

# **Educational Infrastructure Prioritization using An Intuitionistic Fuzzy AHP Approach**

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## **Abstract**

Saskatchewan's public schools have long depended on visual inspections and reactive maintenance, leading to inconsistent funding and missed priorities. This study introduces an Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) framework to strengthen capital planning by combining expert judgment with limited data. The model assessed 10 criteria to prioritize five anonymized schools, translating expert input into fuzzy numbers to capture uncertainty in decision weights. Though demonstrated on a small sample, the framework can scale to larger systems and be integrated into existing planning. Overall, it provides public-sector decision-makers with a practical, transparent, and adaptive tool for more consistent, equitable, and data-driven school infrastructure investments under uncertainty.

## **Keywords**

Educational Infrastructure; Intuitionistic fuzzy set; Analytic Hierarchy Process (AHP); Public Asset Management, Uncertainty.

## **1. Introduction**

The condition of school infrastructure is a critical determinant of student learning outcomes, public health, and equitable access to education. Well-maintained school facilities support student engagement and safety, whereas deteriorating buildings can negatively affect academic performance, well-being, and community confidence. Despite its importance, determining which schools should be prioritized for repair, rehabilitation, or upgrade remains a complex challenge. Decision-makers must often operate under conditions of incomplete or inconsistent data, diverse local and regional contexts, and competing stakeholder priorities (Herath et al., 2023; Abdullah & Najib, 2016).

Effective school infrastructure planning extends far beyond simple visual inspections or the identification of visible signs of deterioration. Instead, it requires robust, evidence-based decision-making frameworks that account for long-term asset performance, user satisfaction, lifecycle risks, environmental considerations, and financial constraints. Over the past several decades, researchers have proposed a variety of decision-support approaches to aid infrastructure

prioritization, particularly in public-sector settings where funding limitations and data uncertainty are persistent challenges.

However, current infrastructure prioritization practices continue to rely heavily on rigid scoring templates or basic condition assessments. Such approaches often struggle to accommodate uncertainty, incomplete information, and differing expert judgments. Moreover, traditional models tend to overlook critical factors such as service disruption risks, environmental impacts, and the integration of multiple expert perspectives into a unified decision-making process (Moslem et al., 2023; Yasin et al., 2022). Although existing studies have explored various methods for evaluating and prioritizing school facilities, a practical and adaptable tool that fully captures the complexity and uncertainty inherent in real-world public school systems remains limited.

These limitations are particularly evident in the Canadian context. Many school authorities continue to depend on conventional inspection-based methods and fixed scoring systems, which are often insufficient for managing aging infrastructure spread across large geographic regions. In provinces such as Saskatchewan, where schools are widely dispersed and climatic conditions accelerate asset deterioration, there is a pressing need for more flexible, transparent, and uncertainty-aware decision-support tools.

To address these gaps, this research proposes an Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP)–based decision-support framework for prioritizing educational infrastructure investments. By explicitly incorporating uncertainty and expert judgment, the proposed framework enhances transparency, robustness, and adaptability in infrastructure decision-making. The specific objectives of this study are to:

- Develop a transparent and adaptable IF-AHP–based framework for prioritizing school infrastructure projects in Saskatchewan.
- Produce actionable and defensible rankings of school facilities using a comprehensive set of technical, functional, and risk-based criteria to support fair, evidence-based investment decisions.

## **2. Literature Review**

Effective school infrastructure planning extends beyond visual inspections or reactive maintenance practices; it requires evidence-based decision-support approaches that account for long-term asset performance, user satisfaction, lifecycle risks, and financial constraints. Across many education systems, aging facilities, increasing enrolment pressures, and deferred maintenance have intensified the need for systematic infrastructure prioritization. These challenges are particularly pronounced in public-sector contexts, where funding limitations and data uncertainty constrain proactive decision-making. Table 1 summarizes the different studies.

