Haronian E. & Korb. S. (2024). Magical vs Methodical: Choosing by Advantages as Antidote to the Planning Fallacy. In D. B. Costa, F. Drevland, & L. Florez-Perez (Eds.), *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction* (IGLC32) (pp. 1099-1110). doi.org/10.24928/2024/0115

MAGICAL VS METHODICAL: CHOOSING BY ADVANTAGES AS ANTIDOTE TO THE PLANNING FALLACY

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ABSTRACT

Cost and schedule overruns are the bane of construction projects, in part due to overly optimistic predictions of project progression. This "optimism bias" is called the planning fallacy, a form of "magical thinking" where planners convince themselves that their project will be different (and better) than others. "Choosing by Advantages" (CBA) is a methodical approach for decision-making. By engaging "slow thinking" at the organizational level, CBA can help counteract the tendency to default to best-case scenarios when selecting among designs and production methods, even in the middle of a project. In this paper, a case study of a Pumped Hydroelectric Energy Storage facility that had to choose between a bottom-up raise boring and a top-down shaft sinking construction method for the vertical shaft connecting the reservoirs is presented. The paper then examines how CBA helped shift the thinking of the project team away from fallacious planning and overcome the sunk-cost fallacy.

KEYWORDS

Choosing by Advantages, Optimism Bias, Planning Fallacy, Risk Management, Monte Carlo

INTRODUCTION

The planning of a construction project is a process that involves making a number of assumptions (Gao et al., 2014). While construction professionals draw on their knowledge and experience, as well as the use of computer simulations and archived data, there comes a time when the humans involved with the planning are making their best assumptions: assumptions about durations of project tasks, likely contingences and how to react to them, and – if the project involves any excavation – what lies beneath the surface of the construction site. Again, these assumptions may be informed guesses that rely on models and empirical evidence like core sampling (in the case of the ground substrate), but until the project is underway there is no way of knowing exactly what the truth may be.

Thus, human psychology comes into play in the planning of any construction project. Humans are prone to some illogical thought patterns, including the optimism bias (Weinstein, 1980), which is a tendency to assume the best case scenario when considering future events. It is likely in part due to this tendency that construction projects experience a mismatch between how they are planned to be carried out versus the reality of their implementation, leading to the budget overruns and schedule delays that plague the industry (Egan, 1998).

During tendering (especially in tenders that put most of the weight on price) owners and contractors often have a tendency to take an optimistic approach (Chadee et al., 2021; Son & Rojas, 2011), which allows a lump sum fixed price to be reached. But once construction begins,

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it may turn out that risks have been underestimated, and assumptions regarding various aspects – including the construction methods selected to complete the project – must be re-examined. The question at this point is what do they do – continue as planned or re-think? Here too, human psychology comes into play, as there is a tendency to want to continue an earlier-planned course despite new information coming to light. This is referred to as escalation of commitment (Staw, 1981) or the sunk cost fallacy (Arkes & Blumer, 1985). Overcoming these innate tendencies is difficult in practice, and again runs into the optimism bias. Project personnel tend to want to project an aura of competence and project optimism, not wanting to expose bad news that could make them, or the project, look bad.

One way to combat these fallacious approaches is to institute rigorous approaches to decision making. The Choosing by Advantages (CBA) method (Suhr, 1999) is a systematic decision-making strategy that can help to confront hard truths. When implemented in a project, it can assist in addressing issues more effectively at an earlier stage, rather than “kicking the can down the road” due to the combined forces of the optimism bias and the sunk cost fallacy. The CBA method is transparent, which helps in communicating the issues across the project organization and building consensus. And yet, the existing literature has not explicitly used CBA to address the planning fallacy.

In this paper, we attempt to close that knowledge gap by presenting a case study of an infrastructure construction project which encountered the issues described above. After planning the project for a “best case” scenario, upon commencing the project it was discovered that the reality of the implementation did not meet the assumptions. CBA was used to assist a mid-course correction, selecting a construction method that, while costing more in the short term, would lead to the best outcome for the project. We present the issues at play in the project and how CBA helped address them, showing that methodical approaches like CBA can serve as an “antidote” to tendencies like optimism bias.

