Joint CSCE Construction Specialty & CRC Conference 2025
Conférence conjointe spécialisée en construction de la SCGC et CRC-2025

Montreal, Quebec
July 28-31, 2025 / *28-31 juillet 2025*

UNDERSTANDING A DECADE OF CHANGE IN PROJECT DELIVERY SYSTEMS AND THEIR IMPACT ON PROJECT PERFORMANCE

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ABSTRACT: This paper serves as a selection manual for project delivery systems (PDSs). This decision is both an early one – the selected PDS informs many of the procedural elements of a project (e.g., contract structure, timelines) – and a critical one – tailoring the selection of PDS to the project's unique conditions can improve results. The objective of this manual is to aid owners in selecting a delivery method that will promote success for their project. This manual is composed of four parts. (i) The concept file defines the four most prevalent PDSs. These include 1) Design-Bid-Build (DBB), 2) Design-Build/Engineer-Procure-Construct (DB/EPC), 3) Construction Management (CM) and 4) Integrated Project Delivery (IPD). (ii) The decision support tool offers the user a series of driving statements with predictive scores to help decision-makers winnow down the PDS options. (iii) Within the four PDSs, the research team identified 11 subsystems variants based on responsibility allocation, contracting strategies, and/or relationships among project parties. The subsystem selection tool uses flowcharts modeled on the driving statements to offer a model decision-tree approach to isolating the best subsystem available for that PDS. (iv) A performance analysis of the four principal PDSs using a performance metric called the Project Performance Score (PPS) was completed to compare the relative performance of each PDS on various projects. IPD was the best performing on average, followed by CM, DB/EPC, and DBB. Other comparisons were also performed to determine the relative success of each PDS in terms of key performance.

1. INTRODUCTION

One of the earliest and most essential decisions that must be made in any construction project is the owner's selection of which delivery method to use. Since the choice of project delivery system (PDS) will dictate the language in the contract and the timing of its signing, the owner must decide even before collaborative partners can be brought on board. Much of the existing literature regarding PDSs does not accurately reflect the current practice in delivering construction projects, showing cause for developing the manual. Over the last 20 years, there has been an increase in the literature published concerning PDSs, this trend has both fueled and fed off an industry-wide surge of interest in PDSs. In 2019 CII's Downstream and Chemicals (DCC) Sector Committee perceived that there was a need to reexamine the methods being used in the DCC sector to achieve several objectives: (i) Understand how PDSs were being used, (ii) Update commonplace terminology that had become outdated, (iii) Determine quantitatively the benefits and limitations of the PDSs then in use.

This goal of this document is to augment the existing body of knowledge that concerns PDSs and synthesizes the findings into a unified decision-making tool that project stakeholders can use. This report spells out the decision-making process within a project to help owners arrive expediently at the optimal delivery system and to present to all project parties a means of understanding the objectives of every other party, to better facilitate collaboration and the integration of the project unit. To achieve this objective, the research team devised a comprehensive survey (not contained in this document) that collected both the quantitative and qualitative factors that make up the owner's choice of a delivery system and that shape the lifetime performance of the project. The survey questions were based upon a review of existing literature, the research team's academic experience, and a collaborative discussion among the research team members. This report is designed to serve as an "owner's manual" for the decision-making process that surrounds selecting a PDS. It is composed of the following parts. The first part explains the concept file, which defines the indicators of applicability of each PDS and the conditions for successful application of that PDS. This will give the owner a good initial sense of which delivery system(s) to use. The second part contains the PDS assessment rubric, which provides the owner with an intuitive method of assessing the possible PDSs. The rubric assigns each major PDS a numeric score (on a 1 to 3 scale) and adds several guiding statements. By answering a series of questions, the user follows a path that ends with the subsystem that is best suited for the current project from within the selected PDS. The third part identifies the 11 subsystems variants based on responsibility allocation and/or relationships among project parties to offer a model decision-tree approach for isolating the best subsystem available for that PDS. The fourth part compares the PDSs to explain the analyses that underpin the team's recommendations throughout this manual. In addition, the final part summarizes the team's findings and deliverables.

