Proactive Detection of Pedestrian Crossing Occlusions: Transforming Dashcams into Mobile Smart City Sensors

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Abstract. Ensuring visibility at pedestrian crossings is crucial for urban safety, yet traditional audits remain costly, infrequent, and localized. This paper proposes repurposing standard dashcams as nodes in a scalable Mobile Sensor Network for proactive infrastructure monitoring. The introduced concept employs YOLOv11-based tracking, semantic segmentation, and monocular depth estimation to quantify visual occlusions autonomously. To validate the feasibility of this approach for city-scale analytics, a pilot deployment was conducted on a custom dataset covering over 70 hours of driving. The system successfully executed over 7,700 automated audits, demonstrating the capability to generate comprehensive reports on pedestrian crossing safety without human intervention. These results confirm that fusing low-cost visual sensors with deep learning effectively democratizes access to safety data, offering a foundation for a continuously updated, self-monitoring, innovative city system.

Keywords: Mobile Sensor Networks · Pedestrian Safety · Smart City · Computer Vision · Dashcam footage · Deep Learning Fusion

1 Introduction

Pedestrians remain the most vulnerable road users. Road traffic death rate at pedestrian crossings across the European Union is highest in Poland and Lithuania [13]. In Poland, 2024 statistics [8] reveal that pedestrian-related accidents accounted for 21.9 % of all road incidents. Notably, more than half of them occurred at pedestrian crossings, resulting in 131 deaths and over 2,500 injuries.

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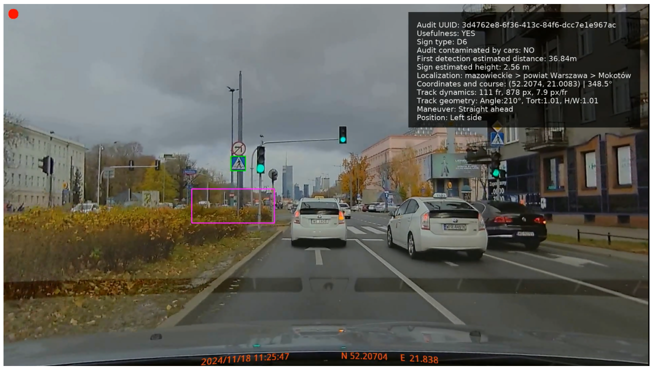

Audit UUID: 3d4762e8-6f36-413c-84f6-dcc7e1e967ac
Usefulness: YES
Sign type: D6
Audit contaminated by cars: NO
First detection estimated distance: 36.84m
Sign estimated height: 2.56 m
Localization: mazowieckie > powiat Warszawa > Mokotów
Coordinates and course: (52.2074, 21.0083) | 348.5°
Track dynamics: 111 fr, 878 px, 7.9 px/fr
Track geometry: Angle:210°, Tort:1.01, H/W:1.01
Maneuver: Straight ahead
Position: Left side

Fig. 1. Visualization of the automated safety audit. For every analyzed crossing, the system generates a short video clip available for human verification. This crossing was assessed as 26 % occluded (implying 74 % visibility).

Police reports typically attribute these tragedies to a driver's "failure to yield" or a pedestrian's "sudden entry", but we argue that the underlying systemic issue is a mutual lack of visibility. The studies examining acute visibility obstructions demonstrated that point occlusions increase accident risk: guardrails blocking pedestrian visibility endangered children [12]. At the same time, simulation analysis showed that occlusion from parked vehicles posed substantial detection hazards to vulnerable road users [14]. Other research found that, in scenarios where pedestrians are partially obstructed, their safety is at risk, with pedestrians being struck in every test scenario [10]. In [3], authors emphasize the need for careful roadside vegetation design, as improper placement can compromise driver awareness. Whether the vehicle is operated by a human driver or an Advanced Driver Assistance System (ADAS), reaction time is constrained by the line of sight, since solid occlusions blind both human vision and onboard sensors [1]. While real-time solutions like V2X communication [4] exist, they remain prohibitively expensive to deploy at scale. We propose a higher-level, preventive approach. Leveraging the ubiquity of dashcam footage, potentially crowdsourced from private vehicles (see Fig. 1) or public transport fleets, enables scalable data acquisition. Our system generates comprehensive reports on static occlusions, distinguishing between vegetation and infrastructure, enabling data-driven decisions on pedestrian crossing design.

