Owner and contractor solution strategies for industrial commissioning

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Abstract

Purpose – The purpose of this study is to discover which solution strategies to common industrial commissioning and startup (CSU) problems (Hot Spots) owner and contractor organizations identify as most effective and to identify which strategies are identified by one or both organization types.

Design/methodology/approach – Ratings for the relative value provided by strategies, and the effort required to implement strategies were solicited from CSU industry experts employed by owner or contractor organizations via a survey. Quantitative modelling using the Possible, Implement, Challenge, Kill (PICK) chart method distinguished high-value, low-effort strategies from other strategies.

Findings – Owners and contractors identify distinct sets of CSU solution strategies as high value and low effort, with some overlap. Of 178 total strategies, 40 (22.5 per cent) were identified by owners and 34 (19.1 per cent) by contractors, with 19 (10.7 per cent) of those strategies in common. Strategies with the greatest differences in opinions between owners and contractors are also identified.

Research limitations/implications – Research findings are limited to industrial-type, operational systems-intensive facilities. Similarities may exist with other systems-intensive project types, such as some commercial or infrastructure projects. The survey sample size is relatively small (n = 35), but close to that of other CSU-related surveys. The majority of survey participants were based in North America at the time of participation. Further, the number of contractor and owner participants differed slightly.

Practical implications – CSU managers and personnel should consider using high-value, low-effort strategies before resorting to other less effective strategies, as applicable on their projects. Depending on which organization is executing CSU, or if both organization types share CSU responsibilities, different solution strategies may be most effective.

Originality/value – Differences in owner and contractor perspectives and opinions have been noted in other aspects of the project lifecycle but never for CSU solution strategies. Use of the strategies identified will support more effective CSU execution.

Keywords Commissioning, Startup, Industrial construction, PICK chart

Paper type Research paper

Introduction

Research motivation

Construction, commissioning and startup (CCSU) are some of the most critical phases of an industrial capital project (Cagno *et al.*, 2002; Deloitte and Touche, 2012). Lager (2012) characterizes startup as an extreme event for multiple types of industrial facilities. Aside from the resources committed during CCSU to solve problems, the relative success of CCSU can have a lasting effect on facility production rates (Bagsarian, 2001; Deloitte and Touche, 2012;

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Lager, 2012; Leitch, 2004). Because they come as the final phases of industrial capital projects, commissioning and startup leave a lasting impression on owner organizations of contractor organizations' performance (O'Connor *et al.*, 1999; O'Connor *et al.*, 2016a). Industrial capital project CCSU shows the potential for substantial improvement and savings (Leitch, 2004).

The critical nature of CCSU to industrial capital project success, and the potential for improvement and savings serve to motivate this research. Specifically, this research explores the efficacy of solution strategies to the most common CCSU problems from owner and contractor perspectives. Owner and contractor organizations have separate project roles and, thus, may have differing motives, objectives and viewpoints as to CCSU. Roles and responsibilities may even be different from project to project depending on the project delivery model utilized. The difference in roles will also shift because project teams are seldom the same from one project to another – both individuals and organizations may be replaced between projects.

Research objectives

The authors set several objectives for this research. Primarily, this research sought to find which CCSU solution strategies owner and contractor organizations identify as having high value and requiring low effort. Secondarily, the research sought to compare contractor and owner high-value, low-effort solution strategies to identify whether any strategies overlap. Finally, the authors sought to validate the results via statistical significance testing for both owner and contractor high-value, low-effort solution strategies. Herein owner organizations are defined simply as the organization which will have legal ownership of the physical asset upon project completion. Contractor organizations are defined broadly as organizations which contract with the owner to execute the project.

Research scope

The research presented in this article is limited in scope in several ways. Common CCSU problems and solutions are limited to post-design phases (construction through project close-out). CCSU problems arising during the planning or design stages are not considered. Comparisons between organization types are limited only to the comparison between owner and contractor organizations. The identification and testing of solution strategies based on all survey responses as a whole (regardless of organization type) is outside the scope of this article, as this research focuses on the comparison of solution strategies identified by owner and contractor organizations. Parallels likely exist between this research on industrial CCSU and CCSU for other project types (e.g. commercial, infrastructure, etc.), especially those that are systems-intensive. However, these other categories of construction are not considered within the scope of this article.

Literature review

Commissioning and startup perspectives

Definitions for commissioning and startup (CSU) are many and varied across industrial sectors (Kirsilä *et al.*, 2007). Herein the authors define commissioning and startup broadly as the stage of an industrial capital project when disparate systems are made to work together as a process to produce some product (Construction Industry Institute [CII], 2017). The academic corpus surrounding industrial CCSU is not extensive (Almasi, 2014; O'Connor *et al.*, 2016b; Sohmen, 1992), indicating a need for further investigation of industrial CCSU topics. Knowledge sharing between organizations and industrial sectors is also limited because of the industry tendency away from corporate transparency for reasons of liability and competitive advantage. Many other sources cite commissioning with respect to commercial and other construction applications. Notably from *Construction Innovation: Information, Process, Management*, Kantola and Saari (2014), Li *et al.* (2013), Nahmens and Reichel (2013) and Shari and Soebarto (2014) all reference commissioning with respect to commercial construction sustainability.

Drawing from the literature that is available, it is clear that there are multiple perspectives on CCSU (Lawry and Pons, 2013). As mentioned in the introduction, delivery models vary from project to project, and as such, the roles and responsibilities of owner and contractor organizations will change from project to project (CII, 2017; Lager, 2012; Sohmen, 1992). Even so, owner organizations most often function in a supervisory capacity, while contractor organizations are more likely to be active executing at the workface (CII, 2017). The involvement of multiple parties with differing expectations and objectives makes the CCSU process quite complex (Cagno *et al.*, 2002; CII, 2017). While many literature sources make little or no distinction of differences between owner and contractor perspectives for project CCSU, several do. Rodgers (2005) highlights the owner organization's perspective on the commissioning of mechanical systems. Leitch (2004) identifies that owner and contractor organizations (and even departments within those organizations) can become siloed; he stresses the need for alignment between organizations and departments. A Construction Industry Institute (2015a) report on CCSU critical success factors also stressed the need for alignment between the owner, construction contractor and other organizations.

Multiple authors have also demonstrated differences in owner and contractor perspectives for other aspects of construction projects. Tymvios *et al.* (2012) compared the opinions of owners and multiple types of contractors on some aspects of construction safety via analysis of survey responses. Serag *et al.* (2008) sought to reconcile owner and construction contractor views on productivity. Pinto *et al.* (2009) compared the perspectives of owners and contractors on trust relationships between the parties. O'Connor and Woo (2017) found owner and contractor opinions about problematic design deliverables to be similar.

