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Evaluation and Selection of Tower Crane Stabilization Control Systems Using a Multi-Criteria Decision-Making Approach

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Abstract

This study applies the Choosing by Advantages (CBA) decision-making method to evaluate and select appropriate stabilization control systems (SCS) for retrofitting the КБ-235 tower crane. Recognizing the widespread use and inherent instability of legacy crane models under dynamic wind and load conditions, two SCS alternatives are compared: a Passive Stabilization Control System (PSCS) and an Active Stabilization Control System (ASCS). The evaluation incorporates both technical and operational factors, including responsiveness to load swing, wind resistance, installation complexity, maintenance, and system precision. Attributes of each alternative are assessed using expert-validated criteria, followed by the quantification of each system's advantages (IoA). Cost versus IoA analysis reveals that although the ASCS demands higher investment, it delivers superior stability performance and safety outcomes, with an IoA approximately five times that of the PSCS. The method was validated using assumed values from industry literature and expert input. These findings support the integration of structured decision-making frameworks in construction engineering and provide practical insights for upgrading legacy lifting equipment in resource-constrained environments.

1. Introduction

Tower cranes are indispensable assets on modern construction sites, yet their towering structures and dynamic loads present serious stability challenges. Academic research underscores concerns that these machines are central yet hazardous since they hoist and transport loads near and above people in crowded, overlapping work zones [21]. The КБ-235 exemplifies such high-capacity cranes, boasting a maximum load of 10 t and a reach up to 65 m. Its widespread use—particularly in Eastern Europe and parts of Asia—amplifies the imperative to address its stability, especially under variable wind and heavy-lift conditions [12]. To mitigate instability, several strategies are available: improving foundation rigidity [2, 13], adding structural braces [11], deploying wind monitoring systems [3, 38], or integrating Stabilization Control Systems (SCS) [3, 7, 37]. Among these, retrofitting an SCS offers real-time adjustments to counteract crane sway and oscillation [7]. However, such systems come with trade-offs [16]. They may necessitate significant control-system integration, induce additional downtime, impose weight burdens that alter load characteristics, and require ongoing calibration and maintenance—all of which can offset their intended benefits.

The decision to adopt an SCS demands a structured evaluation—yet most studies on crane safety focus on design optimization or risk assessments, with little emphasis on systematic decision-making frameworks. Notably, the Choosing by Advantages (CBA) method—developed by Jim Suhr in 1986—has not been applied to selecting SCS for tower cranes [29]. Unlike traditional MCDM methods, CBA offers enhanced transparency and traceability in decision logic. CBA offers a transparent, advantage-oriented approach that prioritizes factual differences over subjective weighting. In construction, this enhances collaborative decision-making, minimizes bias, and anchors choices in objective project requirements [6].

This research asks: how can Choosing by Advantages be applied to evaluate and select the most appropriate Stabilization Control System for the КБ-235 tower crane? To answer, this study aims to: (1) establish evaluation criteria reflecting technical, operational, cost, and safety considerations for SCS; (2) gather and compare candidate SCS solutions suitable for КБ-235 integration; and (3) apply CBA to determine the optimal solution grounded in documented advantages.

The paper proceeds as follows: a literature review frames current crane stabilization strategies and MCDM applications; the methodology section defines the multi-criteria framework and details the CBA process; results and discussion present comparative findings and interpret implications; and the conclusion synthesizes outcomes, acknowledges limitations, and outlines directions for future research and industry adoption.

