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APPLICATION OF CHOOSING BY ADVANTAGES DECISION-MAKING SYSTEM TO SELECT FALL-PROTECTION MEASURES

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ABSTRACT

The construction industry is one of the most dangerous industries in the United States. According to the U.S. Bureau of Labor Statistics, one in five work-related fatalities in the U.S. occur in construction. Safety managers are frequently faced with a dilemma when making safety decisions and typically surrounded by overwhelming boundaries that affect their safety selections. Yet, literature does not provide safety practitioners with a sound decision-making system to be used during the process of specifying safety solutions that is not mainly based on subjective judgments using personal experience. Making sound safety decisions is crucial toward ensuring worker safety. This paper presents a detailed case study example of how a lean thinking concept called Choosing by Advantages (CBA) can be implemented on a construction project to make safety design decisions regarding the permanent features of a facility. In this case study, three fall-prevention measures on a one-story physical utility building on a medical facilities campus are examined. The present research builds upon previous research to extend the use of the CBA tabular method to the safety arena of the construction industry for the first time. The result indicates that CBA is a sound decision-making system that can be used by project teams to make safety decisions during early stages of design.

KEYWORDS

Choosing by Advantages, decision-making, lean thinking, fall-protection, safety.

INTRODUCTION

The construction industry remains one of the most hazardous industries in the United States. According to the U.S. Bureau of Labor Statistics, the number of fatal work injuries in the U.S. construction industry in 2014 was 874 (BLS, 2015). Falls from heights are still the leading cause of fatal occupational injuries in construction (BLS, 2015). While several safety measures have been identified, their effectiveness in reducing the rate of fatalities remains uncertain. Safety managers are frequently faced with a dilemma when making safety decisions and typically surrounded by overwhelming boundaries that affect their

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safety selections, such as construction cost, project schedule, and other critical factors to project success. Yet, literature does not provide safety practitioners with a sound decision-making system to be used during the process of specifying safety solutions that is not mainly based on subjective judgments using personal experience. Safety practitioners are desperately in need for a systematically sound decision-making method. Making sound safety decisions is crucial toward ensuring worker safety.

POINT OF DEPARTURE

Lean thinking offers many strategies that can be used to enhance collaboration between project teams. For example, the process of set-based design (SBD) typically involves generating as many design alternatives as possible up-front to allow for optimal trade-offs. The SBD process involves delaying the decision regarding which design alternatives to choose until the last responsible moment to enable cross-functional teams (CFTs) to make design decisions with more flexibility and less subjectivity. Design decisions have greater impact on building performance than decisions made during the construction process (Abraham et al., 2013). Design decisions do not only impacts aesthetics and cost of the project, but also safety performance, construction schedule and other outcomes of the building process. However, the process of SBD may lack formal and sound decision-making that ensures the selection of the best design alternative. The Choosing by Advantages (CBA) decision-making system can fill this gap as a sound and congruent decision-making system. Parrish and Tommelein (2009) claimed that the CBA process can enhance the implementation of SBD. Other research reveals that CBA methods and lean thinking are aligned in many ways (Arroyo et al., 2012). For instance, the CBA process defers subjective judgments until the end of the decision-making process, as will be discussed, which is consistent with lean thinking strategies especially the concept of SBD.

The aim of the present study is to examine the practicality and feasibility of applying CBA by safety practitioners in practice to make safety design decisions regarding the permanent features of the facility. A detailed case study example is selected to explain the process of implementing CBA tabular method on a construction project to make early design decisions that impact occupational safety.

CHOOSING BY ADVANTATAGES (CBA) AND LEAN THINKING

CBA is a lean decision-making system (Arroyo et al., 2012) originally developed by Jim Suhr (Suhr, 1999). Even though CBA is a form of multiple-criteria decision analysis (MCDA), it was found to be superior to other MCDA methods, such as Weighting, Rating, and Calculating (WRC) (Suhr, 1999) and Analytic Hierarchy Process (AHP) (Arroyo et al., 2012, 2015; Kpamma et al., 2015). CBA encourages the use of correct data as well as using data correctly by basing decisions on anchoring questions, relevant facts, and the importance of differences between advantages of alternatives (Suhr, 1999). This process leverages and facilitates the achievement of lean thinking by improving the work-flow when translating the activity of generating design alternatives into construction operations through a more consistent (Arroyo et al., 2012) and less subjective (Suhr, 1999) decision-making process when deciding among alternatives. CBA vocabulary must be clearly understood before using the CBA system in the process of evaluating alternatives (Suhr, 1999). Definitions of CBA vocabulary are available in Suhr (1999).