CCSU problems and solutions

Common CCSU problems and solutions have been listed by some sources. Cagno *et al.* (2002) identified four factors which cause difficulties during CCSU for process plants. Horsley (1998) gives a brief list of 20 typical CCSU problems for process plants, along with seven underlying causes. Killcross (2012) gives examples of things that can go wrong for various common CCSU activities, also on process plants. Al Ahbabi and Alshawi (2015) cite general commissioning inefficiencies in general across sectors. Many literature sources give anecdotal evidence of common problems which have occurred during CCSU, and the solutions which were used for those individual projects: Al-Bidaiwi *et al.* (2012) for oil and gas projects in Qatar, Bagsarian (2001) for several steel mills, CII (2015b) for four power and process projects, Walker and Rahamani (2016) with reference to a water treatment plant and Vilbrandt *et al.* (2015) for an experimental nuclear fusion reactor. To the best of the authors' knowledge, CII (2017) gives the most comprehensive organized listing of common CCSU execution problems and solution strategies. The CII report referenced lists the 20 most commonly problematic CCSU activities (known as "Hot Spots") and from five to 14 solution strategies for each.

Quantitative modelling

Multiple quantitative models for describing and assessing decision-making have been put forward in published literature, such as decision trees (Lave and March, 1993), utility function analysis (McNamee and Celona, 2008), analytical hierarchy processing (Saaty, 1977) and the method of choosing by advantages (Suhr, 1999). An outline of some of these models, among others, is given by Heidenberger and Stummer (1999), including reference to traditional scoring models, which can be effective when more complex methods are not justified (Jackson, 1983; Krawiec, 1984). One type of traditional scoring model used in various contexts is the Possible, Implement, Challenge, Kill (PICK) chart model, which aids in comparing action strategies to one another according to payoff and difficulty measures (Badiru and Thomas, 2013). The PICK chart model is well-suited to compare CCSU solution strategies, as demonstrated in the research methodology section.

Knowledge gap

Although common problems and solution strategies have been identified for CCSU execution, to the authors' knowledge, no mention has been made in academic literature on the differing perspectives of multiple stakeholder organizations with respect to CSU solution strategy effectiveness. This research seeks to fill this gap in the body of knowledge by comparing the effectiveness of solution strategies for CCSU problems from both owner and contractor perspectives.

Research methodology

Data collection

To fulfill the research objectives, the authors collected data via means of an electronic survey. A mix of CCSU experts from both owner and contractor organizations were solicited for survey responses. The extensive listing of solution strategies for commonly problematic CCSU Hot Spots, compiled by CII (2017), served as the foundation for the survey. In addition to the input of the 23 CCSU experts who contributed to the listing of solution strategies, an external validation panel of 11 CCSU experts reviewed the solution strategies for each Hot Spot (CII, 2017). Validation reviewers had a total of 152 years of CSU experience on 169 projects, for an average 13.8 years of CSU experience on an average of about 29 projects (O'Connor and Mock, 2019). These 11 experts made suggestions for adding solution strategies which were missing and deleting/combining repetitive strategies (O'Connor and Mock, 2019). Survey respondents rated solution strategies for each Hot Spot according to two metrics: level of implementation effort required and relative value from implementation. Of the 80 CCSU experts approached to participate in the survey, 8 had invalid contact information. Of the remaining 72 experts solicited, 36 responded to the survey, giving a response rate of 50 per cent. Yusof *et al.* (2017) indicates that relatively low response rates are common in construction research, and Akintoye (2000) indicates that a 20-30 per cent response rate can be considered normal for postal surveys in the construction industry. While the response rate for this survey was appreciably higher, it was also administered electronically. The 50 per cent response rate is also comparable with the response to Sohmen's (1992) survey on CSU success factors. One respondent's survey responses were not used in the analyses, because that respondent's experience was in non-industrial sectors. Of the remaining 35 respondents, 32 (91.4 per cent) completed the survey in its entirety, while the other three respondents gave partial responses. Other surveys on industrial CSU have had similar response sample sizes (O'Connor *et al.*, 2016a; Sohmen, 1992). This sample was drawn from the broader population of industrial CCSU experts from owner and contractor organizations. Most potential survey participants solicited had some tie with CII research or were referred by someone who did. With 178 solution strategies being rated according to two metrics each, survey fatigue was of concern to the authors, however, does not appear to have substantially impacted the survey completion rate, as 33 of the 36 survey participants (91.7 per cent) completed the survey to the end. The original list of solution strategies and the survey are both shown within the context of the entire research methodology as part of Figure 1, the methodology flowchart. The flowchart gives a graphical representation of how the discrete parts of the methodology relate to one another.

The ratio between owner and contractor respondents was relatively even. Of the respondents, 19 (54.3 per cent) were employed by owner organizations and 16 (45.7 per cent) were employed by contractor organizations. Respondents had total industry experience of 941 years, 517 of which were in CSU specifically. Contractor–employed respondents had an average of over 30 years of industry experience, with an average 17 years in CSU. Owner–employed respondents had an average of over 24 years of industry experience, with almost 13 of those being in CSU, on average. In total, respondents had participated in CSU on over 1,600 projects. Contractor respondents had participated in CSU on an average of slightly over 76 projects, while owner respondents had participated in just over 22, on average. The reason for this substantial disparity is likely that owner employees are more likely to stay on

