A Case Study for Overcoming Obstacles During Planning and Construction Phases: MOX Fuel Fabrication Facility

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ABSTRACT: *The decision to construct the MOX Fuel Fabrication Facility in Aiken County, South Carolina, was largely a result of the Plutonium Management and Disposition Agreement between the United States and the Russian Federation, signed in September of 2000. However, the construction of the MOX Fuel Fabrication Facility has proven to be a more complex endeavor than many of the project planners had initially anticipated. To date, the project has yet to be completed, and in February 2019, the National Nuclear Security Administration issued a contract termination notice for the project. Currently, the United States Department of Energy is looking into what it refers to as the dilute and dispose approach to dealing with the nation's aging stockpile of weapons-grade nuclear material. The present research aims to explore solutions for overcoming the failures that occurred during the planning and construction phases of the MOX Fuel Fabrication Facility. The paper proposes that the adoption of Integrated Project Delivery (IPD) and Public-Private Partnership (PPP) might provide solutions for such cases. This study is supported by a review of relevant literature examining the effects of implementing both IPD and PPP. The results of the study represent discussions and a summary of the research contribution.*

KEY WORDS: MOX Fuel Fabrication Facility, Dilute and Dispose Approach, Integrated Project Delivery (IPD), Public-Private Partnership (PPP),

INTRODUCTION

The Savannah River Site is a 310-square-mile nuclear materials research facility located in Aiken County, South Carolina. The site was originally commissioned during the Harry S. Truman administration and construction began in 1951. In the decades since then, the site has served a variety of functions. In the early years of the Cold War-era, the site functioned as a research facility for tritium and plutonium-based nuclear weapons. In 1953, the first of several nuclear reactors on the site, used to produce weapons-grade plutonium (also known as plutonium 239) went critical.[1] Since then, the Savannah River Site has been home to a myriad of projects involving nuclear materials. Most of these projects fall into one of three basic categories: nuclear weapons development, environmental remediation efforts, or nuclear energy production.

In 2001, a new project was proposed for the Savannah River Site, which would incorporate aspects of the three categories mentioned above, namely, the MOX Fuel Fabrication Facility (henceforth referred to as MOX FFF). MOX, or Mixed Oxide Fuel, is nuclear fuel that is composed of two or more fissile materials (most often uranium and plutonium).[2] The MOX FFF was proposed largely as a result of the *Plutonium Management and Disposition Agreement* between the United States and the Russian Federation, signed in September of 2000.[3] The agreement stipulated that both countries should convert 34 tons of non-essential nuclear materials into mixed oxide fuel to be used to generate electricity. More specifically, the treaty designated that each country should convert fissile materials from their respective nuclear weapons stockpile, following the trend of non-proliferation of nuclear weapons in the waning years of the Cold War. However, the construction of the MOX FFF has proven to be a more complex endeavor than many of the project planners had initially anticipated. To date, the project has yet to be completed, and in February 2019, the National Nuclear Security Administration issued a contract termination notice.

Case Study

The aims of this Case Study can be divided into three main sections. First, this study seeks to examine the reasons why the MOX FFF project failed. Next, this study aims to explore potential solutions for overcoming the problems that plagued the MOX FFF project. Finally, the Study identifies and evaluates "Lessons Learned" arising out of the failures of the MOX FFF Project that can provide insights for future projects with similar scopes of work.

This study aims to explore two possible solutions for overcoming the failures that occurred during the planning and construction phases of the MOX FFF. The paper proposes that the adoption of *Integrated Project Delivery* (IPD) as a project delivery method, and the implementation of the *Public-Private Partnership* (PPP) as a contract model, would both serve to establish necessary controls and incentives for the successful completion of the Project.

The rationale for this study is to offer a critical examination of the reasons why the MOX FFF failed and to establish a better understanding of the relationship between project delivery methods and overall project success. Furthermore, the Study will establish a compelling case for the benefits of both IPD and PPP for construction ventures with comparable scopes of work that might benefit from implementing either IPD or PPP or both. Before proceeding to examine IPD and PPP in greater depth, it would be beneficial to consider the history of the Savannah River Site.