CBA's fundamental rule is to initially identify only advantages of alternatives as opposed to traditional thinking of weighting both advantages and disadvantages of alternatives to avoid double-counting and omissions (Suhr, 1999). Advantages and disadvantages are exactly the same except for their perspective (Abraham et al., 2013). The second rule is to separate cost from value. Cost is a constraint, not a factor, and thereby should be given special attention when making a decision. It should be noted that other confounding variables may also be considered constraints such as contractual requirements. Most importantly, CBA relies on a major cornerstone principle which calls for basing decisions on the importance of differences between advantages of alternatives, rather than the importance of factors as is the case in other conventional MCDA methods (Suhr, 1999). This distinction helps decision-makers to limit personal judgment by providing a point of reference, so a decision can be rooted to its relevant facts instead of primarily relying on factors which may be irrelevant as when two alternatives possess the same quality and/or quantity of attributes.

RESEARCH METHOD

The focus of the present study is to explore the use of the CBA decision-making system in evaluating potential safety interventions for implementation on construction projects. Through a case study project, three fall-prevention measures on a one-story physical utility building on a medical facilities campus are examined. Six key participants were chosen to participate in the study, in which all were Ph.D. students in the School of Civil and Construction Engineering at Oregon State University (OSU), based on their background and qualifications. Practical construction site experience among the participants ranged from zero to twelve years. All of the students are doctoral researchers working on safety related topics. All of the participants have completed a design for safety course taught as part of the Construction Engineering Management program at OSU. Even though safety and lean knowledge were taken into consideration in addition to experience when inviting students to participate in the study, the sample size was conveniently selected.

A three-day workshop, facilitated by the research team, was conducted to train the participants and to explore the potential of incorporating CBA into safety design solutions. A similar protocol to those used by Arroyo et al. (2015) and Kpamma et al. (2015) was followed. The workshop was divided into three sessions. In the first session, background information including the importance of sound decisions and the bridge design experiment (see Suhr, 1999) was covered. In the second session, applications of different forms of MCDA were applied on a detailed case study example to provide participates with the fundamental knowledge of different insights of the decision-making process. In the final session, participants were asked to implement the process of the CBA tabular method to choose a safety measure on a flat roof for a particular case study project. During the workshop, which was videotaped to enable interaction between participants to be recalled for further analysis, participants critically discussed the assumptions behind CBA and other MCDA methods. A short questionnaire survey was also distributed at the end of the workshop to document the participants' perception on the use of CBA and to investigate potential barriers and enablers of implementing CBA in selecting safety designs. Although some work has been carried out in the application of CBA in the Architecture, Engineering, and Construction (AEC) industry (Abraham et al., 2013; Arroyo et al., 2012, 2014, 2015; Kpamma et al., 2015; and others), no work has been conducted on the application of CBA in the safety area of the construction industry. The outcome of this research is expected to provide safety practitioners with a systematic sound procedure to make safety decisions using the CBA tabular method.

CASE STUDY DESCRIPTION

A detailed case study example adapted from Rajendran and Gambatese (2013) was selected to perform the CBA analysis. The project included the construction of a single-story 930 square meters (10,000 SF) physical utilities building on a medical facilities campus. The project involved extensive mechanical construction operations within the facility and on the rooftop of the building. A concrete foundation with structural steel core and shell was selected for this building by the design team. Metal panels with steel stud backup system along with glazed curtain wall covered the exterior envelope of the building structure. The original design called for a 30.5-cm (12-inch) tall parapet around the perimeter of the roof, which does not meet Occupational Safety and Health Administration (OSHA) guardrail height requirements.

