Revolutionizing Road Transportation with Artificial Intelligence Empowered Technologies

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Vice Chair of the ASCE Committee on Technical Advancement

for

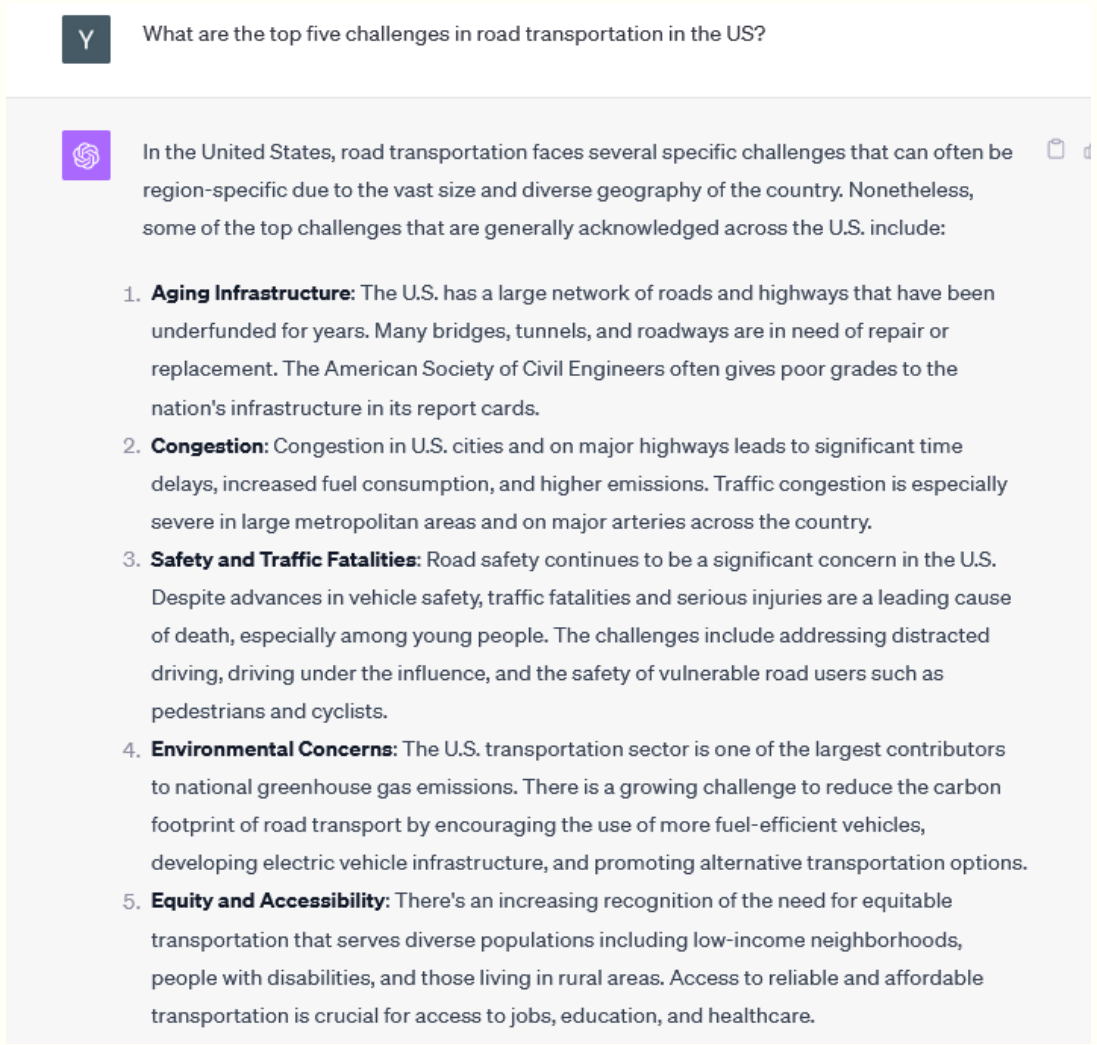
2023 ASCE Francis C. Turner Lecture

November 15, 2023

Road Transportation Is Important

Source: Google images

Road Transportation Challenges



Y What are the top five challenges in road transportation in the US?

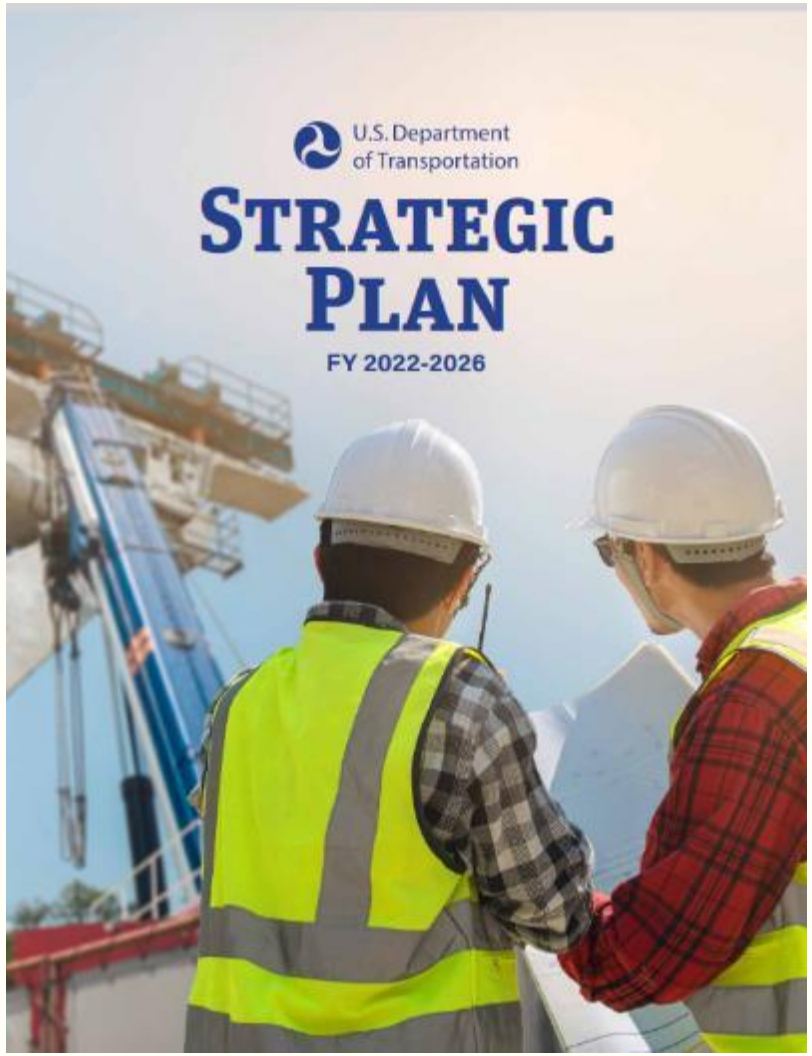
In the United States, road transportation faces several specific challenges that can often be region-specific due to the vast size and diverse geography of the country. Nonetheless, some of the top challenges that are generally acknowledged across the U.S. include:

1. **Aging Infrastructure**: The U.S. has a large network of roads and highways that have been underfunded for years. Many bridges, tunnels, and roadways are in need of repair or replacement. The American Society of Civil Engineers often gives poor grades to the nation's infrastructure in its report cards.
2. **Congestion**: Congestion in U.S. cities and on major highways leads to significant time delays, increased fuel consumption, and higher emissions. Traffic congestion is especially severe in large metropolitan areas and on major arteries across the country.
3. **Safety and Traffic Fatalities**: Road safety continues to be a significant concern in the U.S. Despite advances in vehicle safety, traffic fatalities and serious injuries are a leading cause of death, especially among young people. The challenges include addressing distracted driving, driving under the influence, and the safety of vulnerable road users such as pedestrians and cyclists.
4. **Environmental Concerns**: The U.S. transportation sector is one of the largest contributors to national greenhouse gas emissions. There is a growing challenge to reduce the carbon footprint of road transport by encouraging the use of more fuel-efficient vehicles, developing electric vehicle infrastructure, and promoting alternative transportation options.
5. **Equity and Accessibility**: There's an increasing recognition of the need for equitable transportation that serves diverse populations including low-income neighborhoods, people with disabilities, and those living in rural areas. Access to reliable and affordable transportation is crucial for access to jobs, education, and healthcare.