2. Literature Review

2.1 The КБ 235 and Alternatives for Integrating Stabilization Control Systems

2.1.1 KB-235 Overview

The KB-235 tower crane is manufactured in Russia under the brand of the Unikran Group (ГК «Юникран») at the Stroytekhnika LLC (ООО «Стройтехника») plant in Donskoy, Tula region. Its design process involved foreign companies, with critical components such as electronics and electromechanical parts fully supplied from Italy, while metal structures are produced domestically in Russia. This blend of international and domestic manufacturing suggests a strategic approach to quality and cost-efficiency [41]. This crane is specifically described as a "light hydraulic tower crane"[41] and a "light self-erecting tower crane" [40]. Its design is particularly suited for low-rise construction projects, with an optimal application range for buildings up to 6 stories high, reaching a maximum hook height of 30.5 meters. 3 It is widely used in the construction of various commercial and residential structures, including shopping and entertainment centers, country houses, warehouse complexes, and industrial facilities.

The КБ-235 is a Soviet-designed, quick-assembly tower crane widely used for low- to mid-rise construction projects (Picture 1). Despite its age, the KB-235 remains widely used in developing countries, especially in Vietnam and other post-Soviet countries, where legacy equipment is still employed in both public infrastructure and private construction projects. Its affordability and familiarity among local operators make it a staple on many job sites. Developed during the Soviet era, this crane is known for its simple structure, fast erection time, and suitability for construction sites with moderate lifting needs. Its key features include:

- Quick installation time: Can be assembled in approximately 1 hour, making it ideal for projects that require rapid deployment.
- Compact and mobile: Designed for use in constrained urban environments or small residential buildings.
- Smooth and Precise Operation: The crane incorporates modern mechanisms designed to ensure smooth and rapid load movement, minimizing swaying during operation. This contributes to enhanced safety and efficiency on the construction site.
- Imported components: Electrical and hydraulic systems are often retrofitted or supplied from Italy, while the steel structure is of Russian origin.

Fig. 1 *Pictures of the tower crane КБ-235, Source: [41]*

Key Technical Specifications of The КБ-235 can be found in Table 1.

Table 1 *Key technical specifications of the КБ 235*

Parameter	Value
Crane class	Category II
Hook height (horizontal rope)	~22 meters
Hook height (inclined rope 30°)	~30.5 meters
Maximum lifting capacity	4 tons
Load at maximum outreach	1 ton
Hoisting speed	~40 m/min
Trolley (cart) speed	~34 m/min
Slewing speed	~0.8 rpm
Electrical power consumption	~15 kW
Operating temperature range	−40°C to +40°C

Source: [40, 41]

2.1.2 Stabilization Control Systems Technologies

In modern construction environments, the operational stability of tower cranes is critical—not only for safety but also for efficiency and precision. The KB-235, while mechanically reliable, lacks inherent stabilization mechanisms, making it vulnerable to:

- Wind-induced vibrations
- Load swing during acceleration/deceleration
- Structure resonance at tall heights
- Unintended motion during emergency stops

To address the limitation of the КБ-235 tower crane—notably its lack of modern stabilization control systems (SCS), wind resistance features, and automation—retrofitting with advanced control technologies is a feasible solution that significantly enhances its performance and safety in dynamic and adverse conditions. Modern SCSs, such as input-shaping, model predictive control (MPC), and fuzzy logic-based systems, have demonstrated high efficacy in suppressing oscillations and improving load handling accuracy [27, 28, 34]. Integrating such systems enables legacy cranes like the КБ-235 to perform reliably in wind-prone or congested urban environments, where precise load positioning is critical. Additionally, upgrading wind resistance features—such as reinforced tower sections, slewing brake systems, and real-time wind monitoring sensors—can mitigate risks associated with sudden gusts or sustained wind loads [23]. However, retrofitting requires careful system integration planning to avoid excessive downtime and structural overload [8].