2 Materials and Methods

The custom dataset (available upon reasonable request) collected within the Masovian Voivodeship (Poland), predominantly in Warsaw (see Fig. 2), was employed to evaluate the proposed system (see Fig. 3). More than 70 hours of driving footage were recorded over seven months (October 2024 – April 2025),

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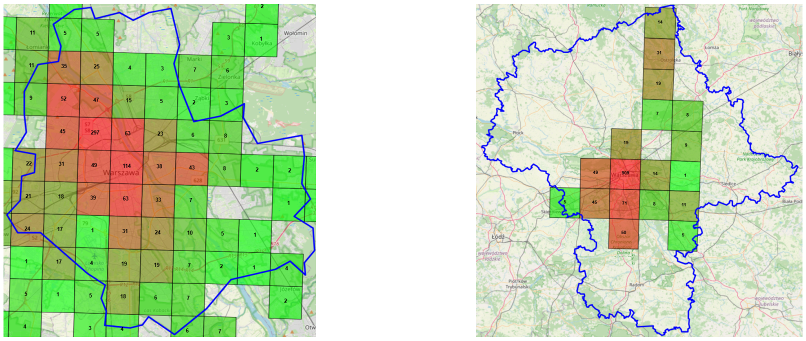
using a standard consumer-grade dashcam (MIO MiVue C595W) operating at 1080p resolution and 30 frames per second with HDR enabled.



(a) Warsaw and its closest surroundings ($3 \times 3\,\mathrm{km}$ grid)

(b) Masovian Voivodeship ($25 \times 25\,\mathrm{km}$ grid)

Fig. 2. Spatial distribution of the collected dataset. The heatmaps illustrate the density of recorded videos. Panel (a) shows Warsaw and its closest surroundings, while (b) shows the broader regional context within the Masovian Voivodeship borders.

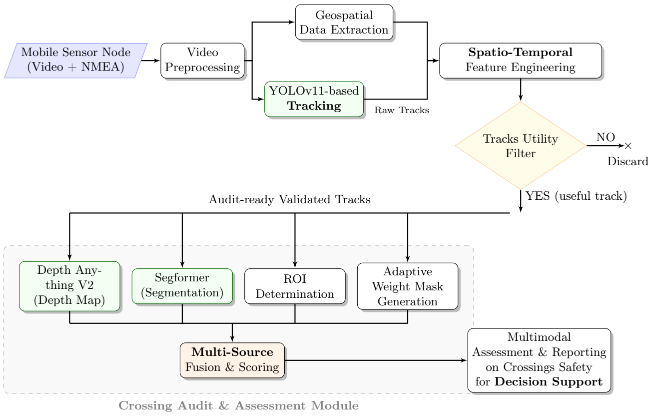


Fig. 3. Proposed solution architecture overview.

The camera's lens distortion is rectified using chessboard-calibrated intrinsics, whereas the Field of View data enables spatial reconstruction. Extrinsic parameters (mounting height, tilt) are fixed per vehicle. In our setup, tilt was experimentally tuned to align with the ground truth. Physical distance is estimated via a linear regression model that maps inverse bounding-box height to real-world distance, calibrated using reference Polish traffic signs: D-6 (indicating nearby pedestrian crossings) and D-6b (for combined pedestrian and cyclist crossings). Pedestrian crossings are identified using a YOLO model. The YOLO

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architectures are applied in various segmentation and detection tasks [9]. The employed SOTA YOLOv11 model [7] was trained on manually labeled ≈250,000 frames (mAP50=0.99) to detect D-6 and D-6b signs. Detections are then associated across frames into continuous tracks. To filter noise, based on the sign's position and car maneuver, we extract kinematic (screen-space distance and velocity) and geometric (tortuosity, bounding box aspect ratio, and exit angle) features from each track. Tracks that are too short or where the distance and height estimation fail are discarded. For validated tracks, we sample 30 frames for depth estimation and semantic segmentation. We also define a Region of Interest that approximates the critical pedestrian entry zone for each selected frame. Occlusion quantification follows a three-stage pipeline:

1. Depth Masking: Pixels located closer to the camera than the sign's plane (and those right behind it) are isolated as potential occlusions.
2. Dynamic Object Filtering: To distinguish between static illegal parking and moving traffic, we apply a conservative filter; audits are discarded if vehicle-related occlusion ($> 10\,\%$ of ROI) persists across $> 50\,\%$ of frames. This prioritizes data purity (minimizing false positives) over recall.
3. Semantic Scoring: Remaining static occlusions are mapped to specific classes (Vegetation or Infrastructure) and weighted by the adaptive mask (road-adjacent occlusions are considered as more dangerous).

The final Obstruction score (O_s) is the median of the frame scores, ensuring robustness against outliers. Finally, the system generates comprehensive decision support assets. A static safety report (see Fig. 4) that aggregates quantitative metrics and categorizes occlusion sources, enabling data-driven maintenance decisions, is generated for every audited crossing. To complement this, a verification video clip (see Fig. 1) is generated for each crossing, visualizing the detected sign and the computed Region of Interest.