This research effort undertook two principal tasks: (i) It identified, defined, and classified the various delivery systems currently employed in the downstream and chemicals sector. (ii) It created an easy-to-use resource that describes a methodology by which an owner may discern which PDS is most appropriate for a given project. The research team hopes that the use of this document can enhance and augment the decision-making process of industry members who choose to apply it, but the team does not intend that this should completely supplant any existing project delivery system selection tools that may be present. As with all CII-developed tools, readers should use this resource as but one element of their processes.

2. MAIN TEXT:

2.1 Concept File

This section introduces the definitions and descriptions of each delivery system discussed in this report to give the reader a greater familiarity with the four PDSs covered within this report.

Design-Bid-Build (DBB): Design-Bid-Build (DBB) is perhaps the most traditional process for delivering a project. The owner contracts with a design firm that performs the initial design and is responsible for generating 100% issued-for-construction design documents. That design is then put out to competitive bid, and contractors typically issue fixed price bids to perform the work. In most cases, the contract is awarded to the low bid, and the structure is then built to plans and specifications. **Design-Build/Engineer-Procure-Construct (DB/EPC):** Design-Build (DB) is a project delivery system that is characterized by a single contract between the owner and an entity that will perform both design and construction under a single design-build contract. In about 95% of cases the entity will be a contractor, though it may also be a designer/architect or a specialty design-build firm. DB permits subcomponents of the work (either design or construction) to be subcontracted to other companies, if necessary, though the DB entity may self-perform work that is within its capability. This system can (to an extent) be referred interchangeably with Engineer-Procure-Construct (EPC), as is commonly done in the DCC sector. **Construction Management (CM):** Construction Management is a mechanism of delivering projects whereby the owner separately retains a design firm to provide the plans and specifications for the project, and a contractor who will provide construction management services and supervise execution of the project. It is atypical for the construction management contractor to self-perform work on the project. It is typical that the contractor who is selected for the CM role will have an opportunity to provide input to the design process. The CM role typically takes one of two forms: Construction Manager as Agent (CMA) or Construction Manager at Risk (CMR). CII defines both CMA and CMR as mechanisms within the larger CM delivery system (CII 1997) and, as such, this report will treat them accordingly. Under CMA, the CM role typically acts as the owner's representative, making subcontracts necessary to ensure work is performed. Under CMR, the CM contractor typically agrees with the owner on a guaranteed maximum price (GMP). This amount is the project's budget and the point where the owner is no longer liable for payments. That is, once the owner has paid the GMP sum, it owes the construction manager no further money.

2.2 PDS Selection Rubric

The research team developed the PDS assessment rubric as a tool that increases understanding of the relative merits of the project delivery systems (PDSs) that this research effort examined. It also permits project participants to evaluate a new project before the contract has been signed. Primarily this means owners, but contractors may also find value in the project factors as a tool to improve team alignment in integrated and/or collaborative settings. The rubric is structured around a series of driving statements. To use the PDS assessment rubric, first review each driving statement and determine whether it applies to the project to be evaluated, then score each applicable question for the PDS(es) being evaluated.

The scoring system uses a three-point scale: 3 – Most Appropriate. This PDS has the highest degree of success in achieving the goal of the driving question or statement. 2 – Somewhat Appropriate. This PDS will permit some objectives of the driving question to be achieved but may not do so as intuitively or as completely as a PDS that scores "3." 1 – Least Appropriate. Using this PDS may make it difficult to realize the objective of the driving question. Consider other choices. X – Does Not Apply. This PDS, due to either its contracting mechanism or other internal factors, does not permit the driving statement to be achieved. This PDS should not be chosen.

To use the rubric, assemble a small group of individuals with knowledge of the project. Not every participant needs to come from executive leadership – feel free to include estimators, project managers, and labor supervisors (foremen), if available. As a group, discuss whether each driving statement applies to the project in question. If not, eliminate that statement. Next, users will score the PDSs they are considering by using the tailored list of statements. At the end, the PDS that scored the highest will be the one that the company should consider first. If this PDS does not meet project criteria or is opposed by the company, the group should suggest the PDS with the second highest score. Table 1, which can be found in the appendix, steps through the scoring rubric. Each factor's commentaries can be available upon request.