Several studies highlight the prevalence of deferred maintenance in school systems worldwide. Herath et al. (2023) note that many education authorities operate under chronic budget shortfalls, resulting in reactive “fix-after-failure” strategies rather than preventive maintenance. Although best practices recommend annual reinvestment of approximately 2–3% of asset replacement value to sustain acceptable facility conditions, this threshold is rarely met. Similar challenges have been reported in both developed and developing contexts, including Canada, Australia, and South Africa, where institutional fragmentation and weak inter-agency coordination hinder long-term infrastructure planning (Britz, 2023). These structural issues underscore the limitations of traditional condition-based assessment approaches that focus narrowly on physical deterioration.

To address this gap, some researchers have proposed integrating technical assessments with stakeholder perspectives. Dahuri et al. (2025), for example, combined physical condition evaluations with user satisfaction metrics using the SERVQUAL framework to better capture how infrastructure deficiencies affect service quality and learning environments. By linking facility conditions to user experiences, their approach provides a more socially responsive basis for prioritization, moving beyond purely technical indicators.

Given constrained budgets, several studies emphasize the importance of risk- and impact-based prioritization models. Thohir et al. (2018) applied knapsack optimization to prioritize low-cost, high-impact interventions—such as ceiling and window repairs—in Indonesian schools, demonstrating that targeted investments can yield substantial functional benefits. Similarly, Mohamed et al. (2022) introduced a hybrid model combining Data Envelopment Analysis (DEA) and Linear Programming (LP) to balance urgency, efficiency, and educational impact in Egyptian schools. These

models improve transparency and fairness but often rely on deterministic inputs, limiting their ability to handle uncertainty and subjective judgments.

User-centered perspectives further reveal gaps in conventional infrastructure assessments. Au-Yong et al. (2023) showed that seemingly minor factors—such as cleanliness, functional utilities, and indoor comfort—strongly influence student satisfaction in residential facilities. Such findings suggest that technical condition scores alone may fail to capture dimensions that meaningfully affect educational outcomes, reinforcing the need for multi-criteria decision-making (MCDM) frameworks (Table 1).

Table 1. Literature Review Summary

Reference	Country	Focus Area	Method/Tool
Dahuri et al. 2025	Indonesia	Multi-perspective assessment of educational infrastructure	BCA + SERVQUAL
Purnawan & Aldy 2025	Indonesia	Digital tools in school infrastructure	BIM, GIS, IoT-based framework
Britz 2023	South Africa	Systemic inefficiencies in school asset management	Policy and planning review
Herath et al. 2023	Australia, UK	Lack of proactive funding and planning	Policy benchmarking
Dhansinghani et al. 2022	USA (Virginia)	Fair prioritizing of investments	Equity filter + scoring tool
Mohamed et al. 2022	Egypt	Technical urgency + user impact	DEA + Linear Programming
Siddesh & Veerabhadrapa 2022	India	Spatial inequality in education facilities	GIS mapping
Yasin et al. 2022	Malaysia	Organizational, financial, and human barriers	Survey-based diagnostic analysis
Abdelhamid et al. 2015	Egypt	Planning based on stakeholders and whole lifecycle	SAMF framework

Strategic asset management approaches advocate a shift from reactive maintenance to long-term planning. Abdelhamid et al. (2015) proposed a Strategic Asset Management Framework (SAMF) emphasizing lifecycle thinking, data integrity, and institutional accountability. Their work highlights the importance of proactive interventions to minimize long-term costs and service disruptions. Parallel research has explored the role of digital technologies in infrastructure management. Aktan et al. (2019) discussed the use of sensors and digital twins for infrastructure monitoring, while Purnawan and Aldy (2025) examined the integration of BIM, GIS, and IoT in school facilities management. Despite their potential, these technologies face practical barriers, including high implementation costs and interoperability challenges with legacy systems.

Persistent institutional barriers further complicate effective maintenance planning. Yasin et al. (2022) identified inadequate planning capacity, limited technical expertise, and insufficient funding as key obstacles in Malaysian educational institutions—issues that are also evident in many Canadian school systems. Britz (2023) further argues that short political cycles and fragmented governance structures discourage lifecycle-based investment strategies, exacerbating deferred maintenance and long-term risk exposure.

