Integrating Passenger and Freight Transport: The DELPHI Approach to Modern Mobility Challenges

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Abstract

Traffic congestion has become a pervasive issue with the acceleration of urbanization, resulting to increased travel time, fuel consumption, environmental pollution and travel costs. Accurate and timely traffic congestion detection in case of critical events (such as structural defects on road, bridges, tunnels, and/or traffic accidents) is crucial for effective congestion management and intelligent freight and passenger transportation in multimodal environments. In order to address this issue, this paper presents an overview of modern traffic detection techniques, sensor-based systems (such as vehicle detection (VDS) loops, cameras, GPS, and sensors for structural defects), and machine learning models that analyze real-time traffic data. We explore how these technologies contribute to predicting congestion patterns, predicting traffic flow, and optimizing route planning. The algorithm simulates traffic flow on the Attica motorway in Athens, Greece with emphasis placed on the use of the exponentially weighted moving average (EWMA) to predict traffic congestion problems. The results indicate that intelligent traffic detection systems and advanced algorithms significantly enhance congestion mitigation efforts. Future work focuses on improving real time data fusion originating from critical events of structural defects for improving optimization traffic algorithms.

Keywords: *Multimodal Logistics, Predictive Analytics, Machine Learning, Traffic Optimization.*

1. *Introduction*

In recent years, the transportation sector has faced numerous challenges, including urbanization, the increasing complexity of stakeholder interactions, the rise of e-commerce, and the growing fragmentation of freight transport. These issues have highlighted the inadequacies of current governance and regulatory frameworks, which often treat passenger and freight transport as separate, disconnected sectors.

The DELPHI EU Research Programme aims to address these challenges by focusing on the strategic integration of passenger and freight transport into a unified system. The programme seeks to develop both technical and governance enablers to support a federated network of platforms for multimodal transport. This network will facilitate the seamless and secure sharing of cross-sectoral, multimodal transport data and traffic management information.

To achieve these goals, DELPHI will leverage cutting-edge methodologies for traffic monitoring, including Unmanned Aerial Systems (UAS)-powered monitoring, multi- and inter-modal optimization, sensors for detecting and recognizing structural defects, and AI/ML-powered algorithms and frameworks. The programme will also explore diverse modes of hybrid passenger and freight transport across different ecosystem types.

Attikes Diadromes SA (ATD) will help reduce motorway traffic congestion, noise, and CO2 emissions by re-routing logistics vehicles to multimodal transport options. ATD will also improve system maintenance, including pavement upkeep, by efficiently detecting and re-routing logistics chains to urban transport modes like the metro or buses, ensuring prompt deliveries. WINGS has developed various solutions in the transportation and logistics sector that aim to enhance and alleviate issues in traffic congestion and optimization. Through the developments and implementation of specific functions based on machine learning these solutions aim to offer a cost efficient and advanced system in predicting traffic congestion and structural defects on the Attica motorway. This paper will present traffic detection and structural defects techniques based on sensor systems and machine learning models that analyze real-time traffic data and recommend possible reroute schemes for the drivers for time delay elimination and transport cost improvement.

The Athens pilot will enable logistics vehicles to use the most efficient multimodal routes, considering safety and environmental criteria.

The effectiveness of DELPHI's digital framework and transversal tools will be validated through four pilot projects, each with unique requirements and features, which will demonstrate the potential for maximum interoperability and optimization.

By addressing both technical and regulatory challenges, DELPHI aims to create a cohesive transport network that enhances mobility, reduces fragmentation, and improves overall efficiency in passenger and freight transport.

It has been observed in the Attica motorway (AM), that when there is a critical event such as an accident, fire, road or bridge or tunnel structural defect there is a queue of vehicles moving with almost 0 speed for the ones that are close to the event and others which are at a larger distance are moving with very low speeds. It has been observed that for a vehicle it would be much quicker to exit the AM and go to its destination through another route or detour and re-enter the AM from another exit. It is important with AI techniques to be able to predict the extra time required if someone remains on the motorway where the critical event happened and the extra delay it takes if someone remains driving in it.

Forecast congestion situations based on real and simulate backward propagation of congestion based on parameters that can be estimated on real and suggests to the driver the time saved by selecting the best exit (near the congestion, knowing it spreads backwards) finding the best exit so that the speed does not fall below a specific threshold.