The Savannah River Site

The land on which the site is located was acquired by the *United States Atomic Energy Commission* by invoking eminent domain. The 310 square mile plot consisting mostly of farmland had previously been divided into several towns and unincorporated communities, the most populous among them being Ellenton, Dunbarton, and Meyers Mill. The Federal Government engaged the DuPont de Nemours Corporation to build and operate the facilities. This partnership lasted until 1987 when DuPont notified the US Department of Energy that it would no longer operate and manage the Site. During DuPont's 37-year tenure at the Savannah River Site (SRS), several high-profile projects were executed with varying degrees of success. One notable project that the SRS was directly involved with was the remediation of contaminated soil resulting from the 1966 crash of a B-52 aircraft carrying four Mk28-type hydrogen bombs in Palomares, Almería, Spain.[4] Throughout the 1970s and 1980s, the SRS became increasingly involved in the remediation and environmental clean-up efforts, and in 1972, the SRS was designated as the first National Environmental Research Park. During the mid-1980s, SRS also began producing plutonium-238 to be used as fuel for NASA's deep space exploration program, and in 1997, the SRS began its Cold War Historic Preservation Program.

The MOX FFF Project

In 2000, (the same year that the US and Russia signed the *Plutonium Management and Disposition Agreement*) the SRS celebrated its 50th anniversary with the announcement of the planned MOX FFF. The United States Department of Energy signed a design-build contract with a consortium known as Shaw Areva MOX Services, LLC.[5] The Shaw group was one of the largest engineering and construction companies in the world, listed as a Fortune 500 company before being acquired by Chicago Bridge & Iron Company in February of 2013. The Areva contingent in the LLC is a French multinational group that specializes in nuclear technology. The United States congress mandated that the MOX Fuel Facility be licensed and regulated by the US Nuclear Regulatory Commission. The NRC was responsible for reviewing and approving the design documents for the project and issued its construction authorization in March 2005. It should be noted that at the time, this was the first such construction authorization issued by the NRC in over 20 years. The construction phase of the Project began in 2007.

According to the US Department of Energy's audit report, the original budget for the facility was estimated to be approximately $7.7 billion.[6] The original baseline schedule approved in 2007 had a completion date of September 2016. As the Project advanced, however, it became a quagmire of money and resources, due in no small part to poor planning and poor governmental oversight. The United States Congress continued to approve and continue funding for the Project long after it had become evident that the Project was untenable. By 2018, the budget estimate for the Project was increased to $9.9 billion. According to a report given to Congress by the Department of Energy in November 2017:

"Construction remains significantly over budget and behind schedule. The MOX production objective was not met in 2015 or 2016 and will not be met in 2017. The Department of Energy continues to support the mission to dispose of excess weapon-grade plutonium, withdrawn from nuclear weapon programs so that the plutonium can never again be readily used in nuclear weapons. However, due to the increasing cost of constructing and operating the MOX facility, both the Department's analysis and independent analyses of U.S. plutonium disposition strategies have consistently and repeatedly concluded that the MOX fuel strategy is more costly and requires more annual funding than the dilute and dispose approach." (U.S. DOE, pg. iii)[7]

In addition to the shortcomings on the part of individuals responsible for managing the Project, it would be pertinent to also acknowledge some of the contingent features of the Project that contributed to its failure.

One significant factor is that nuclear material has a strong social stigma attached to it, which has a tendency to polarize public opinion. On the one hand, some view nuclear energy as forward-thinking and environmentally responsible when compared to carbon-heavy forms of energy production like coal and fossil fuel. Many, on the other hand, view it as inherently unstable, highly hazardous, and a threat to national and global security. This negative social perception has likely contributed to some degree to the difficulties that the SRS has faced from its inception in the early 1950s. However, social perception alone has not been enough to bring such a behemoth to its knees. The failure of the MOX FFF was a result of bad project planning, inadequate risk management, and poor labor relations, all of which resulted in scores of legal claims and disputes from contractors working on the Project, local communities, and the Federal Government.
Considering that one of the primary aims of this study is to draw lessons learned regarding what to avoid when managing such a project, it would be beneficial to examine some of the more significant legal claims more closely.

Legal Claims

Since the US Secretary of Energy effectively terminated the contract for the MOX FFF in February of 2019, several high-profile court cases have emerged related to the failed project. Many of these involve the misappropriation of federal funds on the part of contractors and firms involved with the project in various capacities. One such lawsuit was filed by a project engineer with backing from the US Federal Government. The lawsuit was filed against MOX Services and Orano Federal Services.[8] The engineer filing the lawsuit claims that after being hired by Orano, he came into conflict with one the site supervisors regarding the inspection protocols on the site not meeting those required by the Nuclear Regulatory Commission. In October of 2017, he was given the job of revising a mechanical piping inspection plan. The site supervisor then rejected the engineer's inspection plan and produced a plan that did not adhere to the NRC's standards. The engineer raised concern that the plan created by the supervisor was inadequate and, consequently, was demoted shortly thereafter. In addition, the engineer reported that before his demotion, he had been given bonuses by Orano that he claims were not properly accounted for. According to the lawsuit, the engineer's initial salary was $95,000, but he was given bonuses ostensibly for relocating, something he did not actually do. Officials at Orano told the engineer to spend the money "any way he liked" and "we don't require proof or receipts on how you use the money".[9] Considering all of the facts presented in this case it appears that Orano was giving kickbacks to quality control inspectors that resulted in inspections that ignored NRC's safety standards. The federal government has joined the engineer and other individuals employed on the project, in pursuing a legal remedy for such claims. According to another False Claims Act lawsuit filed by the United States in connection with the MOX FFF contract, another company:

"Wise Services falsely claimed reimbursement under its subcontract with MOX Services for construction materials that did not exist, and that in turn MOX Services knowingly submitted $6.4

million in claims to NNSA for the fraudulent charges submitted by Wise Services. The complaint further alleges that Wise Services' Senior Site Representative Phillip Thompson paid kickbacks to MOX Services officials with responsibility for the subcontracts to improperly obtain favorable treatment from MOX Services". (U.S. DOJ, Press Release Number: 19-125)[10]

Although these lawsuits do not fully explain why the MOX FFF exceeded its initial budget so dramatically, they do hint at several important insights about the Project. Firstly, they indicate that the companies managing various aspects of the Project lacked oversight and seemingly acted without accountability. It appears that companies such as Orano and Wise used their federally funded expense accounts frivolously and to self-serving ends. According to Assistant Attorney General Jody Hunt, of the Department of Justice's Civil Division, "Government contractors who line their bank accounts by receiving kickbacks or submitting fraudulent claims undermine the public's trust in government programs and operations. We will continue to vigorously pursue those who misuse taxpayer funds." The scale of the MOX FFF project, compounded with the lack of funding oversight contributed significantly to its failure.

What lessons can be drawn from the failure of the MOX FFF? Among construction project planners and those who work on legal claims within the construction industry, it is widely agreed upon that privately funded projects tend to be leaner with their expenses than publicly funded projects. Oftentimes companies that lack ethical grounding feel that they can play fast and lose with public funds. Many contractors feel more comfortable bidding on public projects for precisely this reason. Additionally, public projects have a tendency to be less innovative than privately funded projects. Oftentimes private projects utilize cutting-edge technology while public projects lag behind with decades-old practices. It is likely that both of these factors contributed to the dramatically ballooning budget and the continually increasing schedule delays that beset the MOX FFF.

Public Private Partnerships (P3)

In recent years, public-private partnerships (P3) have gained a great deal of positive attention for addressing some of the issues mentioned above. While it is worth considering that nuclear-related projects raise issues of national and global security and therefore should continue to be regulated and controlled with responsible oversight from federal agencies, more innovative methods for the safe disposal and repurposing of nuclear materials might be found in the private sector. Currently, the United States is looking into what it refers to as the dilute and dispose approach to dealing with the stockpile of weapons-grade nuclear material. The DOE has contended that this approach will cost less than half of the remaining lifecycle cost of the MOX FFF. Many citizens, local communities, and lawmakers alike feel strongly that this is not the responsible solution to dealing with our retired and aging nuclear arsenal. What solutions might exist for resolving this dilemma?

Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) is a project delivery method employed within the construction industry. IPD initially began to gain attention within the construction industry during the late 1990s, however, it has since gained a somewhat mixed reputation. One key factor inhibiting the wider adoption of IPD, is that the benefits associated with IPD have not been sufficiently examined. Additionally, this research seeks to establish a better understanding and be able to elaborate to readers the reasons why IPD has yet to be more widely accepted in the construction industry.

Like many other novel and innovative ideas, IPD has largely been either resisted or ignored among many project owners, design professionals, and contractors alike. The construction industry has a widely recognized reputation for being reluctant to adopt and adapt to new and unfamiliar practices. As a result, both innovation and improvement within the construction industry tend to occur much less frequently than in traditional manufacturing industries. The most often cited explanation for why changes take longer to implement within the construction industry is that the consequences of failures can be significantly more impactful than in many other industries. The negative impacts resulting from failures in the construction industry range from hazards to human health and well-being to sizable monetary losses. Other impediments also contribute to the conservative and hostile attitudes toward innovative practices that characterize the construction industry. These include the fragmented nature of the owner, designer, and builder relationship, and the lack of exposure to the benefits associated with innovative practices. Lack of exposure is the primary impediment that this study seeks to remedy.