In the case study, three safety solutions were identified to be implemented on the jobsite to mitigate the risk of falling from the roof edges. The first option was to install a temporary guardrail system that meets OSHA guardrail height requirements on the roof during construction and maintenance operations to protect the safety of workers, as shown in Figure 1-a. Specifying permanent roof anchors to provide laborers working on unprotected edges with tie-off points was the second option. The original design included the installation of six roof anchors on the building rooftop, as shown in Figure 1-b. These two options are widely adopted on construction projects that include a flat roof due to affordability and ease of implementation. However, these practices do not necessarily eliminate the risk associated with construction and maintenance operations. Prevention through Design (PtD) solutions have been identified as being more effective in preventing occupational injuries (NIOSH, 2016) than administrative (e.g., worker training) and engineering (e.g., roof anchor system) controls.

Figure 1: Suggested fall-protection systems (Rajendran and Gambatese, 2013)

A typical example of PtD is to increase the parapet height on a flat roof to 99-cm (39-inch), so that it meets OSHA height requirements and eliminates the need for a temporary guardrail/roof anchor system during work operations. Therefore, the implementation of a 99-cm (39-inches) roof parapet was considered as the third option, as illustrated in Figure 1-c.

However, in order to successfully incorporate PtD strategies into a project, early involvement of designers is required to specify unique modifications in construction plans and specifications of the permanent features of the facility. In the United States, current laws and regulations do not encourage or require designers to design for worker safety (Gambatese et al., 2005), and thereby such implementation remains sporadic. Despite the fact that PtD strategies are not frequently implemented in construction, there is a strong ambition to facilitate the use of PtD within the AEC industry.

A STEP-BY-STEP PROCESS OF CBA TABULAR METHOD

Differences in complexity of a decision call for different CBA approaches. Selecting a fall-protection measure for the presented case study is a complex decision that involves a careful examination of three safety design alternatives using a lifecycle approach and consideration of nine factors which will be described later that account for different components of the project. For a moderately complex decision like this one, Suhr (1999) recommended the use of CBA tabular method. The CBA tabular method involves six steps as described below and shown in Table 1.

STEP 1: GENERATING POSSIBLE ALTERNATIVES

Three fall-protection alternatives were identified as described previously.

STEP 2: IDENTIFYING FACTORS AND CRITERIA

Extensive literature review was conducted to document possible factors having potential impact on the selection of a rooftop fall-protection measure. Next, a brainstorming session was held with the participants to decide on the most important factors contributing to the final decision regarding the selection of a fall-protection system. As a result, nine factors (described below) were selected to be the components of the decision for this case study. In addition to factors, the participants identified criteria (left column of Table 1) that they would use to judge the attributes of each alternative.

- Factor 1 (Reliability of safety measure): One of the primary reasons of using the CBA process is to investigate the reliability of the proposed safety measures. The hierarchy of controls, which includes five levels of controls with elimination being the most effective control and personal protective equipment (PPE) being the least preferred control, was used as a mean of determining the feasibility of each safety measure;
- Factor 2 (Ease of implementation): Ease of implementation is a crucial factor when designing a safety program. As discussed previously, safety managers are typically surrounded by many considerations that eventually affect their safety selections. For instance, measures involving the concept of PtD are most likely to require early involvement of designers, while administrative/engineering measures can be solely implemented by the contractor or safety staff;
- Factor 3 (Construction site safety): The construction workforce is “the most valuable resource” involved in the process of constructing a facility (Hinze et al., 2013); therefore protecting the safety of construction workers must be the priority of any planning effort. Any failure to guarantee worker safety may cause serious injuries or illnesses and lead to possible litigation that impacts the project success. The attribute

of each of the alternatives varies in its influence on construction site safety. For example, while a temporary guardrail significantly reduces the risk of falling, it does not eliminate the hazard altogether. Even with such implementation, it is still possible that a guardrail might break during a work operation allowing a serious injury. Similarly, fall-protection gear does not eliminate the hazard even though it may catch workers and prevent them from falling to the ground level. On the contrary, a 99-cm (39-inch) roof parapet eliminates the hazard of falling over the sides of the roof;

