วิศวกรรมสารฉบับวิจัยและพัฒนา
Engineering Journal of Research and Development
วิศวกรรมสถานแห่งประเทศไทย ในพระบรมราชูปถัมภ์
The Engineering Institute of Thailand under H.M. The King's Patronage
ปีที่ 34 ฉบับที่ 4 ตุลาคม-ธันวาคม 2566
Volume 34 Issue 4 October-December 2023
Received 10 July 2023
Revised 8 September 2023
Accepted 16 December 2023

CRITERIA ANALYSIS FOR HEAVY EQUIPMENT PROCUREMENT POLICY IN SMALL AND MEDIUM-SIZED ROAD CONSTRUCTION CONTRACTORS

Jittra Rukijkanpanich[1*] and Kanjanapath Tungsithishok[2]
[1]Associate Professor, [2]Master's Degree Student
Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University
*Corresponding author, Email: jittra.r@chula.ac.th

บทคัดย่อ

นโยบายการจัดหาเครื่องจักรหนักมีผลต่อความสำเร็จของผู้รับเหมาก่อสร้างถนนระดับท้องถิ่น การกำหนดนโยบายที่เหมาะสมสามารถช่วยลดความเสี่ยงที่เครื่องจักรหนักไม่พร้อมใช้งาน งานไม่เสร็จตามกำหนด และป้องกันปัญหาต้นทุนสูงที่กว่าแผนงานก่อสร้างลงได้ งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อเลือกเกณฑ์ที่มีผลต่อการตัดสินใจต่อนโยบายการจัดหาเครื่องจักรหนัก เครื่องมือที่ใช้ในงานวิจัยได้แก่ การวิเคราะห์เชิงลำดับชั้นและการตัดสินใจของกลุ่มผู้รับเหมาระดับท้องถิ่น ขั้นตอนการดำเนินงานเริ่มจาก (1) แบ่งกลุ่มผู้รับเหมาระดับท้องถิ่นเป็นสองกลุ่ม ตามขนาดทุนจดทะเบียนและตามศักยภาพในการซ่อมบำรุงเครื่องจักรหนัก (2) สำรวจปัจจัยต่างๆ เพื่อกำหนดเป็นเกณฑ์ที่สัมพันธ์กับนโยบายของการจัดหาเครื่องจักร (3) สร้างผังโครงสร้างเชิงลำดับชั้นประกอบด้วยเกณฑ์หลัก 6 เกณฑ์ และนโยบาย 3 ทาง (4) ทำการวิเคราะห์เชิงลำดับชั้นและทำการประเมินความเสี่ยงของโครงการควบคู่กัน ผลการวิจัยพบว่า กลุ่มผู้รับเหมาขนาดกลางให้ความสำคัญมากต่อเกณฑ์หลักได้แก่ "ต้นทุนโครงการทั้งหมด" (คะแนนความสำคัญ 0.309) และเกณฑ์ย่อยได้แก่ "ต้นทุนความล่าช้า" (0.405) ในขณะที่กลุ่มผู้รับเหมาขนาดเล็กให้ความสำคัญมากต่อเกณฑ์หลัก "ประสิทธิภาพของทีมซ่อมบำรุง" (0.419) และเกณฑ์ย่อย "ค่าใช้จ่ายในการจัดซื้อ" (0.226) ทั้งนี้ผู้รับเหมาขนาดกลางเลือกนโยบายที่เกี่ยวข้องกับการซื้ออุปกรณ์ใหม่หรือเช่าเครื่องจักรเมื่อมีความเสี่ยงสูงต่อการเสียค่าปรับงานไม่เสร็จตามกำหนด ส่วนผู้รับเหมาขนาดเล็กเลือกนโยบายที่เน้นการซ่อมแซมอุปกรณ์ที่มีอยู่เดิมเนื่องจากความกังวลกับค่าใช้จ่ายในการจัดหาเครื่องจักรสูง

คำสำคัญ: นโยบายการจัดหาเครื่องจักร; การวิเคราะห์เชิงลำดับชั้น; ผู้รับเหมางานก่อสร้างถนน

