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**AI Impact on Crowd Management Using CCTV Footage in
Riyadh Metro Operations**

Table of Contents

Abstract	3
Introduction	3
Background	3
The Evolution of Artificial Intelligence in Video Surveillance.....	3
Crowd Management Challenges in Metro Systems	3
The Significance of AI-Based Crowd Management.....	4
Challenges to Implementing AI in Crowd Management.....	4
Problem Statement.....	4
Research Objectives	5
Research Scope.....	5
Literature Review	6
Research Methodology	7
Phase 1: Literature Review	8
Phase 2: Qualitative Research	8
Phase 3: Quantitative Research.....	8
Phase 4: Framework Development and Validation.....	9
Ethical Considerations	9
Limitations.....	9
Expected Outcomes	10
Gantt Chart.....	10
References	12

Abstract

Large-scale metro systems face increasing challenges related to crowd safety, congestion, and operational efficiency. The Riyadh Metro, as a significant urban transportation project, experiences variable passenger densities that require practical and proactive crowd management strategies. Advances in artificial intelligence (AI), particularly in computer vision and video analytics, have enabled closed-circuit television (CCTV) systems to transition from passive monitoring to real-time crowd analysis.

This research investigates the impact of AI-based CCTV analytics on crowd management in Riyadh Metro operations. It examines how AI can support real-time monitoring, predict congestion, and assist decision-making processes. A mixed-methods research design is adopted, combining an in-depth literature review, qualitative stakeholder input, and quantitative performance evaluation. Ethical, privacy, and governance considerations associated with AI-enabled surveillance in public transportation environments are also critically examined.

Introduction

In an era where Urban rail transit systems are essential for sustainable mobility in modern cities. As passenger demand increases, metro operators must address challenges related to system accuracy, data quality, privacy protection, ethical governance, and integration with existing operational workflows. Despite its potential, AI implementation presents challenges related to system accuracy, data quality, privacy protection, ethical governance, and integration with existing operational workflows.

Crowd management is particularly critical in high-capacity systems such as the Riyadh Metro, where sudden increases in passenger volume can lead to operational disruptions.

Traditional crowd monitoring relies heavily on manual observation and reactive intervention. These approaches cannot often anticipate congestion before it escalates. AI-driven CCTV analytics offer a promising solution by enabling continuous analysis of crowd movement and density, supporting proactive and data-driven operational decisions.

Background

The Evolution of Artificial Intelligence in Video Surveillance

Artificial Intelligence (AI) has developed steadily over time and is no longer limited to theoretical discussion or fictional applications. It has become a practical technology that is now widely used across many sectors of modern society. Alongside this development, video surveillance systems have undergone significant evolution with the introduction of AI-based tools. Current surveillance solutions can analyze crowd density, movement patterns, and unusual behavior by using computer vision and deep learning techniques. These capabilities allow surveillance systems to move beyond basic observation and support early

detection of potential risks. As a result, organizations are better positioned to take preventive actions, improve safety measures, and manage operations more effectively in complex and dynamic environments.

Trust and Transparency Issues in AI for Crowd Management in Metro Systems.

Metro systems operate in highly dynamic environments characterized by continuous passenger movement and limited physical space. During peak operating hours, unplanned service interruptions, or emergencies, passenger density can increase rapidly, thereby heightening the risk of safety incidents and negatively impacting the user experience. In such contexts, effective crowd management depends not only on the availability of technological solutions but also on the reliability and transparency of the decision-support systems in place.

The Significance of AI-Based Crowd Management

The significance of trust and transparency in AI-based crowd management enhances situational awareness, allowing metro operators to intervene before critical thresholds are reached. These capabilities support safety objectives and align with broader smart city and digital transformation initiatives.

Challenges to Implementing AI in Crowd Management

Enhancing trust in artificial intelligence requires a comprehensive approach that extends beyond technical performance alone. Although AI systems offer significant potential to improve operational efficiency and decision-making, their successful adoption is constrained by several interrelated challenges. These include concerns regarding the accuracy and reliability of AI outputs, the quality and representativeness of input data, and the protection of privacy in data-intensive environments. Furthermore, the absence of robust ethical governance frameworks and precise accountability mechanisms can erode stakeholder confidence. Equally important are the practical challenges associated with integrating AI solutions into existing operational workflows, where misalignment with organizational processes and human decision-making practices may limit their effectiveness. Addressing these technical, ethical, and organizational dimensions in a coordinated manner is essential for establishing trustworthy and sustainable AI systems.

Problem Statement

In the rapid growth of urban populations, metro systems are becoming the primary mode of public transportation. During peak hours and on national holidays, these stations often experience overcrowding. Traditionally, metro authorities have relied on manual observation, including CCTV surveillance and station personnel, to monitor crowd movement and respond to incidents. As highlighted by Chen (2020), traditional CCTV monitoring is inefficient, and Liu & Sun (2021) discuss how human operators struggle to efficiently process large visual data streams, resulting in delayed responses.