LITERATURE REVIEW

CHOOSING BY ADVANTAGES

CBA is a Multi-Criteria Decision Making (MCDM) system (Köksalan et al., 2011), developed by Suhr (1999), and applicable for a wide range of decisions, from mundane daily individual-personal decisions through strategic-organizational-collaborative decisions. Though CBA is a relatively new approach in the MCDM field, it has been widely implemented by academic and industry practitioners, assisting project teams in building consensus that includes different perspectives and addresses sometimes-conflicting interests (Arroyo et al., 2022; Arroyo & Long, 2018; Martinez et al., 2016; Parrish & Tommelein, 2009; Schöttle et al., 2019; Schöttle & Arroyo, 2017). Successful applications of CBA can be found regarding design alternatives (Arroyo et al., 2012; Arroyo & Long, 2018; Kpamma et al., 2017; Parrish & Tommelein, 2009) or for operational decisions (Martinez et al., 2016). Arroyo et al. (2012) describe the “Lean” properties of CBA that include: a systemic multidisciplinary approach for global optimization, enhanced involvement of stakeholders, consideration of cost only at the last phase of the process once an objective basis has been established, and good visualization of the process and the outcome which enables transparency and collaboration.

In CBA, it is important to document assumptions (and the thought processes that led to them) for decisions, so they can be revised later in the project when new considerations arise (Parrish & Tommelein, 2009). This becomes even more valid in high-risk projects, as decision makers must re-evaluate their decision as the project progresses. Additionally, CBA may assist in making "difficult" long-term decisions that need to be transparent across the organization in order to be approved by stakeholders (Schöttle et al., 2023).

The seven steps of CBA (Arroyo, 2014; Suhr, 1999) were followed in this project, where the "factors" are the decision criteria for all options whereas "attributes" are the ways in which an individual option realizes a particular criterion:

1. Identify alternatives
2. Define factors
3. Define criteria for each factor
4. Evaluate attributes for each alternative
5. Decide the advantages for each alternative
6. Decide the importance of each advantage
7. Evaluate cost data.

OPTIMISM BIAS AND THE PLANNING FALLACY

Optimism bias is the tendency for people to overestimate the likelihood of positive future outcomes and/or underestimate the likelihood of negative future outcomes (Sharot, 2011). The term was coined by Weinstein (1980) and has repeatedly been documented in a variety of settings (Klein & Helweg-Larsen, 2002). Optimism bias is somewhat insidious in that it resists efforts to "inoculate" people to its effects; efforts to do so can actually increase the amount of optimism bias displayed (Weinstein & Klein, 2002). Since optimism bias reflects a divergence between thought processes/assumptions and objective reality, it constitutes a form of "magical thinking", which entails drawing correlations not based on evidence (Hutson, 2013).

The application of optimism bias to project planning has been called "the planning fallacy" by Kahneman and Tversky (1977). This refers to the tendency to assume only the best-case scenarios when laying out the plan for a project (Buehler et al., 2010), which is reflected in unrealistic project timelines. Planning fallacy contributes to projects costing more and taking more time than expected (Flyvbjerg, 2011). Kahneman (2011) has suggested that while humans have a default thinking mode that is more fallible, deliberate thinking can help arrive at more logical conclusion; these two modes are referred to as "fast thinking" and "slow thinking" respectively. In the realm of Lean Construction, Senior (2012) has looked at documented psychological biases and suggested that Lean Construction techniques such as Last Planner (Ballard, 2000) can combat some of the biases that are inherent to human psychology leading to overly-optimistic planning. Roch et al. (2022) have suggested that cognitive biases like the planning fallacy are an obstacle to the introduction of the Lean concept of "flow" in the construction industry, as human brains have been shown to struggle with internalizing (and exploiting) stochastic and statistical realities.

CASE STUDY: SHAFT CONSTRUCTION METHOD FOR PUMPED-STORAGE HYDROELECTRIC FACILITY

The project in this case study, where CBA was successfully applied to combat the tendency towards optimism bias, is a Pumped Hydroelectric Energy Storage (PHES) facility. PHES is a method of storing excess electricity generation (Rehman et al., 2015) when demand and supply levels are out of sync. In times of excess supply, energy is used to pump water "uphill" from a lower water reservoir to an upper reservoir. In times of excess electricity demand, the flow of water is reversed, with the water from the top reservoir driving generators to put energy back into the grid. An "engineering, procurement, and construction" (EPC) contracting method (Carrillo, 2005) was used, with the PHES project structured as a turnkey project where the General Contractor was responsible for design, procurement, construction, and commissioning.

Within the scope of the PHES facility, the main focus of this case study is the construction of the underground chambers that would connect between the upper and lower reservoirs. The main components of a PHES facility are shown in Figure 1.