Image source: Yinhai Wang's ChatGPT Account, Nov. 5, 2023

- Aging Infrastructure
- Congestion
- Safety and Traffic Fatalities
- Environmental Concerns
- Equity and Accessibility
- **Labor Shortage**

Road Transportation Challenges



Picture source: https://www.transportation.gov/mission/us-dot-strategic-plan-fy-2022-2026

Eight Transformational Technologies

Autonomous Vehicles

Image Source: https://www.autoweek.com/news/green-cars/a41351858/torc-robotics-autonomous-trucks/

Eight Transformational Technologies

Connected Vehicles

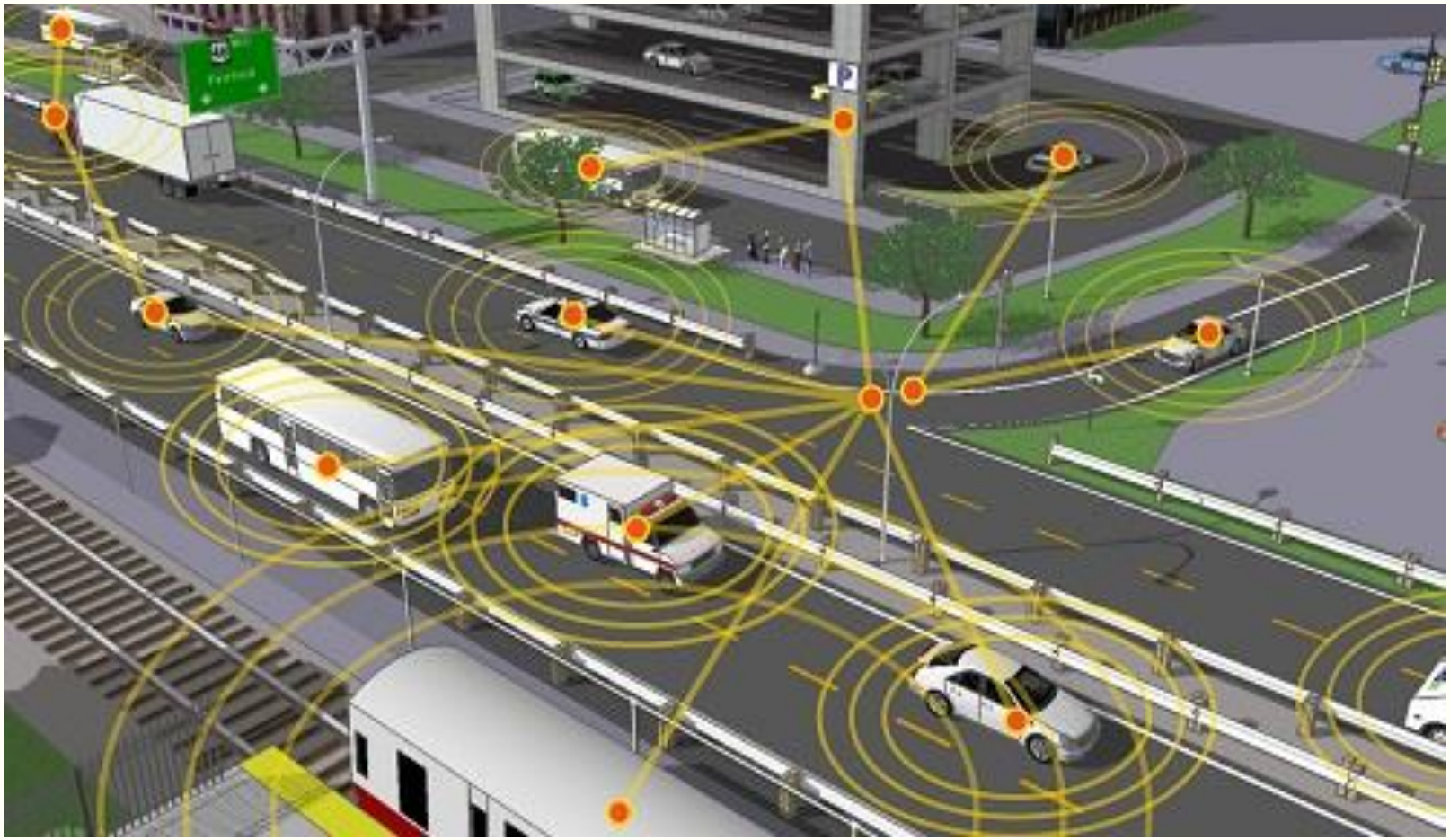


Image Source: https://www.volpe.dot.gov/sites/volpe.dot.gov/files

Eight Transformational Technologies

Electric Vehicles

Image Source: http://nhcleancities.org/wp-content/uploads/2016/08/electric-vehicles-powerered-by-solar.jpg

Eight Transformational Technologies

Smart Infrastructure

Image Source: https://www.2025ad.com/latest/computing-and-autonomous-driving/

Eight Transformational Technologies

Crowdsourcing Data and Applications

Image Source: https://scdn.androidcommunity.com/wp-content/uploads/2012/01/waze-3.jpg

Eight Transformational Technologies

Bigdata Analytics

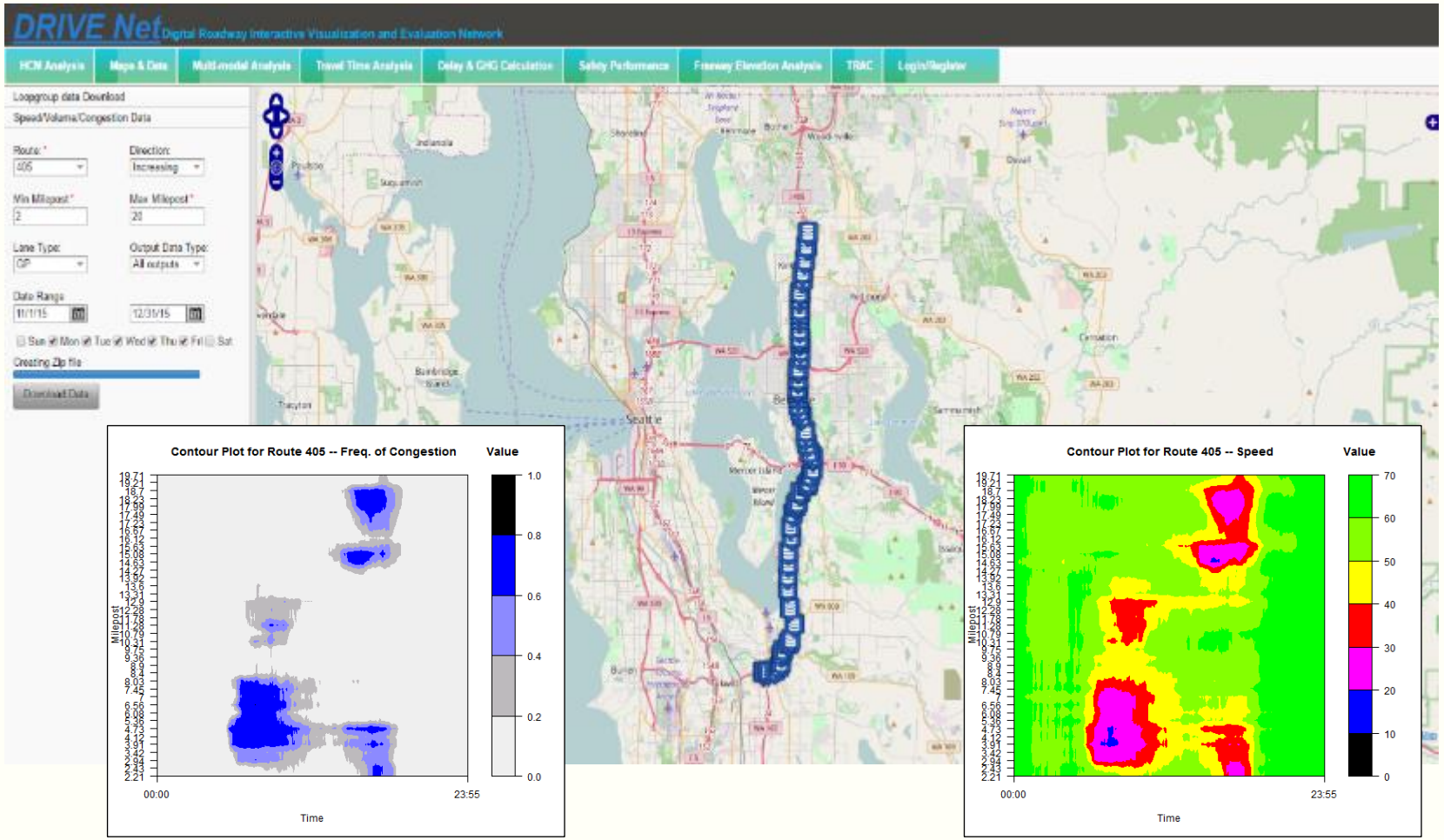


Image Source: http://www.uwdrive.net

Eight Transformational Technologies

Ride Resource Sharing

Image Source: http://www.theyeshivaworld.com/wp-content/uploads/2016/06/14.jpeg

Eight Transformational Technologies

Mobility as a Service (MaaS)

Image Source: http://www.theyeshivaworld.com/wp-content/uploads/2016/06/14.jpeg

AI Is a Critical Binding Agent

Image source: https://www.xcubelabs.com/blog/how-ai-is-transforming-the-transport-industry/

Power of These Disruptive Technologies

Image Source: https://www.ilfuturodelmarketing.it/wp-content/uploads/2017/04/uber-war.jpg

