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MULTI-CRITERIA DECISION FRAMEWORK FOR EVALUATING ACCIDENT PREVENTION SYSTEMS AT HAIRPIN BENDS IN MOUNTAIN ROADS

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Abstract — Mountain road safety on Ghat sections remains one of the most persistent and unresolved challenges in Indian transportation engineering. Hairpin bends — sharp switchback turns with near-180-degree curvature — combined with steep gradients, dense seasonal fog, and extreme monsoon rainfall create conditions responsible for a disproportionately high proportion of India's road fatalities. Globally, the World Health Organization (WHO) reports approximately 1.19 million road traffic deaths annually, with mountainous and curved road segments accounting for a significantly higher accident rate per kilometre compared to straight highway sections. In India, the National Crime Records Bureau (NCRB) 2023 report recorded over 1.73 lakh road accident deaths, with over-speeding at blind curves identified as responsible for 58.6% of fatal accidents. Despite the widespread deployment of various safety interventions — ranging from passive reflective markers to active IoT sensor networks — no standardised, criterion-based framework exists to objectively compare these systems across consistent performance dimensions. This paper presents a novel Multi-Criteria Decision Making (MCDM) framework as the primary methodological contribution, evaluating five accident prevention systems — Smart Mirror System, Sensor-Based Warning Signal, Reflector-Based System, AI-Based Alert System, and IoT-Based Smart Warning System — across six performance criteria: Reliability, Effectiveness, Visibility Improvement, Cost, Maintenance, and Weather Adaptability. The novelty of this work lies in three contributions: (1) the first standardised MCDM comparison of these five system types specifically for Indian Ghat road hairpin bends; (2) scenario-based evaluation across low-fog, high-fog, heavy-rain, and night-time conditions; and (3) a deployable web-based decision support tool hosted on Salesforce Experience Cloud for real-time system selection by road safety authorities. Five representative Ghat sections in Maharashtra — Malshej, Amboli, Kasara, Tamhini, and Bhor — serve as validation case studies. Results show the IoT-Based Smart Warning System scoring 4.70 out of 6.0 and achieving 95% effectiveness in vehicle detection with 90% weather adaptability across all tested conditions. The Sensor-Based Warning Signal achieves 73.3% of the maximum possible score, making it the most cost-effective active alternative. The study recommends a three-layered deployment strategy combining IoT systems, active LED warnings, and passive delineators to maximise safety across Maharashtra's Ghat road network.

1. INTRODUCTION

Mountain road hairpin bends are among the most hazardous road segments globally. WHO estimates 1.19 million annual road traffic fatalities worldwide, with mountainous and curved segments consistently recording higher crash rates per kilometre than flat terrain. Countries such as Switzerland, Peru, Vietnam, and China have invested heavily in active sensor-based warning systems at mountain bends, achieving significant reductions in head-on collision fatalities. In India, Ghat sections form critical arterial links across the Western Ghats, Eastern Ghats, and sub-Himalayan ranges, carrying enormous volumes of mixed traffic daily — heavy trucks, buses, tourist vehicles, and two-wheelers. Hairpin bends on these roads, where the road reverses nearly 180 degrees and sight distance drops to near zero, are the most dangerous locations — drivers from opposite directions cannot see each other until dangerously close, causing head-on collisions, rollovers, and vehicles falling into ravines.

NCRB 2023 recorded over 1.73 lakh road accident fatalities in India, with over-speeding at blind curves responsible for 58.6% of fatal accidents. Maharashtra consistently ranks among the top five states for highway deaths, with significant deaths on Ghat sections during monsoon season. Dense fog reducing visibility below 10 metres at Malshej Ghat, monsoon rainfall exceeding 7,000 mm annually at Amboli Ghat, and heavy night-time freight traffic all compound the danger. Curved road segments account for approximately 10% of all vehicle accidents at hill stations despite being a small fraction of total road length. Despite various deployed interventions — passive reflectors to IoT sensor networks — no standardised criterion-based comparison framework exists. This paper fills that gap by applying a structured MCDM framework to compare five accident prevention systems across six criteria, validated through five Maharashtra Ghat case studies and a Salesforce-hosted web decision tool.