The following components of the PHES facility appear in this figure:

1. Upper and lower reservoirs, that contain the bulk water storage.
2. Power House (PH), in which the pumps/generators/turbines are located.
3. Horizontal tunnel, which connects between the lower reservoir, the PH, and the bottom of the shaft.
4. Vertical shaft, which connects between the elevations of the upper reservoir and the lower reservoir, horizontal tunnels, and the PH

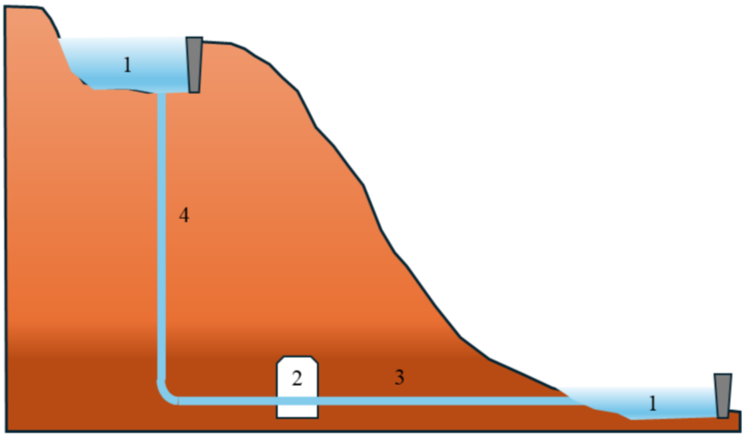

Figure 1: Cross-section of the PHES facility

The main focus of this case-study is on the selection of the construction method that was used to excavate the 700-meter vertical shaft as well as the interplay between the timing of digging the tunnel and the shaft.

BACKGROUND

For this project, two options were considered for the method of excavating the vertical shaft, as shown in Figure 2.

The following sections describe these two methods of drilling, as well as their impact on the project's critical path.

Raise Boring

Raise Boring (RB) is referred to as a "bottom up" method of drilling (Liu & Meng, 2015), and it requires access to the bottom of the shaft for most of the work. A small-diameter pilot hole is sunk from the top of the shaft, just wide enough to accommodate a drill string. Then a large-diameter reamer head is attached to the drill string at the bottom of the shaft (i.e. via the tunnel in this case study). The reamer head is then raised back towards the top of the shaft, which means the drill face for the shaft is oriented towards the bottom of the shaft. The material dislodged by the reamer head falls down the shaft to the bottom (the tunnel) via gravity, where it can be collected and removed with loaders and dump trucks.

Shaft Sinking

Shaft Sinking (SS), by contrast, is a "top down" method of drilling, where the entire excavation takes place from the top side of the shaft (Lashgari et al., 2011). It can be based on conventional "drill and blast" excavation or mechanical equipment, but both the equipment for extraction and the excavated debris enter and exit through the top opening of the shaft. As a safety feature preventing loose or unstable soil or rock from falling into the shaft, the sides of the shaft are supported with shotcrete as the shaft is excavated.

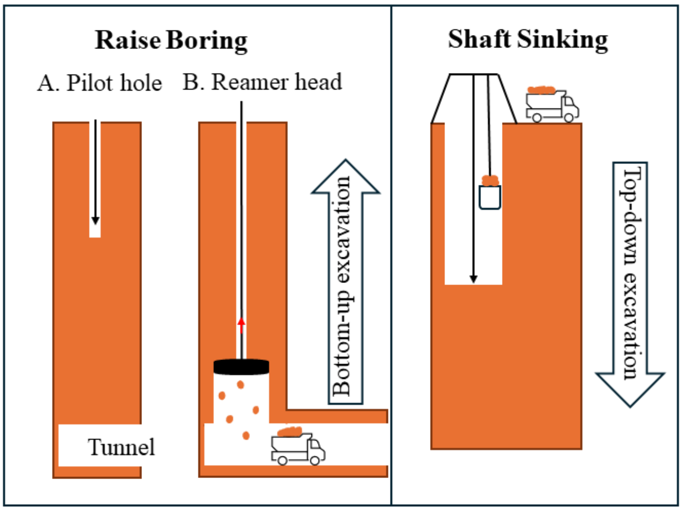

Figure 2: Raise Boring vs Shaft Sinking, for excavating the vertical shaft

Project Timeline and Critical Path

Due to the fact that in RB, the reamer head has to be installed from the bottom of the shaft, in this approach the shaft can only be dug once there is access to the lower level of the shaft. In this case, this meant after the tunnel was completed. Likewise, the rubble that the reamer dislodges must be extracted via the tunnel, which further increases the dependence of RB on tunnel completion. While it is possible to sink the pilot hole prior to tunnel completion, this is a relatively minor component of RB and thus does not effectively decouple the two steps.

SS does not have the same constraint, as the top of the shaft is used exclusively for entry and exit of both equipment and excavated materials. Thus in terms of the project steps, SS can take place in parallel with tunneling – a potential time savings for the project – whereas RB is in series with tunneling. After the tunnel and shaft are completed, the project can progress to testing and commissioning. The two options are portrayed in Figure 3.