This research aims to enhance crowd management efficiency by automating the real-time analysis of CCTV footage through computer vision and deep learning algorithms. Although

Riyadh Metro is equipped with extensive CCTV infrastructure, its use is primarily limited to manual monitoring and post-incident analysis. This limits the ability to predict congestion and manage crowds proactively.

The deployment of AI-based CCTV analytics has the potential to address these limitations; however, its operational effectiveness, ethical implications, and integration challenges require systematic investigation.

Research Objectives

To analyze the role of AI-based CCTV analytics in metro crowd management

This objective aims to investigate how artificial intelligence enhances crowd monitoring and operational awareness within metro environments.

To evaluate the effectiveness of AI techniques in detecting and predicting crowd congestion

This includes assessing how AI models process CCTV data to identify crowd density, movement patterns, and potential safety risks in real time, and comparing their performance with traditional manual monitoring methods.

To identify the operational benefits and technical limitations of AI-enabled crowd monitoring systems

This objective focuses on evaluating system reliability, accuracy, scalability, and integration challenges within existing metro operational workflows.

To examine ethical, privacy, and governance considerations associated with AI-based surveillance in public transportation

Attention is given to issues of data protection, transparency, explainability, and accountability in the deployment of AI-supported monitoring systems.

To develop a practical framework for the responsible integration of AI-based crowd monitoring systems into metro operations

This objective aims to propose actionable guidance for transportation authorities and system developers to support the effective integration of AI solutions within the Metro Operations Control Center (OCC), ensuring operational usability, ethical compliance, and long-term sustainability.

Research Scope

This research focuses on AI-driven analysis of CCTV footage for crowd management within Riyadh Metro operations. The study emphasizes aggregated crowd behavior rather than individual identification and excludes facial recognition applications.

Literature Review

(Author, A. A., 2023). The system combines object detection, density-map estimation, and motion tracking to produce actionable dashboards for station controllers. Tests on simulated transit footage demonstrate reduced operator reaction time and improved decision accuracy. The authors emphasize the importance of integration with existing control systems for adoption. The study is directly relevant to Riyadh Metro because it translates visual analytics into operational cues, an approach consistent with safety-critical contexts.

Zhang et al. (2021) proposed a specialized convolutional neural network designed for crowd monitoring on metro platforms. The model, referred to as MP-CNN, was trained on annotated CCTV footage and demonstrated a significantly lower mean absolute error (MAE) compared to standard crowd-counting models. The architecture effectively addresses common challenges, such as occlusion between passengers and the perspective distortion introduced by fixed station cameras. Their findings emphasize the significance of camera positioning and dataset specificity, indicating that for systems like the Riyadh Metro, the model must be calibrated individually for each platform to maintain high accuracy.

Wong et al. (2023) integrate spatial metadata such as floor plans, corridor widths, and entrance coordinates with visual features. This multimodal fusion reduces false alarms and maps density estimates to actual station geometry, enabling targeted staff deployment. For Riyadh Metro, such mapping could support adaptive signage or escalator control. However, reliance on precise architectural data increases system setup complexity.

Khan et al. (2022) review deep-learning approaches, including density regression, detection-based counting, and hybrid models, and summarize benchmark datasets and metrics. The authors stress that domain adaptation and lightweight models are critical for real-time transit operations. Their synthesis provides methodological guidance for selecting evaluation criteria such as MAE, MSE, and F1-score.

- MAE: Mean Absolute Error

- MSE: Mean Squared Error

-F1-score: A metric used in classification, combining precision and recall into one balanced score

(Author, 2023). Findings indicate that hybrid optical-flow and appearance networks are most effective in capturing sudden changes in crowd behavior. The authors caution that excessive sensitivity increases the likelihood of false positives, a key operational concern. Their insights inform the anomaly alert module proposed for the Riyadh Metro.

Zhang et al. (2024) present a real-world study that combines CCTV analysis, automatic fare collection (AFC) data, and on-site observations. The model simulates spatiotemporal passenger flows and staffing interventions that reduce dwell time by 17%. Although not

specific to the Riyadh Metro, it illustrates how AI analytics translate into quantifiable key performance indicators (KPIs).

The literature on AI in transportation highlights the growing significance of computer vision in crowd analysis, safety monitoring, and operational optimization. Prior studies have demonstrated the effectiveness of AI-based crowd density estimation, while also emphasizing the importance of privacy-preserving design and transparent governance models.