Given the current trend towards upgrading legacy equipment to meet higher safety and performance standards, retrofitting the KB-235 with a Stabilization Control System is a practical step forward, especially for contractors aiming to balance cost-efficiency and modern functionality. By either passive or active control mechanisms, such systems can:

- Reduce oscillations and sway under dynamic load conditions
- Enhance safety for workers and surrounding structures
- Improve operational precision, especially in urban or high-rise environments
- Extend the useful life of older cranes by compensating for structural limitations

The popular alternatives for integration of stabilization control systems to КБ-235 tower cranes include:

(1) Option 1: Installing a Passive Stabilization Control System (PSCS)

Technical Description:

- Install **mechanical dampers** at major joints (between the tower and jib), especially at the interface between the slewing platform and jib.
- Add a **pendulum-type stabilizer** to counter horizontal oscillations of the jib under load.
- Reinforce the tower base with **cross-bracing (X-type)** or stiffening frames at the connection points between the crane tower and the foundation.

Operating Mechanism:

- During wind-induced motion or load swings, the dampers and pendulum systems absorb kinetic energy and gradually suppress oscillation.

One notable advantage of this system is its ease of installation. It can be integrated without disrupting the core control system of the tower crane, making it a convenient upgrade. Once in place, it significantly enhances the stability of both the tower and the jib, particularly under conditions involving wind or dynamic loading.

However, the system also has certain limitations. Its ability to adapt to varying dynamic loads is limited, which may reduce its effectiveness in more complex or unpredictable environments. Additionally, the system functions purely on a passive basis, meaning it helps reduce oscillations without the benefit of active feedback or real-time control.

(2) Option 2: Installing an Active Stabilization Control System (ASCS)

Technical Description:

- Integrate **gyroscopes** and **accelerometers** to detect vibrations and oscillations.
- Install **servo actuators (hydraulic or electric)** at key joints, governed by a **PLC or microcontroller-based system**.
- Interface with the crane's main control system to **automatically correct** jib position when excessive motion is detected.

Operating Mechanism:

- The sensor system continuously monitors abnormal vibration → sends signals to the controller → activates actuators to rebalance the jib or counterweights.

This system offers several compelling advantages. It responds quickly to sudden changes, such as strong gusts of wind or uneven loading, making it highly adaptable in dynamic working conditions. Its precision and responsiveness are especially beneficial when operating on tall structures or during heavy lifting tasks, where safety and accuracy are critical.

On the downside, these advanced capabilities come at a higher cost, both in terms of installation and ongoing maintenance. Furthermore, the system requires skilled technicians for proper calibration and operation, which may present challenges for projects with limited technical support.

Table 2 shows the comparison of the key features of the two alternatives.

Table 2 *Comparison and technical feasibility*

Criteria	Option 1: Passive System	Option 2: Active System
Stability Improvement	Moderate	High
Technical Complexity	Low	High
Practical Implementation	Easily applicable to old cranes	Suitable for long-term or full upgrades
Cost	Low to Moderate	High (equipment + skilled labor)

2.2 The Stability of Tower Crane and Relevant Literature

Rauscher and Sawodny [19] presented a dynamic control-oriented model of a top-slewing tower crane as a flexible multibody system. They assumed the crane and tower to be inhomogeneous Euler-Bernoulli beams and considered the dynamic interactions between the steel structure, load movement, system drives, and ropes. The distributed deformations were discretized using the Ritz method. Experimental results on a full-scale tower crane confirmed the accuracy of the model and demonstrated the effectiveness of the proposed approach. To optimize tower crane selection and support design, it is essential to account for lifting requirements and stability, followed by an evaluation of economic feasibility. Sohn, Hong [30] developed a method for managing support design and selecting the optimal tower crane based on stability considerations. This optimization approach is anticipated to aid engineers in effectively determining the most suitable lifting equipment for their projects.

Zhou, Zhao [39] analyzed tower crane safety from the perspective of complex socio-technical systems by employing both qualitative and quantitative analysis methods. The AcciMap technique was applied to qualitatively construct a general model of tower crane safety, which comprehensively presents the systemic levels and causal pathways of contributing factors. A survey was conducted to quantitatively investigate the tower crane safety system. These findings provide a new perspective on tower crane safety and contribute novel applications of systems thinking to tower crane safety management.