The tunneling was found to be on the critical path for the overall project, which means that RB would also be on the critical path, if selected, whereas SS would not be on the critical path as it takes place in parallel with tunneling.

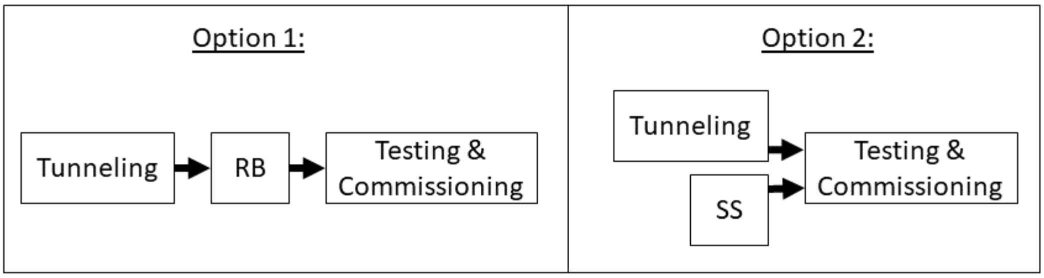

Figure 3: Impact of RB vs SS on project process flow

Before Applying CBA

Prior to project commencement, the project team was faced with the decision about whether to choose RB or SS as the method of digging the vertical shaft for the PHES facility. While CBA (or any other systematic decision-making approach) was not employed, this does not mean that the subject was not given some thought.

The major factor that contributed to the decision was cost. RB is a more "technically advanced" method of shaft digging, requiring less human input, which brings down costs. Removing the excavated material is logistically less complex since it uses loaders and dump trucks running on the effectively-flat tunnel floor. SS, on the other hand, is a more "basic/traditional" method that requires the ground excavated to be removed through the top of the shaft (which becomes progressively further from the drill face as the shaft progresses) as well as shotcrete along the sides of the excavation.

The duration of each alternative also played a part in the initial selection of RB; it was estimated to take 14 months versus 24 months for SS. Finally, the impact of each option on other steps in the project process was a factor, with RB having less impact and SS having more of an impact. This was due to the fact that SS required more logistical work in and around the upper reservoir, which also was undergoing construction (including drill and blast excavation) at the time same time.

Though at the time of the decision to use RB these factors were not formally tabularized, we have done so in this paper to sum up the considerations, as shown in Table 1.

Table 1: Factors leading to the selection of RB prior to applying CBA

Factor	RB	SS
Price	Lower	Higher
Sophistication/ Resources	High: advanced equipment, low labor input	Low/Traditional: basic equipment, extensive labor input required
Duration	14 months	24 months
Impact on other works	Low	High
Logistics	Low complexity	High complexity

For all these reasons, and mostly due to the cost, the choice that seemed obvious was to select RB, and that was what was indeed done on the eve of commencing the project.

APPLYING CBA

Soon after the project got underway, it became clear that certain assumptions that had been made during the project planning phase might not be correct. In particular, the ground consistency was not in line with the statistical assumptions that had been made regarding the geological condition of the site. The excavation method, equipment, and required levels of support for the tunnel/shaft, were planned according to the Geological Base Report (GBR), which reflects statistical analysis of field investigations for the soil classification.

However, once construction of the tunnel commenced, the project began to encounter unpredictable and problematic ground conditions that differed from the initial assumptions, instabilities potentially leading to cave-ins. The worse-than-expected ground conditions significantly affected the tunneling works, as much greater support levels were required than what was planned, causing schedule delays, cost overruns, and unexpected safety hazards. As a result, questions arose regarding the construction method for the vertical shaft: was the execution method that was initially selected suitable for the latent ground conditions? Was it reasonable to rely on a construction method that required the completion of the lower tunnels to begin the work on the vertical shaft? Given the developments with the ground conditions, risk considerations rose to a more prominent position in terms of project attention, so it was decided to reexamine the alternatives for the vertical shaft.

A team was assembled that consisted of six engineers (with professional experience that ranged from 15 to 40 years each): the Project Manager, the Construction Manager, the Head

Tunneling Engineer, the Head Civil Engineer, the Project Geologist, and the Planner (also the first author of this paper). The team was tasked with re-evaluating the construction method for the shaft in light of the difficulties encountered during the tunneling. In order to work as methodically as possible, and make sure decisions made sense to both members of the committee and the ownership of the construction company, the decision was made to work according to CBA.

It was at this time that the factors listed in Table 1 were formally codified. Three additional risk factors were recognized and added to the analysis: schedule risk, soil stability risk, and safety risk.