ABSTRACT

The success of local road construction contractors greatly depends on establishing an efficient heavy equipment procurement policy. Negligence in policy planning can pose risks related to equipment availability, project execution delays, and cost overruns. This research aims to examine the criteria that influence the decision-making process for heavy machinery procurement policies. The methodology employed hierarchical analysis and group decision-making for local contractors. The research process *commenced with the following steps: (1) dividing local contractors based on registered capital size and ability to repair, (2) investigating relevant factors to establish criteria for selecting an equipment procurement policy,(3) establish hierarchical structures which encompassed six main criteria and three policies, (4) performing a hierarchical analysis process and conducting a project risk assessment in parallel. The findings of the study revealed that medium-sized contractors placed the highest priority on the main criterion " Total project cost" (priority score = 0.309) and the sub-criterion "Delay cost" (0.405). Conversely, small-sized contractors prioritized the main criterion "Efficiency of maintenance team" (0.419) and the sub-criterion "Procurement cost" (0.226). (4) Both groups of contractors' risk assessment to select appropriate policies. According to the risk assessment results, medium-sized contractors opt for policies that involve purchasing new equipment or renting machinery when they anticipate potential fines due to work delays. On the other hand, small contractors focus on repairing their existing equipment for fear of incurring the high costs of acquiring machinery.*

KETWORDS: Procurement policy; Hierarchical decision analysis; Group decision; Road construction

1. Statement of problem

Road construction projects in Thailand hold significant value, and late delivery incurs penalties. One of the causes for delays is the unavailability of machinery [1-3]. Efficient construction project management encompasses maintenance planning, machine condition assessment, and the procurement of replacement machines. These measures can effectively reduce downtime, enhance construction quality, and lower overhead costs [4-6]. As previously mentioned, adept construction project management plays a crucial role in increasing heavy machinery productivity and mitigating construction project delays. One such approach is to establish a well-defined heavy machinery procurement policy prior to project initiation.

The implementation of a heavy machinery procurement policy relies on the size, capabilities, and resources of each organization. Similar to road construction, examples of medical device replacement policies include buying new equipment based on budget availability, renting equipment, or repairing used equipment [7, 8]. These policies are applicable and advantageous for contractors, contributing to improved project management efficiency. Therefore, comprehensive project management considerations before commencing a construction project are paramount, encompassing all relevant factors.

Numerous factors influence operations within the construction industry. Ammar [9] analyzed the risk factors that led to high costs in road construction projects, emphasizing the need for identifying and prioritizing these elements. Similarly, Xu and Chen [10] employed multi-criteria decision-making to analyze the operating risk factors of hydraulic turbines in generators.

The Analytic Hierarchy Process (AHP) stands as one of the most widely used tools in multi-criteria decision-making [11]. Previous studies have successfully applied AHP to assess machine readiness, such as utilizing hierarchical analysis to priori tize medical devices for equipment replacement decisions [7].

In this research, the Analytic Hierarchy Process (AHP) and group decision-making to analyze the significance of factors influencing the decision-making process for machine procurement policies were employed. Additionally, the study categorized these factors into internal and external factors, conducting research among eleven local medium and small-sized contractors. These factors would be adjusted as decision-making criteria influencing the effective heavy equipment procurement policy for each group of road construction contractors.

2. Internal and external factor impact policy for road construction business

Decisions regarding machinery procurement policies can be categorized into three types: the procurement of new machines to replace old ones, machine rental, and the repair and restoration of old machines. However, several factors influence these policy decisions, including both internal and external factors.

Internal factors pertain to elements within an organization that can be controlled and can have either positive or negative effects on the organization. The outcome depends on the organization's planning and implementation. Examples of internal factors include plans, policies, labor, machinery, and assets. For this research, relevant previous studies were reviewed to select intrinsic factors and establish corresponding criteria, as presented in Table 1.

On the other hand, external factors refer to elements outside the organization's control. These factors are often challenging to predict, necessitating organizations to remain adaptable in ever-changing environments. Examples of external factors include the current economic situation, legislation, surrounding infrastructure, and customer needs. Similarly, for this research, intrinsic factors were identified based on relevant previous studies, and corresponding criteria were established, as outlined in Table 2.