3 Results

The system successfully conducted fully automated audits for 7,748 pedestrian crossings. For reporting purposes, we classify the safety level of each crossing using illustrative thresholds based on the computed obstruction score:

- Safe: $O_s < 10\,\%$ (minimal obstruction),
- Moderately safe: $10\,\% \leq O_s \leq 30\,\%$ (partial obstruction, see Fig. 1),
- Unsafe: $O_s > 30\,\%$ (critical occlusion).

The overall analysis reveals that 8.9 % of all audited crossings are critically unsafe. Notably, as illustrated in Fig. 5, a disparity exists between the capital and the surrounding areas. Warsaw demonstrates a higher safety profile (8.1 % unsafe, 67.9 % safe) compared to municipalities outside the capital, where the share of unsafe crossings rises to 11.9 %, with only 65.2 % classified as entirely safe. This suggests that vegetation maintenance and infrastructure planning in satellite towns may lag behind those of the metropolitan area.

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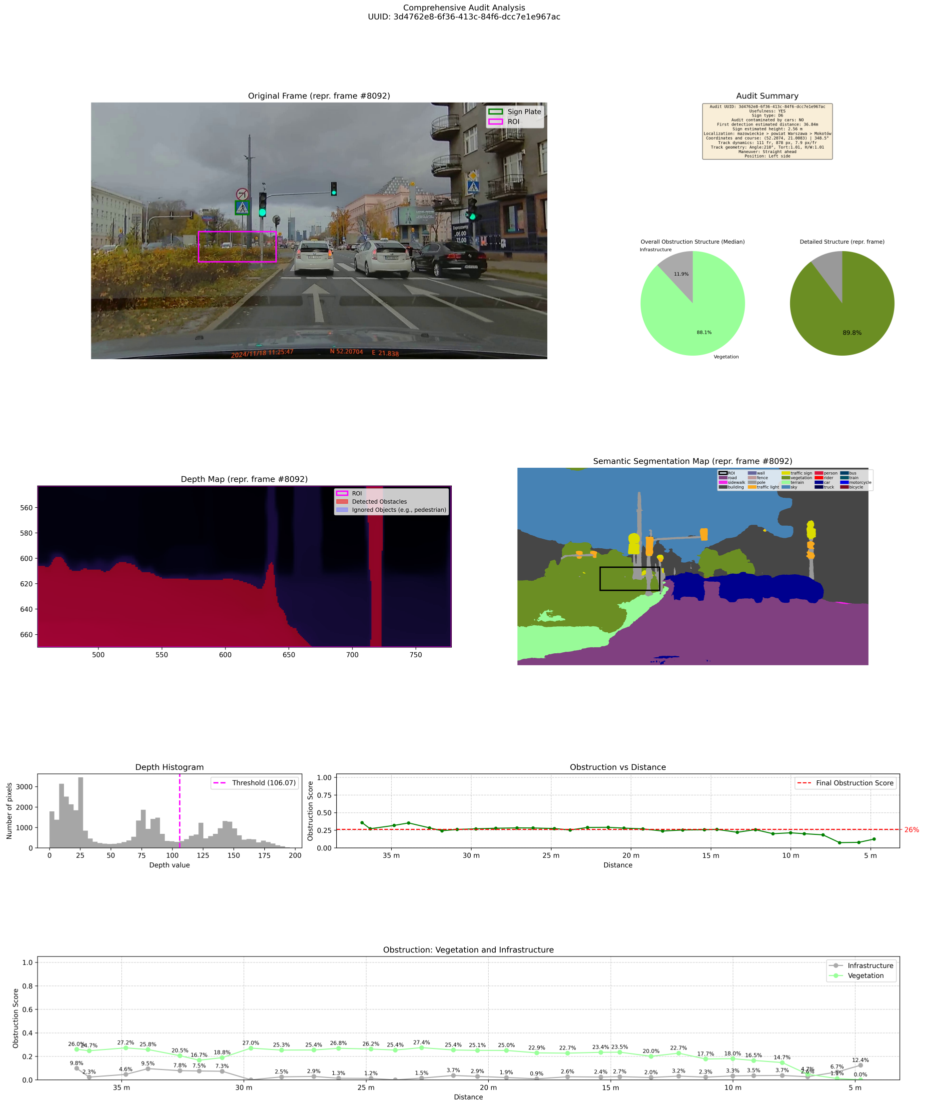

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Fig. 4. Sample Safety Report. Every report visualizes a representative frame with the analyzed Region of Interest and provides a quantitative breakdown of visibility-limiting factors, enabling data-driven maintenance decisions.

