual phase activities described in the previous section. The designs for the Hoover Dam evolved over several years of careful study, representing the combined efforts of many Bureau of Reclamation engineers and various consulting boards. The design work continued until January 1931 when the bid documents were made available and continued until November 1932 when the final design was approved by the consulting board after updating the design and incorporating the changes required for addressing unforeseen conditions of the project. At the same time, the Bureau of Reclamation initiated pre-construction activities, including work on building Boulder City to accommodate construction workers, on the railroad spur linking Las Vegas and Black Canyon, to access the site, as well as the communication line.

Originally the dam was broken into 119 separate projects, with a late performance penalty of $3000/day (Rogers, 2010a). Several initial bids were made, and "Six Companies, Inc." bid significantly less than their competition, at $48,890,955. Six Companies was comprised of various construction firms (W.A. Bechtel Co., Kaiser Paving Co., Utah Construction Co., MacDonald & Kahn Construction Co., Morrison-Knudsen Co., J.F. Shea Co., and Pacific Bridge Co.) who decided to pool their resources, and elected Frank T. Crowe to serve as the General Superintendent for the Hoover Dam due to his impressive qualifications and experience with managing previous dam projects (Rogers, 2010a).

In March 1931, the Six Companies, Inc. consortium was announced as the winner of the dam construction contract, the largest single contract ever let by the United States government. Six Companies, Inc. immediately began mobilization and logistics activities and started operations related to constructing the four diversion tunnels, the mixing plant and high scaling the canyon walls. Construction of the railroad spur connecting Las Vegas to the jobsite in Black Canyon by Union Pacific, and a 10.3 miles spur from Boulder City to the canyon by Lewis Construction Company, were also undertaken.

The initial phases of construction activity were completed approximately one year ahead of the schedule and made it possible for the contractor to reroute the Colorado River in November 1932. In the meantime and eight weeks before completion of the diversion tunnels, construction of the upstream and downstream cofferdams began to allow for foundation work as soon as preparation activity was complete. Work on the foundation was also accomplished one year ahead of the baseline schedule and was followed by the concrete work on the body of the dam.

Technical and productivity innovations contributed to the accelerated schedule. The use of electric lighting throughout the site enabled a 24 h a day work schedule using three 8-hour shifts per day. A series of aerial tramways transporting huge steel buckets for pouring massive amounts of concrete were also deployed (Dunar and McBride, 1993). Beside construction of the main structure of the dam, operations on other elements of the dam complex included penstocks, spillway tunnels, powerhouse foundation, and intake tunnels that were also underway at this time. As a result of the increase in the number of construction activities, the number of workers on the job reached its peak in July 1934 when 5251 workers were employed (Stevens, 1988).

2.4. Close out phase

In early 1936, after installing hydroelectric power equipment and transmission lines, Six Companies, Inc. and the federal government reached final agreement on the fulfillment of the construction contract and resolution of the disputes that had arisen. The dam and power house were turned over to the Interior Department in February 1936, 26 months ahead of schedule (Stevens, 1988) and $15 million under budget (Herczog, 2010). Six Companies, Inc. was also able to overcome many obstacles in the construction of the dam and secure a profit of $13 million (Hiltzik, 2010).

3. Hoover Dam Project challenges and innovative management

We have presented this section into nine subsections to discuss various organizational, managerial, planning, and implemental challenges, obstacles, solutions, and suggestions related to the Hoover Dam project. Sections 3.1 to 3.3 discuss issues from macroeconomic and companies' point of view for strategic value creation (Chang et al., 2013; Jia et al., 2011; Sun and Zhang, 2011) then, Sections 3.4 to 3.6 describes innovative project management practices that helped to complete project successfully (Giezen, 2012). Finally, Sections 3.7 to 3.9 devote discussions dealing with human resources including managing workers relations (Toor and Ogunlana, 2010), providing healthcare, and lack of safety programs.

3.1. Economical and managerial challenges

A review of the Hoover Dam project history from a project management perspective reveals the other dimensions of its prosperity that are highlighted when project challenges and issues are brought into consideration. Apart from the technical and technological difficulties involved with the design and construction of a structure with the characteristics of the Hoover Dam, there were significant managerial challenges that included the following.