Chen, Fang [9] proposed an adaptive tracking control method that achieves satisfactory tracking performance in the presence of parameter uncertainties and external disturbances. Specifically, leveraging the passivity property, an energy-like function was designed as a Lyapunov candidate, based on which an adaptive tracking controller was developed to handle parameter uncertainties. Using Lyapunov stability analysis, along with LaSalle's invariance principle, the closed-loop system was proven to be asymptotically stable. Experimental tests were conducted to verify the performance of the proposed method.

The importance of ensuring the stability and safety of tower cranes has been widely recognized in the construction sector, given their frequent use in high-risk, high-density urban environments. Numerous studies have explored the causes of tower crane instability, pointing to factors such as wind loads, dynamic movements, operator error, and insufficient structural or foundation design. According to Shapira and Lyachin [22], accidents involving tower cranes often stem from inadequate responses to external forces or insufficient monitoring of crane behavior under load, underscoring the necessity of adopting technological enhancements to improve crane stability. One of the most effective technological interventions to improve lift precision and reduce oscillations is the deployment of anti-sway and stabilization control systems (SCS). Techniques such as input shaping, fuzzy logic, and model predictive control (MPC) have been extensively studied in the context of overhead cranes. For example, Tang et al. (2023) propose a combined optimization and input-shaping control scheme that significantly reduces residual vibration in cranes with parameter variation [33]. The stability and operational safety of tower cranes, particularly in dense urban construction projects, have been a growing concern in the construction engineering literature. Shapira and Lyachin [21] conducted structured interviews with crane professionals and identified that wind conditions, site constraints (such as proximity to power lines and limited space), and human factors (like communication and operator experience) are key contributors to tower crane accidents. Similarly, Tam and Fung [32] emphasized environmental conditions, particularly high wind speeds and poor visibility, as frequent root causes of crane instability.

One of the most extensively researched technical solutions to mitigate instability is the use of anti-sway systems or broader Stabilization Control Systems (SCS), which actively reduce oscillations of the crane hook and suspended loads. A study by Tang, Ma [33] proposed a hybrid optimization and input-shaping control strategy that successfully reduced residual vibration in cranes under varying parameter conditions. Furthermore, Chen, Fang [8] introduced a Model Predictive Control (MPC) algorithm capable of maintaining swing-angle constraints in underactuated overhead cranes, thereby significantly enhancing safety during lifting operations. A comprehensive review by Smoczek and Szpytko [26] also confirms the efficacy of neural-fuzzy and hybrid control strategies for crane swing suppression and positioning precision. These technologies are especially valuable when cranes operate in wind-prone environments or near high-rise structures.

Despite these technical advancements, retrofitting existing tower cranes with SCS poses several challenges. Integration with legacy control systems often involves extended downtime, increases in crane self-weight, and frequent recalibration, which can reduce productivity and inflate maintenance costs. Industry guidance from WorkSafe and several crane safety case studies support the conclusion that retrofitting advanced control systems must be carefully evaluated for their technical feasibility and long-term cost-effectiveness.

As decisions regarding SCS adoption involve both technical and economic trade-offs, Multi-Criteria Decision-Making (MCDM) approaches are increasingly employed to support complex evaluations in construction engineering. Methods such as the Analytic Hierarchy Process (AHP), TOPSIS, and ELECTRE have been widely used in decisions involving formwork systems, materials selection, and construction technologies [20, 24]. While effective, these methods often depend heavily on subjective weightings, which can obscure the factual advantages of alternatives.

In contrast, the Choosing by Advantages (CBA) method, developed by Suhr [31], offers a transparent and logic-based decision framework that emphasizes the importance of documented advantages rather than preferences or utility scoresand [14]. CBA encourages decision-makers to explicitly identify, compare, and prioritize advantages, making it particularly useful in collaborative environments. It has been successfully applied in construction design, procurement, and planning decisions, with studies by Zimina and Ballard (2015) and Wątróbski, Jankowski [36] affirming its value in enhancing decision quality and stakeholder engagement.