More recently, equity and spatial considerations have gained prominence in infrastructure prioritization. Dhansinghani et al. (2022) proposed a two-stage framework that explicitly evaluates need and fairness before technical scoring, ensuring that underserved communities receive priority. Complementing this, Siddesh and Veerabhadrapa (2022) demonstrated how GIS-based analyses can reveal spatial inequities in access to basic school services, supporting more geographically informed decision-making.

Despite these advances, a practical and uncertainty-aware prioritization tool suitable for real-world public school systems remains limited. In Canada, many organizations continue to rely on rigid scoring templates and visual inspections that inadequately address incomplete data, divergent expert opinions, and uncertainty-challenges that are particularly acute in geographically dispersed regions such as Saskatchewan. To address these limitations, this study proposes an Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP)-based decision-support framework that explicitly captures expert hesitation and ambiguity. By enhancing transparency, adaptability, and usability—particularly through accessible platforms such as Excel—the proposed framework aims to support more robust, equitable, and evidence-based school infrastructure prioritization.

### 3. Methodology

This study applies the IF-AHP to prioritize infrastructure investments in Saskatchewan’s public schools. The decision framework, illustrated in Figure 1, is designed to guide strategic renovations and long-term planning for educational facilities. Ten evaluation criteria, identified through literature review and expert input, were used to assess and rank five randomly selected schools (labeled School A to School E) from provincial statistics (Figure 1).

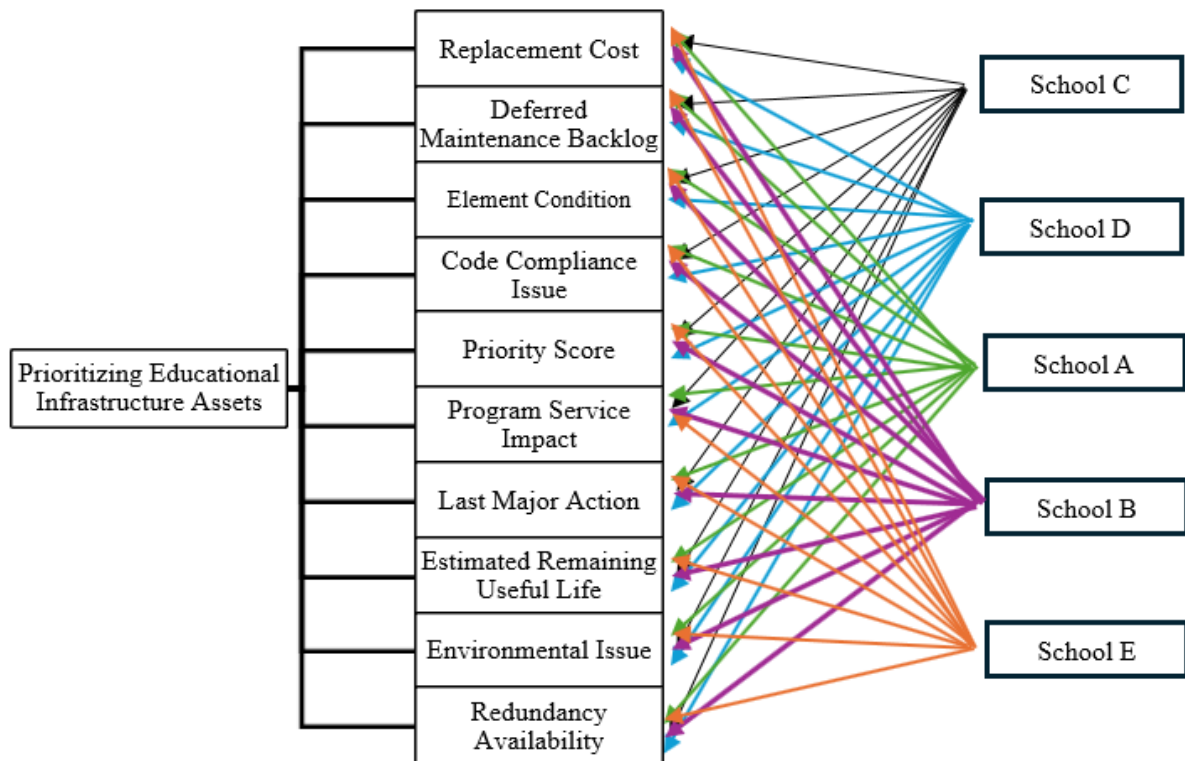


Figure 1. Hierarchical Fuzzy framework for prioritizing the educational infrastructure

