



Development of a Vision-Based Landside Traffic Management System for Congestion and Safety Monitoring at Airports

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Overview

Airports serve as crucial nodes in the global transportation network, and the efficient movement of passengers and vehicles within the airport, particularly on the landside, impacts airport operations and safety. In the absence of an effective landside traffic monitoring system, congested zones can quickly spiral, resulting in bottlenecks and potentially increased crash risk.

The Port Authority of New York and New Jersey (PANYNJ) currently utilizes a combination of traditional traffic data collection methods and manual observations from their cameras to monitor landside traffic at the John F. Kennedy (JFK) International Airport. Effective monitoring is especially significant given JFK's ongoing \$19 billion expansion and its daily service to nearly 62 million passengers.

The project aimed to develop a novel vision-based analytics tool in collaboration with PANYNJ that leveraged JFK's existing cameras and provided real-time traffic data extraction, assisting the Transportation Management Center (PA-TMC) and Airport Operation Center (PA-AOC) in their decision-making processes. By using JFK as a demonstration, this pilot sought to enhance the efficiency of airport traffic monitoring, ultimately benefiting the New York regional economy and improving passenger satisfaction. The project team coordinated with PANYNJ Traffic Engineering, as well as staff representing the PA-TMC, PA-AOC, ITS department, and Landside Operations throughout the project for feedback and direction.

Methodology and Findings

Using footage from JFK traffic cameras, the project explored two artificial intelligence (AI) use cases 1) Advanced Queue Detection and 2) Curbside Traffic Monitoring.

Advanced Queue Detection

The goal of this use case was to automate speed and queue detection across the JFK airport roadway system. Key challenges included:

- Wide and changing camera angles
- Obstructions reducing detection reliability
- Perspective-induced errors in speed estimation due to 3D-to-2D projection

To address these challenges, the team employed a perspective transform, a mathematical technique in computer vision and image processing that compensates for changing camera angles by re-mapping images to a consistent viewpoint. This approach allows corresponding points to be identified and matched across multiple views even when a camera is tilted, thus improving spatial consistency and measurement accuracy. Next, the team applied a 2D-to-Satellite transformation to align the camera views with satellite images to ensure uniform speed estimation, addressing possible camera view obstructions (Figure 1).

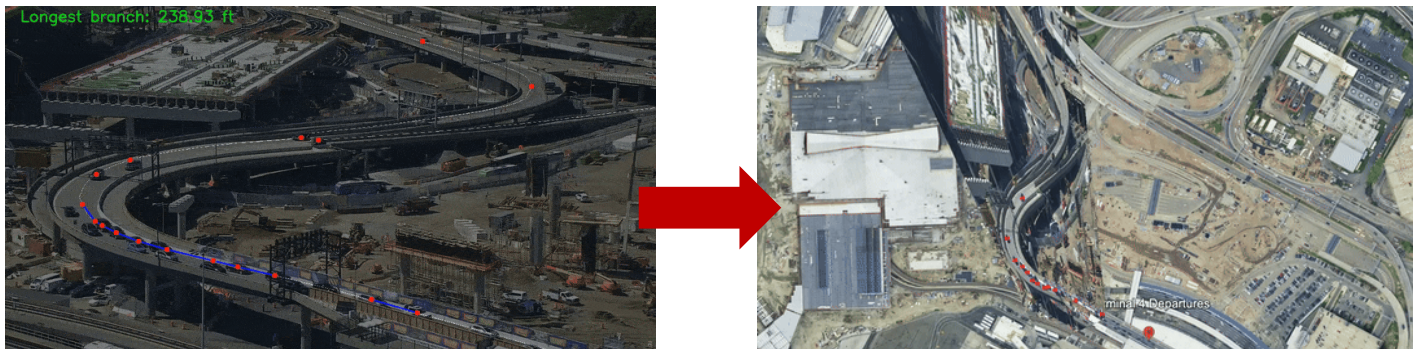


Figure 1: 2D-to-Satellite Transformation for Speed and Queue Length Computation.

These steps allowed for queue length computation by roadway zone and the dynamic assignment of colors using on real-time vehicle density (see Figure 2). The system is specifically customized to detect **moving queue dynamics**, capturing slow-rolling congestion that traditional queue detection methods may not fully capture. The team also proposed and evaluated example performance metrics including vehicle counts by class per zone, queue length, and trajectory heatmaps.

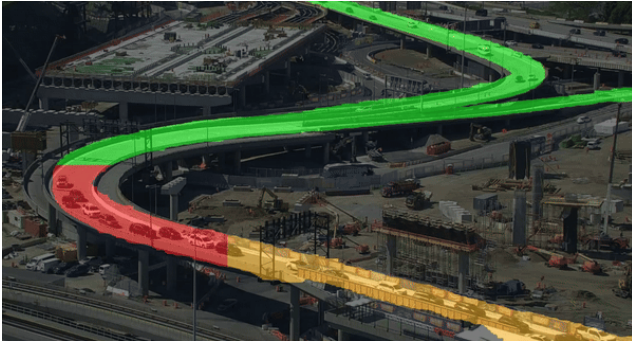


Figure 2. Zone-Based Color Mapping for Queue Detection.