Table 1 Internal criteria affecting heavy machinery procurement policy for local road construction

Criteria	Description	Reference
Total project cost	Costs incurred from the start to the end of the project include maintenance costs, operating fees, and other expenses.	[6]
Procurement cost	The cost during the procurement processes encompasses activities such as sourcing, purchasing, contracting, and spare parts management.	[12]
Operation cost	The operational cost of manufacturing consists of three key components: materials, power, and manpower. These components contribute to the overall expenses incurred during the manufacturing process.	[13, 14]
Maintenance cost	The costs associated with machinery repair include expenses for repairing the machinery itself, such as labor and replacement parts.	[13, 14]

Table 1 Internal criteria affecting heavy machinery procurement policy for local road construction (continue)

Criteria	Description	Reference
Delay cost	Costs incurred due to delays refer to the additional expenses incurred as a result of project time delays. These costs can include contract costs, which may increase due to extended project duration and associated contractual obligations.	[15]
Efficiency of maintenance team	A trained technician possesses the expertise to identify and address small repairs, thereby enhancing the efficiency of your equipment. By conducting regular inspections, they can ensure the safety of workers and help prevent any potential hazards or accidents.	[16]
Residual life of equipment	Machines or equipment may experience derated or fatigued conditions over time. These conditions can manifest through various signs of local defects, such as cracks, corrosion, excessive deformation, or functional obsolescence.	[17]
Device and equipment age	Actual heavy devices and equipment service life.	[7]
Technology age	"Technology Age" refers to the time period since the equipment's initial introduction into the market. For example, construction of a road in hilly region involves complex processes. Technological developments in equipment make work more convenient, safer, and more efficient.	[7]
Frequency of breakdowns	The frequency of breakdowns has a significant impact on operations and leads to increased costs. These factors, in turn, influence the selection of maintenance policies or the decision to make changes.	[18]
Vendor support	Vendor support is readily available and encompasses various aspects such as warranties, maintenance contracts, documentation, and training.	[7]
Value of construction equipment	It means appraisal of construction equipment value. Accurately predicting the resale value of equipment plays a crucial role in making an informed replacement decision. The value of the equipment, which is influenced by factors such as specifications, age, mechanical condition, and geographical location, has a significant impact on the decision-making process.	[6]

Table 2 External criteria affecting heavy machinery procurement policy for road construction

Criteria	Description	Reference
Economic conditions	Poor economic conditions serve as indicators that significantly increase the cost of the procurement phase and contribute to cost overruns. Various factors associated with economic conditions, such as exchange rates, inflation rates and interest rates.	[12, 19]

3. The Analytic Hierarchy Process (AHP) and group decision-making

In this research, AHP is a powerful tool for conducting complex analyses and determining the relative importance of different criteria. It involves comparing criteria pairwise and enables decision-makers to select, classify, and prioritize alternatives, thus enhancing decision-making in the construction industry.