- Ensuring the profitability of the project due to uncertainty in availability of buyers for the generated hydroelectric power;
- Determining the hydroelectric power rate in order for the project to compete with other sources of electricity and be

attractive for potential buyers while ensuring profitability for the government;
- Dividing the water and power equitably between the seven Basin states and other potential buyers;
- Ensuring the design and engineering aspects of the project. To address this, a board of consulting engineers was assigned by Congress in 1928 to advise the Bureau of Reclamation during the design process. This board was in charge of approving the final design of the project and any design changes during construction;
- Supporting the construction activities in Black Canyon, which was located in a remote area with harsh climatic conditions, making housing, feeding and general care for the workers as well as transportation and supply of equipment, water, and electricity difficult;
- Safety and health issues of the construction workers in Black Canyon, which were intensified by the extensive number of operations needed to be undertaken at the same time;
- Finally, the unusual size of the project and other parameters made delivery of the project impossible for an individual construction company. The extremely high bid and performance bonds required of bidders by the government meant that few if any individual companies could qualify to bid. The five million dollars performance bond was one of the main reasons that led to the establishment of Six Companies, Inc.

3.2. Government relations

Henry Kaiser's unique prior relationship from his lobbying work provided this project an additional strength when contractual issues arose. Unauthorized overtime was fined by the government, but later greatly reduced when Kaiser reached out to his contact in the department (Tassava, 2003). The Hoover Dam project faced significant fines for unauthorized overtime work, which were later greatly reduced due to Henry Kaiser's positive relationships with government officials.

There is not an agreed upon number for this fine, but one version is that it was reduced from $350,000 to $100,000 (Davis-Bloom, 2011). According to Tassava (2003), Kaiser used his high-level contacts to persuade Harold Ickes, Secretary of the Interior under President Franklin D. Roosevelt, to reduce a massive fine for violating eight-hour-day laws, to convince the government to accept the dam in March 1936 (two years ahead of schedule), and to pay a $2.5 million completion bonus. This venture proved extremely profitable as a result and the group continued to function as a joint venture when bidding on additional infrastructure projects including the Bonneville and Grand Coulee dams (Wolf, 1996). Other organizations performing public works' projects may not have had this prior relationship and would have suffered larger losses from fines. It is important to note that this type of relationship and favoritism would be heavily scrutinized and most likely would not have resulted in as lenient a decision today.

In addition to innovations in the financial management aspects of the project by Six Companies, Inc., the Hoover Dam project was one of the first examples of a partnership between public and private sectors where a link between government funding and private-sector expertise was formed. In the early 1930s Unites States was experiencing a period of extreme economic depression and federal funds were constrained. To achieve the project goals, in 1934 the Congress authorized that expenses incurred for the construction of the Hoover Dam be paid back over a period of fifty years to the Federal Treasury by selling electricity. This helped the government find partners in the private sector and partners in the developers of many big cities in the southwest (Elkind, 2008). Successful public–private partnership in the Hoover Dam project paved the way for similar partnership in other mega projects including the Golden Gate Bridge.

Companies and governments continue to partner in modern times in order to complete projects most effectively and promote growth. While these relationships are often difficult to construct, it has been acknowledged that governments can be served by relationships such as public private partnerships (PPPs) to complete necessary projects (Savas, 2000). Understanding government relations and culture could be a critical success factor as more and more projects are organized in a PPP scheme (van Marrewijk et al., 2008).

3.3. Joint ventures

The construction of the Hoover Dam was not only one of the biggest engineering and construction projects at that time, it was also accompanied with a broad array of innovations in management of its business aspect. Rogers (2010a) note that foremost among innovative managerial solutions was the employment of a joint venture involving eight different firms, organized into six partners. In fact, the Hoover Dam was the first public project in which a joint venture of more than three firms was used. With an approved budget of $165 million, the Hoover Dam was the largest federal contract of its time. To participate in the bid, a $2 million bond had to accompany each bid and after winning the bid, a $5 million performance bond was needed. The project size was so significant that no single company had the financial and technical resources required to bid the job alone. As far as construction of the dam, each member of the Six Companies consortium brought special expertise to the project to perform different aspects of the job, including temporary trestles and suspension bridges, building the early railroads, concrete work, tunnel building, and other underground work.