Research Methodology

This research employs a mixed-methods approach to systematically examine the impact of artificial intelligence on crowd management, utilizing CCTV footage within Riyadh Metro operations. The methodology is designed to analyze both the technical performance and the operational implications of AI-based crowd monitoring systems, while also addressing issues related to trust, transparency, and decision support in metro environments. By combining qualitative insights from operational stakeholders with quantitative evaluations of AI system outputs, this approach enables a comprehensive understanding of how AI technologies influence the effectiveness of crowd management. The integration of both methods ensures a balanced assessment of practical implementation challenges, system reliability, and ethical considerations within real-world metro operations.

Phase 1: Literature Review

The first phase of this research involves conducting a comprehensive literature review to examine existing studies on the use of artificial intelligence in crowd management, particularly through the analysis of CCTV footage in metro and mass-transit environments. The review aims to synthesize findings from prior academic and professional work to understand how AI-driven video analytics contribute to monitoring passenger flow, enhancing operational efficiency, and improving safety in public transportation systems such as the Riyadh Metro. The literature review will cover peer-reviewed journal articles, conference proceedings, industry reports, and relevant regulatory, legal, and ethical guidelines governing the use of AI and surveillance technologies. This phase aims to establish a clear understanding of current practices, identify research gaps, and highlight the challenges and opportunities associated with AI-based crowd management systems, thereby informing the development of the proposed research framework.

Data Sources: Academic databases and digital libraries, including IEEE Xplore, ACM Digital Library, Scopus, and relevant transportation and smart-city publications.

Selection Criteria: Publications from the last ten years with a focus on AI-based video analytics, crowd behavior analysis, intelligent transportation systems, surveillance ethics, and public safety applications.

Analysis Technique: Thematic analysis will be applied to identify recurring concepts, technological approaches, operational challenges, and best practices related to AI-enabled crowd management in metro operations.

Phase 2: Qualitative Research

The second phase of this study employs a qualitative research approach using semi-structured interviews and selected case studies. The objective is to gain insight into stakeholder experiences and perceptions regarding the use of artificial intelligence for crowd management, as observed through CCTV footage in Riyadh Metro operations. This phase examines the perceived effectiveness of AI-based video analytics in supporting safety, operational decision-making, and ethical compliance, while identifying key implementation challenges and organizational readiness.

Participants: A purposive sample of metro operations managers, security personnel, AI system developers, data analysts, and relevant regulatory representatives involved in public transportation and surveillance systems.

Data Collection: Data will be gathered through semi-structured interviews conducted in person or remotely, in accordance with ethical research standards, including informed consent and confidentiality. Selected case studies from metro or comparable mass-transit systems will be reviewed to support the interview findings.

Analysis: Qualitative content analysis will be used to identify recurring themes related to AI effectiveness, operational impact, implementation challenges, and data privacy considerations in crowd management applications.

Phase 3: Quantitative Research

This phase complements the qualitative findings by applying quantitative methods to assess the impact of artificial intelligence on crowd management, utilizing CCTV footage from Riyadh Metro operations. It aims to measure the prevalence of identified challenges and evaluate the effectiveness of AI-based crowd monitoring and management solutions.

Survey Design: A structured questionnaire was developed based on the outcomes of the qualitative phase, targeting a wider group of professionals involved in metro operations, security, and AI-enabled surveillance systems.

Sample: A randomly selected sample of relevant stakeholders, including operational staff, technical professionals, and decision-makers within the public transportation sector, to ensure statistically meaningful results.

Data Analysis: Statistical techniques, including descriptive and inferential analysis, will be used to examine patterns in responses and to identify relationships between variables such as AI effectiveness, operational efficiency, safety outcomes, and user perceptions.

Phase 4: Framework Development and Validation

Building on the findings from the previous phases, this phase focuses on developing a practical framework for the effective use of artificial intelligence in crowd management using CCTV footage within Riyadh Metro operations. The framework aims to support operational efficiency, safety, and ethical compliance in AI-driven crowd monitoring systems.

Development: The framework will be developed by integrating key challenges, operational requirements, ethical considerations, and best practices identified across the literature review and empirical research phases.

Validation will be conducted through expert review, involving academic and industry practitioners in artificial intelligence, transportation systems, and public safety, followed by limited pilot testing within relevant metro or mass transit operational contexts.

Evaluation Criteria: The framework will be evaluated based on clarity, practicality, applicability to metro operations, and effectiveness in supporting AI-enabled crowd management.

Ethical Considerations

Throughout the research, ethical considerations are paramount. This includes obtaining informed consent from participants, ensuring confidentiality and anonymity, and minimizing any potential harm to participants.

Limitations

This research methodology acknowledges Potential limitations, including restricted access to operational data and variability in the quality of CCTV footage. Efforts will be made to mitigate these limitations through careful sampling and data triangulation.