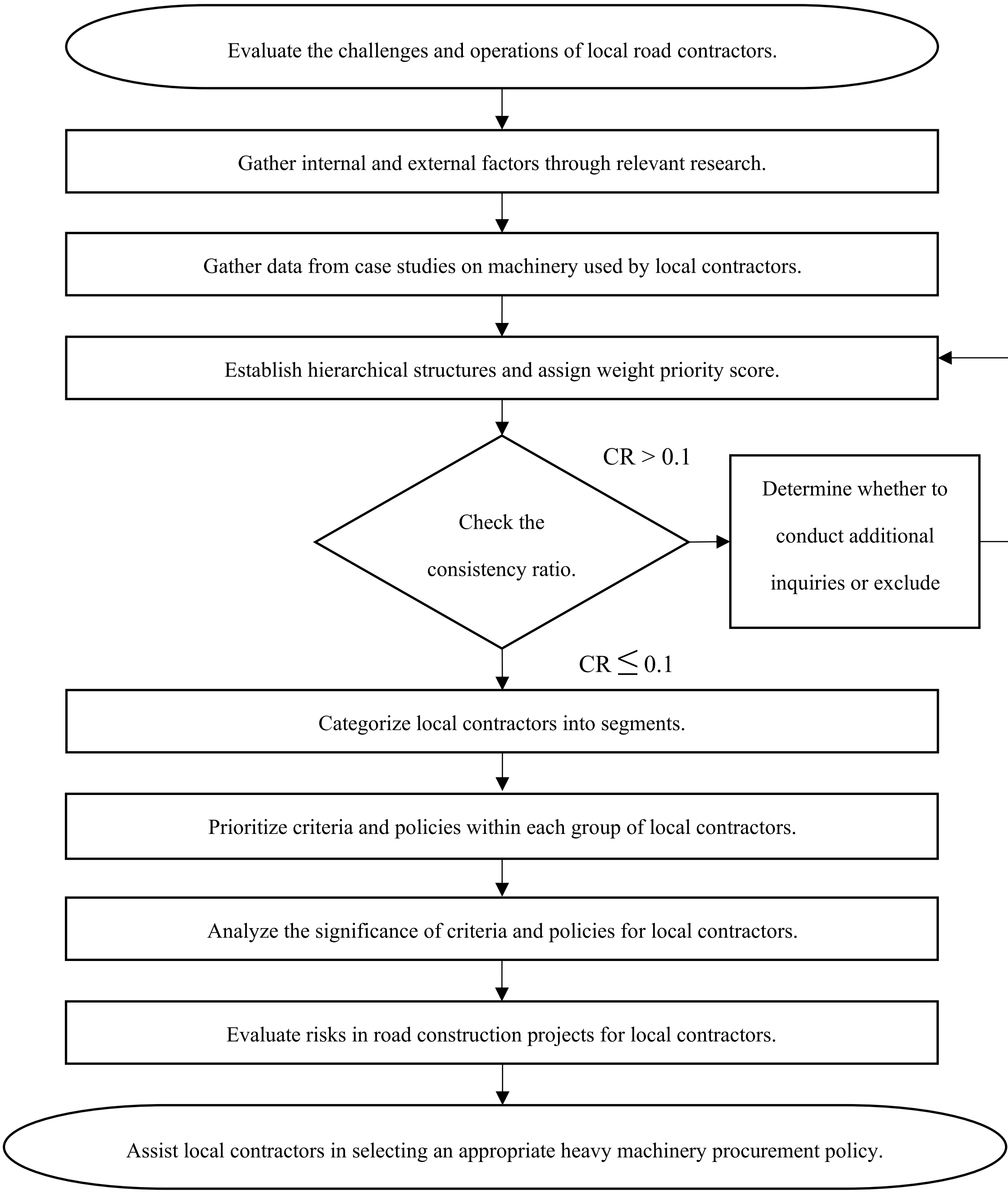
The principles of utilizing AHP [20] encompass several steps: (1) establishing objectives, (2) constructing a hierarchical structure, (3) creating a pairwise comparison questionnaire, (4) developing a pairwise comparison matrix, (5) expert decision-makers assigning importance scores, (6) assigning weighted priorities to each component, (7) checking for consistency (aiming for a consistency ratio below 0.1), and (8) prioritizing each component.

When applying group decision-making (GDM) within the framework of AHP, the neutrality of the results for decision-makers can be enhanced [21]. Group decision-making helps alleviate the limitations that arise from the individual decision-makers' experiences, knowledge, and personal abilities [22]. By involving independent decision-makers, group decisions mitigate the influence of individual biases or the formation of biased alliances within the group [23]. Given the high complexity and value of projects in the construction industry, employing group decision-making serves as an effective approach to reduce the risk of errors or outcomes that do not align with the organization's needs.

4. Methodology

4.1 Research methods

The research analysis flowchart for selecting the heavy equipment procurement policy of local road construction contractors is presented in Figure 1. The flowchart consists of the following steps: 1) evaluate the challenges and operations of local road contractors, 2) gather internal and external factors through relevant research, 3) gather data from case studies on machinery used by local contractors, 4) establish hierarchical structures and assign weight priority score, 5) check the consistency ratio, 6) categorize local contractors into segments, 7) prioritize criteria and policies within each group of local contractors, 8) analyze the significance of criteria and policies for local contractors, 9) evaluate risks in road construction projects for each groups of local contractors, and 10) assist local contractors in selecting an appropriate heavy machinery procurement policy.



Note : consistency ratio (CR) ≤ 0.1 accept the estimate of weight score.
consistency ratio (CR) > 0.1unaccepted the estimate of weight score.