Table 1: CBA tabular method

Factors	Alt.1: Temporary Guardrail		Alt.2: Roofing Anchor System		Alt.3: 99-cm (39-inch) parapet	
1.Reliability of safety measure	Att: Engineering control.		Att: Engineering, PPE, Administrative.		Att: Elimination.	
Criterion: Elimination is the most preferred, Eng. control is the least	Ad: More reliable and a little safer.	IofA: 15	Ad:	IofA:	Ad: *Much more reliable and safer.*	IofA: 20
2.Ease of implementation	Att: Easy to install; Only contractor involved.		Att: Two parties involved in implementation; Easy to install.		Att: Three parties involved in implementation; Moderate to install.	
Criterion : The easier to implement, the better	Ad: *More known; fewest people involved; less technical.*	IofA: 70	Ad: Fewer people involved.	IofA: 60	Ad:	IofA:
3.Construction site safety	Att: Significantly reduce falling over the side; Requires installation while no barrier is present; Requires admin. control.		Att: Prevents falling to the ground; Reduces severity of injuries; Requires PPE and admin. control; Partial permanent control.		Att: Prevents falling over side; Permanent control.	
Criterion: Eliminating hazard is preferred	Ad:	IofA:	Ad: Permanent over portion of construction phase. More structurally stable.	IofA: 35	Ad: *Permanent during portion of construction phase. "It's there." Fewer admin. controls needed.*	IofA: 100
4.Safety of maintenance personnel	Att: Significantly reduce falling over the side; Requires installation while no barrier is present; requires admin. control.		Att: Prevents falling to the ground; Reduces severity of injuries; requires PPE and admin. control; Partial permanent control.		Att: Prevents falling over side; Permanent control.	
Criterion: Eliminating hazard is preferred	Ad:	IofA:	Ad: Permanent. More structurally stable.	IofA: 25	Ad: *Permanent. "It's there." Fewer administrative controls needed.*	IofA: 50
5.Safety of end-users	Att: Unlikely to be used by end-user.		Att: Unlikely to be used by end-user.		Att: Permanent protection provided. Prevent falling over side.	
Criterion: Enhancing end user's safety is preferred	Ad:	IofA:	Ad:	IofA:	Ad: *Allowing user to conduct work safely without installing another system or using PPE.*	IofA: 35
6.Aesthetics	Att: No impact.		Att: No impact.		Att: Taller exterior wall. Prevents seeing equipment; Nice looking from below.	
Criterion: The nicer, the better	Ad:	IofA:	Ad:	IofA:	Ad: *Nicer looking (hiding maintenance equipment).*	IofA: 10
7.Productivity of workers	Att: Some impact on productivity due to distraction		Att: Decrease productivity for construction and maintenance workers by 15% due to wearing fall protection gear		Att: No impact	
Criterion: Higher productivity is preferred	Ad: Higher productivity	IofA: 50	Ad:	IofA:	Ad: *Highest productivity*	IofA: 55
8.Effort needed before maintenance/installation	Att: Significant extra effort required to install if work near edge.		Att: Some extra effort required to attach lanyard if working near edge.		Att: No extra effort required.	
Criterion: Less effort is better	Ad:	IofA:	Ad: Less extra effort required.	IofA: 13	Ad: *No extra effort required*	IofA: 15
9.Construction schedule	Att: No impact		Att: No impact		Att: No impact	
Criterion: The faster, the better	Ad:	IofA:	Ad:	IofA:	Ad:	IofA:
Total IofAs		**135**		**133**		**285**

- Factors 4 and 5 (Safety of both maintenance personnel and end-users): The safety of maintenance personnel and end-users are considered in a similar manner to the safety of construction workers, but weighted differently;
- Factor 6 (Aesthetics): Building aesthetics is an important element when designing a building not only for designers, but also for owners. The contractor and designer want to ensure a nice looking building to keep the owner satisfied. A tall parapet can improve the building aesthetics by keeping maintenance equipment unseen (Gambatese et al., 2005). Because extensive mechanical construction operations are expected to be carried out on the one-story building's roof, this factor may have a substantial impact on the selection of decision-makers represented by participants in this case study;
- Factor 7 (Productivity of workers): The safety measures may potentially impact productivity which, if negative is considered a type of waste. Any task that generates waste should be undesirable, and clearly distinguished during the decision-making process. Rajendran and Gambatese (2013) quantified the impact of a roof anchor

system on the efficiency of workers as opposed to working on a well-protected roof, and found a 15% reduction in worker productivity due to the use of fall-protection gear as it restricts worker movement and requires greater effort to tie-off. It has also been decided that the temporary guardrail system can impact worker productivity negatively due to distraction. In contrast, PtD solutions improve the quality of the final product and productivity of construction workers (Gambatese et al., 2005);