This new organizational structure was not without its challenges, especially as each company vied for leadership, but each issue was addressed and overcome (Tassava, 2003). Six Companies Inc. individual firms originally were competitors as well, but their joint venture arrangement strengthened their ability to compete with other project bids by offering the most value and expertise at the lowest price. Competing organizations continue to work together in order to bring greater value to consumers. Current business practices frequently utilize this type of formation, suggesting that the Hoover Dam project management team left a long-lasting impression on management techniques nationally and globally.

3.4. Innovative project management techniques

Because of the challenges and the unique characteristics associated with the Hoover Dam project, many individuals and companies questioned the feasibility and potential success of the project from the beginning. In retrospect, construction of the Hoover Dam turned out to be one of the most successful experiences for the project's owner and contractors, and documented by many as an example project management framework for future megaprojects.

Early in the project, Six Companies, Inc. intentionally submitted a high bid for rock excavation work—$8.50 per cubic yard, asking $13,285,000 for 1,563,000 cubic yards of tunnel excavation. Later, to balance this act, they bid the concrete placement well below market price. This provided a great deal of cash income up front, to balance out the $5 million performance surety secured by the partners at the beginning of the job. As Rogers (2010a) notes, this approach, known as item-price loading, helped Six Companies gain about $13 million in profits on a $53 million job (including the extras).

Crowe also had superior skills in project scheduling and used the Critical Path approach, that helped Six Companies split the excavation of diversion tunnels into separate stages and helped to complete them a year ahead of schedule (Rogers, 2010a, 2010b). Additionally, Crowe also used a specific item price loading known as the unbalanced bid to seek greater compensation for material excavation, handling, and placement early in the job.

The construction phase was completed on budget and two years ahead of schedule, leaving a huge amount of profit for the contractor followed by collaborating on a series of similar projects with the Bureau of Reclamation. All of these accomplishments happened during the tough economic situation of the Great Depression. Success of the project also brought significant advantages to the Bureau of Reclamation, including employment opportunities, reclamation and irrigation, power supply, an effective flood control mechanism, and most importantly, high publicity of the project. Additionally, the idea of building Boulder City to accommodate the project's workers proved very successful and helped the government and other interested parties recognize all dimensions of the benefits of megaprojects (Stevens, 1988).

3.5. Innovative resource allocations

Hoover Dam was the first project that used "unbalanced bids" to reserve much needed resources early in the project (Rogers, 2010a). The contractor's unit costs were controlled carefully to seek greater resource allocation early in the project to compensate the cash bond that the winning contractor had to pay to initiate the project. For example, Frank T. Crowe estimated $8.50 per cubic yard for rock excavation, a very high price, but just $2.70 per yard for mass concrete in-place that was 20% below Reclamation estimates and 35% below their nearest competitor. However, Crowe was manipulating the unit price per work to collect as much resource (cash) as possible at the beginning of the project to offset the $2 million performance bond.

Unbalanced loading received attention as a cost management approach for contactors after two decades. According to Cattell et al. (2008), Gates (1959) was the first individual who identified the role of item price loading as a strategy. In item price loading, different mark-ups are used for individual items within a project to realize advantages that are not likely to be gained by allocating a universally constant mark-up to all work items. If high prices are allocated to items scheduled to arise early in the contract's project plan, the contractor will receive larger amounts of money for the first few interim payments. This practice is known as 'front-end loading' in project management literature and help contractors' initial cash flow for the contract.

The project managers involved in the construction of the Hoover Dam allocated substantial amounts of resources to wages and machinery. Rigorous scheduling, seven days a week in 100° heat pushed the project towards an early completion (Hecox, 2011). Additionally, long work hours were supplemented with the intensive use of heavy machinery and managers pushing capital into the project as far as possible in the first year (Tassava, 2003). This initial push of man and machine power into the project was paramount to the overall success and early finish time of the Hoover Dam.