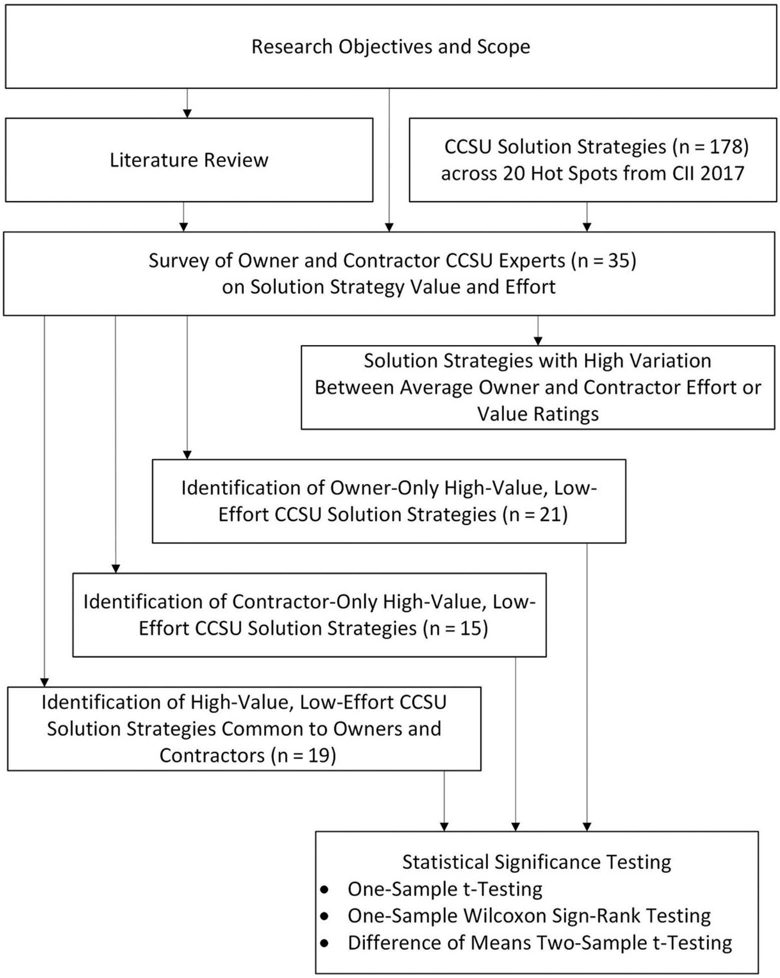

Figure 1.
Methodology flowchart

a project for much of its duration, whereas contractor employees may only participate on a project for a short time and then move on to the next project. Respondents came from various industrial sectors, including petrochemicals, pharmaceuticals, power, oil and gas and mining/metals manufacture, among others. Owner companies tended to be larger in size, while contractor companies covered a wide range of sizes. Projects in which respondents had participated in CSU ranged in budget from several hundred thousand to several billion US Dollars. Project CCSUs used a range of project types (greenfield and brownfield), delivery methods and commissioning team types. The authors felt that the respondents, with their deep experience in CCSU across multiple sectors, were able to provide responses representative of the current state of industrial CCSU.

Data quantification

As mentioned previously, survey participants rated CCSU solution strategies according to two metrics: level of implementation effort required and relative value from implementation. Participants were given the option to skip a solution strategy if they were not familiar with it (i.e. they were not forced to give responses for every solution strategy). This option served to prevent uniformed or spurious answers to survey questions. Respondents rated these two metrics along a three-step scale with high, medium and low options for both metrics. Similar metrics and scales have been used in other industrial settings outside of construction. George (2003) describes the use of a PICK chart in a lean manufacturing setting to compare the viability of solution strategies. In the model, the most beneficial strategies fall into the 'Implement' quadrant. These strategies have a big payoff (high value) and are easy to implement (low effort). Biloshapka *et al.* (2016) also put forward a similar tool called a value matrix which helps assess business model viability. Taylor *et al.* (2012) used the same quadrant method to group highway project work items according to two metrics and Kang *et al.* (2013) used a quadrant method for rating construction project information technology best practices. Similarly, the authors of this article used a PICK chart method to classify Hot Spot solution strategies according to the two aforementioned metrics. The PICK chart method also acts as a clear and concise way to measure the level of consensus between owner and contractor organizations as to which strategies provide both provide high value and require low effort.

Survey questions on solution strategies were very explicit in nature, referencing either the effort or value of a specific solution strategy with respect to a specific Hot Spot. The specificity of the questions serves to counteract some of the variation in the way that owner and contractor respondents perceive the metrics and survey scale. Further, the size of the samples will also counteract some of the statistical noise inherent in the different experience/background of each respondent. Respondents were asked to rate solution strategies according to their experience, but not with respect to any specific project(s). This style of question promotes the independence of responses. Further, as previously stated, each Hot Spot's solution strategies had been checked for overlap/repetition by a panel of CCSU expert validators.

To allow for the comparison and testing of strategies, high, medium and low ratings were converted to numeric ratings for both metrics. For the value metric, high = 3.0, medium = 2.0 and low = 1.0; for the effort metric, high = 1.0, medium = 2.0 and low = 3.0. Note that the numeric values are inverted between the two metrics. The authors sought to give the optimal outcome for each metric (high for value and low for effort) the largest numeric rating. Numeric scale conversion of this kind is not unique to this research; it has also been applied to survey data in other construction engineering studies (Barry *et al.*, 2014; O'Connor *et al.*, 2016b;

O'Connor and Woo, 2017). The high, medium, low scale lends itself well to this simple numeric conversion, as it has three discrete levels.

The authors used a numeric threshold to distinguish between higher-value, lower-effort strategies and all other strategies. Several factors were used to determine the threshold. It needed to be greater than the medium rating for both metrics, to ensure that strategies identified were not in fact medium value and effort. The threshold also needed to be high enough to allow for the possibility of finding average scores to be statistically significantly greater than the medium score. Conversely, the threshold could not be so high that it excluded all strategies. Balancing all these requirements, the authors settled on a value of 2.15. The fact that this value falls within the narrow range of values where the statistical tests conducted begin to find significance also justifies its use. Using the same threshold across all 20 Hot Spots allowed the authors to identify a list of comparable high-value, low-effort strategies across the Hot Spots, as the survey used the same response scale for both metrics and for the strategies of all 20 Hot Spots. Other methods of threshold definition include average score values, as used by Taylor *et al.* (2012) and score sample standard deviation, as used by O'Connor and Woo (2017). In the context of this study, values from either of those methods might fall below the medium 2.0 values for either metric and, thus, might identify strategies which are not in fact high value, low effort. Using thresholds to split the ratings into quadrants provides a simple way to measure the level of consensus between owner and contractor organizations by allowing a binary measure of whether each strategy was considered high value, low effort by owner and contractor organizations or not. Strategies which fell into this category are listed specifically in the findings section, as well as the total percentage of strategies which owners and contractors agreed on as high value and low effort.

Identification of any strategies (high value, low effort or otherwise) with large differences between owner and contractor ratings was also important. Average contractor ratings for effort and value for each strategy were subtracted from the corresponding average owner ratings. This resulted in a positive value, negative value or zero value (when average ratings values were the same) which shows the difference of average scores for contractors relative to owners for each solution strategy. Strategies with the greatest differences in average scores were compiled and then analyzed for possible trends.

Statistical testing

Statistical tests were used as a method to judge statistical significance of the strategies with average scores from owner and/or contractor participants above 2.15 for both effort and value metrics. Owner and contractor response scores were tested separately. Initially, the authors performed one-sample *t*-testing to find strategies which had numeric effort and value scores significantly greater than 2.0. This translates to effort significantly lower than medium, and value significantly higher than medium. Various forms of *t*-testing are commonly used in construction management research, such as studies by Choi *et al.* (2017) on construction safety, Lam and Siwingwa (2017) on project risk management and Han *et al.* (2017) on construction productivity. This particular statistical test was chosen by the authors for two reasons. First, for those strategies with average ratings significantly higher than 2.0, this test proves that they are not rated higher merely because of random variability in the sample data. Second, testing against the 2.0 value also largely substitutes for testing high-value, low-effort strategies against other strategies which have low-value and/or high-effort, as by definition those strategies have scores lower than 2.0 for value and/or effort; if an average score is significantly greater than 2.0, then it would also be significantly greater than any value lower than 2.0. Because effort and value metrics were rated separately, each strategy with average values equal to or greater than 2.15 had two *t*-tests performed for owner and/or contractor scores, one for effort scores and one for value scores. The base alpha value used was 0.10. This value provided a good balance between the likelihood of false-positive and false-negative results and is appropriate for the size of the data set (Noymer, 2011). The Holm–Bonferroni method was used to adjust the base alpha value to account for multiple comparisons (Holm, 1979), as the authors conducted a large number of tests. The Holm–Bonferroni method is preferable to other methods because it reduces the chance of false-positive results while increasing the power of the tests (Abdi, 2012). Base alpha values were adjusted in blocks, with tests for either effort or value scores for each Hot Spot treated as a single block. The *t*-test is well-suited to these data because of the relatively small sample sizes for both owner and contractor survey participants (Stone, 2012b). The majority of the individual strategy ratings appear to be roughly normally distributed with the greatest number of ratings given as 'medium', thus accounting for the normality assumption for statistical testing even of relatively small sample sizes, as explained by Stone (2012a, 2012b).