#### 3.1 Data Collection

The data for this study was collected from multiple sources, including reports from Saskatchewan’s Ministry of Education and Infrastructure Planning on Facility Condition Index (FCI) and renovation audits, reviews by engineering experts providing cost estimates and impact evaluations, and field observations conducted by assessors in compliance with Saskatchewan’s environmental guidelines. Purposive sampling was used to select subject-matter experts with backgrounds in public infrastructure, engineering, and school asset management.

### 3.2 Intuitionistic Fuzzy AHP

Each expert conducted structured pairwise comparisons, applying linguistic scales such as “moderately more important” or “strongly more important” to evaluate the criteria. The linguistic ratings were then converted into Intuitionistic Fuzzy Numbers (IFNs)  $(\mu, \nu, \pi)$ , where  $\mu$  represents the degree of membership,  $\nu$  the degree of non-membership, and  $\pi$  the hesitation degree  $(1 - \mu - \nu)$ . All responses were transformed into fuzzy numbers under the condition that  $\mu + \nu \leq 1$ . If this condition was violated, the expert was asked to revise the response. Hesitation values were calculated using the defined equation, thereby capturing expert uncertainty within the model. Finally, the geometric mean method was applied to aggregate the fuzzy pairwise comparison matrices into a consensus group judgment.

$$\mu_{agg(i,j)} = (\mu^1 \times \mu^2 \times \dots \times \mu_n)^{\frac{1}{n}}$$

$$\nu_{agg(i,j)} = (\nu^1 \times \nu^2 \times \dots \times \nu_n)^{\frac{1}{n}}$$

The fuzzy weights were determined for each evaluation criterion using the following equation.

$$\text{Fuzzy Preference Score: } \delta(i) = \frac{(\mu_i + \pi_i)}{(\mu_i + \nu_i + \pi_i)}$$

$$\text{Normalized } \delta(i) = \frac{\delta(i)}{\sum \delta(i)}$$

Step 6: Normalizing Alternative Data

We turned each school's raw score for all ten criteria into a scale from 0 to 1 so that they could be compared fairly. This made it possible to use fuzzy-weighted scoring with the data.

- For benefit criteria (higher value = better):

$$\text{Score}_{normalized} = \frac{(X_{actual} - X_{min})}{(X_{max} - X_{min})}$$

- For cost criteria (lower value = better):

$$\text{Score}_{normalized} = \frac{(X_{max} - X_{actual})}{(X_{max} - X_{min})}$$

Step 7: Calculate the weighted scores and rankings

To get the final score for each school, we multiplied each normalized criterion score by the fuzzy weight that went with it:

$$\text{Score}_{school(i)} = \sum [ \text{Criterion}_{score} \times \text{Criterion}_{weight} ]$$

Using the IF-AHP weights, we created rankings where the schools at the top of the list represent those requiring the most immediate funding, while the lowest-ranked schools are considered lower priority due to their relatively better overall conditions.

## 4. Application of the Framework

The dual fuzzy MCDM framework was applied to five anonymized public schools in Saskatchewan, labeled School A through School E. Ten criteria (Cri 1: Replacement Cost; Cri 2: Deferred Maintenance Backlog, Cri 3: Element Condition, Cri 4: Code Compliance Issue, Cri 5: Priority Score, Cri 6: Program Service Impact, Cri 7: Last Major Action, Cri 8: Estimated Remaining Useful Life, Cri 9: Environmental Issue; Cri 10: Redundancy Availability) are considered based on the literature review presented in Table 1 and experts feedback.