However, a review of the existing literature reveals that CBA has not yet been applied to the evaluation of stabilization control systems for tower cranes, including widely used models such as the КБ-235. This absence presents a clear research opportunity to introduce a structured, advantage-based decision-making approach in an area with significant implications for safety and operational efficiency.

Accordingly, this study applies the CBA method to the evaluation and selection of SCS alternatives for the КБ-235 tower crane. By integrating both quantitative criteria (e.g., cost, installation time, system responsiveness) and qualitative benefits (e.g., operator compatibility, ease of integration), the research aims to develop a transparent and replicable evaluation model for construction equipment planning.

One widely studied solution is the integration of anti-sway and stabilization control systems (SCS), which are designed to reduce oscillations and improve handling accuracy during operations. Research by Ab Rahim, Roslan [1] presents a fuzzy-logic controller that achieved sway reduction of up to 81%, significantly outperforming traditional PID control systems. Similarly, Smoczek and Szpytko [25] reviewed advanced control techniques such as neural networks and fuzzy logic in crane operations and found them to be highly effective in minimizing swing amplitudes and improving operational safety. Fang et al. (2023) further demonstrated the success of input-shaping and model predictive control algorithms in suppressing load oscillations during lifting and slewing, contributing to safer and more efficient operations.

However, despite these advantages, SCS systems—particularly when retrofitted—often require significant control-system integration, induce installation downtime, impose added structural weight, and require ongoing calibration and maintenance. These trade-offs were discussed in both engineering case studies and construction decision-making literature [14], which highlight the practical difficulties of integrating new control systems into legacy crane models and the need to balance technical performance with feasibility and cost.

Making decisions about adopting SCS therefore requires structured evaluation methods that account for a wide range of criteria. Traditional methods like cost-benefit analysis (CBA) or risk-based decision frameworks have been used in construction for equipment selection but often fall short in capturing qualitative or project-specific benefits. In response, multi-criteria decision-making (MCDM) techniques have gained traction in the construction management domain. Tools such as the Analytic Hierarchy Process (AHP), TOPSIS, and ELECTRE have been used to select formwork systems [20], construction materials [24], and construction technologies based on a combination of technical, economic, and environmental indicators.

Yet, these methods often rely on subjective weighting and numeric scores, which can obscure factual advantages and create bias in decision outcomes. To address this, the **Choosing by Advantages (CBA)** method offers a transparent, logic-based framework that focuses on the *advantages* of each alternative rather than abstract weights [14, 31]. CBA emphasizes clear reasoning, stakeholder dialogue, and evidence-based comparisons, making it especially valuable in complex, multidisciplinary construction decisions.

Despite these benefits, a comprehensive review of the literature reveals a notable gap: no documented application of the CBA method has been found in evaluating stabilization systems for tower cranes, including for widely used models like the КБ-235. This absence highlights an opportunity to apply CBA to a high-impact technical decision with direct implications for site safety, project efficiency, and equipment modernization.

In light of this, the present study contributes to the literature by introducing CBA as a decision-making framework for evaluating and selecting SCS alternatives for the КБ-235 tower crane. By incorporating both quantitative criteria (e.g., cost, installation time, system responsiveness) and qualitative advantages (e.g., ease of operator use, compatibility), this research aims to develop a practical, transparent, and replicable evaluation model that can be extended to similar decisions in construction equipment management.

2.3 Choosing by Advantages: Method

Choosing by Advantages (CBA) offers a remarkably transparent and grounded alternative to traditional decision-making methods. Developed by Jim Suhr while with the U.S. Forest Service, CBA is designed around one clear premise: decisions should be based on the importance of differences—specifically, the advantages one option holds over another [15]. In contrast to score-based or pairwise-ranking methods, CBA focuses on the beneficial distinctions among alternatives, avoiding pitfalls like double-counting pros and cons or relying on subjective weighting. Its emphasis on anchoring discussions to documented facts enhances objectivity and accountability in group decisions [4]. CBA simplifies complex decision-making by dividing it into five phases [18]: (i) The Stage-Setting Phase, (ii) The Innovation Phase, (iii) The Decision-making Phase, (iv) The Reconsideration Phase, (v) The Implementation Phase.