The authors also performed one-sample Wilcoxon signed-rank testing as an analogous non-parametric alternative to *t*-testing; this comparability between parametric and non-parametric tests is noted by Albers (2017) and Conover and Iman (1981). Wilcoxon testing does not require the same assumption of normality for the test sample which parametric tests do (Albers, 2017). This justifies using it as a check on the *t*-tests performed, as data for most – but not all – strategies appeared to be normally distributed. The same strategies' effort and values scores were tested, which allows for a comparison of the results between the *t*-testing and Wilcoxon testing. The Wilcoxon tests also tested for effort and value scores significantly greater than 2.0. Other aspects of the testing were also held constant, such as the base alpha value (0.10) and the use of the Holm–Bonferroni method for correcting for multiple comparisons.

The use of two-sample *t*-testing allowed for a difference of means comparison for high-value, low-effort strategies identified only by owner respondents, only by contractor respondents and by both. These tests demonstrate whether the mean average values of owner and contractor respondents were significantly different from one another. Similar to previous tests, the authors performed difference of means testing separately for both effort and value metrics. Data sample sizes, ranges and distributions all fit reasonably within the limits of this testing (Stone, 2012a). Further, the significance level was held at 0.10. Dissimilarly, however, no controlling procedure for multiple comparisons was used. In this case, using a controlling procedure made less sense, as fewer tests were performed. There was also an expectation of finding a significant difference in means for owner-only and contractor-only strategies, as these were identified on the basis of having exceeded the 2.15 threshold for both metrics, which further mitigates the necessity of using a controlling procedure (Rothman, 1990).

Findings

High-value, low-effort solution strategies

Only strategies which passed the set threshold for both effort and value metrics are considered high-value, low-effort strategies. These strategies represent some of the best candidates for implementation on projects where their associated Hot Spots are problematic, as they provide a significant mitigation or prevention benefit, and are easy to implement. Strategies were identified for owners and contractors separately, with owner organization survey respondents identifying 40 strategies as higher value and lower effort. Contractor organization survey respondents identified 34 strategies. Of these strategies, 19 were consensus strategies which were identified by both groups.

At this point, some reference to set theory (Cantone and Ursino, 2018; Venn, 1880) will allow for a clearer and more concise description of the strategies. The complete pool of all solution strategies for all Hot Spots combined sums to 178. Of these strategies, 40 are owner-identified, and 34 are contractor-identified. These two sets have some strategies in common. That is, the intersection between owner and contractor sets comprises 19 solution strategies, while the union of contractor and owner sets comprises 55 strategies. Of the 40 strategies identified by owners, 21 (52.5 per cent) are only identified by owners. Of the 34 strategies identified by contractors, 15 (44.1 per cent) are identified by contractors only (i.e. unique to contractors). As percentages of the overall 178 strategies, the 21 owner-only strategies constitute 11.8 per cent, the 15 contractor-only strategies constitute 8.4 per cent, the 19 consensus strategies constitute 10.7 per cent and the union of all those 55 strategies constitute 30.9 per cent.

The complete listing of strategies identified as high value and low effort by owners, contractors or both is found in Table I. Strategies are grouped by Hot Spot, with the far-right column showing which group identified each strategy. Most Hot Spots had at least one strategy identified by owners and/or contractors; however, 3 (15 per cent) of the 20 Hot Spots had no strategies identified by owners and 5 (25 per cent) of the 20 Hot Spots had no strategies identified by contractors. For owners, these included: system-based execution, start maintenance and team building Hot Spots. For contractors, these included: system-based execution, kickoff alignment, construction turnover packages, start maintenance and operation test procedures. Apparently, these Hot Spots are more difficult to prevent or mitigate for owners and contractors. Hot Spots had an average of 8.9 solution strategies listed. Of those, owners identified an average of 2.0 (22.5 per cent) solution strategies per Hot Spot as higher value and lower effort. Contractors identified an average of 1.7 (19.1 per cent) solution strategies per Hot Spot. For owners, Hot Spots 4 (cleaning and drying), 8 (inspection walkthrough) and 10 (utilities) had the most high-value, low-effort strategies at four, eight and four, respectively. For contractors, Hot Spots 8 (inspection walkthrough), 10 (utilities) and 18 (hazard and operability study closure) had the most high-value, low-effort strategies with four each. These Hot Spots present the most high-value, low-effort options for owner and contractor CCSU decision-makers and may be less difficult to prevent or mitigate than other strategies.

Owner and contractor comparisons

The strategies passing the threshold for high value and low effort were not completely the same for owners and contractors. These distinctions are meaningful – they show that differences in perspective do exist between owners and contractors as to the best ways to solve the most common CCSU problems, as well as some consensus. The reasons for these differences may be manifold; however, some of them are evident: differing motives and objectives, differing organizational cultures and differing capabilities to name a few. Differences between the sets of strategies which were identified by owner and contractor respondents demonstrates that some strategies will serve owner organizations better, and some will serve contractor organizations better. This is not surprising, considering the fundamental differences between these types of organizations.

While the sets of strategies passing the threshold for high value and low effort were not completely the same for owners and contractors, they were not completely different either. Strategies which were identified as high value and low effort by both owner and contractor, designated as consensus strategies, deserve special attention. They represent consensus