Three key stakeholder groups who made decisions gave us the pairwise comparisons for the evaluation criteria:

- Provincial Asset Managers are in charge of making long-term plans and predicting capital investments;
- Engineering Consultants checked the condition of the facilities and gave advice on costs;
- School Operations Coordinators shared their understanding of how things work, including problems and daily obstacles.

The information used to rate schools on the ten criteria came from a mix of:

- Audit reports and maintenance records from the government;
- Documents for facility assessments offered by consultants;
- Lifecycle planning databases kept up by provincial asset management offices;
- Experts' best guesses for areas that are tougher to assess, such redundancy or following environmental rules.

Data of the five schools are summarized in Table 2.

Table 2. Literature Review Summary

Criteria	Code	Schools				
		School - C	School - D	School - A	School - B	School - E
Replacement Cost (\$)	Cri 1	8024323	7227947	6885464	21452594	17984174
Deferred Maintenance Backlog (\$)	Cri 2	3986756	2836267	2181112	10510624	7293606
Element Condition	Cri 3	Fair	Fair	Good	Fair	Fair
Code Compliance Issue	Cri 4	No	No	Yes	Yes	Yes
Priority Score	Cri 5	49.683	39.240	31.677	48.995	40.556
Program Service Impact	Cri 6	0	0	0	0	0
Last Major Action	Cri 7	1963	1960	1960	1960	1954
Estimated Remaining Useful Life (years)	Cri 8	13	10	10	10	4
Environmental Issue	Cri 9	No	Yes	Yes	Yes	No
Redundancy Availability	Cri 10	No	Yes	Yes	Yes	No

Each group sent in their evaluations using structured pairwise comparisons. The final pairwise comparisons and aggregated scores are represented in Table 3 and Table 4, respectively.

Table 3. IF-AHP Pairwise comparison

	Cri 1	Cri 2	Cri 3	Cri 4	Cri 5	Cri 6	Cri 7	Cri 8	Cri 9	Cri 10
Cri 1	1,0,0	0.29,0.6,0.11	.7,0.21,.09	0.75,0.15,0.1	0.41,0.49,0.1	0.39,0.5,0.11	0.4,0.4,0.2	0.5,0.4,0.1	0.7,0.19,0.11	0.6,0.11,0.29
Cri 2	0.15,0.71,0.14	1,0,0	0.43,0.47,0.1	0.6,0.28,0.12	0.4,0.52,0.08	0.3,0.63,0.07	0.1,0.5,0.4	0.35,0.55,0.1	0.5,0.4,0.1	0.3,0.57,0.13
Cri 3	0.4,0.46,0.14	0.5,0.4,0.1	1,0,0	0.55,0.3,0.15	0.22,0.44,0.34	0.44,0.37,0.19	0.5,0.4,0.1	0.6,0.3,0.1	0.4,0.35,0.25	0.4,0.51,0.09
Cri 4	0.5,0.4,0.1	0.43,0.5,0.07	0.3,0.49,0.21	1,0,0	0.41,0.5,0.09	0.2,0.66,0.14	0.57,0.35,0.08	0.25,0.5,0.25	0.6,0.3,0.1	0.4,0.5,0.1
Cri 5	0.38,0.5,0.12	0.61,0.3,0.09	0.45,0.38,0.17	0.6,0.3,0.1	1,0,0	0.5,0.4,0.1	0.59,0.3,0.11	0.4,0.5,0.1	0.5,0.3,0.2	0.42,0.4,0.18
Cri 6	0.7,0.21,0.09	0.3,0.52,0.18	0.48,0.4,0.12	0.18,0.66,0.16	0.34,0.5,0.16	1,0,0	0.4,0.5,0.1	0.3,0.6,0.1	0.51,0.23,0.26	0.6,0.3,0.1
Cri 7	0.33,0.43,0.24	0.4,0.5,0.1	0.75,0.1,0.15	0.4,0.54,0.06	0.7,0.2,0.1	0.22,0.66,0.12	1,0,0	0.3,0.5,0.2	0.3,0.5,0.2	0.6,0.3,0.1
Cri 8	0.43,0.5,0.07	0.7,0.24,0.06	0.58,0.4,0.02	0.49,0.43,0.08	0.4,0.49,0.11	0.38,0.51,0.11	0.42,0.52,0.06	1,0,0	0.6,0.12,0.28	0.14,0.6,0.26
Cri 9	0.5,0.32,0.18	0.6,0.2,0.2	0.3,0.6,0.1	0.5,0.39,0.11	0.5,0.4,0.1	0.65,0.25,0.1	0.27,0.65,0.08	0.56,0.37,0.07	1,0,0	0.52,0.22,0.26
Cri 10	0.58,0.34,0.08	0.3,0.65,0.05	0.4,0.41,0.19	0.27,0.57,0.16	0.5,0.44,0.06	0.4,0.55,0.05	0.5,0.35,0.15	0.47,0.43,0.1	0.35,0.55,0.1	1,0,0