According to Arroyo and Molinos-Senante [5], the CBA Process consists of the following seven steps (Figure 2) :

Step 1: Alternative Identification: Identifying the alternatives that are assessed in the decision-making process.

Step 2: Factors Definition: Identify the factors that distinguish the alternatives, ensuring each factor is directly linked to the respective alternatives.

Step 3: Criteria Definition: Establish the criteria used to evaluate the alternatives; these criteria reflect the basis for making preferences.

Step 4: Alternatives' Attributes Summary: Provide a summary of the features of each alternative; these features represent the inherent characteristics of the options.

Step 5: Alternatives Advantages Determination: Identify the benefits of each alternative by comparing them to the least favorable attribute among all options, using the established criteria as a reference.

Step 6: Advantage Importance Quantification: Assign a value to represent the significance of each advantage (Importance of Advantages – IoA); this value reflects how much each alternative is preferred, based on the factors influencing their relative performance.

Step 7: Evaluation of Advantages' Importance and Cost: Analyze cost versus IoA by plotting IoA (Y-axis) against cost (X-axis), factoring in investment and maintenance expenses to help decision-makers choose the best option within budget limits.

Fig. 2 *The steps of CBA, adapted from [5]*

In essence, CBA transforms decision-making into a narrative grounded in valuable differences rather than arbitrary scores. Its structured, principle-driven approach encourages collaborative dialogue, factual rigor, and defensible outcomes. That makes it particularly well-suited to complex construction equipment decisions—such as selecting a Stabilization Control System for a tower crane—where technical nuance and stakeholder alignment are critical.

3. Materials and Method

This research study applied the CBA with the steps in Figure 2. Since each step requires specific procedures, this study employed a combination of methods.

In Step 1, the alternatives have already been identified, with option 1 being a Passive Stabilization Control System (PSCS) and option 2 being an Active Stabilization Control System (ASCS). In Step 2, the research teams need to define the factors that differentiate the alternatives. Firstly, factors are screened from the literature and then validated with 2 experts. 7 factors have been considered to use in the Step. Similarly, in Step 3, 7 criteria have been adopted for using in the research. A scale of 1 to 5 was used in Step 4.

4. Results

4.1 Step 1: Alternative Identification

The alternatives were put into consideration including:

- **Alternative 1**: Passive Stabilization Control System
- **Alternative 2**: Active Stabilization Control System

The two alternatives are selected based on current retrofit practices for improving crane stability.

- **PSCS** is a conventional method that uses mechanical components (e.g., dampers, pendulum stabilizers, and cross-bracing) which is well-documented in literature for its simplicity and ease of integration into existing systems (see [EN 14439:2006+A2:2009]).
- **ASCS** employs modern sensors (gyroscopes, accelerometers) and servo-actuation mechanisms to actively manage stability. This alternative is supported by studies from the ASCE and Automation in Construction, which show active systems offer significant performance improvements under dynamic conditions.

4.2 Step 2: Factors Definition

Factors Considered:

- Responsiveness to Load Swing
- Wind Resistance
- Adaptability to Dynamic Conditions
- Ease of Installation
- Maintenance Requirement
- Precision of Stabilization
- Technological Complexity

These factors capture the key performance metrics that impact both safety and operational efficiency on construction sites. For example, responsiveness and precision are vital in reducing downtime and preventing accidents. These factors also align with criteria used by regulatory bodies such as OSHA and HSE when assessing equipment safety and efficiency [17, 35].