With regard to worker salaries, the average annual salary was $3650.00, which does not seem significant until compared to the salaries of other positions during that time period. However, Hoover Dam laborers made slightly more annually than doctors who were paid $3382. This meant that laborers were able to provide for their families during times of economic turmoil, subsequently increasingly household cash flow, overall spending, and boosting the economy.

3.6. Technological innovations

The organization of the Six Companies Inc. allowed it to gather experts and efficiently solve technical problems, advancements that marked a breakthrough in construction development. One of the initial challenges faced by the group was the issue of developing a cement formula that would meet their needs (Rogers, 2010b). As stated by Timothy Dolen (2010),

> "*the Boulder Canyon Project Final Reports documented the greatest leap forward in concrete technology ever. This included the pioneering work in cement chemistry, mixture proportioning, compressive strength and elastic properties, permeability, and thermal properties of mass concrete. The scientific methodology followed by numerous civil engineers and researchers provided the foundation for future mass concrete investigations for the next half century*".

Many sources point to the significant role of Frank Crowe, General Superintendent assigned by Six Companies Inc., in the success of the Hoover Dam project. Dunar and McBride (1993) note that understanding of how government works is as important to large-scale construction as knowing the technical details of the

work. Crowe had a twenty-year career history with the Reclamation Service and had attained ample skills at devising timesaving and efficient construction methods. Throughout his career, Crowe developed a reputation as the government's best construction man and had pioneered the use of numerous pieces of new equipment. For example, in order to complete excavation of the diversion tunnels, Crowe made the world's first Jumbo Drill.

Another significant solution he applied was to accelerate supplying concrete. Crowe build high and low concrete mix batch plants working simultaneously to mix the concrete. The initial concrete required for the dam was mixed in a river-level mixing plant which provided the concrete for the linings in the diversion tunnels and for the lower levels of the dam. As the dam rose in height, a new concrete mixing plant was constructed on the canyon rim. At the job site, Crowe used an overhead cableway system to deliver the concrete where needed.

The construction needs of this project were very unique and required innovative solutions to prevent delays. In particular, an adequate system to allow for appropriate cooling and thus curing concrete posed a large obstacle, which was overcome with the installation of cooling pipes, a technology which has previously only been used on a trial basis (Rogers, 2010b). This ensured that while there was a lack of Modified Low Heat (MLH) cement for the project, the supplemented cement product would successfully meet the needs of the project. To solve similar supply issues modern management often utilizes outsourcing, a process that can provide a low-cost alternative to domestic supplies. The negatives associated with this cost-reducing technique include low-quality product and a lack of control over the production process. Additionally it often drives down the need for technological innovation that owners may seek to solve similar problems. A large factor in the need for technological innovation rather than obtaining an outsources supply of MLH cement from abroad was the lack of feasibility of such an endeavor and that shipping time and costs would have been exorbitant.

Additional technological innovations on constructing the dam included the use of an overhead delivery system, which avoided transporting materials over rough, uneven ground (Rogers, 2010b). This cable-car system vastly improved the material delivery process, and prevented possible damage to supplies. Multiple bit drilling jumbos were also utilized in the construction of the Hoover Dam that efficiently bored up to 36 holes into the rock surface at a time (Rogers, 2010a). Traditional methods would have taken significantly larger amounts of time.

3.7. Workers relations and productivity

While some of members of the Six Companies Inc., particularly Kaiser, were known to make managerial concessions in order to increase worker loyalty and devotion, spurring additional energy into the project, Frank T. Crowe, the General Superintendent for the Hoover Dam, had different views. Pushing workers on output and taking a non-negotiation stance with unions, Crowe consistently attempted to maximize jobsite productivity. At one point in the project, Crowe announced to reporters that he would no longer negotiate with the workers for wage increases because they were approximately one year ahead of schedule and were no longer pressured to maintain as large of a workforce (Stevens, 1988). As a result over 1200 workers abandoned the project, but were later replaced with others who were eager for the job opportunity (Wilson, 1931). While Crowe's approach may not have been viewed favorably due to its harsh nature, it was in some manners efficient because of its contribution towards maximizing workers' productivity.