Figure 1 Flowchart of research methods

4.2 Case study

This research focused on the case of medium-sized contractor's machinery that used for a long time or was in poor condition, with a particular emphasis on motor graders. These motor graders were found to have a long service life, ranging from 23 to 2 5 years. Historical data showed that graders had downtime as high as 36% of the total downtime and repair costs up to 30 to 40% of the total repair cost.

4.3 Criteria collection

The process of determining the main and minor criteria involved three steps: 1) review relevant criteria and ask for opinions of local contractors about the influence of each criterion on procurement policies until the internal and external factors are identified as shown in Tables 1 and 2, 2) identifying the main and minor criteria, there were six main criteria and seven sub-criteria, and 3) constructing a hierarchical structure with three procurement policies, as depicted in Figure 2

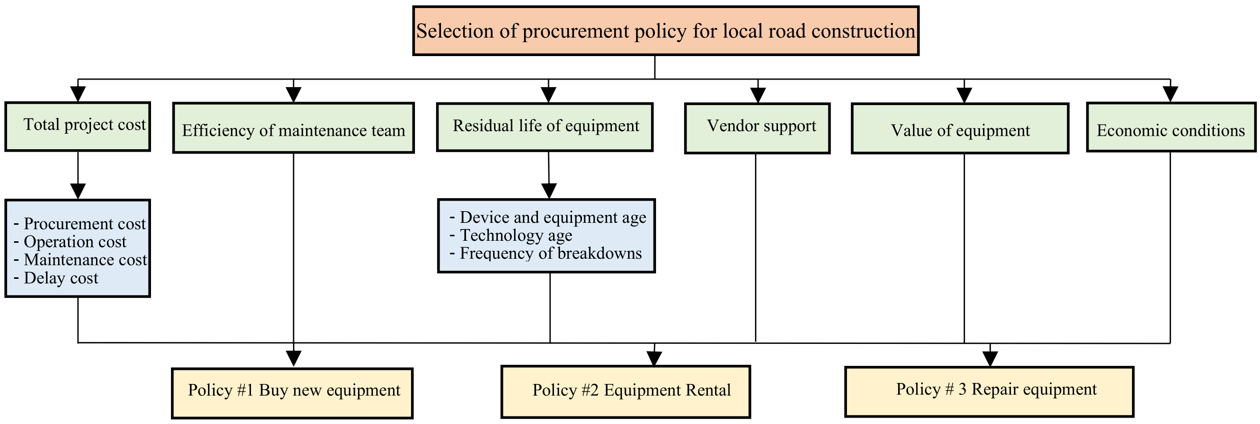


Figure 2 Hierarchical structure

4.4 Judgement for priority score

There were eleven contractors who were interviewed individually on the topic of factors or criteria affecting local road contractors' procurement policy. Inputs through interviews were used to prioritize each enabling factor affecting local road contractors' procurement policy. The question used was to compare the importance of the criteria pair by pair, i.e. “What do you think is more important between total project cost and efficiency of the maintenance team?” “How many times is it important to choose between 1, 3, 5, 7, and 9?” Number 1 means both criteria are equally important and 9 means one is the most important which is nine times more important than the other. Then the priority score was calculated.

4.5 Categorize local contractors

Each contractor provided their own ratings. In this research, we hypothesized that there would be differences in the importance scores based on factors such as contractor size, experience, and position within the company. To test this hypothesis, a single factor ANOVA analysis was conducted. The results showed a significant difference at the 0.05 level. The size of the company and the position within it were found to impact the differences, but the groups formed based on these factors were found to be similar. Therefore, the criterion used for grouping was based on the contractor's size.

This research involved a total of 11 respondents who represented a group of local contractors. The composition of the sample group was as follows: 1) six medium-sized contractors, each with over 30 years of experience. This group consisted of five owners and one project manager, 2) five small sized contractors, each with less than 30 years of work experience. This group comprised one project manager and four engineers.