Table I. Owner and contractor high-value, low-effort CCSU solution strategies

Hot Spot[a] No.[b]	Title[c]	Solution Strategy[d] No.[e]	Name	Identified By[f]	Mean Effort Score[g]	Mean Value Score[g]
1	Resources and facilities for pre-commissioning	7	Involve Startup personnel in the pre-Startup safety review	Both	2.47 (O) 2.31 (C)	2.68 (O) 2.44 (C)
		8	Commissioning and Startup personnel should not report to the construction contractor, but rather to the project manager	Owner	2.63	2.32
2	Execute preservation	2	Develop a project-specific preservation plan as part of project planning	Owner	2.16	2.53
		3	Assign a preservation leader/coordinator with a dedicated mixed-trade crew before construction begins	Contractor	2.19	2.56
		4	Consider having Operations personnel perform preservation; this will allow them to familiarize themselves with the equipment before installation	Owner	2.32	2.32
		8	Educate managers on the importance of preservation, as well as the schedule and budget requirements for successful preservation	Contractor	2.19	2.44
3	System-based execution	n/a	n/a			
4	Cleaning and drying	1	Define cleaning, drying, and other specifications clearly for EPC contractors. Make the specifications/instruction easy to find, read, and use. One example being a piping-class flushing matrix	Owner	2.16	2.42
		2	Hire a specialty contractor to perform flow line cleaning, passivation, preservation and drying. Allow the specialty contractor to suggest the correct method to meet the specification for approval by the client	Contractor	2.33	2.40
		3	If there are problems during cleaning/drying, admit that problems have occurred, and consider repeating those activities properly	Owner	2.26	2.53
		7	Define the collection and disposal of chemical effluents in accordance with environmental authorities and regulations	Owner	2.37	2.32
		8	Isolate instrumentation during cleaning, passivation, and drying. This will prevent damage to the instrumentation	Contractor	2.20	2.80
		9	Use QA/QC personnel to witness cleaning and drying activities performed by the construction contractor	Both	2.16 (O) 2.33 (C)	2.42 (O) 2.27 (C)
5	Punch list	2	Implement a punch-list procedure that is signed-off by all parties	Contractor	2.36	2.43
		4	Assign QA/QC personnel, who do not report to the construction contractor, to identify issues to be resolved before the punch list is created	Both	2.21 (O) 2.29 (C)	2.53 (O) 2.36 (C)
		7	Utilize a change management system	Contractor	2.36	2.64

(*continued*)

Table I.

Hot Spot[a] No.[b]	Title[c]	Solution Strategy[d] No.[e]	Name	Identified By[f]	Mean Effort Score[g]	Mean Value Score[g]
6	Schedule recovery	8	Align on quality standards, code interpretation, and specifications up front	Both	2.16 (O) 2.21 (C)	2.74 (O) 2.50 (C)
		10	Conduct early and thorough QA/QC of installed systems, with consideration of the functional specification	Owner	2.37	2.58
		12	Utilize a change management system	Contractor	2.36	2.31
7	As-built drawings	7	Ensure the participation of qualified QA/QC personnel	Contractor	2.21	2.36
		10	Make one or two people accountable for the whole system. When everyone is in charge, no one is	Both	2.26 (O) 2.40 (C)	2.53 (O) 2.53 (C)
		13	Utilize a change management system	Contractor	2.27	2.40
8	Inspection walkthrough	1	Clearly define mechanical completion and the level of inspection for each system in contract documents	Owner	2.21	2.74
		2	Conduct alignment meetings between the parties who will be present at inspection walkthroughs on the definition of what is agreed to in project contracts	Owner	2.21	2.5
		4	Identify a responsible party to assist in the pre-mechanical completion walkthrough that understands the commissioning prerequisites (e.g., commissioning manager, construction quality assurance)	Owner	2.42	2.68
		5	Ensure that QA/QC of construction work is done by personnel who do not have a conflict of interest	Both	2.42 (O) 2.22 (C)	2.47 (O) 2.40 (C)
		6	Set up a methodology to walk down systems, but only with the disciplines that are needed for each system	Both	2.53 (O) 2.53 (C)	2.16 (O) 2.33 (C)
		7	Ensure labeling and tagging requirements are correct and included in the project specifications package	Owner	2.32	2.37
		8	Make sure to have proper documentation and signatures on the walk-down forms (everything should be recorded so that decisions are not lost)	Both	2.26 (O) 2.47 (C)	2.26 (O) 2.33 (C)
		9	Try to keep walkthroughs simple, with key people from the necessary disciplines. Too many people will complicate the process	Owner	2.42	2.42
		10	Utilize a change management system	Contractor	2.27	2.40
9	Procure materials	2	Appoint one or more Commissioning personnel to work with procurement management early in construction	Owner	2.32	2.26
		3	Ensure that there is a procedure for having timely fabrication of temporary spools for CSU	Both	2.37 (O) 2.20 (C)	2.16 (O) 2.47 (C)

(*continued*)

Hot Spot[a] No.[b]	Title[c]	Solution Strategy[d] No.[e]	Name	Identified By[f]	Mean Effort Score[g]	Mean Value Score[g]
10	Utilities	2	Develop a commissioning and startup matrix that includes the utilities and temporary systems needed for CSU	Both	2.26 (O) 2.20 (C)	2.74 (O) 2.60 (C)
		5	Require vendors/OEMs to provide detailed information on the utility needs of their equipment/materials	Both	2.32 (O) 2.40 (C)	2.42 (O) 2.20 (C)
		7	Include milestones for completion of utility systems and coordination with utility companies in the detailed CSU execution plan	Both	2.26 (O) 2.20 (C)	2.39 (O) 2.33 (C)
		8	Require HSE/LOTO to sign-off on systems before they are energized	Both	2.32 (O) 2.60 (C)	2.58 (O) 2.67 (C)
11	Kickoff alignment	1	Ensure that alignment is obligated contractually	Owner	2.22	2.28
		2	Ensure that all relevant stakeholders attend the CSU alignment meeting	Owner	2.22	2.56
		3	Bring construction managers onto the project early, even as early as the Design phase. This gives them a chance to familiarize with, and contribute to, planning for commissioning activities, especially for brownfield projects	Owner	2.17	2.61
12	Construction turnover packages	3	Ensure the establishment of standard communication for process change documentation from Engineering to the Construction Contractor	Owner	2.38	2.38
		5	Assign one or more turnover package managers	Owner	2.19	2.31
13	Start maintenance	n/a	n/a			
14	O&M involvement	3	Coordinate early with SMEs and take advantage of their expertise to ensure CSU success	Both	2.18 (O) 2.33 (C)	2.41 (O) 2.33 (C)
		4	Establish resource requirements and commitments early during the FEED phase	Owner	2.18	2.24
15	Familiarize operations	1	Ensure that contracts with OEMs/suppliers include provisions for FAT/SAT participation	Both	2.29 (O) 2.40 (C)	2.53 (O) 2.73 (C)
		2	Bring key Operations personnel on the project early enough for them to participate in equipment familiarization during FAT or on-site (or both)	Owner	2.18	2.59
16	Loop and I/O checks	1	Contractual terms need to support the time and resources necessary for these checks	Both	2.18 (O) 2.21 (C)	2.53 (O) 2.50 (C)

(*continued*)

Table I.

Table I.