2.3 Selecting a Subsystem

What distinguishes one PDS from another is the matrix of responsibilities among project stakeholders. Within the confines of this research, the team defined five areas of responsibility: Project Management – includes cost control, schedule control, change management, and safety. Generally, has a larger scope of work than the construction manager and is responsible for defining and administering the relationships among contracting entities. Within this document, the duties of project management are performed either by the owner directly or by an agent the owner has appointed to do so (referred to as the project management consultant or PMC). If the owner retains a PMC to perform project management, the role still has the same scope of work defined in the preceding paragraph. The reasons for hiring a PMC vary and can include the owner's inexperience with the construction type or geographic region, lack of available or trained personnel to conduct project management in-house, or a desire to make a third party responsible for delivering the project on time and on budget. Alternately, the owner might have an existing relationship with the PMC firm that it could leverage. Engineering – includes design detailing, responding to requests for information, variations, scope of change, design administration, document control and reengineering as needed. Procurement – responsible for buying and scheduling delivery of major equipment and supplies throughout the project lifecycle. Construction Manager – responsible for the oversight of day-to-day construction, regulation of the subcontractor schedule, sequencing work to be performed, layout, site risk management, and constructability. Construction – executes the day-to-day construction of the project.

Every project assigns these five responsibilities to stakeholders; however, the precise combination of assignments determines which PDS the owner should utilize. The participants in these arrangements are expressed throughout this manual as equations of a sort. For example, PDS Subsystem 6 is written in the equation "O+E+P+Cm+C," and this describes a situation where the Owner (O) assumes responsibility for project management and contracts with firms for Engineering (E), Procurement (P), Construction Management (Cm), and Construction (C). Table 2 shows how the elements align for every subsystem (plus IPD, which has no subsystems).

IPD is not like the other PDSs for the simple reason that, under an integrated model, IPD stakeholders share responsibility for all elements and, by the nature of IPD, contracts are involved before any design is complete. It is not atypical for an IPD project team to include mechanical, electrical, and plumbing trades alongside the owner, project manager(s), architects/engineers, and the general contractor. For purposes of visualization, Table 2 shows IPD spanning every element. The unique make-up of IPD means it has only one subsystem and thus does not need to be considered in the following section.

Table 2: How the 11 Subsystems Allocate Project Responsibilities and Distribution of Those Projects

PDS*	Subsystem	Project Management	Engineering	Procurement	Construction Management	Construction	Number of Projects **
DB/EPC (27)	1	O	EPC				4
	2	O	EPCm			C	5
	3	PMC	EPCm			C	3
	4	PMC	EPC				7
CM (21)	5	O	EP		Cm	C	1
	6	O	E	P	Cm	C	3
DBB (33)	7	O	E	PC			2
	8***	O	EP		C		11
	9	O	E	P	C		4
	10	PMC	E	PC			1
	11	PMC	E	P	C		2
IPD (15)	IPD Project Team Shares All Responsibilities						0

*Distribution of all projects by delivery systems are included within parentheses (n=96).
**Distribution of the DCC projects by delivery subsystem (n=41).
***Subsystem 8 was used most frequently and is a close match with the “traditional” DBB system.

The 11 Subsystem Equations: To determine the equations for the 11 subsystem combinations observed by the research team, the columns from Table 2 must be added. Refer to Subsystem 6 example above. This table also shows how these subsystems fit into three of the four major project delivery systems. (Three PDSs because the fourth, Integrated Project Delivery, cannot be divided into distinct subsystems. IPD stakeholders share responsibility for all project responsibilities.) More detailed information on each subsystem is available upon request.