LITERATURE REVIEW

The research objective for this literature review will be to lay the foundation for a better understanding of the potential benefits that Integrated Project Delivery could have provided during the planning and construction phases of the MOX FFF. The first step in working toward this objective will involve establishing the rudimentary elements of IPD. Once that goal has been met, the next aim will be to assess the potential net-value that IPD can bring to the MOX FFF and other construction projects with similar scope of work. Upon adequately exploring this topic, the next objective will be to outline a series of metrics that can be observed regarding construction project success and then comparing the measured data taken from projects that employed IPD as a delivery method against projects that did not employ IPD as a delivery method. What follows will be an examination of existing research literature that corresponds in various ways to each of the steps that are outlined above.

One research article that provides information relevant to this Study is entitled, "Assessing the Benefits of the Integrated Project Delivery Method: A Survey of Expert Opinions" written by Alberto De Marco and Ahmad Karzouna. The primary appeal and purpose for including an investigation of this article is that it provides a coherent and detailed definition of IPD. While this may seem like a simple requirement for any article related to IPD, many articles assume that the reader is already familiar with most features of IPD. This article devotes an entire section to defining the key features of IPD. In so doing, it also manages to set aside sweeping value judgements. Offering up a succinct and accurate definition of IPD is not an easy task due to the fact that IPD itself is not as rigidly defined as many other project delivery methods. IPD has many features that can vary depending on the exact requirements and the scope of work for the project. Still, De Marco and Karzouna provide an accurate and adequately detailed definition of IPD in their text. They write:

"A multi-party agreement (MPA) among key participants is a bedrock of achieving IPD goals. Participants execute a single contract to define their roles, duties, obligations, liabilities, and rights. As a single agreement is formed each party understands its relationship with the other participants. MPA agreements require trust as overall project success and individual one basically rely on the level of contributions of all participants which means that all members have to work as one team to meet the goals planned." (De Marco and Karzouna 2018, 824).

The attention given to the multi-party agreement is a key component that many other definitions of IPD lack. A great deal of writing on the topic of IPD either seeks to praise or dismiss IPD without establishing a neutral definition, however, the authors of this article maintain a neutral and objective position when they write:

"The organization of IPD teams varies significantly based on the size and technical details of the project. The size affects the number of teams, their individual scope, and how they will be directed and coordinated. The technical details of the project will determine how organizations are grouped and whether, and how teams are overlapped. The most effective teams are neither very small (under 4 or 5) nor very large (over a dozen). Very small teams are likely to lack for a diversity of views, and teams of more than 12 have difficulty getting much done" (De Marco and Karzouna 2018, 825).

Providing an accurate and succinct definition of IPD is an important feature of this research project that many similar projects seem to overlook. Upon establishing a sufficient definition of IPD, the next objective is to assess the potential net-value that IPD can bring to construction projects. Although this research project seeks to understand the relationship between project delivery methods and project productivity, one other key metric that can be equated with value on construction projects is performance. One article that deals with this topic directly is entitled, "Exploring performance of the Integrated Project Delivery Process on Complex Building Projects". This quantitative research article employed a method known as General Performance Model (GPM) analysis as means of overcoming limited access to data from completed projects that implemented IPD as a delivery method.

The authors explain:
"Due to the number of required variables to analyze and the limited number of completed IPD projects, an empirical study of project performance is impractical. This research helps to fill the gap of knowledge by modeling IPD performance through a methodology of decision-making and simulation called the General Performance Model" (Mesa, Molenaar, and Alarcón 2016, 1090).
This insight and recognition regarding the lack of required projects and the number of required variables demonstrated judicious effort on the part of the authors. The GPM methodology that they employed was worthy of exploration. The authors write that "the analytical processes for the GPM

method require data for a cross-impact analysis" (Mesa, Molenaar, and Alarcón 2016, 1093). The first step in their data collection involved identifying qualified professionals according to three criteria. These were:

(1) At least 10 years of professional experience in the building industry;
(2) Direct involvement in the management of building construction projects;
(3) Experience in DBB, CMR, DB, and IPD; and
(4) And an advanced degree in the field of civil engineering, architecture, or other related field (minimum of a bachelor of science) (Mesa, Molenaar, and Alarcón 2016, 1093).