3.8. Job generations

Another successful aspect of the Hoover Dam project was the generation of jobs during a recession period. Those employed by this project also had an opportunity for overtime work, providing additional money for families during difficult economic times. Infrastructure projects have often been promoted on their ability to generate jobs. However, technological advances in the construction industry over time have eliminated many manual labor positions, and as a result, companies need fewer workers in order to accomplish the same amount of work. Many have suggested that the Hoover Dam project, employing approximately 5200 people at its peak, would be constructed today with far fewer employees given the advances in construction related technologies. Utilizing modern technology no more than 1000 people would work on a bridge of similar magnitude simultaneously (Lexington, 2011). Part of the reason why the Hoover Dam was successful as a public works' project is that it was able to generate a significant number of jobs.

3.9. Workers safety and health issues

A significant failure of the Hoover Dam project was the safety and care of workers. Although workers were well compensated and received housing benefits, it has been well documented that many workers died of carbon monoxide poisoning in tunnels with inadequate ventilation (Rogers, 2010b). On site deaths have been estimated at more than 1000 workers, not including those documented as victims of pneumonia (Smith, 2011). Workers were offered enrollment in special health and housing programs as a result of difficult work conditions (Davis-Bloom, 2011). Special medical dispensaries were positioned on the job site after the deaths of more than a dozen workers in division tunnels without forced-air ventilation. They were equipped with a doctor, nurse, ambulance, and driver in order to decrease the number of work-related deaths (Rogers, 2010b). Unfortunately this solution was not acted upon until after the deaths of many workers, some recorded as pneumonia (Lexington, 2011). As a result, the health risks associated with the project were a major oversight of the project management team.

Other issues were addressed with greater care, such as the provision of hard hats to workers. While the hats were not required, it was strongly suggested that despite the oppressive heat workers in exposed areas don the protective headgear provided by Six Companies (Rogers, 2010b). This saved many workers who would have otherwise been injured or killed by falling rocks and fellow worker's tools.

4. Lessons learned from comparing megaproject framework by the Department of Energy (DOE)

To study the steps undertaken for the project planning, design and construction of the Hoover Dam, Walewski and Sadatsafavi (2010) used the framework developed by the Department of Energy (DOE) that acknowledges four major phases (Preconception, Conception, Execution, and Closeout) for the planning and construction of its projects (NRC, 1998). Because DOE projects have historically been large and complex involving unique systems, processes, and technical challenges, they meet the megaproject threshold. Because of underperformance issues, Congress mandated a series of reviews and assessments of DOE project management procedures by an impartial, independent organization. This review was conducted by the National Research Council's (NRC) Board of Infrastructure and the Constructed Environment (BICE) beginning in 1999. The investigations by BICE found that delivering projects of this magnitude that meet baseline costs and schedules is a constant challenge that requires excellent management (NRC, 1999). An appendix to the original report to Congress was entitled "Characteristics of Successful Megaprojects or Systems Acquisitions", and has become a standalone publication (NRC, 2000) and frequently cited source on structuring government megaprojects.

The board identified key factors that were common to large construction projects delivered successfully from the standpoint of cost, schedule, and scope. NRC (2000) notes that the checklist can be used in different types of projects as a benchmark against generally accepted characteristics of successful projects. More importantly, the checklist is designed with the intention of providing post-mortem analyses for identifying lessons to be shared with other project managers.

Lessons learned from analyzing the project management principles and techniques used in the Hoover Dam project are compared to the characteristics of successful DOE megaprojects to uncover the innovative and creative practices applied in the Hoover Dam project. To this end, general conditions for the success of projects identified and listed in the report prepared by the board in charge of assessing the policies and practices of the DOE's construction projects in 1999 are utilized (NRC, 1999).