2. *Research Overview*

2.1 Research background

Prediction of traffic congestion and routing algorithms to find the shortest route and optimize the means of transporting cargo to its final destination have been widely used in research. Simulation tools like SUMO, MATSim, and VISSIM are extensively used for modeling and simulating traffic systems and testing different optimization schemes [1-3]. Advanced optimization models, including mixed-integer programming and heuristics, are used to minimize delivery time and costs under various constraints (e.g., traffic conditions, delivery windows). In addition, rerouting algorithms and modeling have been developed to reduce emissions and fuel consumption. Computer simulations optimize the planning methods, predict structural flows and improve the efficiency of transportation systems.

2.2 Research work

Our work is based on proactively detecting traffic increase using time series (based on sensor real time and synthetic data) and reactively respond when critical events occur on the road.
An optimizer based on EWMA is developed to find the best ramp exits on the Attica motorway so that each vehicle avoids the congestion and results to help the congestion diminish sooner.
Our research provides results of the best exits based on the backward propagation of the congestion regarding the vehicles' positions (the speed of that propagation showing how fast the congestion spreads can be fine-tuned using data from AM.
The algorithmic flowchart is presented in Figure 2-1:

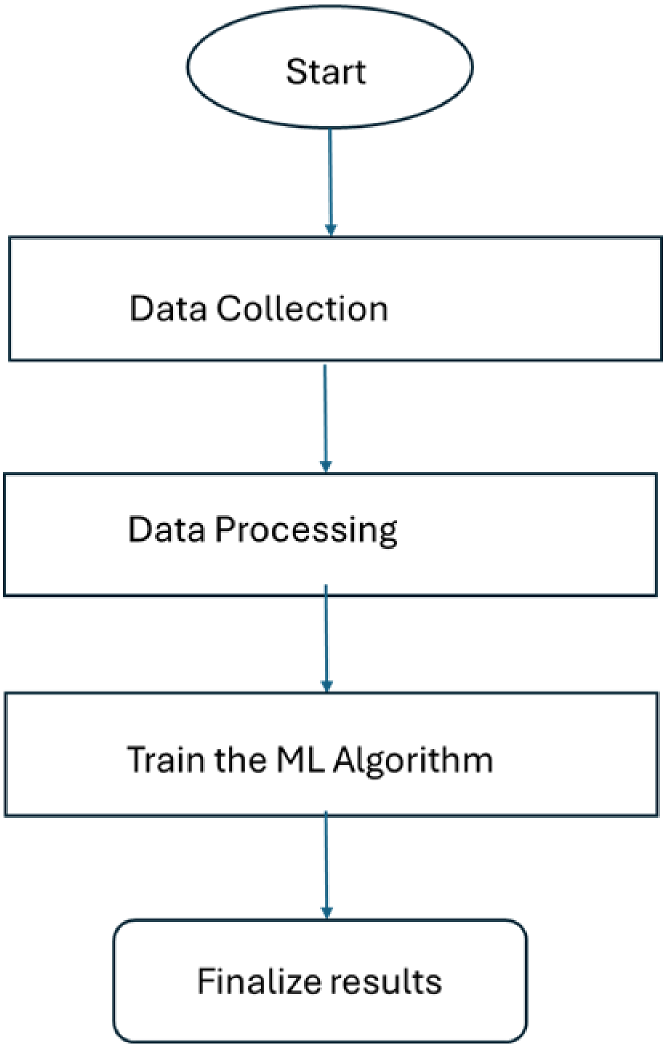

Figure 2-1: Flowchart steps of the EWMA algorithm

2.3 Data fusion and architecture

2.3.1 Data fusion

Data were collected and are presented to the following three Figure **2-2** -Figure **2-3**Figure **2-4**. It can be seen that the traffic congestion is higher at the place close where the critical event took place (Figure **2-2**). The congestion diminishes as we move further from the place of the critical event (Figure **2-3** - Figure **2-4**). In the following Figure 2-5, it can be seen that there is a congestion of traffic at 12:15 when an accident occurred compared to normal traffic seen in Figure 2-6. Therefore the prediction of the traffic at events close to the critical events is very important to be implemented so as to propose to the drivers to take the closest ramp exit and either re-enter the Attica road at another exit where the traffic becomes normal or find another modality to transport the freight to its destination.