2.4 Research Results

This part presents the quantitative results of the analysis. The results of this research informed the recommendations and statements made in the preceding chapters. This report studied 41 projects from the DCC sector and supplemented them with a further 55 institutional projects. Data collection focused on projects completed within the last 10 years for recency and accuracy. Supplementary data collection was necessitated because the team felt that IPD should be included. Since IPD is not in wide circulation in the DCC sector, the team needed to collect additional data from projects outside the DCC. However, the institutional projects chosen were similar in scope and complexity to a typical DCC project and thus made accurate comparators. The ratio of use for the various PDSs was not evenly distributed. Table 2 breaks down the complete set of 96 projects by PDS and shows the 41 projects from the DCC sector separated by delivery subsystem. These results reflect the sector’s strong preference for some subsystems. The analyzed projects ranged in size from less than $10 million to over $200 million, but most projects from the DCC sector were over $50 million. To facilitate comparing various delivery systems that were different at the surface level, a standardized metric was needed. Research at UW–Madison had developed the Project Performance Score (PPS), which offered a multifaceted method for analyzing the performance of projects regardless of their delivery system (Labib 2019). PPS allowed RT-DCC-06 to make “apples to apples” comparisons between dissimilar projects. The formula given for the PPS within this document and in previous literature standardizes and weights the six performance metrics used within it, so a $10 million project delivered under IPD can be compared with a $3 million project delivered under DBB. Shown in Figure 1, the PPS is composed of five assessment areas, each with associated factor(s) commonly used in construction and defined in accordance with CII’s standard definitions. The factors shown in Figure 1 were modeled and synthesized into the logistic regression model, Eqn. 1, for calculating the PPS.

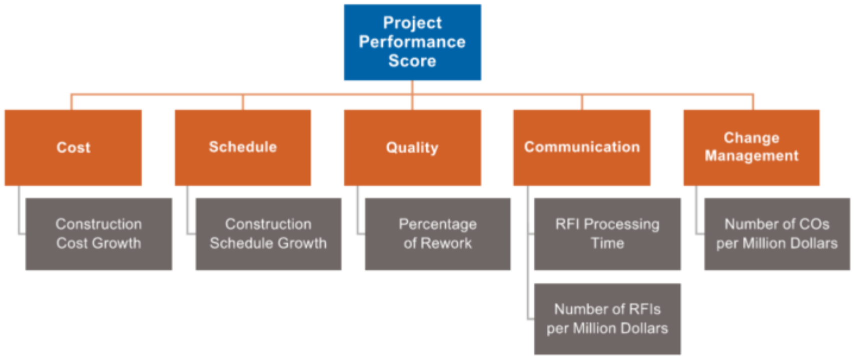

Figure 1: Project Performance Score Hierarchy

[1] $PPS = f(z) = 1/(1 + e^{-z})$

Where **z** is the weighted sum of coefficients:

z = 3.0426 – 7.5223 × Construction Cost Growth *[The percentage of change (increase or decrease) in project cost as compared to the base bid (CII 2009)]* **– 5.4789 × Construction Schedule Growth** *[The percentage of change (increase or decrease) in project duration measured against the contractual construction duration (CII 2009)]* **– 1.7480 × Percentage of Rework** *[The percentage of the direct cost of field rework divided by the adjusted final construction cost (El Asmar et al. 2015)]* **– 0.1253 × RFI Processing Time** *[The number of days a contracting firm must wait to receive a final response to its submitted RFI (CII 2018)]* **– 0.2216 × Number of RFIs per Million Dollars** *[The number of requests for information submitted from the construction team to the design team, divided by the adjusted final construction cost (CII 2018)]* **– 0.1058 × Number of Change Orders per Million Dollars** *[The number of change orders made to the construction contractual agreements, divided by the final construction cost (Ibrahim 2021)]*.