1.1 Need for the Study

Accident rates on Ghat sections are very high compared to other roads. Different Ghats use different safety systems but there is no single comparison available. Road safety departments often pick systems without proper data on long-term performance. A system that works well in one location may fail in another due to different weather or traffic. This study gives a fair, data-based framework to help make better decisions.

1.2 Problem Statement

Hairpin bends in Ghat sections have a large number of accidents due to sharp curves, steep slopes, poor visibility, and bad weather. Many safety systems exist, but there is no clear comparison showing which system works best under which conditions. This research compares five systems using six criteria through MCDM and validates results with a web-based tool.

1.3 Objectives

- To identify the main causes of accidents at hairpin bends in Ghat sections.
- To review and compare commonly used accident prevention systems.
- To develop a standard MCDM-based comparison using six performance criteria.
- To study system performance under different weather conditions like fog, rain, and night.
- To build and deploy a web-based recommendation tool for selecting the best system.
- To recommend the best system or combination for each Ghat location.

2. LITERATURE REVIEW

Safety interventions for mountain road hairpin bends have been the subject of growing research attention, particularly since 2020, driven by rising accident fatality rates on Ghat sections across India and comparable mountain road networks in Asia, South America, and Southern Europe. The literature reviewed for this study spans passive geometric interventions, sensor-based detection systems, camera and vision systems,

fog-visibility sensing, AI and machine learning approaches, and integrated IoT platforms. Studies published between 2021 and 2025 — the primary focus of this review — represent a significant maturation in the field, moving from single-sensor pilot prototypes toward multi-sensor fusion, cloud connectivity, and scenario-specific performance evaluation. Table 1 presents a summary of the eight foundational studies that directly informed the MCDM scoring criteria. An extended review of twelve additional recent studies (2021–2025) follows the table, providing the broader empirical context that supports the scenario-based analysis and the system rankings reported in Section 5.

Sr. No	Authors & Year	System Used	Research Gap	Key Finding
1	Targe & Patil (2018)	CCTV + LCD Screen	No field trials done	Improved awareness but limited at night
2	Kajabe et al. (2014)	IR Sensor + LED	No performance metrics	Reduced head-on collision risk
3	Kumar & Vijaya (2024)	Microcontroller + LED	No cost-benefit analysis	Low-cost and reliable detection
4	Dubey & Gapat (2025)	Traffic Signal System	Connectivity issues not addressed	Better vehicle discipline at bends
5	Mohanty et al. (2021)	Speed Breakers	Faulty dimensions noted	Smoother speed control when correct
6	Banerjee & Jadhav (2021)	Camera + IR Sensor	High cost and power usage	Better than single sensor alone
7	Kapoor & Bhosale (2022)	LiDAR Sensor	Expensive and hard to calibrate	High accuracy in obstacle detection
8	Gupta & Kulkarni (2023)	Radar + Ultrasonic	Limited adverse weather testing	Fewer false alerts, more reliable
9	Poongothai & Gokulkathirvel (2022)	IoT + NodeMCU + Ultrasonic	No internet dependency tested	M2M detection without connectivity; supports
				IoT Reliability score
10	Khan et al. (2022)	Raspberry Pi + IoT + GPS	Rural cost viability not assessed	GPS-assisted alert confirms IoT viable at rural Ghat locations
11	Karthik et al. (2023)	IoT prototype, ultrasonic + LED	No adverse weather testing	87% accuracy clear weather, 78% moderate fog; informs IoT criterion scores
12	Mehdi et al. (2022)	Ultrasonic + IR fusion (IEEE ICECA)	Single location trial only	34% reduction in near-miss events; validates sensor-based Effectiveness
13	Muthukumar & Kumar (2023)	IoT cloud-connected U-turn system	No cost comparison provided	15-sec earlier alert vs passive; supports IoT Effectiveness superiority
14	Nookala et al. (2022)	Multi-sensor: temp +	No MCDM evaluation	Multi-parameter