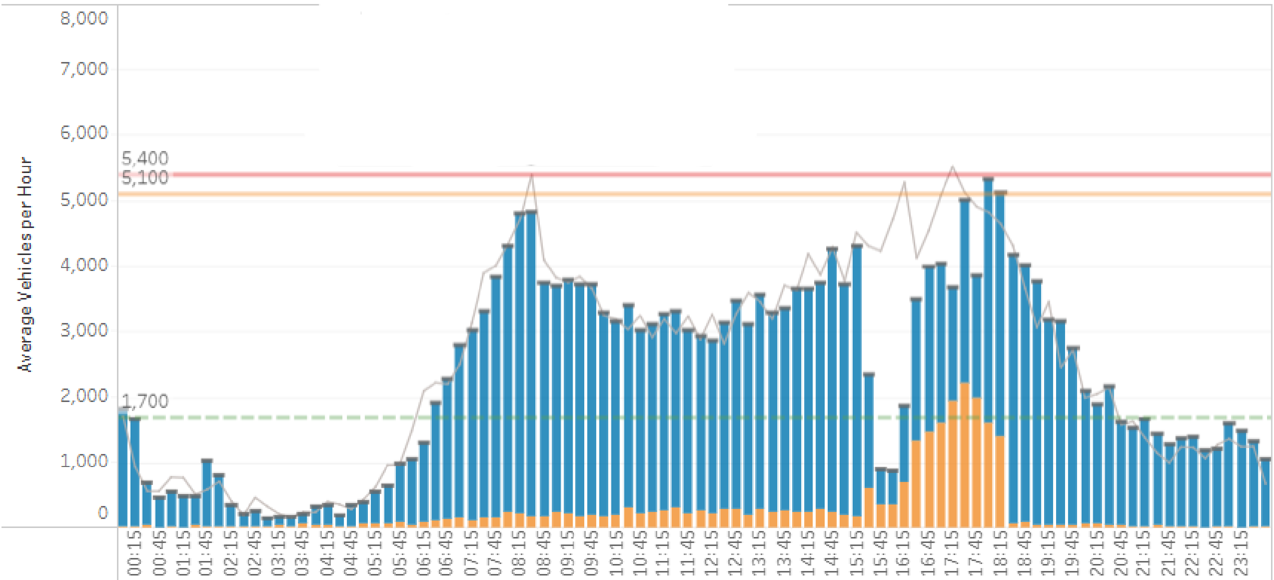

Figure 2-2: Overview of traffic very close to the critical event

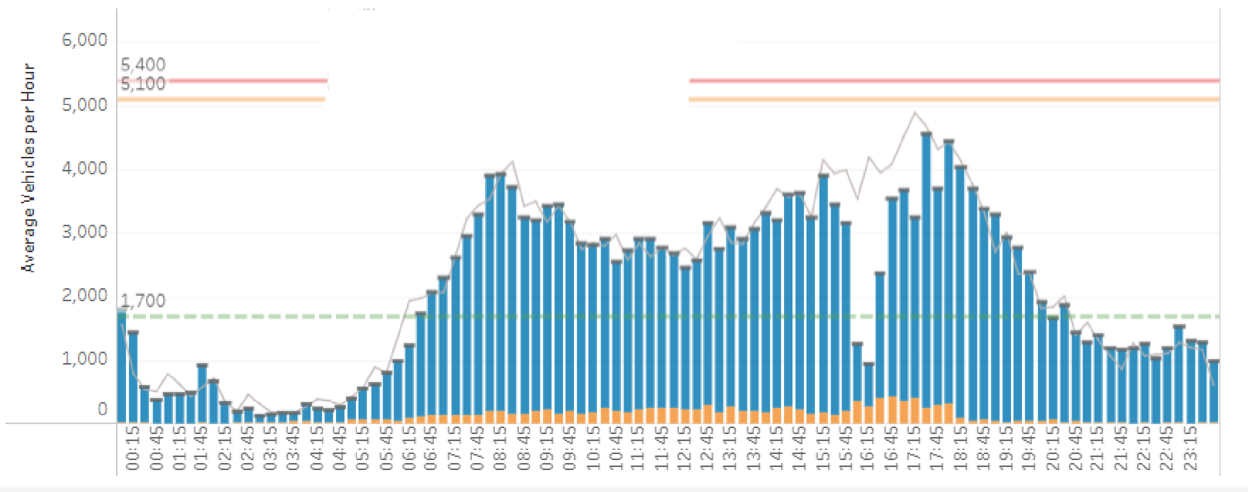

Figure 2-3: Traffic a bit further from the critical event

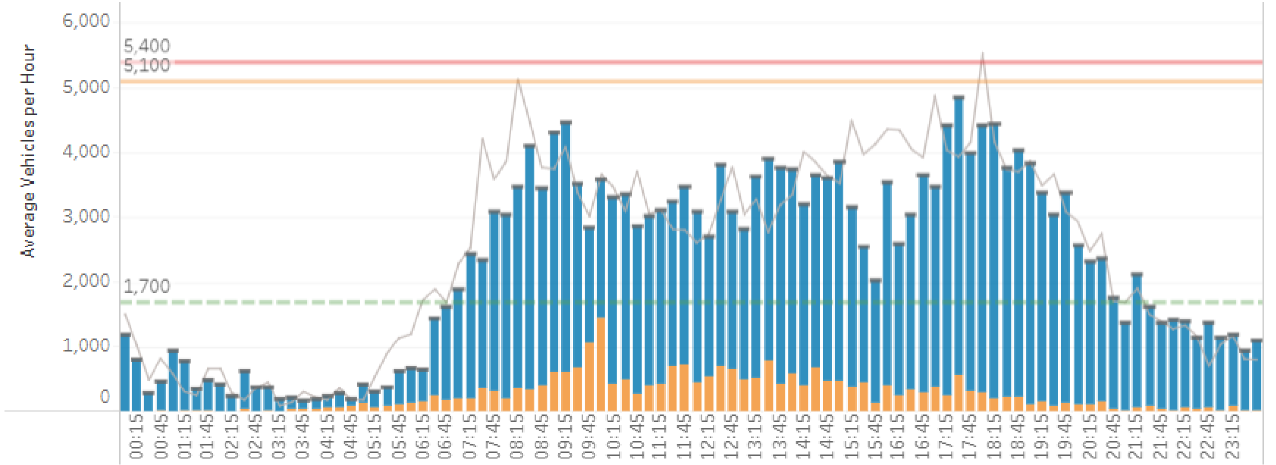