Proof of the Effectiveness

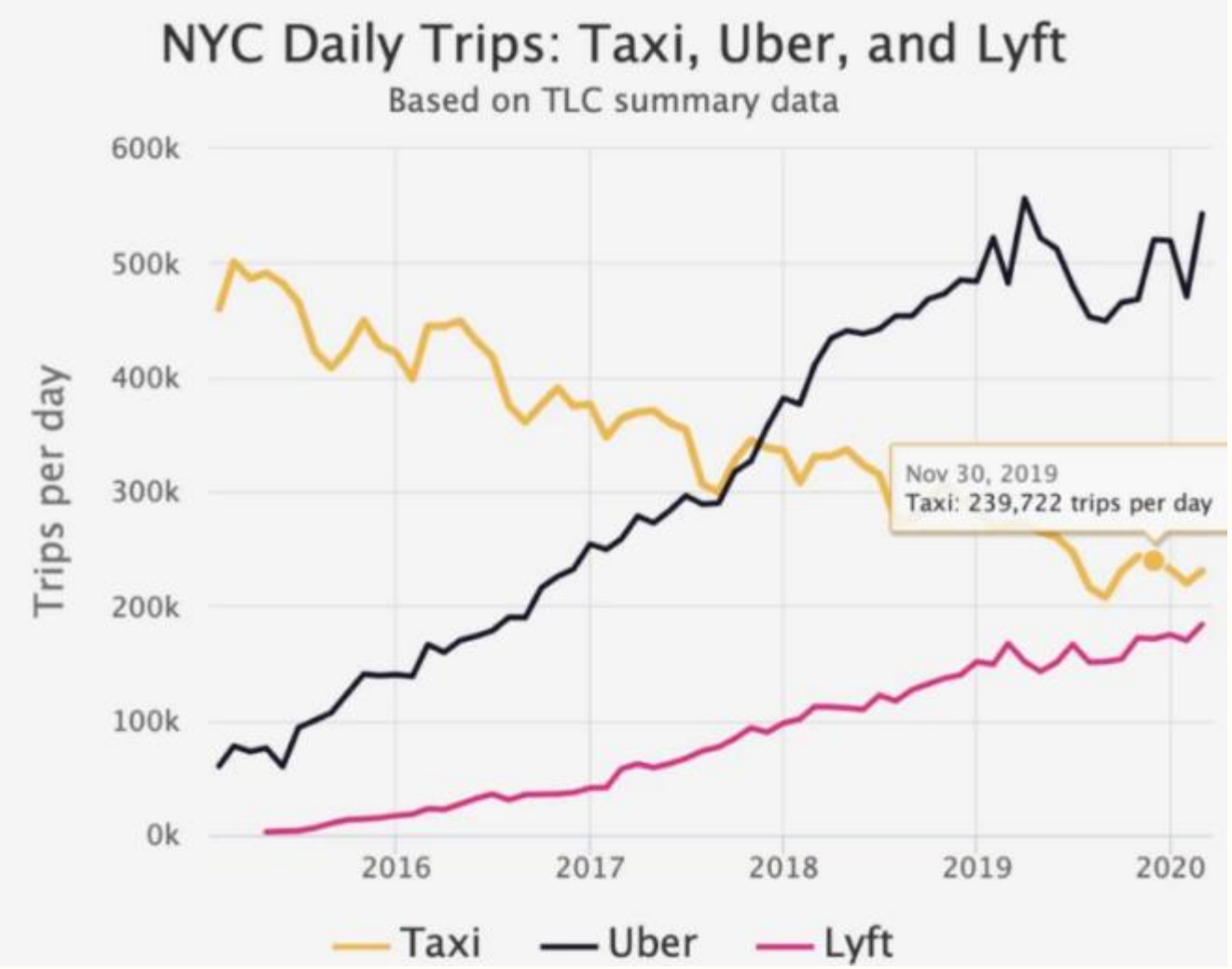


Image Source: https://arekskuza.com/the-innovation-blog/uber-business-model/

AI Applications in Transportation

Transportation is likely to be one of the first domains in which the general public will be asked to trust the reliability and safety of an AI system for a critical task.

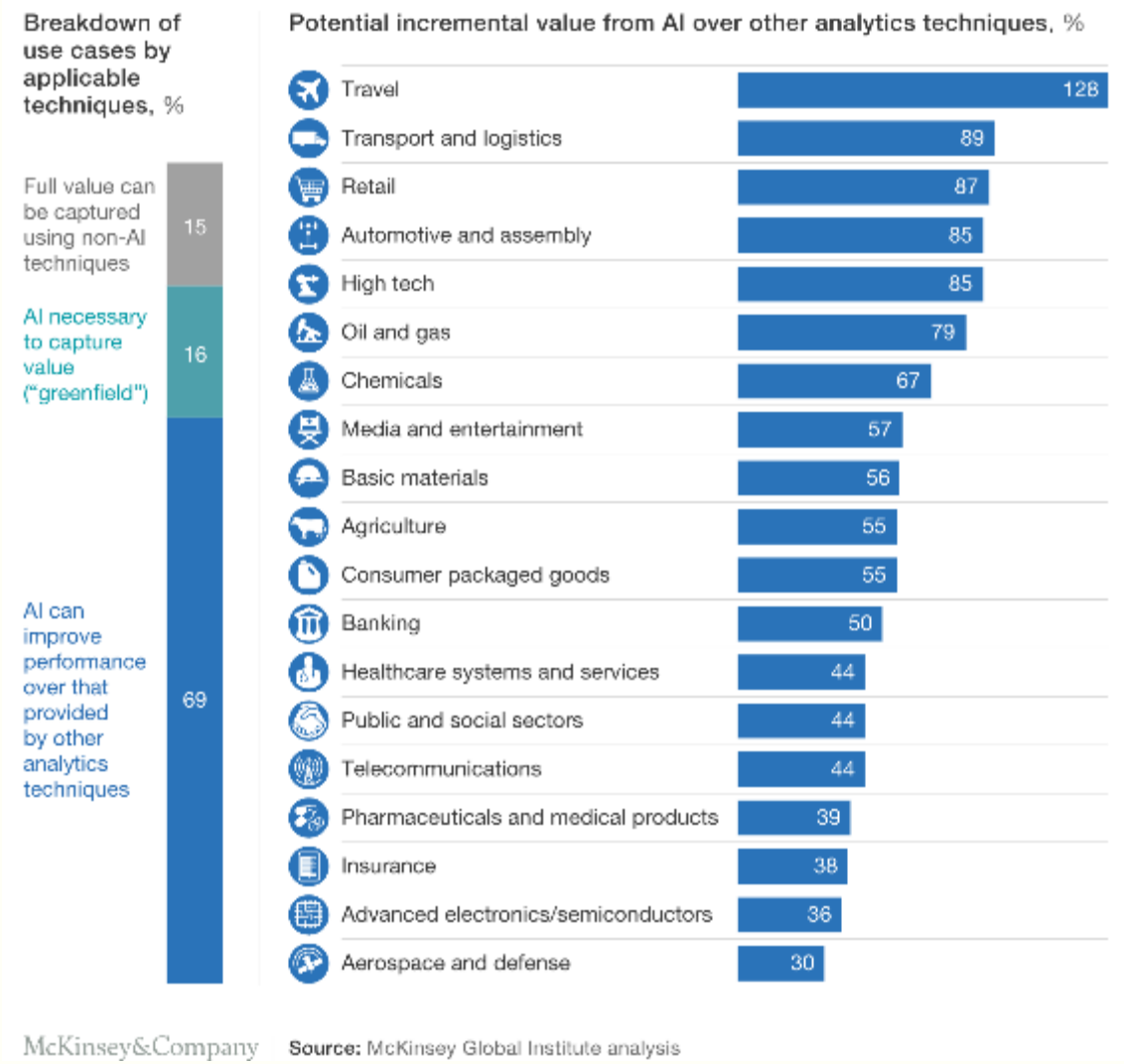
- One Hundred Year Study on Artificial Intelligence (AI100), Stanford University,

Image source: Google Images

AI & Transportation

AI can improve performance beyond that provided by other analytics techniques. The top five potential incremental value from AI:

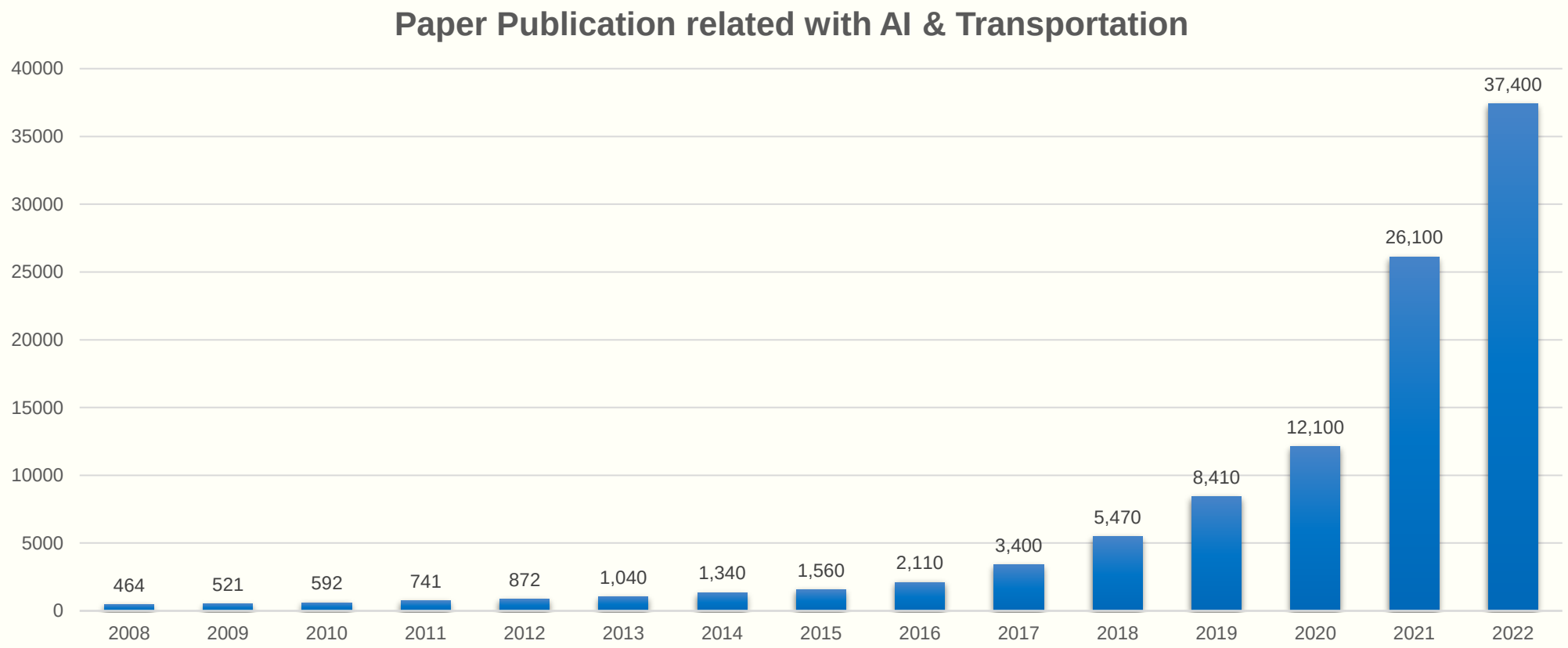
1. **Travel**
2. **Transport & Logistics**
3. Retail
4. **Automotive and assemble**
5. High tech