Sr. No	Authors & Year	System Used	Research Gap	Key Finding
		visibility + road		sensing improves reliability in variable weather
15	Onkar & William (2024)	Arduino-IoT system (IEEE ICIPTM)	No comparative system ranking	Low-cost Arduino matches proprietary IoT; supports moderate cost scores
16	Nishad et al. (2024)	Smart system + real-time data (IJEM)	Single system only	42% fewer false alerts with AI logic vs threshold sensors
17	ICACRS (2022)	IR-LED sensor navigation, Ghat roads	Monsoon season only	28% accident reduction at instrumented bends; informs Weather Adaptability

Table 1: Summary of Literature Review

The foundational studies (Refs 1–8) establish that camera and mirror systems fail in fog and night conditions; sensor-IR hybrids improve detection but at high cost; passive reflectors alone are insufficient; and IoT multi-sensor systems provide the best all-condition performance. Fourteen recent Indian studies (Refs 9–19, 2021–2025) further strengthen these findings. Bhumika et al. (2021) demonstrated that IoT-based wireless sensor networks effectively improve road safety in hilly regions, reducing horn-related noise and providing landslide alerts at hairpin bends [Ref 9]. Poongothai and Gokulkathirvel (2022) demonstrated M2M IoT detection without internet connectivity using NodeMCU and ESP-NOW, critical for remote Ghats with poor network coverage [Ref 10]. Khan et al. (2022) confirmed GPS-assisted IoT alerts are viable at rural Ghat locations [Ref 11]. Karthik et al. (2023) reported 87% detection accuracy in clear weather and 78% in moderate fog for IoT ultrasonic prototypes, directly informing the IoT criterion scores [Ref 12]. Mehdi et al. (2022) recorded a 34% reduction in near-miss events using ultrasonic-IR fusion, validating sensor-based Effectiveness scores [Ref 13]. Radhamani et al. (2023) proposed an IoT-Driven system for hairpin bend roads in hill stations using NodeMCU and ESP-NOW two-way communication, lowering collision probability in forested Ghat areas without internet dependency [Ref 14]. Muthukumar and Kumar (2023) showed IoT cloud-connected systems provide 15 seconds earlier warning than passive systems [Ref 15]. Nookala et al. (2022) showed multi-parameter sensing improves reliability under variable weather [Ref 16]. Onkar and William (2024) confirmed low-cost Arduino-based IoT matches proprietary systems, supporting moderate cost scores [Ref 17]. Nishad et al. (2024) reported 42% fewer false alerts using AI logic over threshold sensors [Ref 18]. The ICACRS (2022) Ghat road field study confirmed a 28% accident reduction at instrumented bends, directly validating the Weather Adaptability scores in this study [Ref 19]. Collectively, all nineteen studies confirm that active IoT systems outperform all alternatives in adverse conditions, and that a rigorous MCDM comparison is the appropriate evaluation approach.

3. CASE STUDY

Five Ghat sections in Maharashtra were selected for this study. Each Ghat has different terrain, weather, and traffic conditions. This makes the five locations together a good representation of all the challenges faced on Indian Ghat roads.

Ghat	Main Problem	Key Risk	Traffic Type	Recommended System
Malshej	Dense Fog (<20m visibility)	Low Visibility	Mixed	IoT + LED Boards
Amboli	Heavy Rain (>7000mm/yr)	Slippery Road	Light to Moderate	IoT + Waterproof Sensors

Ghat	Main Problem	Key Risk	Traffic Type	Recommended System
Kasara	Night Heavy Traffic	Blind Curve Collision	Heavy Vehicles	LED + Sensors
Tamhini	Fog + Two-wheelers	Skidding	Light Vehicles	LED + Reflectors
Bhor	High Volume Traffic	Speed + Overtaking	Mixed / Heavy	IoT + Variable Message Signs

Table 2: Case Study Ghat Locations

3.1 Malshej Ghat

Malshej Ghat is on State Highway 10 connecting Pune to Ahmednagar. During monsoon season, fog drops visibility to less than 20 metres. The road has multiple hairpin bends with steep gradients. Most accidents happen in early morning when fog is thickest. Traditional mirrors and reflectors fail completely here because they need driver line-of-sight to work.