Figure 2-4: Traffic quite further from the critical event

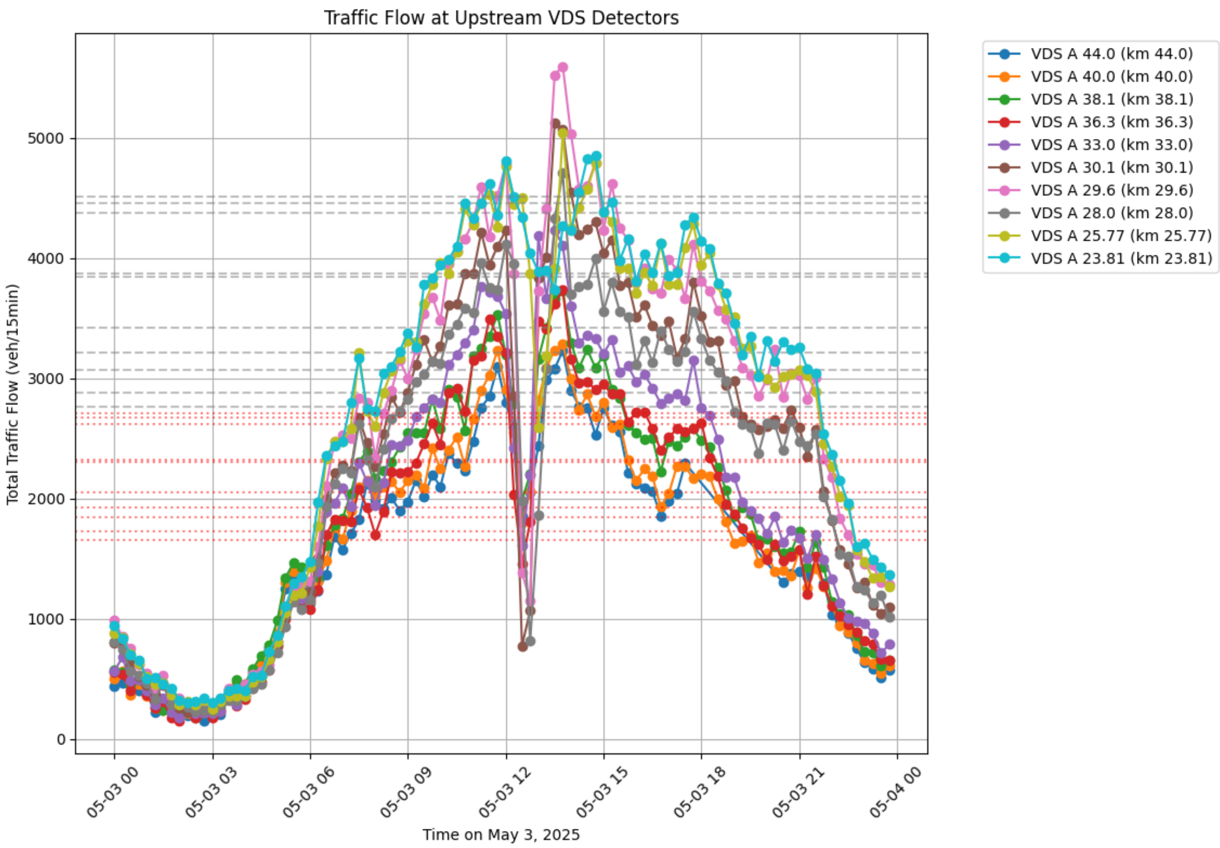

Figure 2-5: A traffic view where an accident took place at 12:15 pm

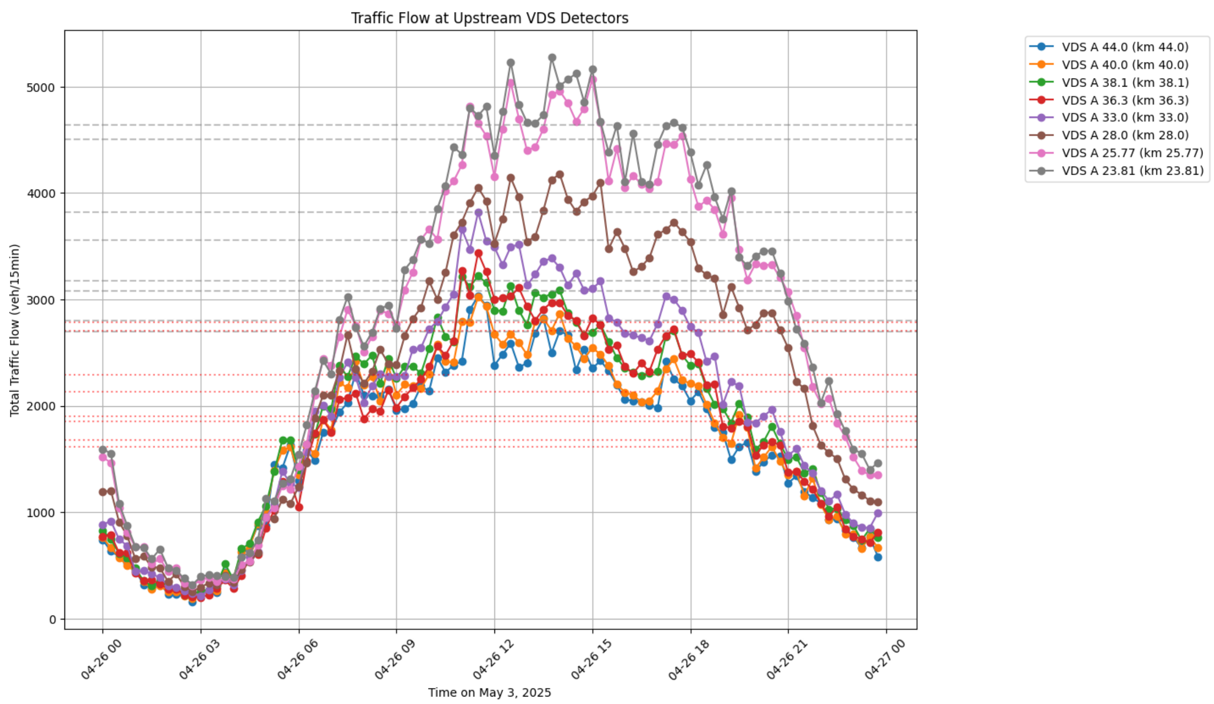

Figure 2-6: A traffic view with normal traffic

2.3.2 Architecture

The proposed architecture is presented in the following Figure 2-7. From this figure it can be seen that data are collected from various sensors and devices which are fed to train an ML algorithm. The data are then processed to predict congestion of traffic at various positions on the motorway.