Curbside Traffic Monitoring

The goal of this use case was to automate detection of curbside activities and generate useful traffic monitoring mobility measures, such as lane utilization and dwelling vehicles. The team had to consider seasonal and operational variations that could lead to different traffic patterns, as well as stop-and-go movements and heavy passenger activity in terminal frontage curb lanes.

Figure 3 illustrates the automated detection workflow, which processed the PA-AOC videos for object detection and tracking using bounding boxes, lane masks, points matrix-based lane checking. The team customized the detection model to account for airport-specific operational conditions, including high-frequency stop-and-go vehicle behavior, nonstandard lane formations, and curbside passenger loading and unloading occurring within active travel lanes. Targeted retraining, specifically for the airport’s shuttle buses, significantly improved shuttle bus detection accuracy from 57% to 96%, compared with approximately 90% accuracy for passenger cars in the original model.

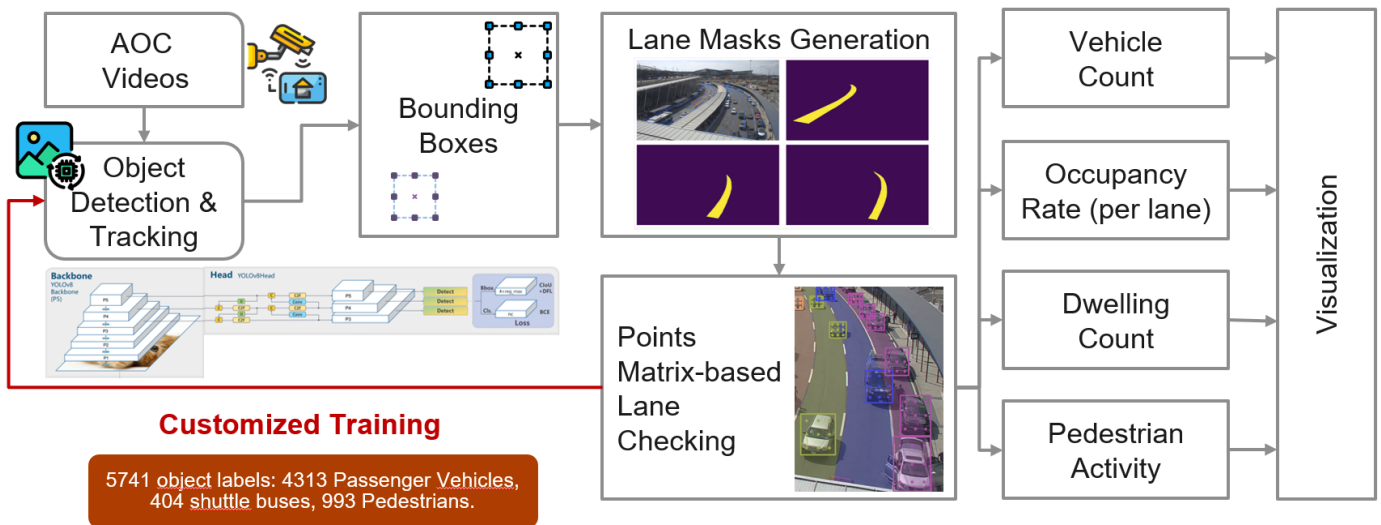


Figure 3: Automated Detection Methodology.

As seen in Figure 4, green dots represent detected vehicles. Vehicles can be flagged in orange if they dwell for more than 90 seconds, or in red if they dwell for more than 180 seconds.

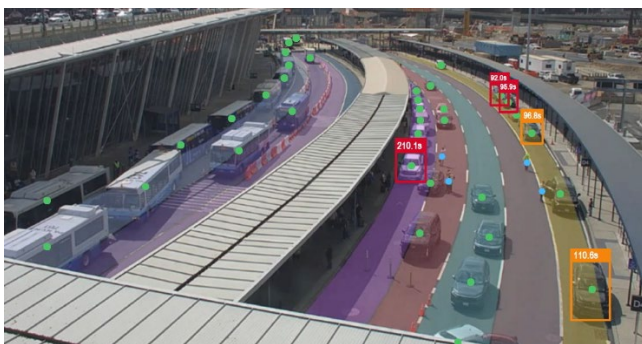


Figure 4: Automated Curbside Activity Detection Output at the Arrivals Terminal.

Dwell time analysis was performed by tracking individual vehicles across curbside and active travel lanes within the airport arrivals landside area, measuring the duration each vehicle remained stationary or moving below a defined speed threshold. Key metrics including average and maximum dwell duration as well as average and peak vehicle counts by lane.