Table 4. Aggregated values and score

Criteria	Aggregated Membership Degree	Aggregated Non-Membership Degree	Aggregated Hesitation Degree	Normalized Defuzzified Score
Cri 1	0.538	0.292	0.124	0.117
Cri 2	0.346	0.478	0.117	0.083
Cri 3	0.469	0.378	0.147	0.1044
Cri 4	0.422	0.463	0.118	0.0907
Cri 5	0.524	0.354	0.125	0.1091
Cri 6	0.432	0.441	0.14	0.0952
Cri 7	0.448	0.358	0.12	0.1035
Cri 8	0.464	0.374	0.092	0.1007
Cri 9	0.508	0.354	0.116	0.1075
Cri 10	0.446	0.485	0.095	0.0889

Figure 2 presents the weight of the criteria using intuitionistic Fuzzy AHP method. Based on the data presented in Table 2 and weights of the criteria highlighted in Figure 2, the IF-score and the rank of the each school demonstrated in Table 5.

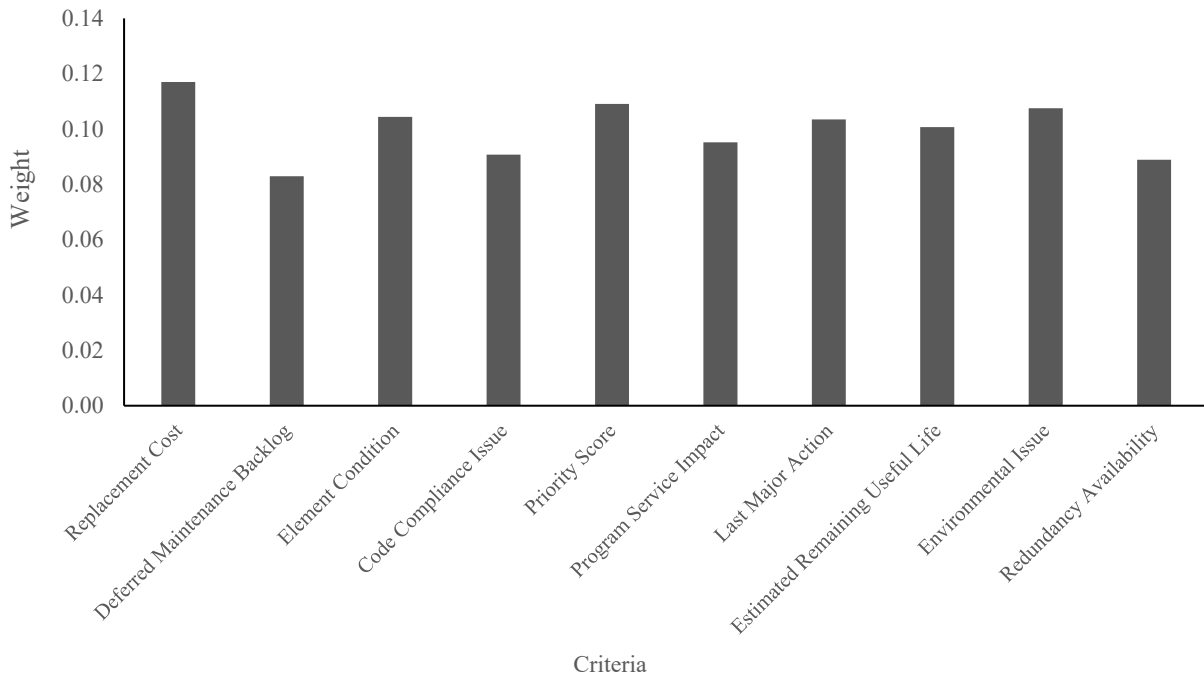


Figure 2. Weight of the criteria using intuitionistic Fuzzy AHP method

Table 5. IF-AHP weights, IF-Score, and school rank

Criteria	Weight	School - C	School - D	School - A	School - B	School - E
Cri 1	0.117	0.374	0.337	0.321	1.000	0.838
Cri 2	0.083	0.379	0.270	0.208	1.000	0.694
Cri 3	0.104	0.600	0.600	1.000	0.600	0.600
Cri 4	0.091	0.000	0.000	1.000	1.000	1.000
Cri 5	0.109	1.000	0.790	0.638	0.986	0.816
Cri 6	0.095	1.000	1.000	1.000	1.000	0.500
Cri 7	0.104	0.000	0.333	0.333	0.333	1.000
Cri 8	0.101	0.000	0.231	0.231	0.231	0.692
Cri 9	0.108	0.000	1.000	1.000	1.000	0.000
Cri 10	0.089	0.000	1.000	1.000	1.000	0.000
Score		0.342	0.560	0.669	0.810	0.619
Rank		5	4	2	1	3

#### 4. Results and Discussions

The results show that Replacement Cost (0.117), Priority Score (0.109), and Environmental Issue (0.108) emerged as the most influential factors in prioritizing school infrastructure projects. Meanwhile, Deferred Maintenance Backlog (0.083) and Redundancy Availability (0.089) carried relatively lower weights, though still contribute to the overall decision-making process. The IF-AHP results indicate that School-B (0.810) is the top priority, followed by School-A (0.669) and School-E (0.619). In contrast, School-D (0.560) and School-C (0.342) rank lower, suggesting they are less urgent for infrastructure prioritization.

The criterion  $\mu + \nu \leq 1$  in IF-AHP tended to make weight distributions more concentrated. It put the most weight on obvious, measurable signs like: Backlog of Deferred Maintenance, Index of Facility Condition (FCI), Service Interruption for the Program. Experts seemed to agree more confidently in these areas, which is what other researchers like Boran et al. (2009) have found: IF-AHP works effectively when the data is structured and consistent.