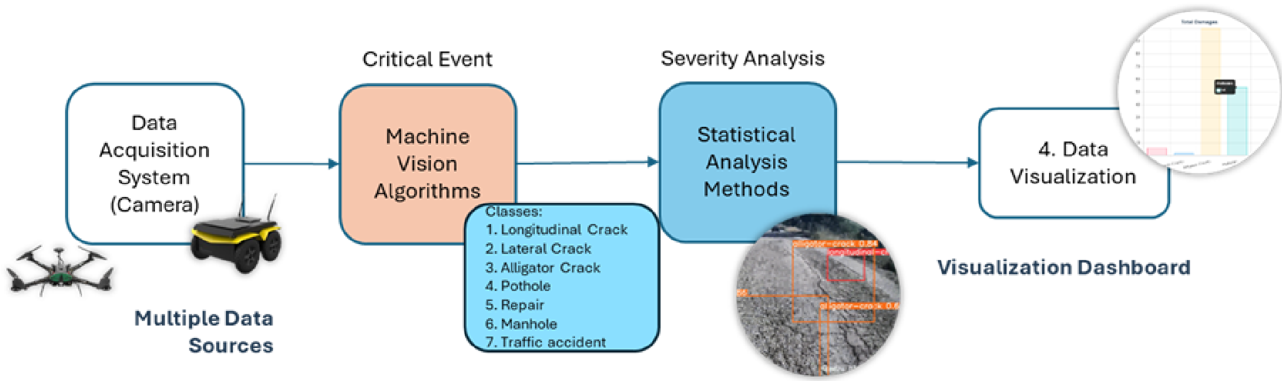

Figure 2-7: Architecture of our solution

2.4 Real time data train models using ML techniques

This section details the simulation outcomes based on the mathematical framework and parameterization by following an exponentially weighted moving average (EWMA) on the measurements to predict the place where the congestion will start on the motorway (or where they will need to go to fix the road) and calculate with a shockwave model when the wave of traffic reaches each exit. Then, for each exit, we compare the time that someone would spend in the congestion on the motorway with the detour time and find which exit gives the greatest benefit in minutes. Thus, we suggest to the driver to take the exit with the maximum benefit, without needing to know the entire rest of the route that he wants to follow. We analyze the system's behavior under a specific incident scenario, focusing on the dynamic selection of optimal diversion ramps and the resultant travel time savings.

The core of the simulation relies on a kinematic wave model for congestion. An incident at motorway location x_{inc} (31 km) at time $T_{0,inc}$ (0 min) generates a backward-propagating shockwave. The speed $v(x,t)$ at any point x and time t along a motorway segment is determined by its position relative to the shockwave front

$$x_{front}(t) = x_{inc} - W_{shock}(t - T_{0,inc})$$

A logistic function provides a smooth transition between free-flow speed (assuming $V_{free} = 100\frac{km}{h}$) and jam speed (assuming $V_{jam} = 10\frac{km}{h}$) across a zone of width $\sigma_{transition,km}$ (2.0 km) centered at $x_{front}(t)$.
The remaining motorway travel time if exiting at ramp r at km-marker r_{km} given a warning at time t_{dep} when the truck is at x_{dep}, is denoted $T_{AO}(r_{km}, x_{dep}, t_{dep})$. It is calculated by summing the travel times over subsequent motorway segments:

$$TT_{AO}(r_{km}, x_{dep}, t_{Dep}) = \sum_{i \in edges\ after\ r_{km}} \frac{L_i}{v(x_i, t'_{arr,i})}$$

where L_i is the length of segment i, and $v(x_i, t'_{arr,i})$ is the speed on segment i at the truck's projected free-flow arrival time $t'_{arr,i}$ at that segment's center x_i, starting from (x_{dep}, t_{dep}).
A ramp r is considered eligible if its forecast speed $v_{fore}(r_{km}, t_{dep})$ (i.e., the speed at r_{km} at time t_{dep} is above a tolerance V_{tol} (60 km/h). The optimal ramp r^* (t_{dep}) is the eligible ramp that minimizes TT_{AO}.