- *Condition cited as essential to success by DOE*: Project sponsors know what they need and can afford, where they want to locate the project, and when it must be ready for use or otherwise completed. The project has a purpose, and the benefits are clearly defined and understood by all participants.
  - *Comparable lesson learned from the Hoover Dam project*: The essential need for flood control as a part of the idea supporting construction of the Hoover Dam was well understood by both public and private agencies leaving no doubt about approving the project idea. Later activities related to project development were also supported by extensive studies and effort during the 4-year period the legislation was under review in Congress. All the revenue and benefits generated by the project including water and power products were divided long before the operation of the dam in the way agreed by all the interested parties.
- *Condition cited as essential to success by DOE*: The project has a champion in the owner's organization whose position and influence enable him or her to affect behavior and performance in the owner's organization that would benefit the project.
  - *Comparable lesson learned from the Hoover Dam project*: The Bureau of Reclamation, as the government agency in charge of the project, maintained a close relationship with the parties involved with different phases of the project and helped the entire project team overcome serious challenges, such as debates and critics during review of the legislation in Congress, labor strikes during the construction phase, lobbying to secure the adequate annual funds, and resolving the situations in which the project team had to address the conflict between public against private interests and state against state benefits.
- *Condition cited as essential to success by DOE*: Open communications, mutual trust, and close coordination are maintained between owner/users and project management during planning, design, construction, start up, and turnover of the completed project to the owner.
  - *Comparable lesson learned from the Hoover Dam project*: One of the factors key to the success of the Hoover Dam project was the constructive relationship between the contractor of the project and governmental agencies involved with the project lead by the Bureau of Reclamation. Cooperation between Six Companies' project personnel and the resident construction engineer assigned by the Bureau of Reclamation helped the project team overcome various technical and operational difficulties of the project. As mentioned above, a good relationship also existed between the contractor and federal officials in the executive level from early after the contract was awarded until the end of the project.
- *Condition cited as essential to success by DOE*: Project managers (in owner's as well as contractor's organizations) are experienced professionals dedicated to the success of the project. Each demonstrates leadership, is a project team builder as well as a project builder, possesses the requisite technical, managerial, and communications skills, and is brought into the project early.
  - *Comparable lesson learned from the Hoover Dam project*: Apart from the interior secretary who paid principal attention to the overall progress of the project and helped in addressing financial and political considerations of the project, and apart from the commissioner of the Bureau of Reclamation who was playing the role of project champion for the owner from the early days of the project through construction, a resident construction engineer was assigned to the project by the Bureau of Reclamation as soon as the construction phase started. Additionally, after commencement of construction operations, to strengthen the chain of command between site superintendent and company's senior management, the Six Companies Inc. assigned an executive committee consisting of four members.

- *Condition cited as essential to success by DOE*: Contract incentives are clear and unambiguous, appropriate to the performance objectives, and adequately compensate the contractor for the use of resources, risks, and performance contribution to the owner's objectives.
  - *Comparable lesson learned from the Hoover Dam project*: One of the driving forces of the Hoover Dam project, specifically during the construction period, was completing the project on time. To guarantee the timely execution of the project, the construction phase had been divided into major sub-phases and specific deadlines were set for each one of them. To make sure the contractor was meeting the deadlines, a particular clause was incorporated in the contract specifying a penalty for each day the contractor violated the deadline. For instance, the deadline for diversion of the Colorado River was set as October 1st, 1933. The fact that the contractor had to pay $3000 for each day passing this deadline persuaded the contractor to work on the four diversion tunnels at the same time during winter 1931–1932 and finish the job before spring when the water level rises. This strategy also contributed to the project team's early stage acceleration of the project and finishing the project two years ahead of the schedule.
- *Condition cited as essential to success by DOE*: The half life of the political sponsors that decided to proceed with the project exceeds the half life of the project. Thus, there will be no change in the political will during the execution of the project.
  - *Comparable lesson learned from the Hoover Dam project*: The Hoover Dam project team enjoyed a supportive relationship with the federal government during the course of the project from the initiation phase to the final stages of the construction. However, in 1933 when the Hoover administration gave way to the Roosevelt administration, the Hoover Dam project experienced significant challenges including the nullification of immunity from state taxes which was established by the Hoover administration. This gave the state of Nevada the right to collect taxes on the contractor's property within the Boulder Canyon Project site as a result of which Six Companies Inc. was required to pay $182,000 (Stevens, 1988).