https://www.mckinsey.com/featured-insights/artificial-intelligence/the-promise-and-challenge-of-the-age-of-artificial-intelligence

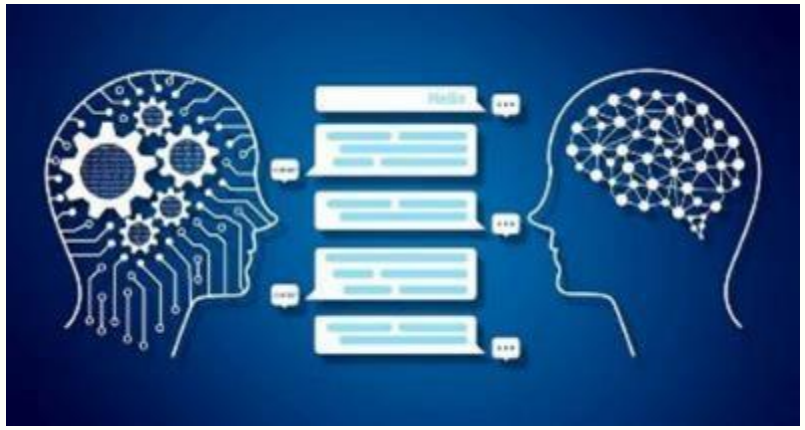
AI Is Hot in Transportation Research

Published papers on AI research and applications in transportation
Data source: Google Scholar