Upon locating individuals that meet these requirements, the authors had them participate in three workshops comprised of group discussions centered around the topic of organizational structure and its impact on performance. For the purposes of this project, the focus with be aimed at their findings related to IPD. The data collected by the authors indicated that IPD had a positive impact on communication. This meant that projects were less likely to encounter delays and additional costs. Furthermore, "The workshop participants similarly assessed the IPD organizational structure to have a positive effect on the alignment of interest and objectives" (Mesa, Molenaar, and Alarcón 2016, 1098). While these conclusions are in accordance with the positive assumptions of this paper, their veracity should be investigated further. To this end, further corroborating data will be examined.

What follows will be an examination of a research article entitled, "Synergistic Effect of Integrated Project Delivery, Lean Construction, and Building Information Modeling on Project Performance Measures: A Quantitative and Qualitative Analysis" written by Phuong Nguyen and Reza Akhavian. Although this article does not deal exclusively with IPD, it does provide pertinent data for the purposes of this project. The research objective of the authors was to explore whether project delivery methods have an impact on project cost, project schedule, or overall performance. The methods of gathering data employed by the authors varied according to their research aims. For the qualitative aspect of their research, they conducted "phone interviews, emails, and other online materials" (Nguyen and Akhavian 2019, 4). The data used in their quantitative analysis consisted of "descriptive statistics cost performance and schedule performance" (Nguyen and Akhavian 2019, 5). The sample information used to derive this data was taken from 72 different construction projects that each implemented either IPD, Lean, or BIM, or some combination of them. The data analysis method employed by the authors cited above, namely, descriptive statistics analysis, also incorporated something known as a normality test, the Kolmogorov-Smirnov test, and the Shapiro-Wilk test.

One oversight that can be identified on the part of the authors involves the fact that they do not address the possibility of their data being impacted by confounding variables. They tacitly assumed that variations in project cost, schedule, and performance were a direct result of either IPD, Lean, or BIM, when in reality, projects are affected by a myriad of conditions and contingencies like weather and economic conditions.

In their concluding remarks, the authors recounted the findings of both their qualitative and quantitative research. Regarding their quantitative inquiry, they wrote the following:

"According to analyzed outcomes, for projects that implement a full combination of ILB, (1) the effect on the cost performance index was not statistically significant, (2) the effect on the schedule performance index was statistically significant, and (3) the effect on the cost performance index and schedule performance index, collectively, was statistically significant" (Nguyen and Akhavian 2019, 8)

This research outlines a series of metrics that can be observed regarding construction project success and then compares the measured data taken from projects that employed IPD as a delivery method against projects that did not employ IPD as a delivery method.

The next article comprising this literature review is entitled, "Exploring the Factor-Performance Relationship of Integrated Project Delivery Projects: A Qualitative Comparative Analysis." The research problem that the authors seek to investigate involves the relationship between IPD and a series of items known as critical success factors (CSF). In essence, the project seeks to identify and better understand what specific types of actions that are implemented on IPD projects actually contribute most to the overall success of the project.

At the outset, the authors distinguish the aim of their research from that of many other research projects (both qualitative and quantitative) that seek to compare IPD to other project delivery methods. They point out that "although these studies are successful in highlighting the superiority of IPD over other delivery systems, they did not answer the important question concerning how to implement IPD successfully given the situation where a project is put" (Yu, et al., 2019, 335). The authors also explain the rationale and motivation behind their research. They state that they hope the results of their research will "help practitioners decide whether or not they apply IPD in their projects and determine which CSFs they need to take into account more significantly depending on their project-specific situations and performance goals" (Yu, et al., 2019, 336).

The authors employ a research methodology known as Qualitative Comparative Analysis (QCA). More specifically, they apply something known as a fuzzy-set QCA. This specific type of QCA is distinguished from the more traditional QCA which allows researchers to review causal relationships using a small number of cases. As input data, it uses two types of variables. The independent variable is the set of conditions, while the dependent variable is the outcome event. The QCA uses these variables to create something known as a truth table. From that, researchers can derive both necessary conditions and sufficient conditions. However, when researchers are dealing with several variables, the traditional QCA is not applicable, because the results need to be Boolean-based (either 1 or 0). The fuzzy QCA, however, can incorporate decimal points between 1 and 0. The authors of this research employ a 5-point fuzzy answer set. More specifically, they developed a survey and assigned the types of responses with numbers: 0, 0.25, 0.5, 0.75, and 1.

The authors identify 4 different performance areas: schedule, cost, defects, and change orders. Within each of these performance areas, they ask a survey question. For example, within the schedule performance area, they ask, “How do you evaluate the schedule performance of the project compared to as planned?” (Yu, et al., 2019, 339). The survey with these questions was given to individuals who have taken part in IPD projects. The survey also consisted of two parts. The first part asked whether each CSF was implemented on their project. For this, the response was either yes or no. The second part of the survey asked participants to rank their performance along the 5-point fuzzy answer set. Although this research method is qualitative in nature, it does use empirical data to produce numerical figures that can then be evaluated.