5. Conclusions

The Hoover Dam project was very successful in the 1930's despite the depression for many reasons. Unfortunately it is highly probable that a similar megaproject would not be successful if it started today. This is due to several factors, including changing relationships between government and business, technological advances, and outsourcing. Additionally regulations regarding safety and overtime do not allow for the same practices that were utilized in the construction of the Hoover Dam. With respect to unique characteristics of the Hoover Dam project, including the location of the site, its geologic and topographic features, and the unusual size of the dam structure that necessitated use of new construction technology and equipment, the project team encountered considerable technical and managerial difficulties in the planning, design and construction phases. Despite all these challenges, construction of the Hoover Dam turned out to be a grand achievement and brought significant benefits to the owner, contractor, and other interested parties involved with the project.

The most important characteristics of the project, which are believed to have the highest contribution to the success of the Hoover Dam, can be summarized as follows:

- Project development activities including feasibility study, site selection, and conceptual design essential for satisfying legislative requirements as a result of which project mission, scope, and challenges were clear for all the parties involved with the project and helped them overcome project issues;
- Close relationship between project participants specifically Bureau of Reclamation and Six Companies, Inc. both at the field level and the executive level;
- Ensuring the design and engineering activities by assigning a design review board and implementing effective change management processes which minimized rework and delay during construction;
- Establishing a clear chain of command in the owner and contractor organizations to adjust relationships both internally and externally; and
- Supporting the project by securing adequate annual funding and relevant legislative and regulatory facilities.

A review of the Hoover Dam project history reveals the fact that to overcome project challenges, the project team came up with a number of strategies and practices that are comparable to practices recommended as critical success factors for today's megaprojects (Brady and Davies, 2010; Eweje et al., 2012; Kwak and Smith, 2009). Constructive relationships between project participants, effective project development and change management practices, and commitment of the project owner to support the project are among the key factors and innovative practices used by project participants (NRC, 1998, 1999, 2000).

References

Brady, T., Davies, A., 2010. From hero to hubris—reconsidering the project management of Heathrow's Terminal 5. International Journal of Project Management 28 (2), 151–157.

Cattell, D.W., Bowen, P.A., Kaka, A.R., 2008. A simplified unbalanced bidding model. Construction Management and Economics 26 (12), 1283–1290.

Chang, A., Chih, Y.Y., Chew, E., Pisarski, A., 2013. Reconceptualising mega project success in Australian defence: Recognizing the importance of value co-creation. International Journal of Project Management 31 (8), 1139–1153.

Davis-Bloom, Dylan, 2011. How Henry J. Kaiser and the government built the West. Academic Program Pages at Evergreen. (Evergreen. Web. 13 Sept. 2011. <http://academic.evergreen.edu/curricular/ageofirony/aoizine/dylan.html>).

Dolen, Timothy P., 2010. Advances in mass concrete technology—Hoover Dam studies. Hoover Dam 75th Anniversary History Symposium. American Society of Civil Engineers, Reston, VA, p. 58 ((2011). Print).

Dunar, A.J., McBride, D., 1993. Building the Hoover Dam: An Oral History of the Great Depression. University of Nevada Press, Reno, Nevada.

Elkind, S.S., 2008. Private power at boulder dam: utilities, government, power, and political realism. Department of the Interior, Bureau of Reclamation,