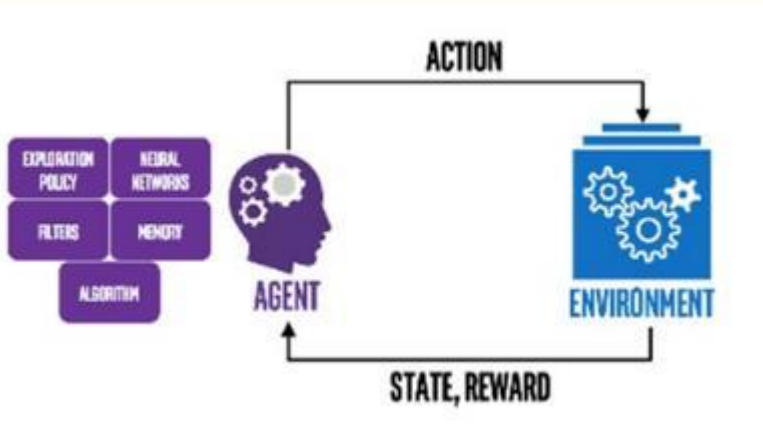
Hot Topics in AI for Transportation

Natural Language Processing



Recommendation System

Reinforcement Learning



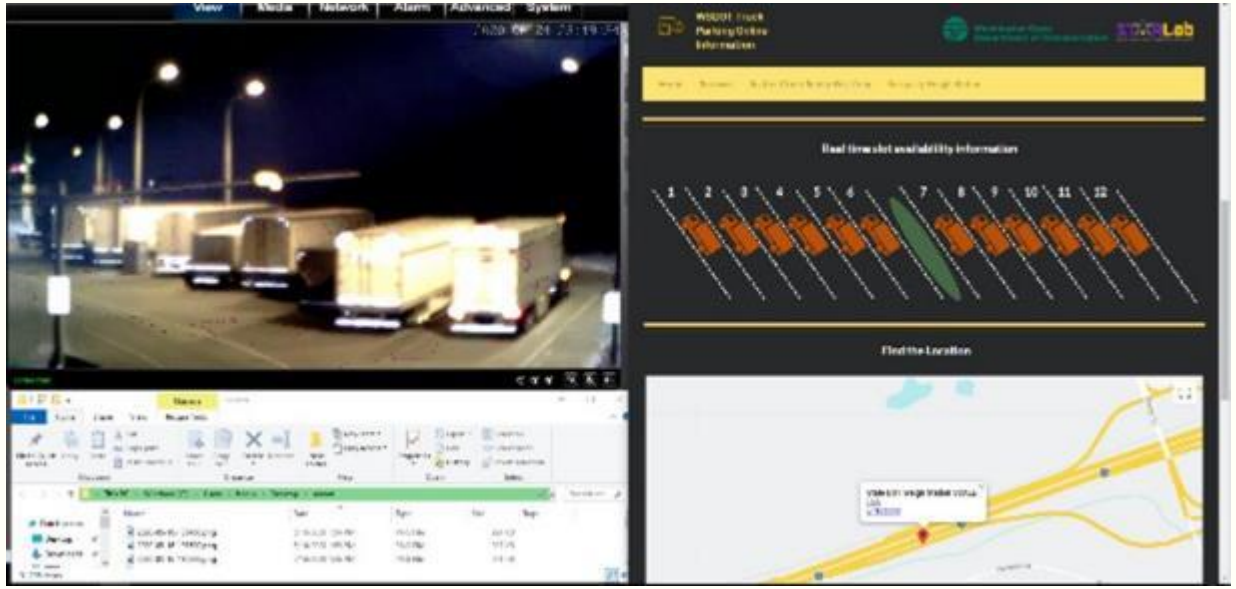
Graph Neural Network

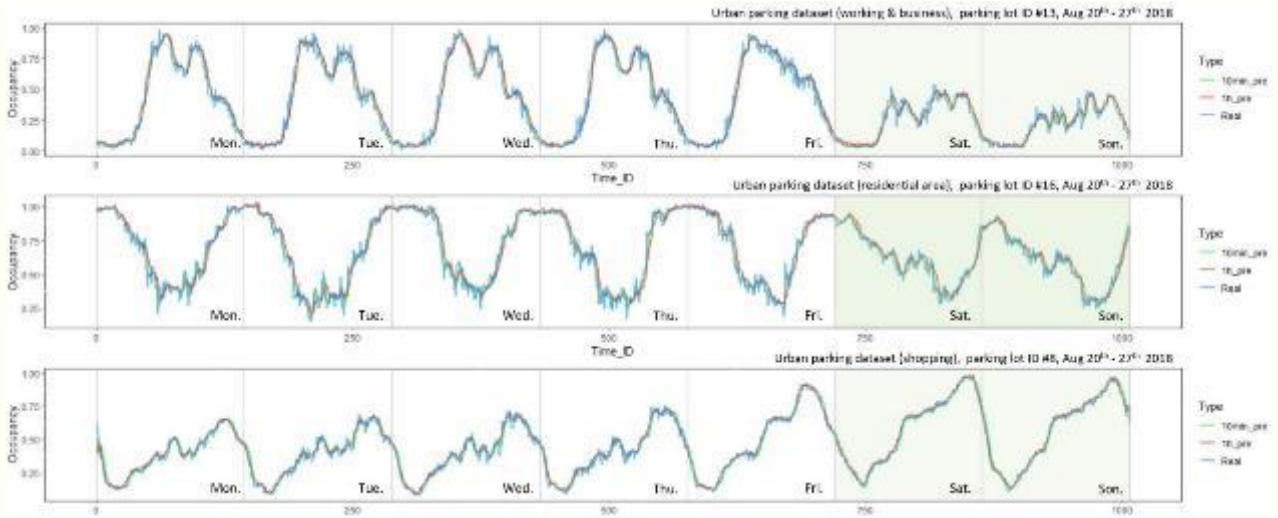
Block Chain

Computer Vision & Edge AI

NLP Method for Truck Parking Prediction

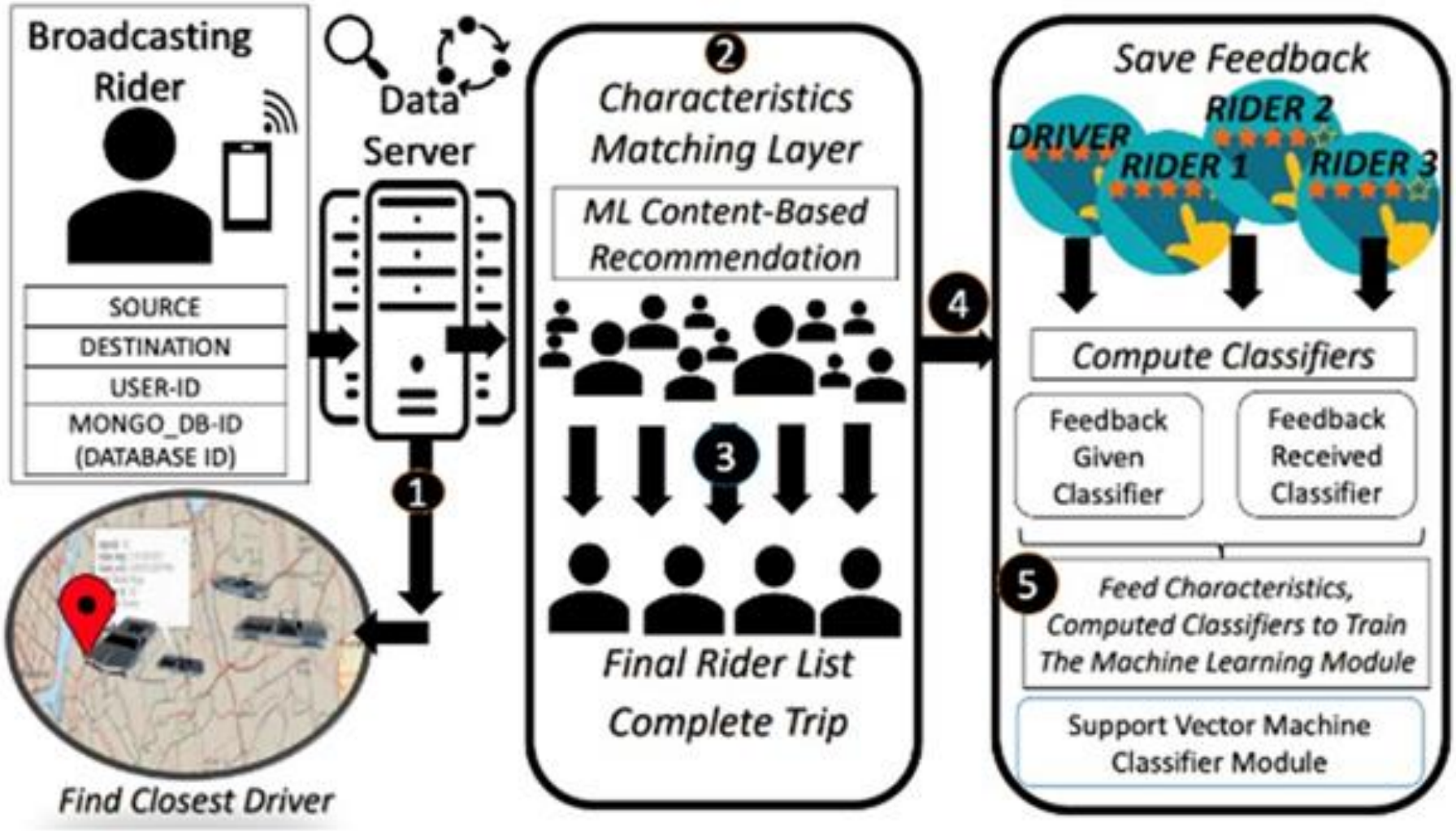
- Cost-effective solution for truck parking using NLP techniques
  - Sensor-fused detection
  - Customized Machine Learning



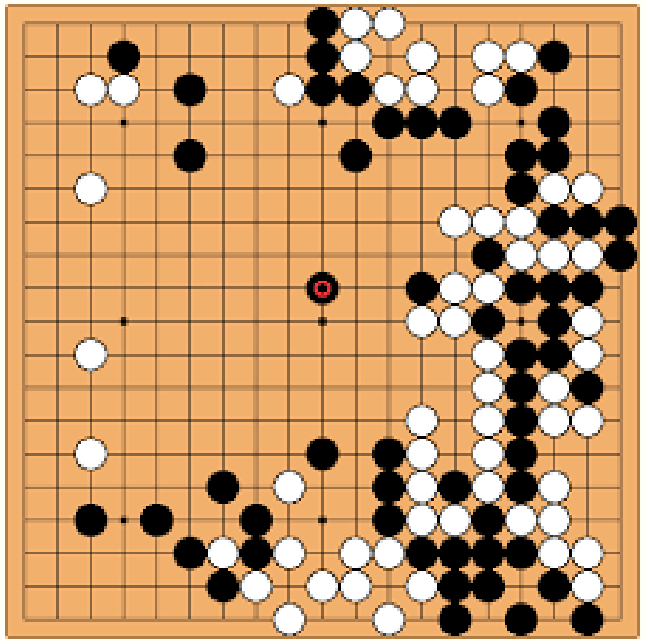


Yang, et al. 2022: https://ieeexplore.ieee.org/abstract/document/9582619

Ride Sharing Recommendation

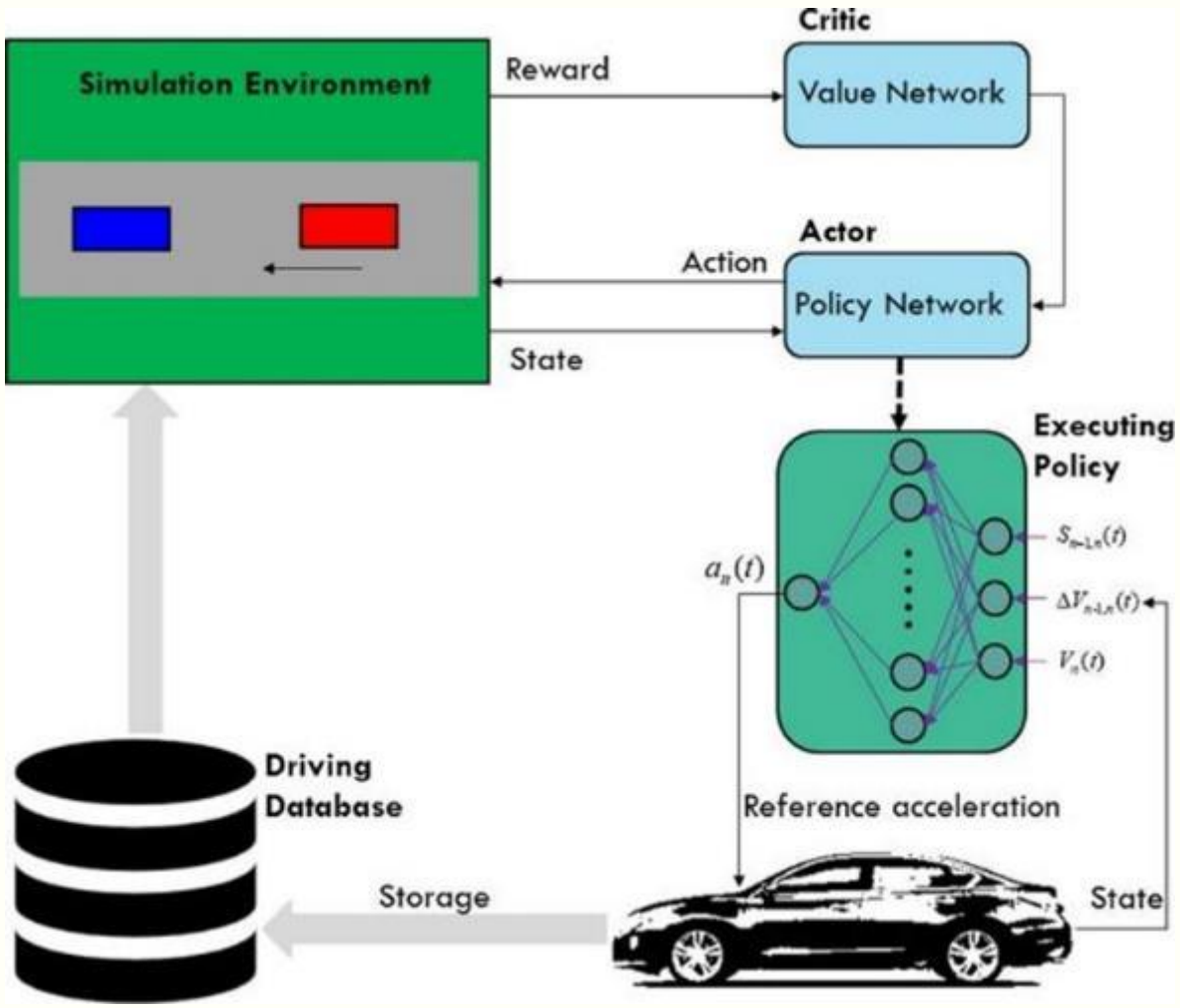


Reinforcement Learning (RL)