Schedule Risk

With the tunneling works delayed, the start of RB would also be delayed. Likewise, the ground instability that plagued the tunneling could possibly delay the RB progress. As these both were on the critical chain if RB was selected, a much more detailed analysis was required. A Monte-Carlo simulation (Mohsen et al., 2022) was used to assess the probability that the project would be completed on time, due to the uncertainties regarding the underground soil, which affected the tunneling excavation rate and introduced possible risks during the shaft excavation (due to groundwater ingression or shaft collapse).

First, the Monte-Carlo simulation examined the tunneling works, as these would need to be completed in either case. The duration of the tunneling tasks were represented by a beta probability distribution function, which required defining three scenarios: optimistic, most likely, and pessimistic. The tunneling works were divided into several segments with different geological properties. For each segment, the duration was calculated according to the segment length and the production rate for the three scenarios. For the optimistic scenario the duration was calculated according to the assumptions regarding structural reinforcement made in the preliminary design and the GBR. For the most likely scenario the duration was calculated according to the actual decrease in the production rate in the tunneling work up to the date the simulation was run. For the pessimistic scenario, the duration was calculated according to the most conservative structural reinforcement.

Then, both RB and SS were simulated in a similar manner. Since SS includes the installation of supports throughout, it was more robust in the face of the uncertain ground conditions as opposed to RB. RB remained the faster option, taking six fewer months to complete, but as shown in Figure 3, because SS could be conducted in parallel to tunneling, it had the advantage. It was found that RB would lead to a probability of less than 30% of completing the project on time, whereas SS would introduce a Total Slack of several months, which meant that the probability of completing the project on time was higher.

Soil Stability Risk

With the soil instabilities that were discovered, this factor examined the risk of collapse of the shaft excavation. The evaluation criteria employed a 5x5 Impact-Probability Matrix (Ni et al., 2010) to quantify the risk, by multiplying the impact ranking (which ranged from 1 [negligible] to 5 [catastrophic]) by the probability ranking (from 1 [Rare] to 5 [Almost Certain]). The resulting product was graded as very low (1-2), low (3-4), medium (5-9), high (10-12), very high (15-19), and extreme (20-25).

For RB, in light of the unpredictable ground conditions, it was decided that instability events were likely (ranked 4). Based on experience from previous projects in which incidence of instability occurred, it was decided that the damage that could be caused by such an event would be major (ranked 5). Thus, the rank for the risk was extreme (a total of 20).

For SS, support work is performed on the walls of the shaft as the excavation progresses. As a result, the risk of instability events was unlikely (ranked 2), and if an event occurs, the coping ability would be good leading to a relatively minor impact (ranked 2). Thus, the rank for the risk was low (a total of 4).

Safety Risk

Underground instabilities in the ground condition meant that worker safety had to be considered. Similar to the soil stability risk, this criterion was evaluated with a 5x5 Impact-Probability Matrix, as part of the periodic risk management meetings.

For RB, the excavated material falls down to the bottom of the shaft, which is a significant safety risk for the workers tasked with removing it through the tunnel. Based on experience from previous projects, it was assumed that the probability for safety events caused by the removal of material through the hole made by the reamer head was possible (ranked 3). If a safety event had occurred it could lead to costs of human life, and therefore was severe (ranked 5). Thus, the total rank was very high (15).

For SS, the safety risks derive from possible collapses and falling pieces of rock and soil from the shaft walls down to the working area. Because temporary supports are erected along the shaft as a matter of course, the risk of collapse and falling debris was deemed unlikely (ranked 2). If a safety event were to occur it could lead to costs of human life, ranked as severe (ranked 5). Thus, the total rank for the risk was high (10).

Applying CBA Weighting to the Factors

The additional factors that were identified are summed up in Table 2

Table 2: Additional Risk Factors

Factor	RB	SS
Schedule Risk: Probability of completing project on time	Low: <30%	High: >90%
Soil Stability Risk	Extreme: 20	Low: 4
Safety Risk	Very high: 15	High: 10

In the CBA method, once the factors have been enumerated and evaluated for the options, the next step is to compare the factors to decide their relative weighting. The factor that is considered the most significant is pegged at a weighting of 100, and then the others are scaled accordingly. The option with the greatest advantage for that factor receives the full value of the weighting for that factor, and (in the case of two options like in this project) the other option receives zero. This process is carried out collaboratively by the team, and necessarily carries a degree of subjectivity, while based on the objective observations gathered previously. Then the values are summed to determine the relative advantage of each.

Schedule risk was given the highest weighting, since the project team felt that delivering the project late to the owner would have negative side effects in terms both financial and reputational, and even possibly litigious. Of note, cost is not on this list, as under CBA, cost is not an advantage. Only once the advantages have been assessed is the cost considered, and a determination is made about whether the cost is justified to obtain the advantages of the respective option.