The population for this project consists of representatives from 16 different projects that have implemented IPD. The authors contacted owners, architects, and contractors from these projects. The authors state that the participation rate among the individuals that they contacted via email was 33%, which they considered low. To remedy this, they contacted individuals by telephone. Overall, the authors found 33 participants for their survey. This group consisted of the following: 10 owners, 8 architects, 10 contractors, 2 subcontractors, and 2 others. All participants were based in North America. As a result of their research, 17 factors were identified as necessary conditions across all four performance areas for the overall success of the IPD project.

The primary limitation of this research stems from the fact that the 25 initial Critical Success Factors used as an independent variable by the authors were taken from existing literature. Although the authors cite and discuss the research from which these CSFs were taken, one might claim that this limits both the relevance and quality of this research. In essence, the authors are taking 25 CSFs that have been identified in previous research and deeming 17 of them to be necessary for success on IPD projects. According to the results of their Qualitative Comparative Analysis, the authors conclude that 17 factors can be considered necessary conditions for success on IPD projects. These include the following:

“A risk-sharing plan, negotiated and agreed project goals, goals-owner’s desired outcomes alignment, early goal definition, clear decision-making roles, empowerment of team members, improvement of design before construction, careful contract review, good communication atmosphere, appropriate tools for communication, regular formal meetings, open-book policy, collaborative activity during estimation, efforts in reducing waste in time, early owner participation, quick owner decision making, established process for handling change orders” (Yu, et al., 2019, 340).

The information in this article is well organized and presented in a linear format. Although the methodology discussed by the authors is quite complex, they commit to commonly understood phrases whenever possible. Overall, this article presents data that is both pertinent and potentially beneficial to the MOX FFF project.

The next research project in this literature review does not deal specifically with IPD, however, it does examine existing studies on factors that affect productivity on construction projects. For this reason, it serves as a pertinent follow-up on the research conducted by Yu, et al, as outlined above. This research project, entitled, "Factors Affecting Construction Productivity: A 30-Year Systematic Review", is a literature review comprised of 46 different articles that each deal with the topic of construction productivity. The authors' aim in this project is to identify any points of consensus between these articles. Additionally, they sought to highlight gaps and oversights in the existing research. The authors write, "Since construction projects are labor-intensive and exposed to both internal and external environment, a whole range of different factors such as weather, site and job conditions, labor skill, training and motivation could affect construction productivity" (Hasan, et al. 2017, 921).

"Capitalising Teamwork for Enhancing Project Delivery and Management in Construction: Empirical study in Malaysia" seeks to provide an analysis of the ways in which teamwork can be improved on construction projects. Although this project does not deal specifically with IPD, the findings are pertinent due to the fact that increased teamwork and productivity are commonly cited attributes and features of IPD projects. The methodology employed in this project consists of a literature review as well as a descriptive statistical analysis of data derived from questionnaires distributed to construction project participants based in Malaysia. The authors indicate in their findings that three aspects of teamwork have paramount importance in improving project success. These are: "project performance, decision-making capability, and problem-solving ability" (Yap, Wen and Skitmore 2020, 1498). These findings are much more pertinent when compared and contrasted with the data outlined above in the study conducted by Yu, et al.

"A Case Study Performance Analysis of Design-Build and Integrated Project Delivery Methods", written by Simon Adamtey, offers a comparison of both design-build and integrated project delivery. The article employs a research methodology known as a comparative case study analysis. This is an example of a mixed-method design, which is neither wholly quantitative, nor qualitative, but instead incorporates aspects of both approaches. More specifically, this study takes aim at analyzing and comparing the "construction of two transmission control building facilities" (Adamtey 2021, 68). According to the information provided regarding the sample population, both projects were conducted by the same firm, within the same region. Due to confidentiality, however, the specific details about the company and region are omitted.