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4.3 Step 3: Criteria Definition

Each factor is evaluated on a "higher is better" scale based on 7 criteria:

- **Responsiveness:** Faster reduction in load swing is preferred.
- **Wind Resistance:** Higher resistance means the crane can operate safely under stronger winds.
- **Adaptability:** Better adaptation to changing load and wind conditions.
- **Ease of Installation:** Simpler systems reduce installation time and potential errors.
- **Maintenance:** Lower maintenance requirements reduce overall downtime.
- **Precision:** More precise control ensures accurate load placement.
- **Technological Complexity:** Lower complexity generally implies higher reliability and ease of troubleshooting.

The defined criteria reflect both operational safety and efficiency. Standards from EN 14439 and findings from ASCE studies support the importance of these factors in crane operations. For instance, precise stabilization minimizes oscillation and improves load handling accuracy, which is critical in urban construction environments [10].

4.4 Step 4: Alternatives' Attributes Summary

For each alternative, we assign assumed values on a scale of 1 to 5 (where 5 indicates best performance) for each of the 7 factors based on literature and industry best practices. For the purposes of this research, the values are assumed in Table 3.

Table 3 *Comparison and technical feasibility*

Criteria	Option 1: Passive System	Option 2: Active System
Responsiveness to Load Swing	2	5
Wind Resistance	3	5
Adaptability to Dynamic Conditions	2	5
Ease of Installation	5	2
Maintenance Requirement	4	2
Precision of Stabilization	2	5
Technological Complexity	2	4

Source: Author

These values are assumed based on relevant comparative studies, including [27, 28], and [34]. For example, active systems typically offer high responsiveness and precision, but they also involve greater installation difficulty and require specialized maintenance. Conversely, passive systems are simpler and more reliable in terms of installation and maintenance but generally provide lower performance in dynamic stabilization.

4.5 Step 5: Alternatives Advantages Determination

For every factor, the alternative with a higher score relative to the "least preferred" alternative gains an advantage. Each advantage is proportional to the difference in scores.

- For example, comparing the factor of **Responsiveness to Load Swing**:
  - **ASCS** scores 5 vs. **PSCS**'s 2, yielding an advantage difference of 3 for ASCS.

This process is repeated for each factor. This step highlights the marginal benefit of adopting one alternative over the other, allowing decision-makers to focus on performance benefits that directly impact safety and efficiency. The concept of comparing to the least preferred attribute is rooted in the CBA methodology and is supported by decision-making frameworks in industrial engineering.

4.6 Step 6: Advantage Importance Quantification

Weights have been assigned to each factor based on their criticality, with examples such as:

- Responsiveness (Weight = 4)
- Wind Resistance (Weight = 3)
- Adaptability (Weight = 5)

- Ease of Installation (Weight = 2)
- Maintenance Requirement (Weight = 2)
- Precision (Weight = 4)
- Complexity (Weight = 3)

Using the attributes provided:

- **Passive SCS (PSCS):** Total IoA = 10
- **Active SCS (ASCS):** Total IoA = 51

The weighted scores reflect the practical benefits observed in research and reported by safety agencies. A higher IoA for ASCS indicates significant potential improvements in operational performance and safety, as quantified in studies like those found in the literature. These scores help capture the broader social and environmental benefits, including reduced accident risks and improved efficiency.

4.7 Step 7: Evaluation of Advantages' Importance and Cost

To validate the proposed approach the proposal in this research study, the costs for each alternatives were assumed:

- **PSCS:** Approximately $40,000
- **ASCS:** Approximately $90,000

In the cost vs. IoA graph (Figure 3), Y-axis shows Importance of Advantages (IoA) while X-axis represents the cost (in thousands of USD). This visual evaluation shows that although ASCS demands a higher financial investment, it offers an IoA that is more than five times that of PSCS, suggesting a higher overall benefit in enhancing operational stability and safety.

From the graph, it is noted that economic decisions in construction equipment retrofit must consider both capital expenditure and the broader benefits such as enhanced safety and longer equipment life. Incorporating cost alongside IoA provides a balanced assessment that is supported by cost–benefit analyses in engineering management literature, ensuring that environmental and social benefits are not obscured by initial costs.