RL for Autonomous Driving

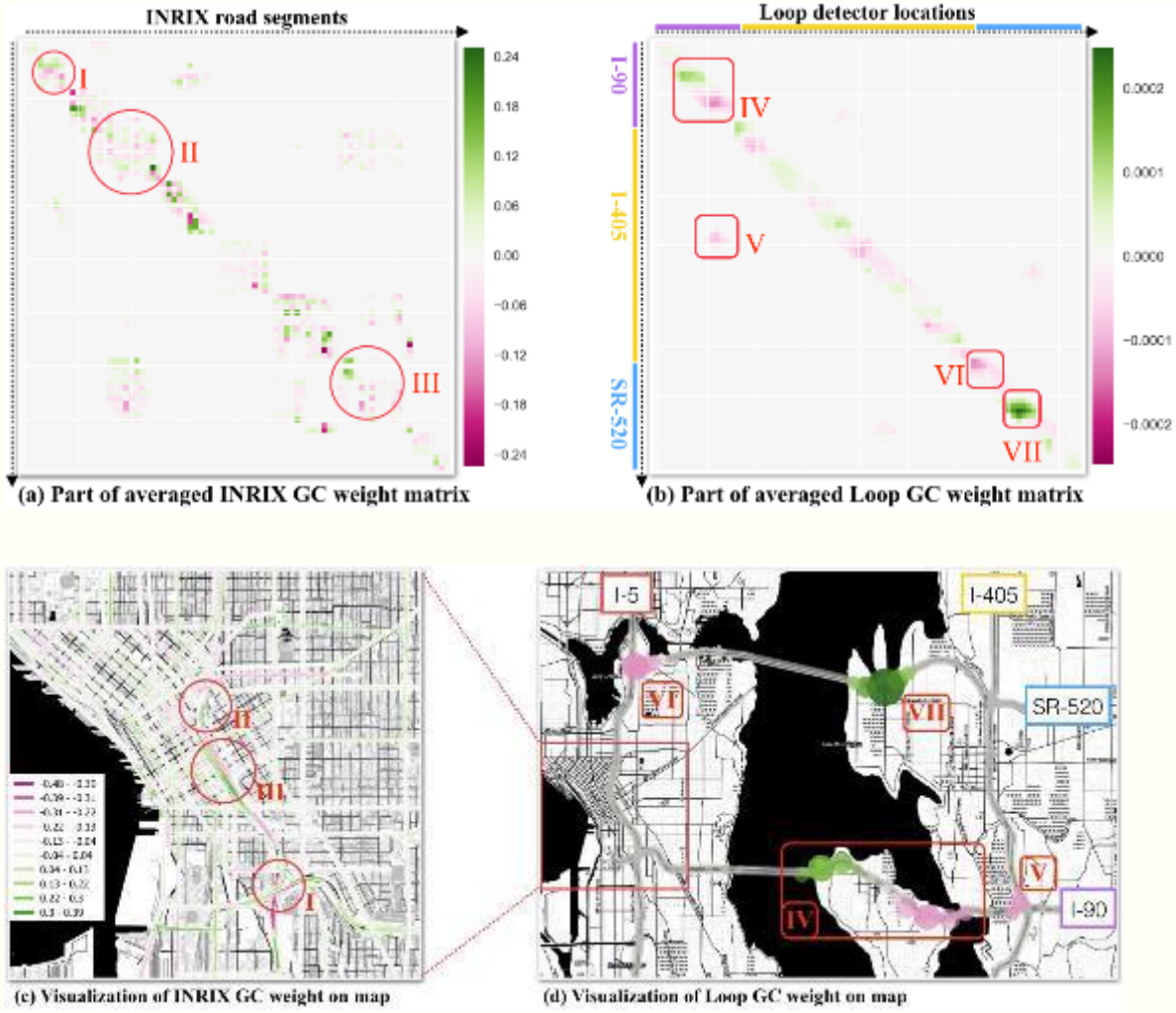
- Motivations
  - Autonomous driving consists of multiple tasks. For example, higher-level tasks pertain to decision-making based on reasoning of the surrounding environment.
  - Long-term decisions are hard to model in traditional models
  - Uncertainties are interrelated in autonomous driving scenarios.
- Applications
  - Lane changing
  - Car following



Zhu et al., 2020: https://doi.org/10.1016/j.trc.2020.102662

GNN for Traffic Forecasting

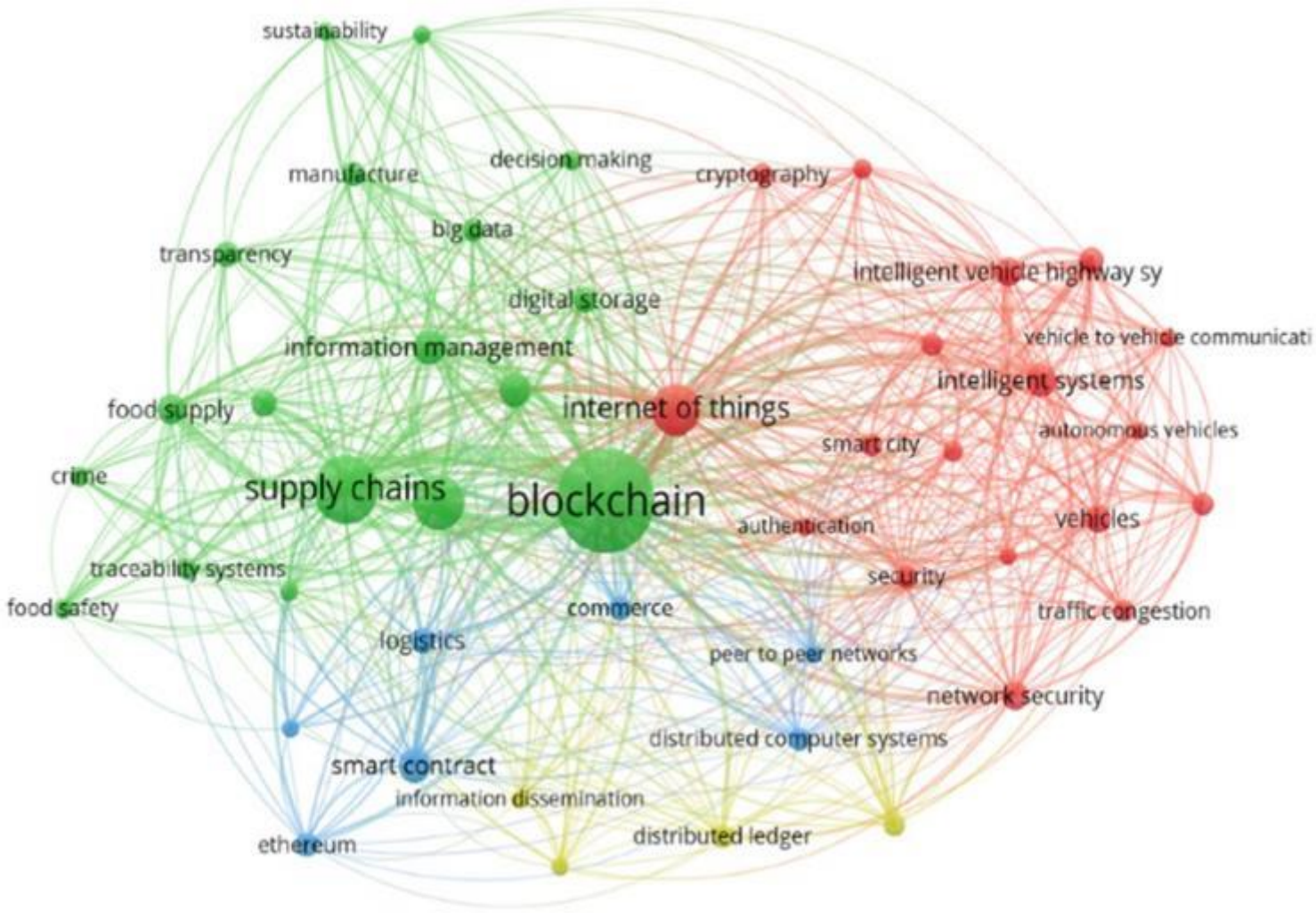
- Motivations
  - Measurements of traffic variables on transportation networks are becoming increasingly common.
  - Two data points might be spatially close in Euclidean space but interact independently. The true distance is roadway driving distance.
  - The need to predict traffic characteristics in a short or long future time horizon for different ITS applications is strong.
- Solutions
  - GNN + recurrent NN variants (vanilla RNN, LSTM, sequence to sequence)