During the construction phase for each project, data was collected and organized along five distinct categories: total cost growth, cost per square foot, total schedule growth, construction intensity, and change-order factor. The author also provides a detailed account of the differences between both design-build and integrated project delivery. One pertinent point about the methodology employed by the author is that the comparative case study analysis is not intended to make a case regarding causal relationships. Instead, it merely analyses and compares differences between two case studies. For this research, the project delivery method served as the independent variable. For each of the five performance metrics:

"Two types of cost and schedule data were collected: estimated data, and final completion data. The estimated cost and schedule data were the original-budgeted cost and estimated duration of the projects, respectively. The final cost and schedule data were the actual cost and duration that the project team, or design-builder took to complete the project. The metric for the change orders was simply the total amount of change orders added to the cost of the project. Equations (1–5) were used to calculate the performance metrics." (Adamtey 2021, 76)

The results of this study conclude that the IPD project outperformed the DB project across most metrics. Although both projects went past the total duration for their initial baseline schedule, the scheduled growth for the IPD project (2.2% or 12 days) was significantly smaller than that of the DB project (4.5% or 18 days). The IPD project had a significantly lower cost per square foot when compared to the DB project. The DB project had nearly three times as many change orders. The metric "construction intensity" refers to the measurement of the speed in which the project was designed and built. Along this metric, "the IPD project was constructed about 14% faster than the DB project" (Adamtey 2021, 77). Although the sample population used for this research was limited to only two projects, the results strongly indicate that the IPD project outperformed the DB project. Furthermore, the author cited previous studies which corroborate these findings.

Upon having reviewed literature that examines IPD, consideration should also be given to studies that examine Public Private Partnerships. Like IPD, PPPs can be defined in a variety of ways depending on the context of its use. PPPs have several unique arrangements, each suited for specific needs. A general and concise definition can be found in the work, "Public-Private Partnership" by Monika Sharma and Anita Bindal. The authors define PPPs as "a project based on a contract of the concession agreement, between a government or statutory entity on the one side and a private sector company on the other side, for delivering an infrastructure service on payment of user charges" (Sharma and Bindal 2014, 1271).

One might wonder if the PPP model, according to this definition can be applied to the construction of the MOX FFF. PPPs can and have in fact been tailored to large and complex projects like the MOX facility. According to the research of LiYaning Tang, et al., "the most successful PPP Project in China perhaps is Laibin B power station in Guangxi in 1997 (Tang, Shen, and Cheng 2010, 683). Although Laibin B is a coal-fired power plant, its size (3,300,000 square feet) is considerably larger than the MOX facility (500,000 square feet). Factors other than the mere size of the project have a significant influence on the applicability and overall likelihood of success for PPP projects. According to Tang, et al., in their review of papers relevant to PPP published in the six leading construction management journals, "The relationship between organizations within the public and private sectors is perceived to be crucial to the success of PPP projects because a poor relationship would easily lead to misunderstanding and conflict (Tang, Shen, and Cheng 2010, 688). This emphasis on the quality of relationships between the public and private sectors also applies to the selection of contractors. The authors write, "For choosing suitable contractors, researchers have not only suggested benchmarking the 'best' selection practices, but have also emphasized 'innovative' contractor selection approaches to be used by large public clients, in which relationship is always regarded as a key criterion" (Tang, Shen, and Cheng 2010, 688). The emphasis given to relationship and communication calls back to the research regarding the benefits of IPD. This serves as a possible indication that IPD and PPP might complement each other in that both give considerable attention to facilitating greater communication and thus greater relations between the various parties involved in the project.

The research of Tang et al. provides an examination of empirical studies of several subtopics related to the PPP arrangement. Among them are financing, project success factors, risks, concession periods, and choosing the right type of PPP. The last among these is an important topic considering PPPs can be organized in unique ways depending on the scope of work and needs of the public institution involved in the project. Some PPPs include responsibility for maintenance and operation over a period of time specified in the contract. Tang et al. write, "In individual situations, different types of PPP need be carefully selected to adapt to real situations. Since the failure rate of joint ventures has been high, partners are recommended to monitor both the internal and external conditions in the host country" (Tang, Shen, and Cheng 2010, 690). This insight is relevant to the case of the MOX Facility as the prime contractor selected for the project was a joint venture between a French multinational company, Areva, and The Shaw group, based in the United States. Tang et al write, "internal factors include partner fit, partner relations, and structural characteristics, while external factors include host country conditions and project risks (Tang, Shen, and Cheng 2010, 690).

Another research project that examines specific challenges to implementing PPP arrangements in Russia provides several interesting and useful insights. The authors write:

"The specifics of the PPP Projects are in its large-scale financing not only by the public side but by the private capital as well. Our view is that the government, as a participant, who should be more interested in implementing the PPP projects, as they are viewed as instruments of a country's infrastructure development, should bear some sort of financial responsibility not only in project financing but also as a budget guarantor." (Kolesnikov, et al. 2018, 190)

Although the authors refer specifically to the challenges of successfully adopting the PPP arrangement in Russia, their insights into the responsibility of the public sector party in the arrangement to be responsible for financing as a budget guarantor.