Hot Spot[a] No.[b]	Title[c]	Solution Strategy[d] No.[e]	Name	Identified By[f]	Mean Effort Score[g]	Mean Value Score[g]
		3	Align construction and CSU on the standards and procedure for loop and I/O checks of systems. If possible, reference these standards and procedures in contract documents	Contractor	2.21	2.71
17	System walk-downs	3	Ensure that each system has an individual identified as responsible for coordinating that system's walkdown for turnover	Both	2.41 (O) 2.33 (C)	2.41 (O) 2.33 (C)
		4	Accurately assess the time and manpower required for system walk-downs during CSU planning	Contractor	2.20	2.20
18	HAZOP closure	2	Assign the parties responsible for closing HAZOP action items during the HAZOP review	Both	2.65 (O) 2.27 (C)	2.41 (O) 2.40 (C)
		4	Require the closure of HAZOP action items before startup/operations on safe mode	Contractor	2.20	2.67
		6	HAZOP completion and close-out documentation should be a requirement for the pre-startup safety review (PSSR)	Both	2.53 (O) 2.27 (C)	2.76 (O) 2.47 (C)
		10	Create a detailed definition/formulation for which items qualify as HAZOP items	Contractor	2.20	2.47
19	Operation test procedures	3	Staff one or two key personnel, with experience in operational testing, early enough to provide meaningful input to test development	Owner	2.24	2.71
20	Team building	4	Develop an open culture where project team members of any level are able to identify problems and bring them to the attention of the group without fear of being looked down upon	Contractor	2.20	2.53

Notes: [a]Hot Spots are CCSU activities which were identified as most commonly problematic on industrial projects; [b]Hot Spots are listed in order of commonality, with the first being the most common; [c]Hot Spot activities have specific names (CII, 2017), but only abbreviated titles are shown here; [d]Solution strategies can be meant to either prevent or mitigate Hot Spot problems (CII, 2017); [e]Solution strategies are numbered only according to their listing by CII (2017) and do not reflect any particular order; [f]Strategies can be identified by owner-respondents, contractor-respondents or both; [g]Mean effort and value scores are denoted as (O) for Owner or (C) for Contractor when a particular solution strategy was identified by both groups among owners and contractors and are likely to be good candidates for implementation on any project CCSU having trouble with their associated Hot Spots.

The survey asked respondents to rate solution strategies with respect to their associated Hot Spots. Figures 2 and 3 contrast owner and contractor effort and value ratings for Hot Spot 1 (resources and facilities for commissioning) as scatter plots. Numeric data point markers help differentiate between the solution strategies for each Hot Spot and are taken from the original list order of strategies (CII. 2017), but are not otherwise indicative of any other measure or metric. These strategy numbers are consistent between all figures and tables. The comparison between the ratings for both effort and value metrics of owner and contractor respondents in Figures 2 and 3 shows that owner and contractor respondents had substantially varying opinions about many of the strategies for Hot Spot 1. For example, contractors rated the value of Strategy 9 (asset data management/wireless instrumentation) substantially higher than owners. Owners indicated that Strategy 8 (CSU personnel reporting) requires much less effort than contractors did.

Figures 2 and 3 show average responses for only one of the 20 Hot Spots. Similar differences between owner and contractor organizations can be found between strategy ratings for the other Hot Spots as well, but scatter plots for the other 19 Hot Spots are not included here because of length limitations.

Sample standard deviations for Hot Spot average owner and contractor value and effort scores range from 0.068 to 0.429, indicating that some Hot Spots have a wider range of solution strategy value and effort than others. The average of all standard deviations across Hot Spots for owner ratings are 0.21 (effort) and 0.28 (value). Contractor ratings' average standard deviations are 0.19 (effort) and 0.22 (value). These averages show that both owner

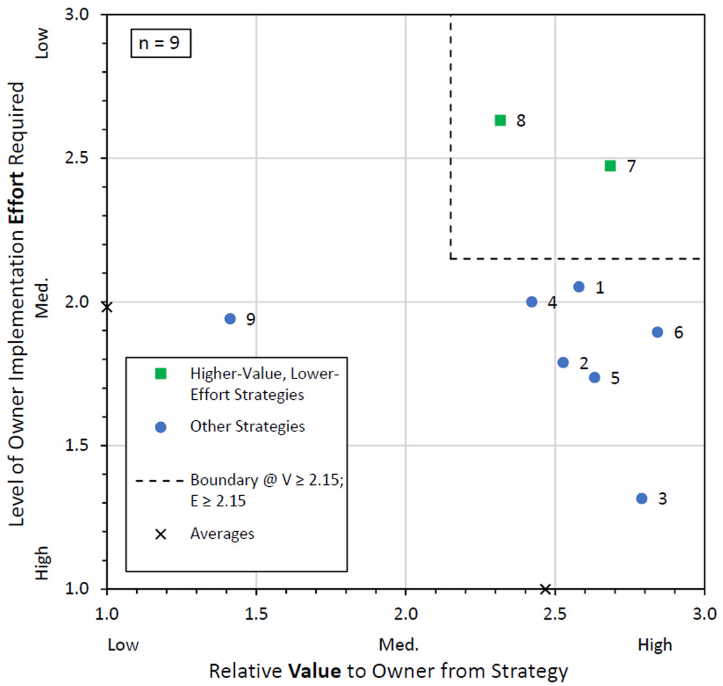

Figure 2.
Owner respondents' average solution strategy ratings for Hot Spot 1: resources and facilities for pre-commissioning

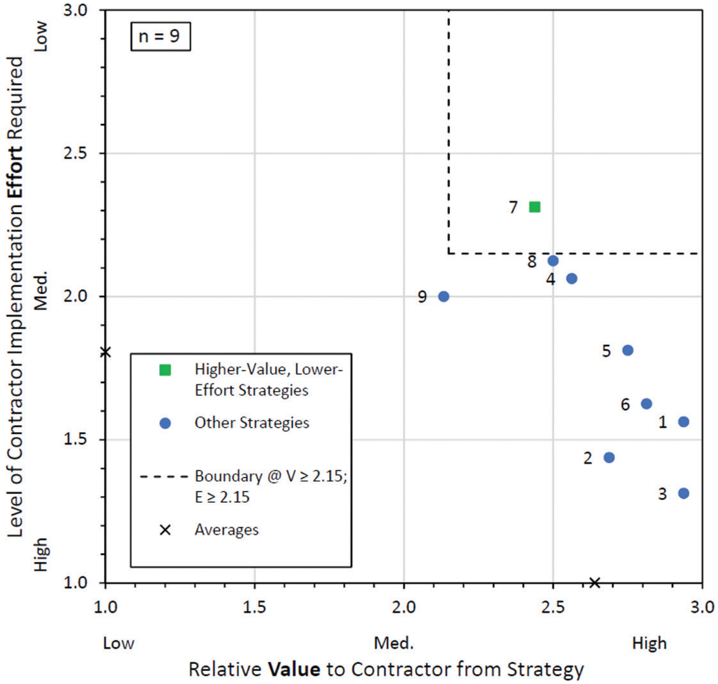

Figure 3. Contractor respondents' average solution strategy ratings for Hot Spot 1: resources and facilities for pre-commissioning

and contractor ratings have slightly higher variability for value than for effort, in general. Average sample standard deviations also show that owner ratings have slightly higher variability than contractor ratings.