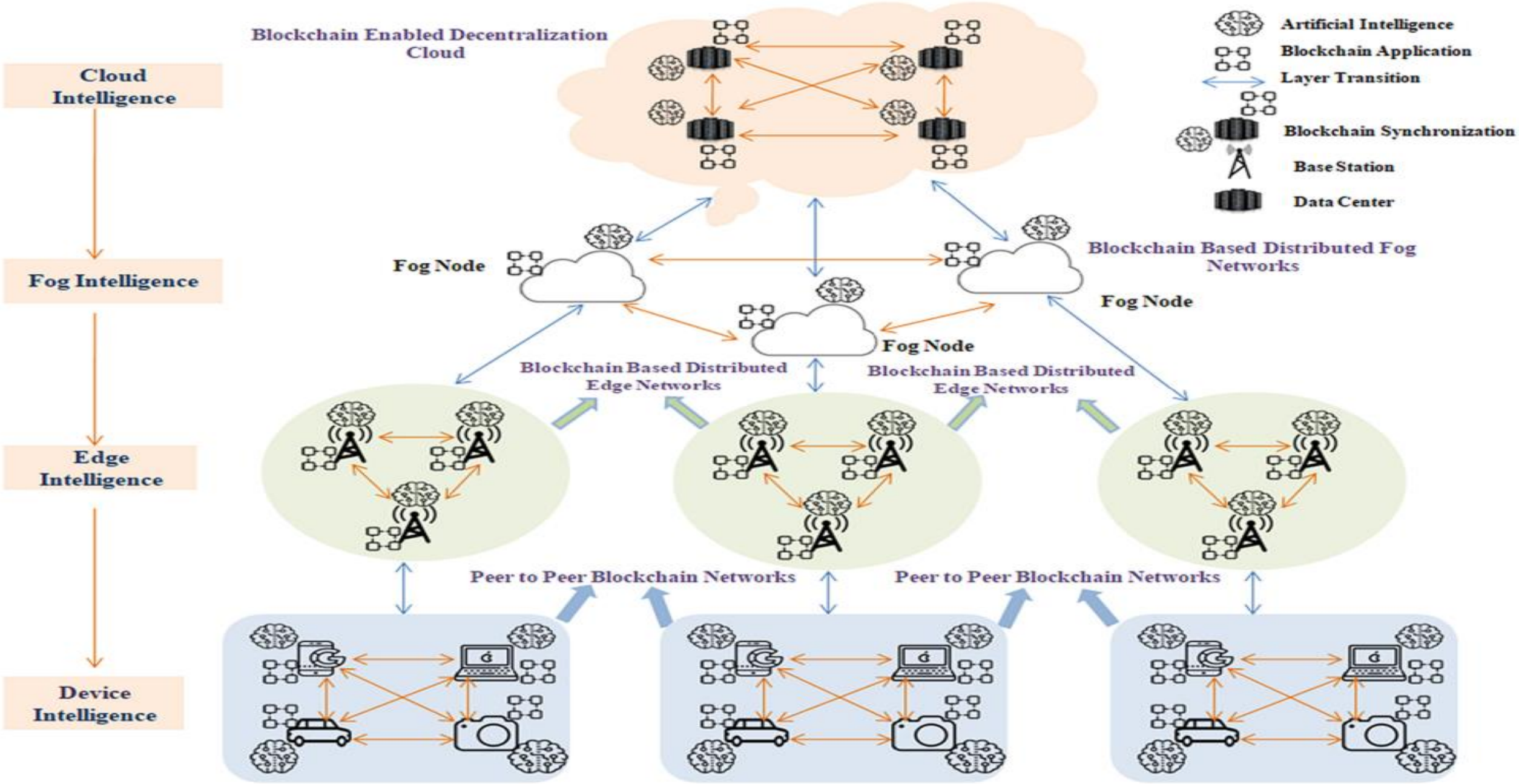


Cui et al., 2020: https://doi.org/10.1016/j.trc.2020.102674

Block Chain for Transportation

- Supply chain
  - Lack of information for consumer about the origin of food products
- Electric vehicle charging
  - Allow customers to query charging stations for the lowest available price
- Smart vehicle
  - Malicious attacks can compromise passengers' safety





Singh, et al., 2020: https://www.sciencedirect.com/science/article/abs/pii/S0167739X19316474

Blockchain + AI for Transportation

A Blockchain-enabled Intelligent IoT Architecture with Artificial Intelligence

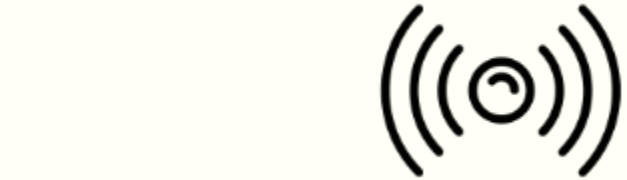
- **Edge intelligence:**
  - **AI uses analytic tools for reliable data mining (feature extraction, scaling, and representation) of big unstructured data from IoT devices.**
  - **Blockchain technology provided peer to peer connection to unstructured IoT devices in networks for security and privacy.**
- **Fog intelligence:**
  - **AI technologies are deployed to train machine learning models and make decisions as rapidly as possible at fog intelligence.**
  - **Blockchain technology provides a distributed repository in which every device has its copy of the whole ledger.**
- **Cloud intelligence:**
  - **Intelligent agents of AI are used in cloud intelligence to collect, select, analyze the data from ambient environments using centralized methods.**
  - **Blockchain provides the distributed pattern for secure big data analysis in IoT.**

Singh et al., 2020: https://www.sciencedirect.com/science/article/abs/pii/S0167739X19316474

Edge-AI for Traffic Sensing

Traditional Sensing Tech

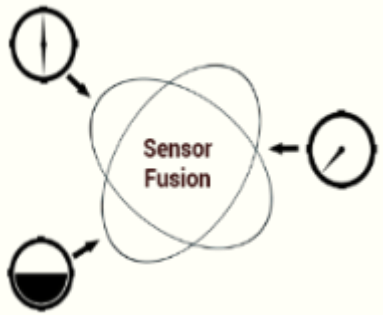
OR



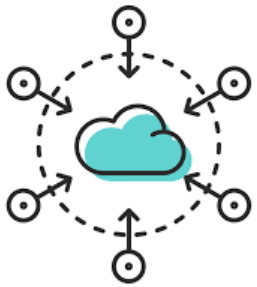
Cooperative Sensing

Computer Vision

ALL IN ONE



Sensor Fusion



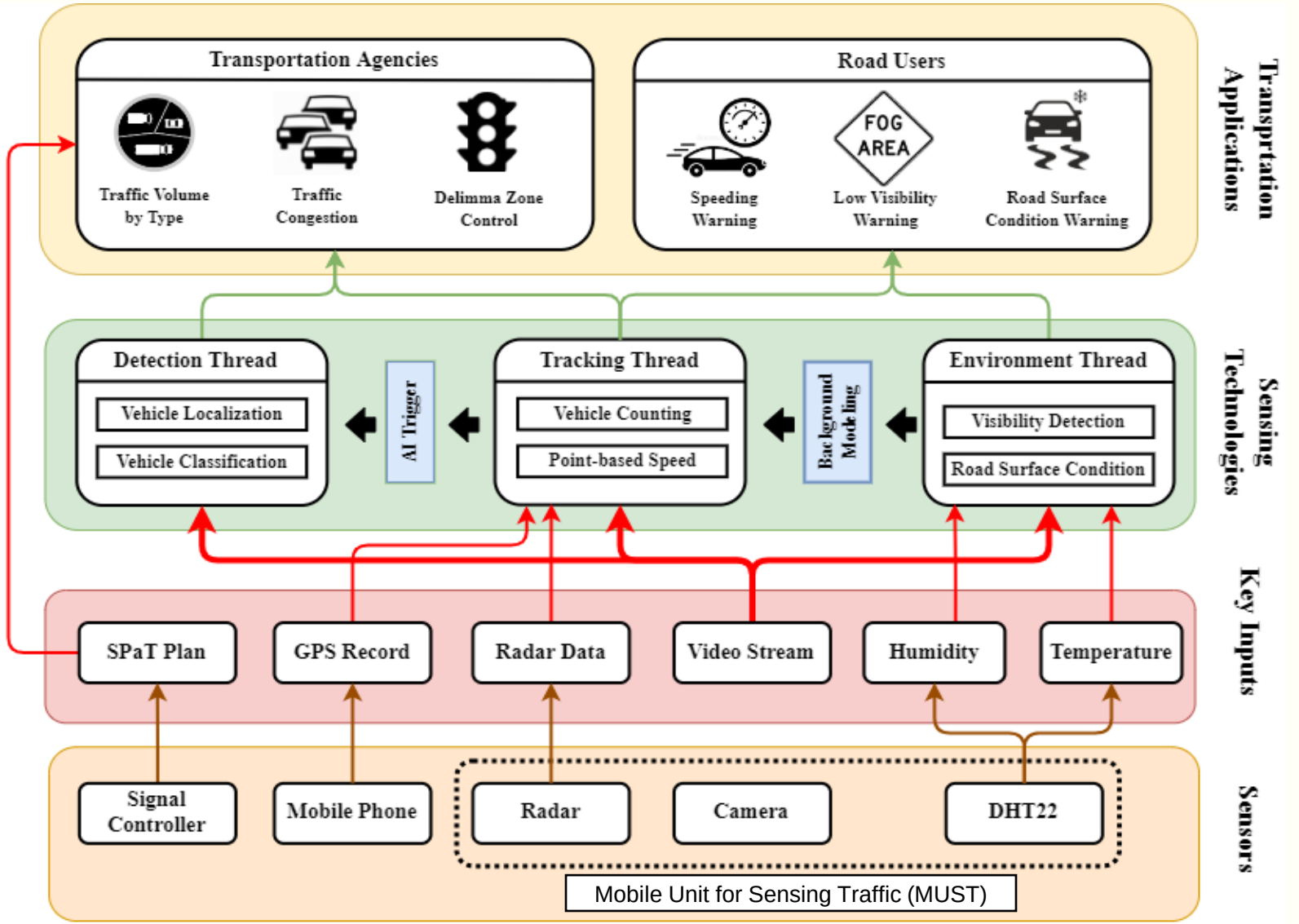
Edge Computing

Human-Machine Interaction

AI empowered Sensing Tech

Edge-AI for Traffic Sensing

- Sample Applications
  - Various Speed Limit
  - Volume by 13 Classes
  - Adaptive Control
  - Hazard Warning
  - Traffic Environment Sensing
  - …