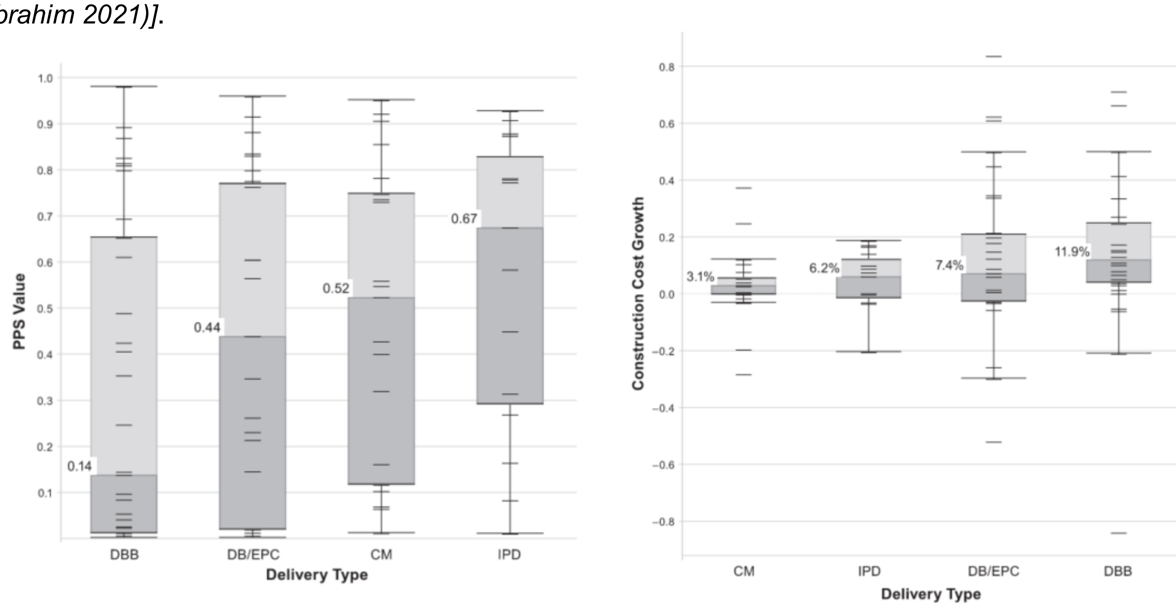

Figure 2: PPI Scores of Examined Projects by PDS (L) and Construction Cost Growth by PDS (R)

When the research team applied the PPS formula to the projects in this data set, the results were clear: DBB was the delivery system with the poorest overall performance, while IPD had the best overall performance. The results were confirmed via the Kruskal-Wallis test to be statistically significant at the 90% confidence level ($p=0.082$). Figure 2 shows the relative performance of delivery systems in terms of PPS values. (Noted values show the median for each respective system). Applying the basic theory of box-plot interpretation shows that, while IPD (median: 0.67) significantly outperforms DBB (median: 0.14), the variance within their respective results was such that a high-performing DBB project (which would represent an outlier compared to most of the data) could perform at a similar if not greater threshold in terms of PPS as an IPD project. This underscores the importance of using the selection methodology laid out in the preceding chapters of this manual.

Construction Cost Growth: Construction cost growth is defined as the ratio of the change in construction cost to the base construction cost; like the percent delta used in the PPS score. As Figure 2 shows, DBB was consistently the poorest performing delivery system in terms of cost growth (median value: 11.9%). DBB presents with this kind of cost growth due to the lack of mandated relationship between designer and constructor, and the reduced frequency at which constructability analysis is performed in this delivery system. CM had the lowest cost growth, which makes sense given the prevalence of GMP compensation in that delivery system. IPD had the second-lowest cost growth, with a far lower degree of variability than CM. These results were validated at the 90% confidence level (p=0.077) via the Kruskal-Wallis test.