- Factor 8 (Effort needed before maintenance/installation): Preparation needed before carrying out maintenance/installation operations may substantially affect the total task duration. For instance, the extra effort required to install a temporary guardrail is significant compared to the effort needed when working near protected roof edges; and
- Factor 9 (Construction schedule): The construction schedules required for different designs can differ greatly depending on the complexity of the design as well as the construction means and methods used on the jobsite. The original design of the case study building calls for a 30.5-cm (12-inch) tall parapet, while alternative #3 involves an increase in the parapet height by about 68.5 cm (27 inches), which may affect the construction schedule. However, due to the inherent design of the case study building, the participants decided that there would be no impact on the project duration no matter which alternative is selected. A review of literature equally revealed the same finding, indicating that there are only minor changes in construction means and methods when increasing the height of a parapet (Rajendran and Gambatese, 2013). However, these fall-protection systems greatly impact construction cost differently.

STEP 3: SUMMARIZING THE ATTRIBUTES OF EACH ALTERNATIVE

In this step, the participants summarized the attributes of each alternative in response to each of the nine factors (defined in step 2) using the criteria as a rule of judgment. Some of the attributes were described above.

STEP 4: DETERMINING THE ADVANTAGES OF EACH ALTERNATIVE

In this step, the participants identified the advantages of each alternative, relying on the criterion and attributes for each factor. The following procedure was followed: (1) select the least preferred attribute (shown in underlined font) for each factor; (2) determine the differences between the least-preferred attribute and the other attributes; and (3) decide the most-preferred advantage of each factor (shown in italics). In this step, the determination of the advantages of the alternatives should be an objective task.

STEP 5: DECIDING THE IMPORTANCE OF EACH ADVANTAGE

In this step, the participants assigned a level of importance to each advantage. A scale from 1 to 100 was selected to provide the participants with flexibility in assigning different levels of importance. The paramount advantage, defined by Suhr (1999) as the most important advantage among all, should be determined first and assigned a score of 100. The next task is to weight the rest of the advantages using the paramount advantage as a point of reference. The final stage of this step is to compute the total importance of advantages (IofAs) of each alternative (bottom row of Table 1).

STEP 6: SELECTING THE BEST ALTERNATIVE

In this step, the alternative that provides the greatest value to the stakeholders/decision-makers should be selected. If funds are unlimited, a cost analysis will not be needed. In the case study example, alternative #3 (a 99-cm parapet) will be selected because it was identified as having the greatest value (IofAs). However, cost is seldom unlimited (Suhr, 1999), and thus cost should be considered in the decision-making process. Table 2 summarizes both the initial and lifecycle cost assessments of implementing each system. The cost of maintenance operations includes those cost associated with a full-body harness, self-retractable lifeline, lanyards, and fall protection training program as required by OSHA. These considerations need to be provided regularly (assumed every 5 years) due to aging, obsolescence, and turnover when the roof anchor system is adopted.

Table 2: Cost assessment analysis (data from Rajendran and Gambatese, 2013)

Temporary Guardrail		**Roofing Anchor System**		**99 cm (39-inch) Parapet**	
Work description	Cost	Work description	Cost	Work description	Cost
Material cost of a guardrail system	$1,173	Material cost 6 eng. roof anchors	$2,638	Walls & celling	$19,533
Installation & removal: 24 work hrs	$1,205	Installation of 6 roof anchors/davits	$1,706	Roofing	$4,475
Fall protection equipment	$2,048	Base plates: supply & installation	$1,082	Exterior wall panels	$20,020
Delivery costs & miscellaneous	$600	Miscellaneous expenses	$6,756	Extra design fees	Included
Total initial cost	**$5,026**	*Total initial cost*	**$12,182**	*Total initial cost*	**$44, 210**
Maintenance and training cost	-	Maintenance and training cost	$1,100	Maintenance and training cost	-
Lifecycle cost assessment (50 years)	**$125,650**	*Lifecycle cost assessment (50 years)*	**$23,182**	*Lifecycle cost assessment (50 years)*	**$44, 210**

Figure 2 illustrates a value-cost evaluation of each alternative in the long/short run. Based on the comparison, the temporary guardrail is the most expensive option in the long run even though it is initially inexpensive. The temporary guardrail possesses almost the same value of the roof anchor system, but from a benefit-cost analysis, the roof anchor system is more desirable than a temporary guardrail at least in the long run. On the other hand, the 99-cm parapet possesses a high value (IofAs = 285), but also costs more than the other two systems initially and eventually.