In addition to dwell time, other output performance metrics analyzed were vehicle counts by class, pedestrian activity in moving lanes, vehicle occupancy rate per lane, and frontage hotspots (Figure 5 & 6).

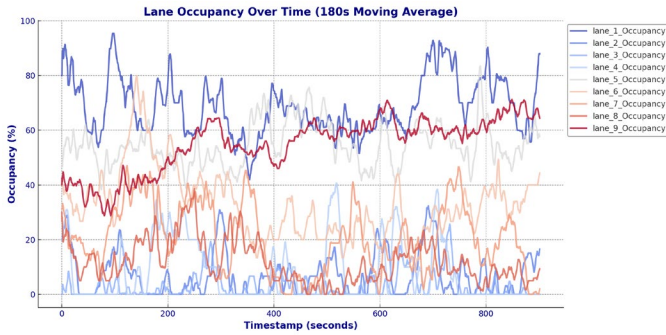


Figure 5: Lane Occupancy Over Time.

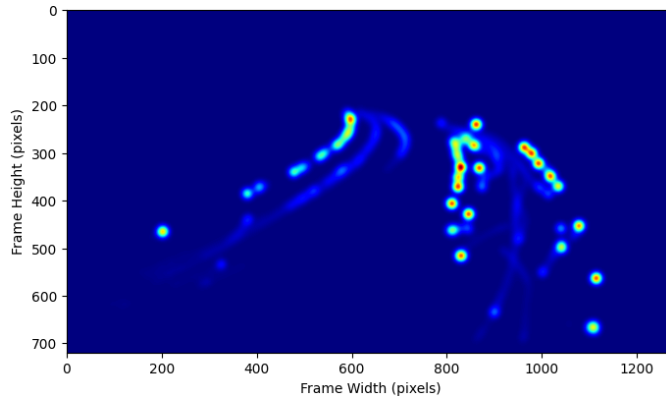


Figure 6: Automated Detection Heatmap for JFK Terminal 4.

To demonstrate the effectiveness of the AI tools, the team also conducted a case study on JFK Terminal 4's remote for-hire vehicle operation, which uses shuttle buses to transport passengers from the terminal to a parking lot for taxi and ride-share pickup. The analysis compared curbside traffic conditions before and after implementation, based on a pair of selected days with similar weather conditions, and revealed a 15% reduction in traffic density along with shorter dwell times across 78% of the lanes post-deployment.

Lessons Learned

- **Camera perspective correction is critical for accurate traffic measurements.** Applying perspective transformations is necessary to ensure spatial consistency and reliable speed and queue estimates across cameras with varying angles and orientations.
- **Airport landside traffic exhibits unique operational behaviors not captured by standard vision models.** Frequent stop-and-go movements, informal lane formations, and curbside loading activities required targeted model retraining and customized detection logic tuning beyond typical roadway applications.
- **Occlusions and operational variability affect detection reliability and must be anticipated.** Obstructions, seasonal changes, and shifting traffic management strategies necessitate careful selection of analysis periods and ongoing validation of model outputs.
- **Dwell time is a robust and operationally meaningful metric for evaluating curbside operations.** Tracking vehicle dwell across curbside and active travel lanes

provided meaningful insights for before-and-after assessments of operational interventions.

- **Close collaboration with PANYNJ improves model relevance and usability.** Continuous feedback from PANYNJ Traffic Engineering, PA-TMC, and PA-AOC staff helped align analytical outputs with real operational needs, ensuring that metrics such as lane-level dwell time, queue zones, and vehicle class counts were interpretable and actionable.

Conclusions and Future Work

Overall, the project successfully developed a proof of concept for an advanced video analytics tool supporting airport landside traffic operations. The team built an automated pipeline to generate new mobility measures from PA-AOC camera feeds and produced a method that could reduce manual effort in before-and-after evaluations of operational strategies such as dedicated shuttle bus lanes. Developed specifically to address the unique challenges of airport operations, this system accounts for factors such as slow lanes caused by pick-up and drop-offs, changed traffic patterns due to airport frontage modifications, and complex curb activities that differ from typical urban street congestion patterns. The team also documented lessons learned in applying vision-based methods.

By improving landside traffic flow at major airports like JFK, these tools not only help reduce congestion but also contribute to a smoother, less stressful travel experience for the millions of passengers served each year.

Opportunities for future work are numerous, both at JFK and other airports facing similar congestion challenges:

- Expanding the video analytics tool to automatically generate safety measures, such as near-misses or identify driver confusion points due to frontage modifications.
- Extending the tool for airport work zone monitoring to enhance worker safety (e.g., detecting jaywalking).
- Monitoring dense crowds.
- Developing customized features, such as identifying passengers with luggage in active travel lanes.
- Scaling up to multiple cameras.
- Using multimodal Large Language Models (LLMs) to generate operations reports.