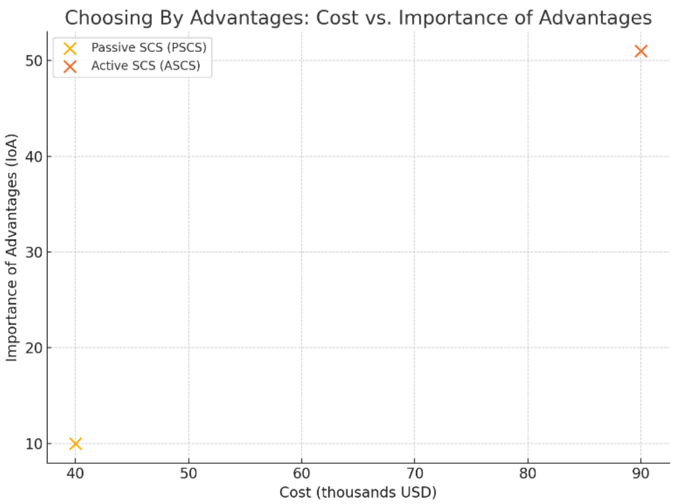

Fig. 3 *The cost vs. importance of advantages*

4.8 Discussion

The alternative costing USD 40,000 yields an IoA of 10. It is considered as an option with lower cost, simpler installation, better maintenance but lower performance in dynamic conditions. Alternative 2, costing approximately USD 90,000, has an IoA of 51. It is considered as an option with higher cost, but superior responsiveness, adaptability, wind resistance, and stabilization precision. Based on this CBA analysis we can come up with the following conclusions:

- **Alternative 2 (Active SCS)**, while more expensive in terms of capital and maintenance, provides a significantly higher importance of advantages (IoA = 51) compared to **Alternative 1 (Passive SCS)** (IoA = 10).
- In scenarios where budget constraints allow, the enhanced performance—such as improved responsiveness, wind resistance, and precision—strongly justify the selection of an active stabilization system.

Decision-makers should plot these values to visualize the trade-offs and make a choice that aligns with budgetary limitations while ensuring maximum operational safety and efficiency.

5. Conclusion

This research contributes to the advancement of construction equipment planning by applying the Choosing by Advantages (CBA) method to assess stabilization control system (SCS) options for the КБ-235 tower crane. The comparison between passive and active stabilization technologies shows that while passive systems are cost-effective and easier to install, they offer limited responsiveness and adaptability in dynamic site conditions. Conversely, active systems provide significant operational advantages, including enhanced precision, real-time responsiveness, and improved safety in adverse environments, albeit at a higher cost.

Through a multi-criteria evaluation framework, this study quantified the importance of advantages (IoA) for each alternative, demonstrating that the Active Stabilization Control System (ASCS) outperforms the Passive Stabilization Control System (PSCS), with an IoA of 51 versus 10. When assessed against cost, the ASCS shows strong value for investment, especially on complex construction projects where safety, speed, and precision are prioritized.

One limitation of this study is the reliance on assumed data values rather than empirical field measurements. However, the study's primary contribution lies in its development and application of a structured, transparent decision-making methodology. Future researchers and practitioners are encouraged to adopt and customize this framework using real-world project data to suit their specific technical and contextual conditions. This ensures that decisions regarding equipment modernization, especially in resource-constrained environments, are evidence-based and aligned with actual operational needs.

The findings underscore the utility of structured, advantage-focused decision-making tools like CBA in engineering applications. Beyond the immediate case of the КБ-235, this methodology can be extended to other equipment retrofit scenarios. Future research may expand the analysis through field-tested case studies, life cycle cost assessments, and environmental impact evaluations to further validate and refine decision-making models in the construction sector.

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Conflict of Interest

The Author declares that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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