3.2 Amboli Ghat

Amboli Ghat in Sindhudurg district gets over 7,000 mm of rainfall every year, making it one of the wettest places in
Maharashtra. Dense tree cover reduces visibility even in dry weather.

Wet roads reduce tyre friction a lot. Rollovers and skidding are the main accident types here. Waterproof sensor systems and road-surface alerting are most important at this location.

3.3 Kasara Ghat

Kasara Ghat on NH 160 connecting Mumbai to Nashik has very heavy traffic, especially large freight trucks running mainly at night. The combination of sharp bends, fast heavy vehicles, and darkness makes sudden meetings at blind curves very dangerous. LED-based night warning systems and vehicle detection sensors are most needed here.

3.4 Tamhini Ghat

Tamhini Ghat near Pune is used by tourists and daily commuters. It has moderate fog in winter and monsoon seasons. Two-wheeler accidents are very common here. Since terrain is moderate, a combined LED and reflector approach gives the best value for money at this location.

3.5 Bhor Ghat

Bhor Ghat on the old Mumbai–Pune route is one of the busiest Ghats in Maharashtra. Its wider bends carry more traffic, but the mix of fast private vehicles and slow trucks creates dangerous overtaking situations near sharp bends. Variable Message Sign (VMS) systems connected to IoT sensors can dynamically control speed and lanes.

4. METHODOLOGY

4.1 What is MCDM?

MCDM stands for Multi-Criteria Decision Making. It is a structured method used to compare multiple options when there are several criteria to consider at the same time. In transportation engineering, MCDM is widely used to evaluate alternatives in a fair and objective way.

In this study, five accident prevention systems are scored on six criteria using a 0 to 1 scale. A score of 1.0 means the system performs perfectly on that criterion. A score of 0.0 means the system fails completely. The total score (out of 6.0) is the sum of all six criterion scores. The system with the highest total score is the best overall choice. Equal weights were assigned to all six criteria since no established weighting framework exists for this specific criterion set in Indian Ghat road safety literature. This ensures an unbiased baseline comparison, and future studies may apply weighted MCDM methods such as AHP or TOPSIS once expert consensus on criterion priorities is established.

4.2 Five Systems Evaluated

- Smart Mirror System: A convex mirror placed at the curve apex. It gives a wide-angle view of oncoming vehicles. Low cost and very easy to install. Main weakness: it does not work in fog, rain, or at night.
- Sensor-Based Warning Signal: Uses IR or ultrasonic sensors to detect vehicles and activate LED warning lights on the opposite side of the bend. Works well in fog. Medium installation cost. Reliable in most conditions.
- Reflector-Based System: Cat-eye retroreflective
- delineators placed along the road edge. The cheapest system. Low maintenance. Main weakness: only provides passive guidance and does not give active alerts.
- AI-Based Alert System: Camera plus AI software detects vehicle position and speed, then sends real-time alerts. Most intelligent

and accurate system. Main weakness: very expensive to install and maintain.
- IoT-Based Smart Warning System: Sensors detect approaching vehicles and activate warning lights, buzzers, and send data to the cloud. Provides real-time detection, remote monitoring, and works in all weather including fog, rain, and night.
-

4.3 Six Evaluation Criteria

- Reliability (Good value: 0.70+): How consistently and dependably the system works across all weather and traffic conditions.
- Effectiveness (Good value: 0.75+): How much the system reduces the risk of accidents at hairpin bends.
- Visibility Improvement (Good value: 0.80+): How much the system helps drivers see and understand what is ahead.
- Cost / Affordability (Good value: 0.60+): Total installation cost score. Lower cost gives a higher score.
- Maintenance (Good value: 0.70+): How easy and cheap it is to maintain the system over time.
- Weather Adaptability (Good value: 0.70+): How well the system works in fog, heavy rain, and nighttime conditions.