Substantial differences for effort and/or value metrics between any of the solution strategies (not only the high-value, low-effort strategies) are important to note. Strategies with the highest ratings disparities for average values of either metric between owner and contractor survey participants are listed in Table II. The listing is limited to strategies with ratings disparities of 0.4 or greater (n = 22) because of length constraints. The most noticeable difference across the Hot Spots is that owners often find innovative CSU technologies (CII, 2015a) considerably less valuable than contractors (see Table II, Hot Spots 1, 3, 7, 12, 15 and 16). Innovative CSU technologies include virtual commissioning and wireless instrumentation, for example. Of the 12 Hot Spots with one or more technology listed as a strategy, half had a difference of 0.4 or greater between average owner and contractor value scores, and in each of those six instances, contractors ranked the value higher than owners. Contractors may see more value in these technologies for solving common CCSU problems because they are more likely to have first-hand experience with them at the work face, as opposed to owner employees who often take on oversight roles.

The authors also observed that for the strategies with the highest ratings disparities, contractors were much more likely to rate value higher and effort lower than owners. Of the 12 value differences shown in Table II, all 12 (100 per cent) were rated higher by contractors. Of the 10 effort differences shown, 7 (70 per cent) were rated lower by contractors. This tendency for contractors to give higher value ratings and lower effort ratings than owners for those solution strategies is likely a reflection of contractors being less prone to think of

Table II. CCSU solution strategies with large differences (≥ 0.4) between owner and contractor average value or effort ratings

Hot Spot[a] No.	Solution Strategy[b] No.	Name	Metric[c]	Difference[d] (Contr. rel. to Owner)
1	1	Allocate appropriate budget for successful commissioning, especially for the timely inclusion of subject matter experts and vendors	Effort	−0.49
	8	Commissioning and Startup personnel should not report to the construction contractor, but rather to the project manager	Effort	−0.51
	9	This hot spot can be prevented or mitigated with the following Innovative CSU Technology (CII 2015a): Asset Data Management/Wireless Instrumentation	Value	0.72
2	1	Ensure that contract documents specify preservation requirements, so that preservation can be contractually set up for success	Value	0.50
	3	Assign a preservation leader/coordinator with a dedicated mixed-trade crew before construction begins	Value	0.46
	9	Work with vendors to identify any equipment for which proper preservation has not been performed	Value	0.51
3	3	Align Construction management and Commissioning management early (shortly after the contract has been signed) on the importance of the transition to system-based execution. Align on what triggers the transition to system-based execution. Get buy-in from field construction supervision (superintendents/foremen) on systems-based completion	Effort	−0.43
	7	Do not penalize in-field construction personnel (craft) for the lower productivity associated with transitioning to systems-based completion. Rather, incentivize delivery of completed systems on time	Effort	−0.59
	8	Ensure timely system turnover by including contract mechanisms to motivate on-time delivery (e.g., payment retention, liquidated damages/incentives)	Effort	−0.53
	11	This hot spot can be prevented or mitigated with the following Innovative CSU Technologies (CII 2015a): — Building Information Modeling/3D Design Models — Completion Management Systems	Value	0.41
6	12	Utilize a change management system	Effort	0.46
7	14	This hot spot can be prevented or mitigated with the following Innovative CSU Technologies (CII 2015a): — Smart Piping and Instrumentation Diagrams — Building Information Modeling/3D Design Models — Asset Data Management/Wireless Instrumentation	Value	0.62

(continued)

Table II.

Hot Spot[a] No.	Solution Strategy[b] No.	Name	Metric[c]	Difference[d] (Contr. rel. to Owner)
8	1	Clearly define mechanical completion and the level of inspection for each system in contract documents	Effort	−0.48
10	9	Make contingency plans (and budgets) for when a utility might not be available on time. For example, if utility air is not available, rent compressors	Effort	0.59
11	1	Ensure that alignment is obligated contractually	Effort	−0.42
12	1	Define requirements for turnover packages more specifically, including schedule milestones and definition of terms	Effort	0.44
	8	This hot spot can be prevented or mitigated with the following Innovative CSU Technologies (CII 2015a): — Smart Piping and Instrumentation Diagrams — Asset Data Management/Wireless Instrumentation — Completion Management Systems	Value	0.44
15	7	This hot spot can be prevented or mitigated with the following Innovative CSU Technologies (CII 2015a): — Asset Data Management/Wireless Instrumentation — Simulation-based Virtual Commissioning and Operator Training	Value	0.48
16	8	Test third-party interfaces as part of the Distributed Control System Factory Acceptance Testing	Value	0.47
	10	This hot spot can be prevented or mitigated with the following Innovative CSU Technology (CII 2015a): Asset Data Management/Wireless Instrumentation	Value	0.50
18	5	Closure of Hazard and Operability Study action items should be tracked in the detailed project schedule	Value	0.55
	10	Create a detailed definition/formulation for which items qualify as Hazard and Operability Study items	Value	0.41

Notes: [a]For Hot Spot titles see Table I; [b]Solution strategies shown in this table are not necessarily identified as high value, low effort; [c]Metric refers to either Effort or Value; [d]Formulated by subtracting average contractor scores from average owner scores any strategy as very desirable or very undesirable. As stated previously, contractors actually identified fewer high-value, low-effort strategies than owners (34 vs 40), and despite the large difference in opinion about value, none of the innovative CSU technologies were identified as high-value, low-effort strategies.

Statistical testing results

Statistical testing described in the research methodology section was of three varieties: one-sample *t*-testing, one-sample Wilcoxon signed-rank testing and difference of means two-sample *t*-testing. One-sample *t*-testing was performed for high-value, low-effort strategy scores from owners and contractors. This parametric test is well-suited for the respective sample sizes of respondents from owner and contractor organizations. Owner-identified strategies totaled 40. Transcribed numeric responses for each strategy were tested for both effort and value scores. Of the 80 tests performed for owner-identified strategies, 69 (86.3 per cent) were statistically significantly greater than 2.0 (the medium value). Solution strategies identified by contractor respondents totaled 34. Of the 68 tests performed for these strategies' ratings (two tests per strategy – one for each metric), all 68 (100 per cent) were statistically significantly greater than 2.0. Findings from the *t*-testing were quite decisive in validating these sets of owner and contractor CCSU solutions strategies as both high value and low effort. Table I includes average scores for effort and value for the 55 strategies identified by owner and/or contractor respondents. In general, findings of statistical significance in these tests are taken to mean that the effect reflects the population from which sample data were retrieved (Sirkin, 2005).