The Bureau of Reclamation: History Essays from the Centennial Symposium, Volume II, Bureau of Reclamation, Denver, CO, pp. 447–465.
Eweje, J., Turner, R., Muller, R., 2012. Maximizing, strategic value from megaprojects: the influence of information-feed on decision-making by the project manager. International Journal of Project Management 30 (6), 639–651.
Flyvbjerg, B., Bruzelius, N., Rothengarter, W., 2003. Megaproject and Risks. An Anatomy of an Ambition. Cambridge University Press, Cambridge, UK.
Gates, M., 1959. Aspects of Competitive Bidding, Annual Report. Connecticut Society of Civil Engineers.
Giezen, M., 2012. Keeping it simple? A case study into the advantages and disadvantages of reducing complexity in mega project planning. International Journal of Project Management 30 (7), 781–790.
Hecox, D.D., 2011. A majestic showcase: the new Hoover Dam bridge reaffirms that American engineering can build great infrastructure despite the current economic challenges. Public Roads 74 (5), 2–7.
Herczog, M., 2010. Frommer's Las Vegas 2010. John Wiley & Sons.
Hiltzik, M., 2010. Colossus: Hoover Dam and the Making of the American Century. John Wiley & Sons.
Hoover, Dam, 2011. from http://www.usbr.gov/lc/hooverdam/index.html.
Jia, G., Yang, F., Wang, G., Hong, B., You, R., 2011. A study of mega project from a perspective of social conflict theory. International Journal of Project Management 29 (7), 817–927.
Kwak, Y.H., Smith, B.M., 2009. Managing risks in mega defense acquisition projects: performance, policy, and opportunities. International Journal of Project Management 27 (8), 812–820.
Lexington, Revisiting the Hoover Dam, 2011. Politics, Economics, Business & Finance. 22 Oct. 2011. Web. 25 Oct. 2011 http://www.economist.com/node/21533393.
Miller, R., Lessard, D., 2001. The Strategic Management of Large Engineering Projects. The MIT Press, Cambridge, MA.
Morris, P., Hough, G., 1987. The Anatomy of Major Projects. John Wiley & Sons, New-York.
NRC, 1998. Assessing the Need for Independent Project Reviews in the Department of Energy. National Research Council, Board on Infrastructure and the Constructed Environment.National Academy Press, Washington, D.C.
NRC, 1999. Improving Project Management in the Department of Energy. National Research Council, Board on Infrastructure and the Constructed Environment.National Academy Press, Washington, D.C.
NRC, 2000. Characteristics of Successful Megaprojects or Major Systems Acquisitions. National Research Council, Board on Infrastructure and the Constructed Environment.National Academy Press, Washington, D.C.
Rogers, J.D., 2010a. Hoover Dam: first joint venture and construction milestones in excavation, geology, materials handling, and aggregates. In: Wiltshire, R. (Ed.), Hoover Dam 75th Anniversary History Symposium: American Society of Civil Engineers.
Rogers, J.D., 2010b. Hoover Dam: construction milestones in concrete delivery and placement, steel fabrication, and job site safety. In: Wiltshire, R. (Ed.), Hoover Dam 75th Anniversary History Symposium: American Society of Civil Engineers.
Savas, E.S., 2000. Privatization and Public–Private Partnerships, 2000, New York: Seven Bridges Press, LLC.
Smith, N.N., 2011. Classic projects: the Hoover Dam. Engineering and Technology 6 (2), 112–113. http://dx.doi.org/10.1049/et.2011.0243 (17509637).
Starr, K., 1993. Watering the land: the Colorado River project. Southern California Quarterly 75 (3), 303–332.
Stevens, J.E., 1988. Hoover Dam: An American Adventure/Joseph E. Stevens. University of Oklahoma Press, Norman.
Sun, J., Zhang, P., 2011. Owner organization design for mega industrial construction projects. International Journal of Project Management 29 (7), 828–833.
Tassava, C., 2003. Multiples of six: the Six Companies and West Coast industrialization, 1930–1945. Enterprise and Society 4 (1), 1–27 (Retrieved from EBSCOhost. Pg 9).
Toor, S., Ogunlana, S.O., 2010. Beyond the 'Iron Triangle': stakeholder perception of Key Performance Indicators (KPIs) for large-scale public sector development projects. International Journal of Project Management 28 (2), 228–236.
Van Marrewijk, A., Clegg, S.R., Pitsis, T.S., Veenswijk, M., 2008. Managing public–private megaprojects: paradoxes, complexity, and project design. International Journal of Project Management 26 (6), 591–600.
Walewski, J., Sadatsafavi, H., 2010. Megaproject success: Hoover Dam construction and pre-construction management ingenuity. In: Wiltshire, R. (Ed.), Hoover Dam 75th Anniversary History Symposium: American Society of Civil Engineers.
Wilson, E., 1931. Hoover Dam. New Republic 68 (874), 66.
Wolf, D.E., 1996. Big Dams and Other Dreams: The Six Companies Story/by Donald E. Wolf; Foreword by Richard Lowitt. University of Oklahoma Press, Norman.