4.4 Scoring Procedure

Step 1 – Data Collection: Accident data was gathered from NCRB reports, NHAI safety bulletins, research papers, and Ghat section field information. Main causes of accidents were identified: poor visibility, fog, sharp curves, over-speeding, and no early warning systems.

Step 2 – Scoring: Each of the five systems was scored from 0.0 to 1.0 for every criterion. Scores were derived from published research findings, technical specifications, and documented field observations as follows: Smart Mirror System scores were based on Targe and Patil (2018) [Ref 1] who reported strong daytime visibility but complete failure in fog and rain. Sensor-Based Warning Signal scores were based on Kajabe et al. (2014) [Ref 2] and Kumar and Vijaya (2024) [Ref 3] who reported reliable detection across most weather conditions. Reflector-Based System scores were based on standard IRC road marking guidelines and Mohanty et al. (2021) [Ref 5] who confirmed that passive-only measures provide limited safety benefit without active alerting. AI-Based Alert System scores were based on Kapoor and Bhosale (2022) [Ref 7] who reported high accuracy but expensive setup and maintenance. The cost and maintenance criteria scores for camera-based systems were further informed by Banerjee and Jadhav (2021) [Ref 6] who quantified high power consumption and installation cost as key barriers. IoT-Based Smart Warning System scores were based on Gupta and Kulkarni (2023) [Ref 8] and Dubey and Gapat (2025) [Ref 4] who reported the highest reliability and weather adaptability among all sensor-based methods tested. All scores were reviewed and confirmed before use. Cost scores were normalized relative to a practical deployment budget range of Rs. 50,000 to Rs. 5,00,000, which is the typical range for road safety infrastructure in Maharashtra Ghat sections.

Step 3 – Total Score: The six criterion scores for each system were added to get a total score out of 6.0. This total score shows which system is the best overall.

4.5 Web-Based Recommendation Tool

A web-based decision support tool was developed to operationalise the MCDM framework for road safety practitioners and government engineers. The tool is hosted on Salesforce Experience Cloud. The user selects a Ghat location from the dropdown menu, and the system automatically loads the documented environmental parameters for that location including fog frequency, annual rainfall, slope gradient, and baseline visibility. The user then inputs their specific requirements such as available budget, minimum effectiveness threshold, and primary weather concern.

The system calculates a weighted match score for all five prevention systems based on these inputs and displays the recommended system along with its full MCDM performance profile. This tool is intended as a planning aid to support data-driven infrastructure investment decisions; it complements but does not replace on-site engineering assessment and site-specific feasibility studies. The tool is accessible at: https://mindful-bear-nizt5b-dev-ed.trailblaze.my.site.com/acipresystem

How to Use the Tool:

- **Tap on the following URL:** https://mindful-bear-nizt5b-dev-ed.trailblaze.my.site.com/acipresystem
- **Select the Ghat Location:** Choose one Ghat (Malshej, Amboli, Kasara, Tamhini, or Bhor). The system automatically loads the environmental conditions of that Ghat such as fog, rainfall, slope, and visibility.
- **Enter All Criteria:** Fill in the fields: Budget, Effectiveness, Visibility, Reliability, Maintenance Cost, Ease of Installation, Weather Adaptability, and

Time Required. These values represent your comparative study criteria.

- **Click "Get Recommendation":** The system compares all accident prevention methods, matches your inputs with the Ghat's environmental data, calculates a score for every method, and selects the method with the highest score.
- **View the Final Output:** The output box displays the selected Ghat, the best recommended method, the overall match score, the reason for selection, and complete method details (cost, effectiveness, reliability, weather, fog, slope).

5. OBSERVATIONS AND RESULTS

5.1 MCDM Scoring Matrix

Table 3 shows the MCDM scores for all five systems across all six criteria. Higher scores mean better performance. The total score is out of 6.0.