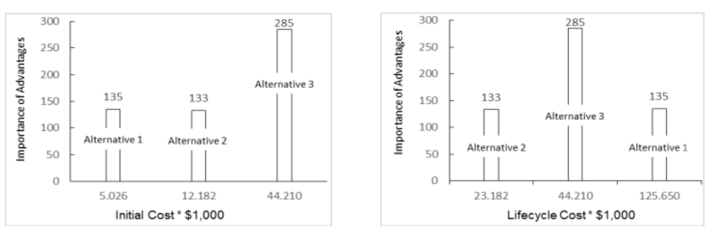

Figure 2: Cost vs. value charts

FEEDBACK FROM PARTICIPANTS: STRENGTHS AND LIMITATIONS

The application of the CBA decision-making system revealed several advantages expressed by the participants during the workshop and in the survey distributed afterward. The most important advantage recognized by the participants is that CBA anchors decisions to relevant facts to produce objective judgments even though determining the IofAs (step 5) is entirely subjective. No decision can be free of personal preference (Parrish and Tommelein, 2009), but it is important that judgments be built upon facts to avoid a high-order of abstraction. The decision-making process of CBA calls for carrying out objective tasks before subjective tasks (Suhr, 1999), so that subjective judgments (deciding IofAs) can be anchored to objective data revealing a valid and sound decision.

Separating cost from value was viewed by participants as a superior advantage of CBA compared to other MDCA methods. This feature enables a value versus both initial and lifecycle cost analysis to be made prior to making a decision which creates more transparency (Arroyo et al., 2014, 2015), clarity, and significance to the decision-making process. Moreover, considering differences between alternatives when making decisions is a unique characteristic of CBA compared to other MCDA methods.

That is no to say that CBA has no disadvantages. Participants identified the inherent complexity of the CBA process as the main shortcoming, contending that the procedure used in the tabular method was complicated and time-consuming. Additionally, CBA is not capable of evaluating a single alternative because the decision stems from a comparison between advantages of alternatives. Arroyo et al. (2014) contended that CBA is inappropriate when decision-making is required in conceptual building design. CBA is also invalid when there is uncertainty in the process of identifying attributes of alternatives. In the end, more positive comments were received from the participants. The participants acknowledged that CBA is a sound, congruent, and effective decision-making system that can be used effectively in the AEC industry to entrench lean thinking, especially in regard to safety.

STUDY LIMITATIONS

Before proceeding to the conclusions, it is worthwhile to mention the limitations of the present study. First of all, participants may lack practical experience in the field of safety even though some of them have worked in the industry. Another potential limitation is that participants were not actually experts in using CBA. The participants were taught how to use CBA in a short time. Suhr (1999) indicated that in order to obtain a sound decision, decision-makers must “learn and skillfully use” CBA. However, the aim of the present study is to explore the potential of introducing CBA to safety practitioners, rather than generalizing a conclusion regarding the most desirable fall-protection system.

SUMMARY AND CONCLUSIONS

The CBA decision-making system is a sound method used to make informed decisions when deciding between alternatives. The use of CBA in the safety field can help safety professionals and project teams select effective measures to protect worker safety. The present research extends the application of CBA to safety for the first time by analyzing the components of a decision involving the selection of a fall-prevention measure on a case study. Through the application of CBA on the case study, it is concluded that CBA is an applicable and sound decision-making system that can be practically used to make safety design decisions about the permanent feature of a building. The case study can be used as a starting point for future safety decisions that involve the use of the CBA method.

The result of the application of CBA revealed both strengths and limitations of using the CBA system in making safety decisions. However, advantages, such as the ability to make informed decisions that account for both initial and lifecycle cost assessment and basing subjective judgments on relevant facts and objective data, were found to outweigh the disadvantages. As the use of CBA maximizes value to project teams, it should be fully incorporated into the application of lean thinking. CBA can be linked to lean thinking in numerous ways; both defer decisions to the last responsible moment to enable project teams the flexibility of making informed decisions by eliminating uncertainties resulting from early assumptions and subjective judgments. The authors recommend that future research explore the benefits of incorporating the CBA method into the Last Planner System (LPS) on lean projects.

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