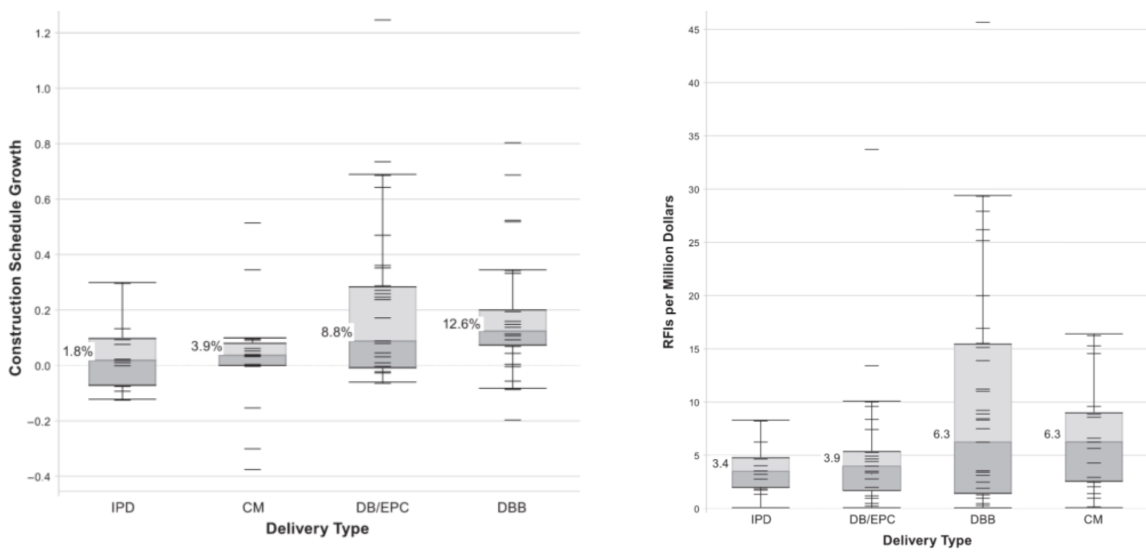

Figure 3: Construction Schedule Growth by PDS (L) and RFIs per Million Dollars by PDS (R)

Construction Schedule Growth: Construction schedule growth is the ratio of the project's duration (in days, weeks, or months, as applicable) to the estimated duration (in the same unit). Once again, as Figure 3 shows, the poorest performance in terms of schedule growth belongs to DBB (median: 12.6%). This is due to the less collaborative design process, the potential for adversarial relationships to develop between designer and constructor, and the lack of early coordination. IPD performed the best in terms of schedule growth (median: 1.8%), while showing lower variance than all other delivery systems. These results were validated at the 95% confidence level (p=0.032) via the Kruskal-Wallis test. **Requests for Information per Million Dollars:** "RFI/$1M" is a shorthand metric for project communication and design quality. In general, more RFIs are a bad sign. Figure 3 shows how DBB and CM performed worst in this metric (median: 6.3), while IPD was once again the top performer (median: 3.4). These results are explained by the early and integral involvement of the designer(s), engineers, procurement agents, and other similar parties in the IPD process. It was not surprising to see a high value in this metric for DBB, because the lack of mandated relationships between design and construction does not easily facilitate the exchange of information. However, the research team was surprised to see CM perform so poorly in this metric. After consideration, the team believes that enough projects within the data set employed the CM delivery system, but they did not retain the CM firm early enough in design to adequately coordinate the constructability of the project. **Change Orders per Million Dollars:** It is common knowledge that the fragmentation of responsibilities inherent to the DBB system leaves it open to a higher-than-average volume of change orders. As such, its placement as poorest performer (median: 0.64) in Figure 4 is unsurprising. IPD and CM performed better because their inherent collaboration enabled them to prevent or proactively minimize change more effectively. CM projects are typically executed as GMP contracts, which limits change through the existence of a cost ceiling. **Rework Percentage:** For this research, rework percentage is analogous to construction performance in the field. The lower rework percentages in Figure 4 (for IPD and CM) can be explained by those delivery systems' early involvement of all stakeholders and collaborative methodology. DB/EPC and DBB suffer in this metric due to their more segmented design processes.