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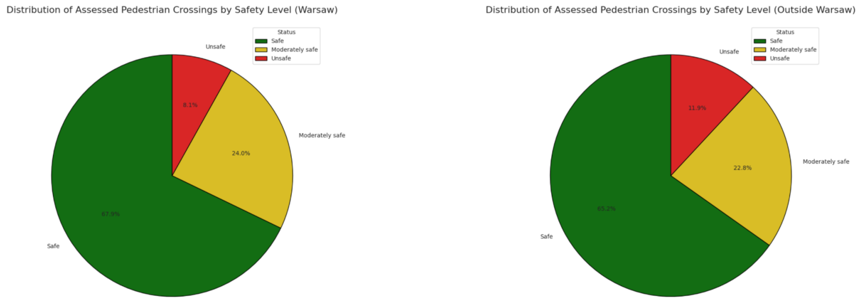
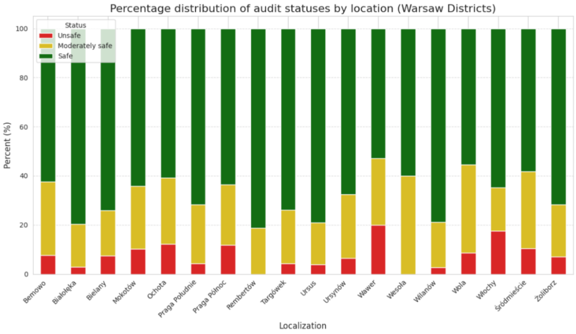
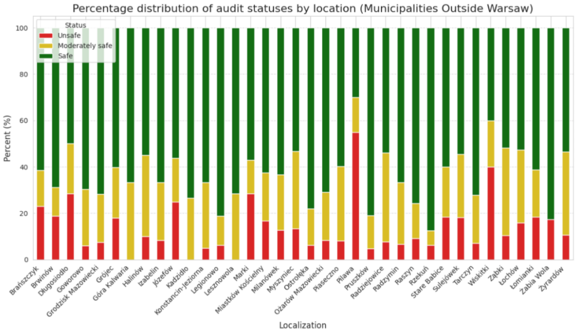


(a) Warsaw (Safety Levels) (b) Outside Warsaw (Safety Levels)



(c) Breakdown by Warsaw Districts



(d) Breakdown by Municipalities outside Warsaw

Fig. 5. Safety assessment results. Panels (a) and (b) compare the overall occlusion levels, highlighting a higher percentage of unsafe crossings outside the capital. Panels (c) and (d) provide a normalized assessment breakdown by administrative unit.

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4 Discussion

The implications of this research extend beyond technical feasibility, introducing a high-level, complementary layer to the existing safety ecosystem. First, we demonstrate that expensive, dedicated sensors are non-essential. Validating standard dashcams allows municipalities to repurpose existing fleets, such as public transport, cars of city officials, and other municipal vehicles, as mobile sensor networks, drastically reducing data acquisition costs. Second, this enables a transition from reactive accident analysis to proactive maintenance. Instead of waiting for tragedies, city managers can mitigate visibility hazards (e.g., overgrown vegetation) before collisions occur. The low-cost approach democratizes access to safety audits, empowering even budget-constrained municipalities to implement data-driven strategies.

The presented system serves as a functional Proof of Concept, validating the automated auditing of pedestrian crossings using standard consumer-grade dashcams. This approach offers a scalable, low-cost alternative to expensive dedicated infrastructure or manual inspections.

Future work focuses on two key directions. Regarding scalability, we aim to develop a web-based Decision Support System to visualize audits on dynamic maps for city officials. Concurrently, we aim to develop robust algorithms that minimize reliance on camera parameters, ensuring a user-friendly configuration process. This flexibility is essential for scaling across diverse public fleets, providing a foundation for other tasks, such as road marking degradation analysis [11]. Regarding methodology, we plan to replace geometric heuristics with explainable ROI definitions based on pedestrian behavioral studies [2,6] and kinematic metrics like Time-to-Collision (TTC) [5]. Finally, we commit to continuously updating the vision backbone using SOTA foundation models (e.g., upcoming iterations of DepthAnything).

5 Conclusions

In this paper, we presented a system for assessing pedestrian crossing safety, shifting the paradigm from reactive accident analysis to proactive safety monitoring. By leveraging deep learning techniques, specifically semantic segmentation and monocular depth estimation on standard dashcam footage, we demonstrated that effective infrastructure audits do not require expensive, dedicated hardware. Crucially, this study validates the concept of transforming public and private vehicles into a scalable mobile sensor network. This approach aligns with the core objectives of modern Smart Cities: leveraging distributed sensing for informed, data-driven decision-making. In the future, the proposed model can serve as a foundational layer for a broader ecosystem of urban analytics, enabling a single visual data stream to simultaneously support pedestrian safety, infrastructure maintenance, and other tasks, advancing the vision of intelligent, self-monitoring urban environments.

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