The CBA summation appears in Table 3, which combines the factors from Table 1 and Table 2 and adds the assignment of the advantage points to each factor/option.

The cost of SS was determined to be roughly double the cost of RB. Thus, at the final stage of the process, considering the costs of the alternatives, it was clear that the decision came down to a tradeoff between cost and risk: a high risk alternative at a relatively lower cost, and a low risk alternative at a relatively higher cost. Ultimately, it was decided that the higher cost of this one component of the overall project was indeed worth the advantages that SS offered, primarily in terms of reduced risk to the entire project, and the decision was made to switch from RB to SS.

Table 3: Summarized Advantages/Conclusions for the Alternatives

Factor	RB		SS	
Schedule Risk (Probability of completing project on time)	Att: Low: <30%		Att: High: >90%	
			Adv: 60% Increase in probability to complete the project on time	Imp: 100
Soil Stability Risk	Att: Extreme: 20		Att: Low: 4	
			Adv: Risk reduction from very high to medium	Imp: 60
Safety Risk	Att: Very high: 15		Att: High: 10	
			Adv: Risk reduction from very high to medium	Imp: 80
Resources	Att: Advanced equipment & low labor input		Att: Traditional equipment & extensive labor input required	
		Imp: 40		
Impact on other works	Att: Low		Att: High	
	Adv: Less impact on other works	Imp: 40		
Logistics	Att: Low complexity		Att: High complexity	
	Adv: Lower complexity	Imp: 35		
Duration	Att: 14 months		Att: 24 months	
	Adv: Shorter duration	Imp: 30		
Total Sum of Advantages		**145**		**240**

DISCUSSION

The case study above demonstrates the phenomenon of optimism bias in construction and suggests a coping mechanism based on sound and transparent decision-making processes, achieved through CBA implementation. It is likely that if we ask the “5 Whys” (Ōno, 2008) regarding many of the faults in construction, optimism bias may be among the root causes. From the contractor’s side, optimism bias may lead to unrealistically low tender-winning prices (leading to the “winner’s curse”), perhaps with the hope that additional profit sources will be found along the way (e.g. change orders, acceleration incentives, etc.). From the owner’s side, optimism bias may push immature projects to the construction phase before all preconditions are met, assuming things will work out along the road. Optimism is also reflected in the way a project status is reported to stakeholders and financing bodies, so funding won’t be jeopardized by hints of doubt. But a dose of reality is often exactly what the project needs to steer it back to on track to a successful outcome.

The case of the PHES facility demonstrates how taking the right action, especially at the last responsible moment (Howell and Lichtig 2008), requires a sound process that relies on objective facts and supporting data (like statistical analyses) that are communicated to decision makers and stakeholders. Despite the hindsight observation that changing construction methods was required once the soil conditions were discovered, in practice it was not simple at all. SS was more expensive and considered “less advanced”, two strikes against it for the instincts of many professionals in the organization. It took a lot of deliberation, and the CBA process was the key to making the right decision for the project. Thus, this implementation reinforces and demonstrates the findings of previous research (Arroyo et al., 2015; Schöttle et al., 2023), emphasizing it being a simple, clear, transparent, and well documented MCDM process, which assists in avoiding falling into optimism bias. Ultimately, using CBA, the team was able to determine that paying more for SS was worth it as it reduced the project risks.

In addition, this paper adds to the body of knowledge on CBA, by providing framework to emphasize risk factors as part of the decision-making process. The Monte Carlo simulation was found immensely useful to quantify the likelihood and impact of the risks to the schedule, which in turn led to it being recognized as the anchored advantage for the CBA analysis. Additionally, it demonstrated how the different (and sometimes fragmented) disciplines of traditional project management practice (budget, schedule, quality, risks, etc.) can be drawn together by the CBA process, making them relevant and influential to the path of the project.

CONCLUSIONS

Decision making in a complex, multi-input and multi-variable setting like a construction project is hard, made only more-so by the innate psychological biases that humans possess. But as shown in this paper, systematic approaches to decision making can help.

The reality is that most people involved in construction projects want the project to succeed, and want to believe that it will succeed. But choosing only the most optimistic interpretations of the situation and future outcomes does not ultimately serve the long-term interests of the project outcomes. Therefore, picking what seems to be the cheapest or quickest path based on those assumptions could lead to getting stuck in a less-globally-optimal path, if it is dependent upon everything going smoothly. CBA can create the space to have the tough conversations in a proactive manner and not only once everything has gone awry, and it puts consideration of cost as the last step, instead of following the industry convention of always going with the low-cost alternative. As such, this paper contributes to the body of knowledge around CBA by suggesting a key use-case for the approach in addressing the planning fallacy.