One-sample Wilcoxon signed-rank tests were used as a non-parametric equivalent to the one-sample *t*-tests. This test is also used as a sanity check, as the original scales for the survey data were ordinal. In general, the results from this kind of test will be more conservative than the results of a *t*-test. This was found to be the case in this instance as well. For owner respondents' survey ratings of high-value, low-effort strategies, 54 (67.5 per cent) of 80 tests found ratings significantly greater than 2.0. Contractor responses had a slightly lower percentage with 33 (48.5 per cent) of 68 tests showing statistical significance. The smaller sample size of contractor respondents may likely have contributed to the difference between the percentage of tests finding significance for owner and contractor responses. While not as compelling as the results from the *t*-tests, the Wilcoxon tests show substantial portions of both owner and contractor survey ratings as significantly greater than the medium 2.0 value. Considered as a whole, these test results further validate the strategies identified as high value and low effort. As noted, statistical significance was not found for every strategy with *t*-testing or Wilcoxon testing. Strategies for which statistical significance was not found are still valid as high-value, low-effort strategies, but the implication is that they may require slightly more effort and/or provide slightly less value than those for which statistical significance was found.

Difference of means two-sample *t*-testing was used as a way to compare ratings values from owner and contractor respondents. In total, tests were conducted for value and effort scores for the 55 high-value, low-effort strategies. The first 21 strategies were those which were identified by owners only. Effort and value scores from owners were tested against the corresponding lower scores from contractors. Of these 21 strategies, 11 (52.4 per cent) had either average effort or average value scores significantly higher than the corresponding contractor scores. The next set of strategies, 15 in number, were identified by contractors only. Of the 15 strategies, 10 (66.7 per cent) had either average effort or average value scores statistically significantly higher than the corresponding owner scores. The final round of tests was conducted for the 19 consensus strategies identified as higher value and lower effort by both owner and contractor survey participants. Only 1 out of 19 (5.3 per cent) of the owner and contractor high-value, low-effort consensus solution strategies had either average effort or average value scores that were significantly different from one another. This result gives strong support to the identification of these 19 consensus strategies. Strategies identified by contractor-only or owner-only respondents were quite likely to have either effort or value scores significantly greater than their owner/contractor counterparts. Strategies identified by both were much less likely to show a significant difference between owners' and contractors' responses. The findings from these difference of means tests are two-fold. First, many of the strategies identified by owners-only and contractors-only as high value and low effort were not rated differently simply by chance, but rather contractors and owners do actually differ substantially in their perceptions of the effectiveness of many of these strategies. Second, the strategies identified by both contractors and owners were rated similarly and are in fact perceived to be more effective strategies by study participants from both organization types.

Owner and contractor ratings, as well as the statistical tests used to validate them, legitimize the CCSU solution strategies (listed in Table I) identified by the authors from owner and contractor survey responses as high value and low effort. The long and diverse collective industrial CCSU experience of survey respondents gives additional credibility to the findings.

Conclusions

Summary of findings

The authors identified CCSU solution strategies which owner and/or contractor organizations identify as high value and low effort. A comparison of strategies identified by owner and contractor organizations found 19 common strategies. Ratings of owner-identified strategies (n = 40) and contractor-identified strategies (n = 34) were all tested for statistical significance against threshold values using two separate statistical tests. Ratings for all strategies identified by either or both organization types (n = 55) were tested to find if the mean averages of owner and contractor scores were significantly different. Results from the tests served to validate the sets of strategies identified by owner and contractor survey participants as being high value and low effort.

This research also produced several other findings of interest. A set of common strategies (n = 19) was identified by both owner and contractor respondents. These strategies, which are perceived as high value and low effort from both owner and contractor perspectives, seem to serve the interests and objectives of both parties. Several Hot Spots did not have any strategies identified as high value and low effort by owner and/or contractor respondents. These strategies are likely more difficult to prevent or mitigate than the other Hot Spots for owners and contractors. Multiple strategies, both high value, low effort and otherwise, were found to have large differences in average effort and value ratings from owners and contractors (Table II). Specifically, innovative CSU technologies (CII, 2015a) were valued less by owners than contractors. However, most of the strategies with large disparities had contractors rating effort lower and value higher than owners. Despite this, contractors identified fewer high-value, low-effort strategies than owners. One reason for this is that contractors are in general less likely to view solution strategies as extremely good or bad – their opinions are more centrist than owners' opinions.

Limitations

This research was limited geographically, as most of the survey respondents were based in North America at the time of participation – however, many of their companies execute projects internationally as well domestically. While the survey sample size was relatively small, it is comparable with other surveys in published literature on this topic. The number of respondents from owner and contractor organization was also not exactly the same.

Contributions to theory and practice

The major contribution of this research to the industrial construction body of knowledge is the identification of the sets of owner-only and contractor-only high-value, low-effort solution strategies for the most common CCSU problems. The listing of exactly which strategies were identified by each organization type is provided in Table I. Further, statistical testing showed that value and effort ratings from owner and contractor employees were significantly different for many strategies. Those disparities help prove that differences in perspectives and opinions about CCSU solution strategies exist between owners and contractors. The identification of owner-only and contractor-only high-value, low-effort strategies helps fill the knowledge gap on the differing perspectives of multiple stakeholder organizations with respect to solution strategy effectiveness. Differing perspectives and opinions may be explained by differences in owner and contractor motives, objectives, organizational culture and capabilities. For example, successful completion for most contractors ends with facility startup, while owners are invested in successful operations and production. These differences likely influence differing perspectives and opinions on CCSU solution strategies.

This research also establishes a novel research methodology using a PICK chart or quadrant style approach to comparing opinions on the effectiveness of CCSU solution strategies between parties and especially as a way to measure how their opinions coincide or diverge. This approach may be usefully applied in the future to comparing solution strategies for problematic activities in other construction engineering contexts.

CCSU decision-makers can apply the findings from this research to industry practice. High-value, low-effort strategies will provide more benefit from the investment of resources than other strategies. In situations where project managers experience CCSU Hot Spots, they can use the recommended solution strategies which best fit the specific circumstances of their projects. Each project is different, and all solution strategies may not be appropriate for each situation, but industrial construction project managers can use the results of this research with greater confidence about the value expected from and the effort required for each strategy. In instances where the project delivery method places most of the work load on one party or another, CCSU managers may receive more value and expend less effort by favoring solution strategies which were identified by the party with the greater responsibility and workload (i.e. owner vs contractor). When the project delivery method utilizes a tandem approach, with owner and contractors working together closely, implementation of solution strategies identified by both may be most beneficial. In general, recognition of the differing perspectives and opinions on CCSU solution strategies should help owner and contractor organizations align on objectives and methods.

Future research

Future research topics could include: parallels between owner and contractor opinions on industrial CCSU solution strategies and owner and contractor opinions on CCSU for other types of construction (commercial, heavy civil, etc.), topical coding of CCSU Hot Spot solution strategies, application of the PICK chart/quadrant methodology to compare opinions between parties on other phases of the project lifecycle (e.g. design, procurement, decommissioning, etc.) and modelling of the CCSU data and documentation cycle. CCSU has both practical and theoretical potential as an emerging sub-discipline which merits further attention from multidisciplinary researchers.

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