Across much of Canada, school infrastructure planning still relies on visual inspections and reactive maintenance, with few systematic tools available to balance objective data and expert judgment in setting priorities. This study responds to that need by presenting an Excel-based decision-support model that is simple to use, scalable across dozens or even hundreds of facilities, and requires no specialized software-making it particularly well-suited for public sector agencies with limited resources. The framework employs a dual fuzzy approach to incorporate both expert perspectives and uncertainty in the planning process, providing a structured pathway for organizations to transition from ad hoc decision-making toward more evidence-based and transparent practices.

#### 6. Conclusion

This study developed an Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) framework to prioritize school infrastructure projects in Saskatchewan. The model integrates facility condition data with expert judgments across ten criteria, enabling decisions that move beyond visual inspections and reactive maintenance. Implemented in Excel, it is transparent, scalable, and practical for resource-constrained public-sector organizations. Results showed that School B ranked highest in priority, demonstrating the framework's ability to handle uncertainty, expert disagreement, and incomplete data. A key advantage is its incorporation of hesitation values, which provides more nuanced insights than conventional scoring methods.

Nonetheless, the study's scope was limited to five pilot schools, and outcomes remain sensitive to subjective expert input and data gaps in areas such as environmental compliance. Future work should expand validation across larger

school systems, incorporate stakeholder perspectives, and develop interactive platforms to further improve usability and support evidence-based educational infrastructure planning.

## **Acknowledgment**

The authors would like to acknowledge Ministry of SaskBuilds and Procurement, SK for the support and cooperation.

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