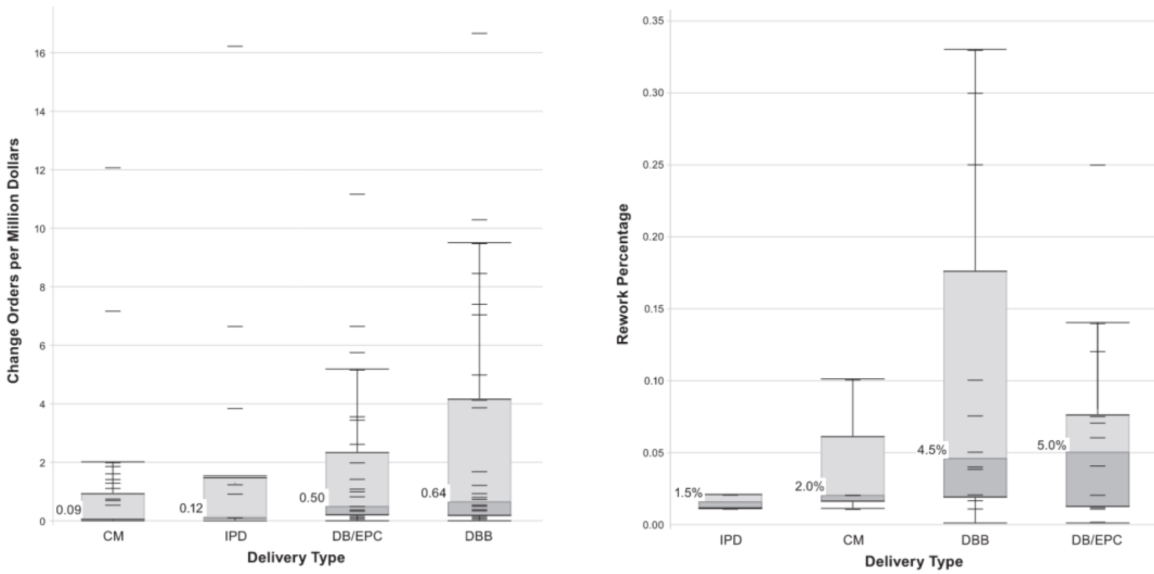

Figure 4: Change Order per Million Dollars by PDS (L) and Rework Percentage per PDS (R)

Table 3 summarizes the figures presented in this section, presenting a median score for each project delivery system beside each metric. The best score for each metric is highlighted in a boldface font, and the worst score is shown in italics. Note that this table, while a useful snapshot, does not consider the variability of each score. For full detailed results of a given score, consult the box plots.

Table 3: Summary of Performance Statistics (best score in **bold**; worst in *itali*cs)

Performance Metric	Project Delivery System			
	DBB	CM	DB/EPC	IPD
Project Performance Score (Maximum 1.0)	*0.14*	0.44	0.52	**0.67**
Construction Cost Growth	*11.9%*	**3.1%**	7.4%	6.2%
Construction Schedule Growth	*12.6%*	3.9%	8.8%	**1.8%**
Requests for Information per Million Dollars	*6.3*	*6.3*	3.9	**3.4**
Change Orders per Million Dollars	*0.64*	**0.09**	0.50	0.12
Rework Percentage	4.5%	2.0%	*5.0%*	**1.5%**

3. CONCLUSIONS

The CII Downstream and Chemicals (DCC) Sector Committee commissioned Research Team DCC-06 to address an observed need to continue the work of Research Team 341, Industrial Integrated Project Delivery, and to examine the state of practice in the DCC sector in terms of PDSs (CII 2019). The report's objective was to present the DCC sector with a comprehensive series of steps to aid the owner in the crucial selection of which PDS to use on a project. This study presented four major PDSs: 1) Integrated Project Delivery (IPD), 2) Construction Manager at Risk or Construction Manager as Agent (CMR or CMA), 3) Design-Build/Engineer-Procure-Construct (DB/EPC) and 4) Design-Bid-Build (DBB). Part 1 presented an intuitive concept file, to ensure that the definitions of each PDS were standardized for the decision support tools in Parts 2 and 3. Part 2 presented a table of driving statements and a method by which the owner can tailor these to reflect their project objectives. These statements are assigned various levels of appropriateness based on the empirical data collected by this research effort and the opinions of the team's industry members. The research identified 11 subsystems within the four major systems. These subsystems constitute variances in contracting practice present within the DCC sector but do not depart from a traditional PDS. Part 3 discusses the subsystems via a series of hierarchical diagrams and decision trees to help an owner understand which alternative is the most effective for the given situation. Part 4 presents the research results comparing them, though an understanding of the statistical and mathematical analysis performed is not necessary to use the decision tools presented in this report. The results of this comparison conclude that IPD was found to be the best-performing on average, followed by CM, DB/EPC, and DBB in that order.