4.5 Risk Assessment of project construction

The road construction industry is characterized by significant risks. To mitigate these risks, conducting risk assessments became crucial as it aids in identifying potential events and formulating appropriate response policies. Risks inherent in construction projects encompass aspects such as time, cost, and work quality [24]. In a study by Zavadskas, Turskis, and Tamošaitiene [25], risk assessment in Yemen's oil and gas construction projects was conducted using a probability-impact matrix (PIM). This matrix evaluates the likelihood of an event occurring in conjunction with the severity of its impact. The standard risk matrix divides risk zones into three levels: green, yellow, and red [26] The green zone represents low-risk situations, while the yellow zone indicates moderately significant risks. The red zone signifies risks of utmost importance. The assessment of contractor risk levels and the formulation of risk policies depend on various factors, including the contractor's objectives, classification, analysis, and response.

During interviews with local small and medium contractors, their perspectives were sought, with particular emphasis on time and cost risks such as delay costs affects and machine readiness affects. Furthermore, the severity of potential risks for these contractors was also evaluated.

5. Results and analysis

From the construction of the AHP tree in Figure 3, the next step is the analysis of the AHP, which is divided into three parts: prioritizing main criteria, prioritizing sub-criteria, and determining policy priorities. Each section follows these steps: Firstly, the priorities are analyzed based on the questionnaire responses. The next step involves analyzing the congruence rate of the rationale. Finally, the results are compared between medium and small contractors.

5.1 Prioritization of main criteria affecting the selection of machinery procurement policies of local medium and small contractors.

The significance of the main criteria is examined based on the importance scores provided by local contractors. Following the analysis, the consistency ratio (C.R.) was determined for medium contractors as 0.02 and for small contract ors as 0.04, both of which are 0.1 as indicated in Table 5.

Table 5 Priorities scores and rank of the main criteria of medium and small contractors.

Main-Criteria	medium contractors		small contractors	
	priority score	Rank	priority score	Rank
Overall project cost	0.309	1	0.196	2
Efficiency of maintenance team	0.259	2	0.419	1
Residual life of equipment	0.079	5	0.087	4
Vendor support	0.091	4	0.080	5
Value of construction equipment	0.204	3	0.167	3
Economic conditions	0.059	6	0.051	6

From Table 5, “Overall project cost” and “Efficiency of maintenance team” are the top two criteria the contractors place importance on. Medium contractors prioritized the highest “Overall project cost”, followed by the “Efficiency of maintenance team” criterion. Small contractors prioritized the highest “Efficiency of maintenance team”, followed by the “Overall project cost” criterion. The value of construction equipment criterion had the third order of magnitude in both groups. Additionally, the other criteria are less important.

5.2 Prioritization of sub criteria affecting the selection of machinery procurement policies of local medium and small contractors.

The prioritization was conducted for the sub-criteria as follows, 1) the sub-criteria under the main criteria of “Overall project cost” are presented in Table 6, 2) the sub-criteria under the criteria of “Residual life of equipment” are shown in Table 7. These sub-criteria were then normalized to compare their significance scores. The results of this comparison can be seen in Table 8.

From Table 6, it was found that the sub-criteria were under the “Overall project cost”. Medium contractors attach importance to “Delay cost” (0.507). The other criteria are of similar importance. Small contractors attach importance to subordinate criteria for “Procurement cost” (0.327). The other criteria are of similar importance.

Table 7 shows that medium and small contractors prioritize the same secondary criterion, "Frequency of breakdowns", which is the most important. For medium contractors is 0.494, and for small contractors is 0.462. The following criteria are "Technology age" and "Device age".

The next step, normalize the prioritized scores for each subcategory. Table 8 shows the importance of secondary criteria affecting the decision to procure heavy machinery. It was found that medium contractors prioritized "Delay cost" (0.405). Next was the criterion on expenses, namely "Procurement cost" and "Maintenance cost". Other criteria were not very prominent.

In addition, small contractors pay attention to "Procurement costs" (0.226), followed by similar importance, namely "Maintenance cost", "Operation cost", and "delay cost". Other criteria are not very prominent.

Table 6 Prioritization of sub-criteria under overall project cost.

sub-Criteria	medium contractors	small contractors
	priority score	priority score
Procurement cost	0.196	0.327
Operation cost	0.124	0.215
Maintenance cost	0.173	0.246
Delay cost	0.507	0.212

Table 7 Prioritization of sub-criteria under residual life of equipment.

sub-Criteria	medium contractors	small contractors
	priority score	priority score
Device age	0.153	0.182
Technology age	0.353	0.356
Frequency of breakdowns	0.494	0.462

5.3 Prioritization of the alternative machinery procurement policies of local medium and small contractors.

This section prioritizes local contractor heavy machinery procurement policy. Medium and small contractors rate the importance of the policy when considering it under both main and sub-criteria. The result shown in Table 9 states medium and small contractors have given the policy to "Buy new equipment" the most important. The priority score for "Buying new equipment" is 0.573 for medium and 0.371 for small contractors. In addition, medium contractors attach importance to "Rental equipment" in the following order. This is different from small contractors who focus on "Repair equipment".