$$r^*(t) = arg\min_r TT_{AO}(r, t)$$

The time saved is:

$$\Delta(t_{dep}) = TT_{AO,baseline}(x_{dep}, t_{dep}) - TT_{AO}(r^*(t_{dep}), t_{dep})$$

While the driver's total trip time to a final destination may depend on post-exit routing, our focus here is exclusively on minimizing time remaining on the motorway segment by ensuring the driver's speed never falls below the set speed threshold before diverting. These results are shown in the following

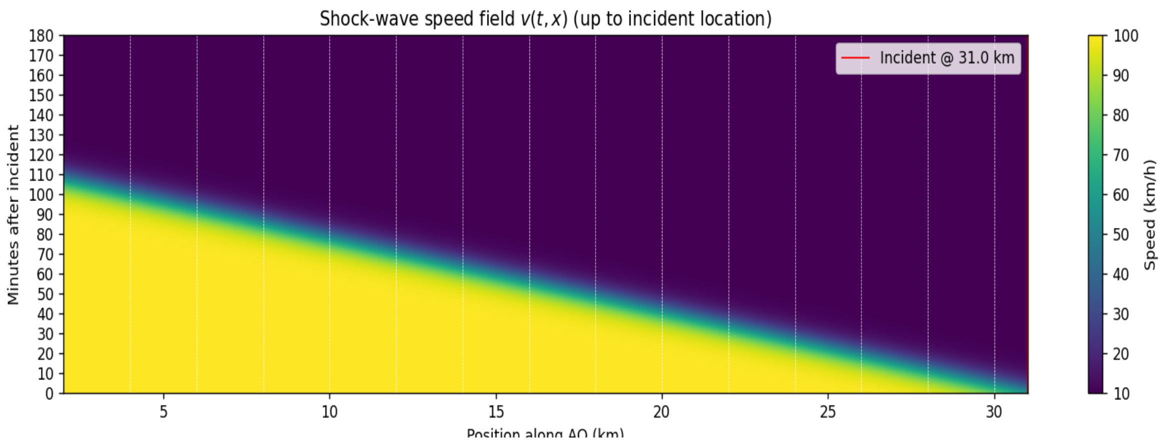

Figure 2-8: Shockwave data

A typical example from the above figure can be presented as
For departure at t=2 min from x=0.0 km :

- optimal exit r* = 30 km
- remaining (Attica Road) AO time if stay = 50.4 min
- remaining AO time via r* = 12.0 min
- delay avoided (saved) Δ(t) = 38.4 min

3. Conclusions

In this paper, we introduced the deployment of advanced cameras and sensors along the ATD Highway which shows that significantly enhancement to monitor and analyze the road network in real time. These devices capture critical data points, including traffic density, vehicle speeds, weather conditions, and the structural health of the road infrastructure. By processing this dynamic data, the Delphi-novelty optimization solution identifies and mitigates potential risks such as bottlenecks, accidents, or infrastructure failures (e.g., potholes, cracks, closed lanes). This enables timely and informed decision-making, guiding drivers toward safer and more efficient routes while ensuring a comprehensive understanding of the network's current conditions.

This holistic, data-driven approach transforms traffic management and route planning by creating real-time feedback loops that enhance efficiency and safety. The integration of actionable insights minimizes idle times and reduces emissions, contributing to an environmentally friendly and sustainable traffic ecosystem. By addressing both current conditions and root causes, this framework optimizes traffic flow while ensuring the long-term health and reliability of the road network.

The approach that we used in the paper has been applied for the Athens Attica Odos roadway. It can be very well applied to a larger scaled environment as it relies on the collection of data from camera sensors in which case we can use a higher number of them and analysis of these data using ML algorithms. Additionally, a cost-benefit analysis of the technique used in this paper can be applied in future research to enhance the obtained results and applicability of the used ML algorithm.

4. Acknowledgements

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