There has been a lack of adoption of IPD across the DCC sector, especially given that previous CII research tailored the Integrated Industrial Project Delivery (I2PD) framework for industrial projects (CII 2019). Given the size (in market share) and scope (in millions) of the DCC sector, the research team urges its leaders to consider IPD or I2PD as an option to improve performance on future projects. The team first hypothesized that IPD would be the second most popular delivery system because all its members were aware of the popularity of DB/EPC. Yet, this was not the case for the data set analyzed. If IPD becomes more widely accepted in the DCC sector, this research effort should be repeated or updated as more DCC-specific IPD data becomes available. Any additional update would further enhance the applicability of the recommendations presented herein. The most essential element of any industry snapshot report such as this one is timeliness. That is not to say that these results will become inaccurate or inapplicable over time, but rather to acknowledge that construction frequently innovates and changes. Future work focused on expanding the data set or including other construction sectors would enhance industry understanding of project delivery, allowing for improvements to the owner's manual and helping project stakeholders make more informed decisions about selecting a PDS for future projects.

ACKNOWLEDGEMENTS
This work was supported by funding received from the U.S. Department of Energy (DOE) Office of Nuclear Energy's Nuclear Energy University Program (NEUP) under contract number DE-NE0009249. Funding was also partially supported by the Nuclear Regulatory Commission under award number 31310023M0047.

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APPENDIX

Table 1: Project and Owner Factors in PDS Scoring Rubric

Factors	Driving Statements	DBB	CM	DB/EPC	IPD
Project Size	This is a “small” project for our company. (*default: less than $100 million)*	3	3	2	2
	This is a “medium” project for our company.	2	3	3	3
	This is a “large” project for our company. *(default: more than $500 million)*	1	3	3	3
Project Cost	The budget needs to be established as early as possible.	3	2	3	3
	The owner’s cash flow for the project is constrained.	3	2	3	1
	Cost growth is a major concern.	1	2	3	3
Project Schedule	Preventing schedule growth is a key project objective.	1	2	2	3
	Project will require the procurement of specialty components with protracted lead times.	2	3	3	3
	The owner wishes to minimize total delivery time (including design and construction).	1	2	3	2
	The project has tight project milestones or deadlines.	1	3	3	3
Project Risk Allocation	The owner wants to transfer design and construction risks.	2	2	3	1
	All parties prefer to carry the risk of mutual protection from litigation.	1	2	3	3
	The owner is willing to have a mechanism in place to share cost and reward risk.	2	3	1	3
	Owner wants to minimize risk of errors and omissions in plans and specs.	1	2	3	3
Project Complexity	The owner wants to reduce the size and frequency of change orders.	1	2	3	3
	Project nature is complex and not highly standardized.	1	3	3	3
	The project is repeatable, highly standardized, or not complex.	3	3	2	2
	The project scope necessitates coordination of multiple trades, especially or additionally with complex work and sequencing.	1	3	3	3
Project Design	The project design is 20% complete.	X	2	3	3
	The project design is approximately 60% complete.	1	3	1	X
	The project design is approximately 100% complete.	3	2	2	X
	The owner wants to benefit from value engineering studies and constructability analysis.	1	3	3	3
	The owner desires to allow for freedom of innovation on both design and construction.	1	2	3	3
	The owner wants to minimize design-related claims.	1	2	3	X
Owner Control and Involvement	Owner willing to share project decision power with key project participants.	1	2	2	3
	Owner prefers to have high degree of control and influence over project.	3	1	1	2
	The owner wants to get involved with the design process.	2	2	1	3
	The owner is not familiar with project specifics and does not want to be involved with day-to-day operations.	2	3	3	1
	The owner prioritizes schedule control.	1	2	1	3
Owner Project Partner Choice	Owner wishes to benefit from competition and a large pool of qualified contractors.	3	2	1	1
	Federal, state, or local ordinances dictate which PDS may be used. (In every case where the research team saw this, IPD was prohibited).	3	2	2	X
Owner’s Relationships	Strong preexisting relationships between contracting parties allow early collaboration, starting from the design phase.	1	2	3	3
	The owner desires to have a direct relationship with the designer.	3	2	1	3
	All parties are willing to have complete transparency.	1	2	2	3
	The owner wants better communication in terms of scope change, RFI processing time, and change order processing time.	1	3	3	3