Table 8 Priority scores and rank after normalized.

sub-criteria	medium contractors		small contractors	
	priority score	rank	priority score	rank
Procurement cost	0.157	2	0.226	1
Operation cost	0.098	5	0.148	3
Maintenance cost	0.137	3	0.170	2
Delay cost	0.405	1	0.148	3
Device age	0.031	7	0.057	7
Technology age	0.072	6	0.110	6
Frequency of breakdowns	0.101	4	0.141	5

Table 9 Prioritization of Alternative**.**

Alternative	medium contractors		small contractors	
	priority score	Rank	priority score	rank
Buy new equipment	0.573	1	0.371	1
Equipment rental	0.224	2	0.289	3
Repair equipment	0.205	3	0.341	2

6. Conclusions

The analysis conducted in this study prioritized the criteria and policy options for heavy equipment procurement among local contractors. It was observed that the size, experience, and position of the contractors influenced the variation in scores. To ensure accuracy, the contractors were categorized based on company size, resulting in six medium contractors and five small contractors. Consequently, policy alternatives for heavy machinery procurement were identified for local small-medium contractors.

When prioritizing criteria based on the input from local contractors, it was discovered that medium contractors assigned the highest priority to the “Overall project cost” criteria (0.309), whereas small contractors prioritized the “Efficiency of maintenance team” (0.419). This divergence can be attributed to the cost-conscious nature of medium contractors and the distinct tasks performed by small contractors, which involve criteria such as “Project value, Maintenance team efficiency, Funding, and Resource availability”. As a result, small contractors emphasized criteria related to ease of maintenance to minimize downtime due to repairs.

Furthermore, in the prioritization of sub-criteria, medium contractors accorded the highest priority to “Delay cost” (0.405), while small contractors prioritized “Procurement cost” (0.226). This suggests that medium contractors face high financial risks and delay costs in their work, whereas small contractors focus on the cost implications associated with machinery procurement before project commencement, such as “Buying new equipment” or “Renting machinery” with high rental rates.

Considering the heavy machinery procurement policy of local contractors, medium and small contractors accorded the highest priority to “Buy new equipment”. The significance score was found to be 0.573 for medium contractors and 0.371 for small contractors. Although the results of the hierarchical analysis were similar for both categories, the actual operations and policies varied. Medium contractors assessed the risks associated with machine availability and penalties, leading them to opt for buying new equipment or renting machinery. On the other hand, small contractors, constrained by limited capital and low project value, relied on repairs to restore their machines rather than investing in new equipment.

Based on these findings, it is evident that the choice of machinery procurement policy among local contractors may deviate from the outcomes of the hierarchical analysis process. The final decision is influenced by the specific risks faced by each contractor. The results of this study serve as a policy guide for medium contractors operating in similar environments or fac ing comparable circumstances, as well as for small contractors seeking to expand their organizations.

Conflict of interest

The authors declared that article has no conflict of interest

Reference

[1] Aziz, RF. and Abdel-Hakam, AA. Exploring delay causes of road construction projects in Egypt. *Alexandria Engineering Journal*, 2016, 55 (2), pp. 1515-1539.

[2] Fashina, AA. *et al*. Exploring the significant factors that influence delays in construction projects in Hargeisa. *Heliyon*, 2021, 7 (4). Available from: https://doi.org/10.1016/j.heliyon.2021. [Accessed 9 July 2022].

[3] Kaliba, C. *et al*. Cost escalation and schedule delays in road construction projects in Zambia. I*nternational Journal of Project Management*, 2009, 27 (5), pp. 522-531.

[4] Hung, Y-H. *et al*. Uncovering hidden capacity in overall equipment effectiveness management. *International Journal of Production Economics*, 2022, 248 (6). Available from: https://doi.org/10.1016/j.ijpe.2022.108494 [Accessed 12 August 2022].