Expected Outcomes

Comprehensive Analysis of AI-Based Crowd Management Challenges: A detailed analysis of the key challenges associated with the use of artificial intelligence for crowd management using CCTV footage in metro operations. This outcome is expected to highlight technical, operational, ethical, and governance-related issues, including data privacy, system accuracy, transparency of AI decision-making, and public acceptance within the context of Riyadh Metro.

Evaluation of Existing AI Crowd Management Solutions: An assessment of current AI-driven crowd monitoring and management solutions employed in metro and mass-transit systems. This evaluation is expected to identify strengths and limitations of existing approaches, particularly in terms of scalability, real-time effectiveness, adaptability to high-density environments, and compliance with ethical and regulatory requirements.

Development of a Practical Crowd Management Framework: The development of a comprehensive and context-specific framework for AI-enabled crowd management using CCTV footage in Riyadh Metro operations. The framework will integrate insights from the literature review and qualitative and quantitative research phases, providing practical guidance for metro operators, system designers, and decision-makers to enhance safety, efficiency, and ethical use of AI technologies.

Actionable Recommendations for Key Stakeholders: The formulation of clear and actionable recommendations tailored to stakeholders involved in metro operations, including transport authorities, security teams, AI developers, and policymakers. These recommendations aim to support effective implementation, governance, and continuous improvement of AI-based crowd management systems.

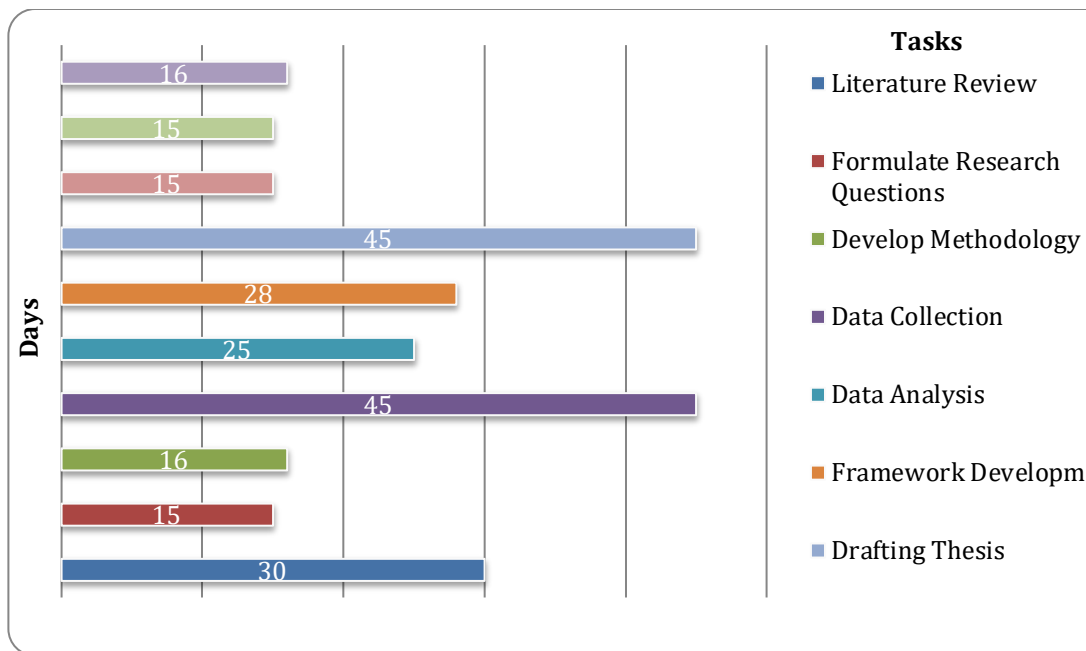
Contribution to Academic and Operational Practice: A meaningful contribution to both academic research and industry practice in the fields of intelligent transportation systems and AI-driven surveillance. The study is expected to bridge the gap between theoretical research and real-world application by offering empirically grounded insights relevant to metro and smart-city environments.

Foundation for Future Research: The establishment of a solid foundation for future research on AI applications in crowd management and public transportation. The findings are expected to identify new research directions related to advanced analytics, ethical AI deployment, and system optimization in large-scale transit operations.

Enhanced Awareness and Informed Decision-Making: An increased level of awareness among practitioners and decision-makers regarding the capabilities, limitations, and responsible use of AI in crowd management. This outcome supports more informed decision-making and encourages responsible adoption of AI technologies in public transportation systems.

Gantt Chart

Task	Start Date	Duration (Days)
Literature Review	1/9/2025	30
Formulate Research Questions	2/10/2025	15
Develop Methodology	2/26/2025	16
Data Collection	4/11/2025	45
Data Analysis	5/6/2025	25
Framework Development	6/4/2025	28
Drafting Thesis	7/19/2025	45
Revisions	9/4/2025	15
Final Submission	9/19/2025	15
Presentation Preparation	10/15/2025	16



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