In terms of limitations, like any case study, our data set is severely limited. The authors think that, on the balance, the case study indicates that CBA can be an effective antidote to the optimism bias, and one that would benefit from further study. The “gold standard” for future work would be a randomized trial, examining outcomes of some projects that employ CBA versus a non-CBA intervention (to combat the Hawthorne Effect (Landsberger, 1961), particularly as a double-blind trial is not feasible in this case), and applying metrics for measuring optimism bias and/or the planning fallacy. This would admittedly be quite a challenge to implement, so at a minimum more case studies could be trialed.

REFERENCES

Arkes, H. R., & Blumer, C. (1985). The psychology of sunk cost. *Organizational Behavior and Human Decision Processes*, *35*(1), 124–140. doi.org/10.1016/0749-5978(85)90049-4

Arroyo, P. (2014). *Exploring Decision-Making Methods for Sustainable Design in Commercial Buildings* [PhD Thesis, University of California].

Arroyo, P., & Long, D. (2018). Collaborative Design Decisions. *26th Annual Conference of the International Group for Lean Construction*, 463–472. doi.org/10.24928/2018/0509

Arroyo, P., Schöttle, A., Christensen, R., & Arthur, C. (2022). CBA as a Differentiator to Win Projects in Pursuit: A Case Study. Proc. *30th Annual Conference of the International Group for Lean Construction (IGLC)*, 844–854. doi.org/10.24928/2022/0196

Arroyo, P., Tommelein, I. D., & Ballard, G. (2012). Deciding a Sustainable Alternative by Choosing by Advantages' in the AEC industry. In I. D. Tommelein & C. L. Pasquire (Eds.), *20th Annual Conference of the International Group for Lean Construction*. www.iglc.net/papers/details/748

Arroyo, P., Tommelein, I. D., & Ballard, G. (2015). Comparing AHP and CBA as Decision Methods to Resolve the Choosing Problem in Detailed Design. *Journal of Construction Engineering and Management*, *141*(1). doi.org/10.1061/(ASCE)CO.1943-7862.0000915

Ballard, H. G. (2000). *The Last Planner System of Production Control* [The University of Birmingham]. www.leanconstruction.dk/media/15590/ballard2000-dissertation.pdf

Buehler, R., Griffin, D., & Peetz, J. (2010). Chapter One - The Planning Fallacy: Cognitive, Motivational, and Social Origins. In *Advances in Experimental Social Psychology* (Vol. 43, pp. 1–62). Elsevier. doi.org/10.1016/S0065-2601(10)43001-4

Carrillo, P. (2005). Lessons learned practices in the engineering, procurement and construction sector. *Engineering, Construction and Architectural Management*, *12*(3), 236–250. doi.org/10.1108/09699980510600107

Chadee, A., Hernandez, S. R., & Martin, H. (2021). The Influence of Optimism Bias on Time and Cost on Construction Projects. *Emerging Science Journal*, *5*(4), 429–442. doi.org/10.28991/esj-2021-01287

Egan, J. (1998). *Rethinking Construction: Report of the Construction Task Force* (03/951; p. 38). HMSO. constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf

Flyvbjerg, B. (2011). *Over Budget, Over Time, Over and Over Again*. Oxford University Press. doi.org/10.1093/oxfordhb/9780199563142.003.0014

Gao, T., Ergan, S., Akinci, B., & Garrett, J. H. (2014). Proactive Productivity Management at Job Sites: Understanding Characteristics of Assumptions Made for Construction Processes during Planning Based on Case Studies and Interviews. *Journal of Construction Engineering and Management*, *140*(3), 04013054. doi.org/10.1061/(ASCE)CO.1943-7862.0000816

Howell, G., & Lichtig, W. (2008). Lean construction opportunities ideas practices. *Introduction to lean design workshop, Seattle, Washington.*

Hutson, M. (2013). *The 7 laws of magical thinking: How irrational beliefs keep us happy, healthy, and sane*. Plume.

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.

Kahneman, D., & Tversky, A. (1977). *Intuituve Prediction: Biases and Corrective Procedures* (Technical Report PTR-1042-77-6). Decision Research, Perceptronics. apps.dtic.mil/sti/pdfs/ADA047747.pdf

Klein, C. T. F., & Helweg-Larsen, M. (2002). Perceived Control and the Optimistic Bias: A Meta-Analytic Review. *Psychology & Health*, *17*(4), 437–446. doi.org/10.1080/0887044022000004920

Köksalan, M. M., Wallenius, J., & Zionts, S. (2011). *Multiple criteria decision making: From early history to the 21st century*. World Scientific.