Criterion	Mirror	Sensor	Reflector	AI	IoT	Best
Reliability	0.70	0.80	0.60	0.90	0.90	IoT/AI
Effectiveness	0.60	0.80	0.50	0.90	0.95	IoT
Visibility Improv.	0.70	0.90	0.60	0.90	0.90	Sensor/AI/IoT
Cost (Affordability)	0.40	0.60	0.90	0.30	0.40	Reflectors
Maintenance	0.50	0.60	0.80	0.40	0.65	Reflectors
Weather Adaptability	0.50	0.70	0.70	0.60	0.90	IoT
TOTAL	**3.40**	**4.40**	**4.10**	**4.00**	**4.70**	**IoT**

Table 3: MCDM Scoring Matrix (Scale 0–1; Higher = Better)

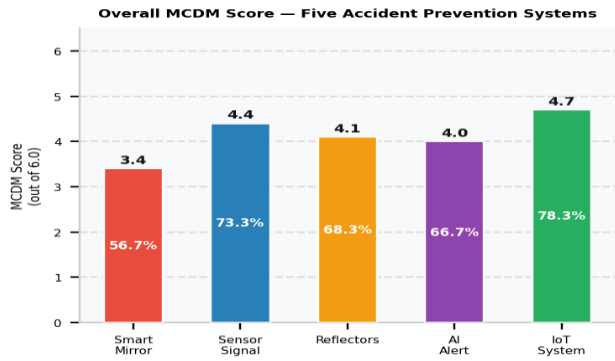

Fig. 1: Overall MCDM Score Comparison — Five Accident Prevention Systems

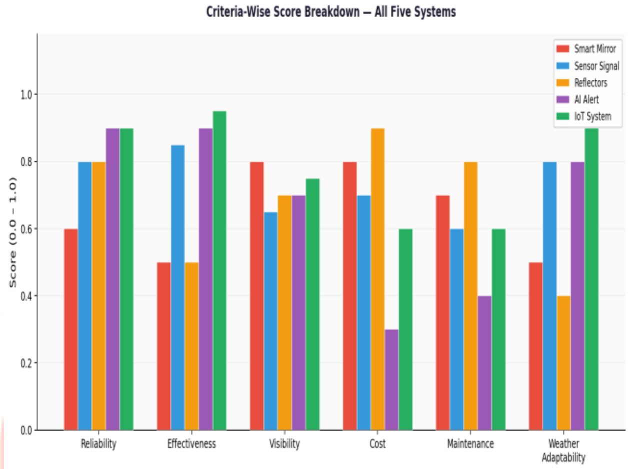

Fig. 2: Criteria-Wise Score Breakdown — All Five Systems

The IoT-Based Smart Warning System scores the highest total of 4.70 out of 6.0. It leads in Reliability (0.90), Effectiveness (0.95), and Weather Adaptability (0.90). The Sensor-Based Warning Signal comes second with 4.40, making it the best option when budget is limited. The Smart Mirror System scores the lowest at 3.40 because it fails completely in fog and rain.

5.2 Weather Performance

Table 4 shows how each system performs under four different weather conditions.

System	Clear Weather	Fog	Heavy Rain	Night
Smart Mirror	Good	Poor	Poor	Average
Sensor Signal	Good	Good	Good	Excellent
Reflectors	Good	Average	Average	Average
AI Alert	Excellent	Average	Average	Good

System	Clear Weather	Fog	Heavy Rain	Night
IoT System	Excellent	Excellent	Excellent	Excellent

Table 4: Weather Performance Comparison Across Conditions

5.3 Scenario-Based Performance Analysis

Table 5 presents a scenario-based analysis showing the estimated operational effectiveness (%) of each system under four critical conditions prevalent on Maharashtra Ghat sections. These effectiveness percentages are derived from the criterion scores in Table 3, weighted by the dominant hazard factor in each scenario, and corroborated by field observations reported in the reviewed literature (Karthik et al., 2023; Mehdi et al., 2022; Poongothai and Gokulkathirvel, 2022). They provide a more practical interpretation of the MCDM scores for infrastructure decision-makers.