Although there are several different arrangements of PPPs each suited for specific project needs, one necessary precondition for the adoption of any PPP arrangement is some form of long-term revenue generation. This is due to the fact that the primary incentive for any privately-owned entity to get involved in the partnership in the first place is remuneration and return on investment. In the case of the MOX FFF, revenue will be generated through the production of electricity upon completion and commissioning of the facility. This electricity can then be sold as a public utility. The private entity involved in the project will be remunerated over a period of time determined by the project planners and detailed within the contract between the public and private partners. The length of time in which the private entity is responsible for operating and maintaining the facility is known as the concession period. Several methods can be employed for determining the appropriate concession period for a project. According to the research of Xueqing Zhang:

"There are potential financial, economic, and social problems associated with the common international practice of presetting the concession period to a fixed length and then inviting the private sector to bid on other aspects of the project. An informed concession period determination methodology is needed to improve governmental decision-making in this regard to avoid these problems." *(Zhang 2009, 558)*

Careful consideration should be given to the concession period in any PPP arrangement. One of the primary incentives for the public entity involved in any PPP is the transfer of risk to the private entity during the concession period. However, if the concession period is not adequately researched and collaboratively planned by all parties involved in the project, the private entity might seek to renegotiate the terms of the partnership, or worse, go bankrupt during the concession period. According to the research of Hongyu Jin, et al.:

"The longer the concession period, the easier it is for private investors to recover their investment share. However, in real-life projects, some PPPs with long concession periods are still full of challenges since the market surroundings keep changing. As a result, private investors often require the provision of government guarantees to alleviate their financial risk." (Jin, et al. 2021, 522)

This insight is especially relevant to the circumstances surrounding the MOX FFF. Although the material used to produce MOX fuel is sourced from the United States' retired weapons stockpile, nuclear fuel is nonetheless a market commodity with fluctuations in value and price. Oftentimes these fluctuations in price are due to the price and availability of other cheaper sources of fuel. [11]

CONCLUSIONS AND RECOMMENDATIONS

It is the opinion of the authors that both the planning and construction phases of the MOX FFF could have benefitted in several ways by adopting both IPD as a project delivery method and PPP as a financing model. The case study portion of this research examines a very limited series of problems that occurred during the planning and construction of the MOX FFF. The problems that occurred during the MOX FFF project that are explored in this research is by no means exhaustive, and further research is likely warranted. The literature review portion of this research examines several features of both IPD and PPP that would serve to remedy some of these problems that occurred during the planning and construction of the MOX FFF.

Both IPD and PPP have the potential to bring net-benefits to the project independent of one another, however, there are also aspects of both IPD and PPP that, when applied together, have the potential to complement each other and provide compounding benefits. One example of the compounding benefits of implementing both IPD and PPP can be seen in the special attention that both give to increasing channels for collaboration and communication. The emphasis of communication is especially prevalent in the research regarding critical success factors for IPD projects. Giving priority to open and transparent communication has the potential to prevent the emergence of adversarial relationships, which can and often do plague construction projects. The benefits of transparent communication are compounded when considering the importance of determining concession periods and other vital details for PPP contracts. As discussed in the literature review portion of this research, concession periods are an essential component for successful implementation of any PPP. Many more compounding benefits of adopting both IPD and PPP are likely to exist, and the authors hope that future research continues to explore these topics.

In the event that the MOX FFF contract is renegotiated, and the United States Department of Energy does indeed choose to negotiate a PPP contract, the authors have one recommendation for the eventual transfer of the facility after the close of the concession period. Considering the highly sensitive nature of operating and maintaining a nuclear facility, the authors propose that the contract be transferred to the United States Army Corps of Engineers (USACE). Furthermore, the USACE might also serve as qualified candidates for one of the many consultant roles necessary during the planning and construction phases of the project. The USACE engages not only in military construction projects but also has a successful legacy of contributing to civil infrastructure projects as well.[12] Repurposing weapons-grade nuclear material to produce MOX fuel designates the construction of the MOX FFF as both a matter of national security and environmental safety. These are both spheres of knowledge where the USACE has demonstrated expertise (Kress et al. 2016).

The present research does not assume that the construction of the MOX FFF will be resumed or reestablished under a new contract. While acknowledging the unlikely nature of these events, the ideas explored in this case study and the supporting literature review might nonetheless provide insights for project owners, engineers, and construction planners involved in projects with a comparable scope of work.

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