Kpamma, Z. E., Adjei-Kumi, T., Ayarkwa, J., & Adinyira, E. (2017). *Strategic Considerations for Applying Choosing by Advantages in Design Process.* 507–514. doi.org/10.24928/2017/0239

Landsberger, H. A. (1961). *Hawthorne Revisited: Management and the Worker: Its Critics, and Developments in Human Relations in Industry*. Cornell University. books.google.co.nz/books?id=dI1-AAAAIAAJ

Lashgari, A., Fouladgar, M. M., Yazdani-Chamzini, A., & Skibniewski, M. J. (2011). Using an Integrated Model For Shaft Sinking Method Selection. *Journal of Civil Engineering and Management*, *17*(4), 569–580. doi.org/10.3846/13923730.2011.628687

Liu, Z., & Meng, Y. (2015). Key technologies of drilling process with raise boring method. *Journal of Rock Mechanics and Geotechnical Engineering*, *7*(4), 385–394. doi.org/10.1016/j.jrmge.2014.12.006

Martinez, E., Tommelein, I., & Alvear, A. (2016). Formwork System Selection Using Choosing by Advantages. *Construction Research Congress 2016*, 1700–1709. doi.org/10.1061/9780784479827.170

Mohsen, O., Naumets, S., & Hamzeh, F. (2022). *Lean Thinking to Improve Curriculum Delivery in Civil Engineering Using Monte Carlo Simulation*. 1–12. doi.org/10.24928/2022/0101

Ni, H., Chen, A., & Chen, N. (2010). Some extensions on risk matrix approach. *Safety Science*, *48*(10), 1269–1278. doi.org/10.1016/j.ssci.2010.04.005

Ōno, T. (2008). *Toyota production system: Beyond large-scale production* (Reprinted). Productivity Press.

Parrish, K., & Tommelein, I. D. (2009). Making Design Decisions Using Choosing by Advantages. In Y. Cuperus & E. H. Hirota (Eds.), *17th Annual Conference of the International Group for Lean Construction* (pp. 501–510). www.iglc.net/papers/details/663

Rehman, S., Al-Hadhrami, L. M., & Alam, Md. M. (2015). Pumped hydro energy storage system: A technological review. *Renewable and Sustainable Energy Reviews*, *44*, 586–598. doi.org/10.1016/j.rser.2014.12.040

Rocha, C. G. D., Wijayaratna, K., & Koskela, L. (2022). *Why Is Flow Not Flowing in the Construction Industry?* 283–294. doi.org/10.24928/2022/0130

Schöttle, A., & Arroyo, P. (2017). Comparison of Weighting-Rating-Calculating, Best Value, and Choosing by Advantages for Bidder Selection. *Journal of Construction Engineering and Management*, *143*(8), 05017015. doi.org/10.1061/(ASCE)CO.1943-7862.0001342

Schöttle, A., Gigler, L. M., & Mingle, B. (2019). *From Concept Development to Implementation: Choosing by Advantages Across an Organization*. 987–998. doi.org/10.24928/2019/0205

Schöttle, A., Guerreiro, R., Haubrich, A., Ditandy, M., & Behme, F. (2023). *Organizing the Argumentation for Changing the Delivery System Using Choosing by Advantages (CBA)*. 990–1001. doi.org/10.24928/2023/0245

Senior, B. A. (2012). An Analysis of Decision-Making Theories Applied to Lean Construction. In I. D. Tommelein & C. L. Pasquire (Eds.), *20th Annual Conference of the International Group for Lean Construction*. www.iglc.net/papers/details/840

Sharot, T. (2011). The optimism bias. *Current Biology*, *21*(23), R941–R945. doi.org/10.1016/j.cub.2011.10.030

Son, J., & Rojas, E. M. (2011). Impact of Optimism Bias Regarding Organizational Dynamics on Project Planning and Control. *Journal of Construction Engineering and Management*, *137*(2), 147–157. doi.org/10.1061/(ASCE)CO.1943-7862.0000260

Staw, B. M. (1981). The Escalation of Commitment to a Course of Action. *The Academy of Management Review*, *6*(4), 577. doi.org/10.2307/257636

Suhr, J. (1999). *The choosing by advantages decisionmaking system*. Quorum.

Weinstein, N. D. (1980). Unrealistic optimism about future life events. *Journal of Personality and Social Psychology*, *39*(5), 806–820. doi.org/10.1037/0022-3514.39.5.806

Weinstein, N. D., & Klein, W. M. (2002). Resistance of Personal Risk Perceptions to Debiasing Interventions. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and Biases* (1st ed., pp. 313–323). Cambridge University Press. doi.org/10.1017/CBO9780511808098.019