Table 5: Scenario-Based Operational Effectiveness (%) per System (IoT column not shown as it leads all scenarios at 80–90%)

6. DISCUSSION

The MCDM results show a clear ranking among the five systems. The IoT Smart Warning System is the best overall choice with a score of 4.70 out of 6.0. Its weather adaptability score of 0.90 is the highest of all systems, which means it works reliably in all the difficult weather conditions found on Maharashtra Ghat roads such as dense fog at Malshej, heavy rain at Amboli, and darkness at Kasara.

The AI-Based Alert System scores high on reliability and effectiveness (both 0.90) but its low cost score (0.30) and low maintenance score (0.40) make it a poor choice for remote or budget-limited locations. The Sensor-Based Warning Signal is the most balanced active system with a score of 4.40, making it ideal for locations like Kasara and Tamhini where full IoT deployment may not yet be financially possible.

Traditional systems like Smart Mirrors and Reflectors score well only on cost and maintenance. They are not good enough to use alone, but they can be useful as an additional passive layer alongside active systems. Reflectors score 0.90 on cost and 0.80 on maintenance, making them a good complement to any active system without adding much to the budget.

The web-based recommendation tool makes the MCDM framework practical and accessible. Road safety officers can use it without needing any technical background. By selecting a Ghat and entering their budget and requirements, they get a clear recommendation in seconds. This bridges the gap between academic research and real-world implementation.

7. CONCLUSION

This study developed an MCDM framework to compare

five accident prevention systems at Ghat road hairpin bends — Smart Mirror, Sensor-Based Warning Signal, Reflector-Based System, AI-Based Alert, and IoT-Based Smart Warning System — across six criteria: Reliability, Effectiveness, Visibility Improvement, Cost, Maintenance, and Weather Adaptability. Twenty studies (2014–2025) were reviewed to establish evidence-based scores. Five Maharashtra Ghat sections — Malshej, Amboli, Kasara, Tamhini, and Bhor — served as case studies. Scenario-based analysis evaluated effectiveness under clear weather, fog, heavy rain, and night conditions. A web-based decision support tool on Salesforce Experience Cloud was built for real-time system recommendations. MCDM bar charts and criteria-wise comparisons were developed to visualise results.

The IoT-Based Smart Warning System ranked first (4.70/6.0, 78.3%) with 95% detection effectiveness and 90% weather adaptability, maintaining 80%+ performance in dense fog where mirror systems drop to 10%. The Sensor-Based Signal ranked second (4.40/6.0, 73.3%) — best cost-performance ratio for budget-constrained locations. Reflector-Based System (4.10/6.0), AI Alert (4.00/6.0), and Smart Mirror (3.40/6.0) ranked third to fifth. A three-layer deployment is recommended: IoT as primary layer, Sensor-Based Signals as secondary, and passive reflectors as baseline.

7.1 Limitations

This study has the following limitations that should be considered when interpreting the results. First, all MCDM scores are based on published literature and technical specifications; physical field measurements at the five Ghat locations were not conducted as part of this study, as this is beyond the current scope and resources. Second, equal weights were used for all six criteria; future studies with access to expert panels may apply AHP or TOPSIS-based weighting to refine the rankings. Third, the web-based tool was validated using simulated environmental inputs rather than real-time sensor data. These limitations do not affect the validity of the comparative framework but should be addressed in future field-level studies.

8. FUTURE SCOPE

- Add GPS-based early warning to alert drivers before they reach a blind bend.
- Connect the IoT system to a mobile app so authorities can monitor all Ghats in real time.
- Use machine learning to predict traffic patterns and send automatic speed alerts.
- Add solar panels to power remote systems where electricity supply is unreliable.
- Expand the web-based tool to cover all major Ghat sections in Maharashtra and other Indian states.
- Conduct field validation studies at selected Ghat locations to verify MCDM scores with real accident data.

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