[5] Jittra Rukijkanpanich and Nurainee Prasertdam. Enhancing machinery repair management in road construction. *Engineering Journal of Research and Development*, 2021, 32(4), pp. 87-100.

[6] Toma, HM. *et al*. Factors affecting the resale value of construction equipment and their relative impact. *Alexandria Engineering Journal*, 2022, 66, pp. 731-738

[7] Faisal, M. and Sharawi, A. Prioritize medical equipment replacement using analytical hierarchy process. *IOSR Journal of Electrical and Electronics Engineering*, 2015, 10 (3), pp. 55-63.

[8] Prasertrungruang, T. and Hadikusumo, BHW. Heavy equipment management practices and problems in Thai highway contractors. *Engineering, Construction and Architectural Management*, 2007, 14 (3), pp. 228-241.

[9] Ammar, T. *et al*. Risk factors causing cost overruns in road networks. *Ain Shams Engineering Journal*, 2022, 13 (5).

[10] Xu, B. *et al*. Priority analysis for risk factors of equipment in a hydraulic turbine generator unit. *Journal of Loss Prevention in the Process Industries*, 2019, 58, pp. 1-7.

[11] Saaty, TL. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, 1990, 48(1), pp. 9-26.

[12] Habibi, M. *et al*. Engineering, procurement and construction cost and schedule performance leading indicators: state-of-the-art review. In: *Proceedings of Construction Research Congress*, 2018, Louisiana, pp. 378-388.

[13] Hartman, JC. and Tan, CH. Equipment replacement analysis: a literature review and directions for future research. *The engineering economist*, 2014, 59 (2), pp. 136-153.

[14] N. Kamble, S. and Rajiv, B D. Machine health monitoring with life cycle cost analysis by condition monitoring. *Materials Today: Proceedings*, 2022, 52, pp. 893-897.

[15] Senouci, A. *et al.* Time Delay and Cost Overrun in Qatari Public Construction Projects. *Procedia Engineering*, 2016, 164, pp. 368-375.

[16] Asadi, SS. *et al*. Strategical construction equipment management using henry garret method. *Materials Today: Proceedings*, 2021, 43(2), pp. 921-927.

[17] Depale, B. and Bennebach, M. Residual Life of Structures and Equipment. *Procedia Structural Integrity*, 2022, 38, pp. 317-330.

[18] Rastegari, A and Mobin, M. Maintenance decision making, supported by computerized maintenance management system. *annual reliability and maintainability symposium (RAMS)*, 2016, IEEE.

[19] Asgari, S. *et al*. Impact of considering need for work and risk on performance of construction contractors: An agent-based approach. *Automation in Construction*, 2016, 65, pp. 9-20.

[20] Samaranayake, P. *et al*. Prioritising enabling factors of Internet of things (IoT) adoption in digital supply chain. *International Journal of Productivity and Performance Management*. 2022, Available from: https://doi.org/10.1108/IJPPM-12-2021-0698 [Accessed 21 December 2022].

[21] Dong, Y. *et al.* Consensus reaching in social network group decision making: Research paradigms and challenges. *Knowledge-Based Systems*, 2018, 162, pp. 3-13.

[22] Yin, X. *et al.* Selection of Strategy for Large Group Emergency Decision-making based on Risk Measurement. *Reliability Engineering & System Safety*, 2021, 208, 107325.

[23] Dong, Y. *et al.* A self-management mechanism for noncooperative behaviors in large-scale group consensus reaching processes. *IEEE Transactions on Fuzzy Systems*, 2018, 26 (6), pp. 3276-88.

[24] Sharma, S. and Gupta, AK. Risk identification and management in construction projects: literature review. *International Journal of Humanities, Arts and Social Sciences*, 2019, 5 (6), pp. 224-31.

[25] Zavadskas, EK. *et al.* Risk assessment of construction projects. *Journal of civil engineering and management*, 2010, 16 (1), pp. 33-46.

[26] Mahamid I. Risk matrix for factors affecting time delay in road construction projects: owners' perspective. *Engineering, Construction and Architectural Management*, 2011, 18 (6), pp. 609-17.