Edge Computing

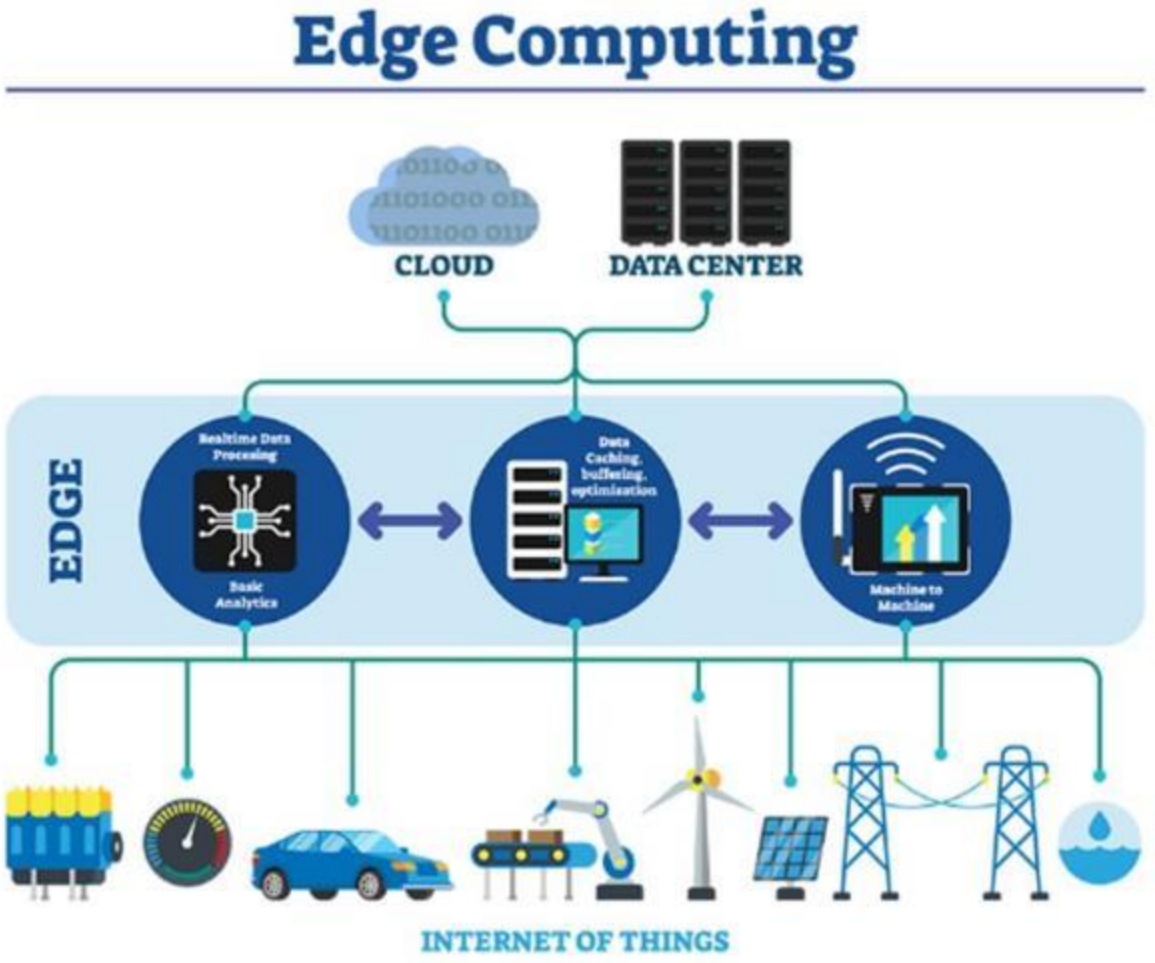
Edge Computing

- Computational processing of sensor data away from the centralized nodes and close to the logical edge of the network (where the data is generated)
- Empowered by AI technologies, data can be processed by an IoT device itself or by a local computer, rather than being transmitted to a cloud data center.

Raspberry Pi

Jetson Nano

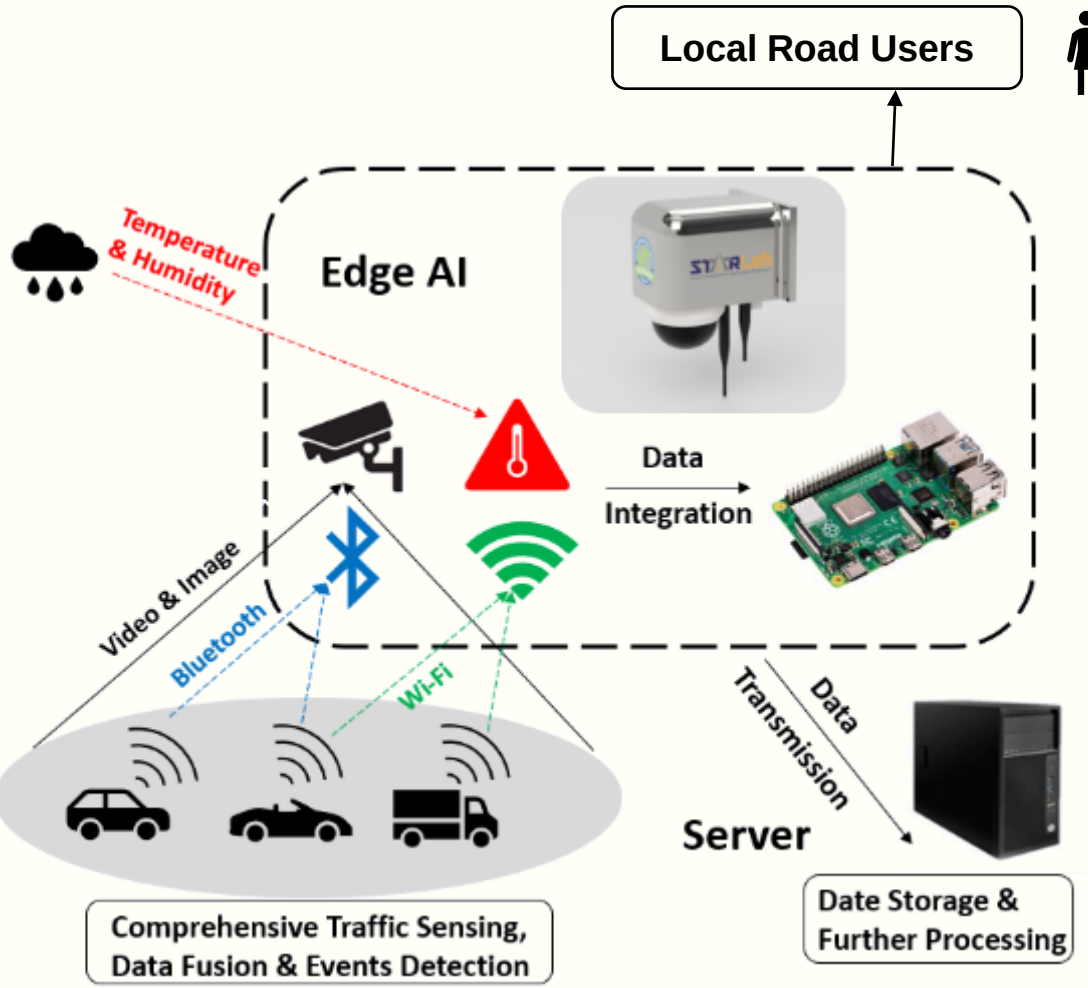
Jetson Xavier NX



Mobile Unit for Sensing Traffic (MUST)

Mobile Unit for Sensing Traffic

Operation Temperature	-40 °C ~ 70 °C
Operation Relative Humidity	10% ~ 90%
Ingress Protection	IP 65
Power Supply	12V(DC)
Energy Consumption	< 35Watts
CPU	ARM1176JZF-S 700 MHz
Communication	3G/4G/5G, Ethernet
Operation System	Linux
Local Data Storage	Micro Secure Digital (SD) Card
Weight	10 pounds
Dimensions	170 mm (length), 170 mm (width), 300 mm (height)



Edge-AI for Traffic Sensing

Object Detection and Classification

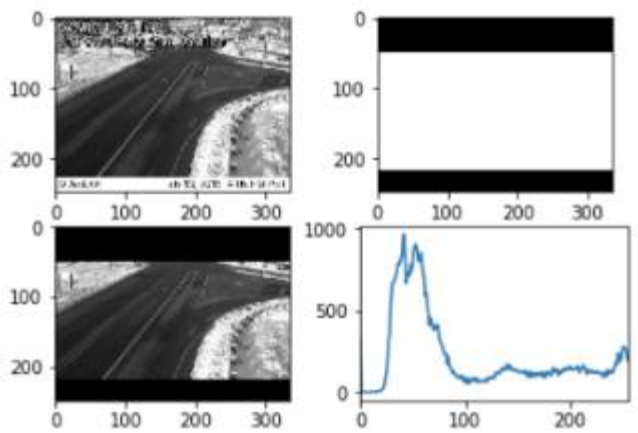
Edge-AI for Traffic Sensing

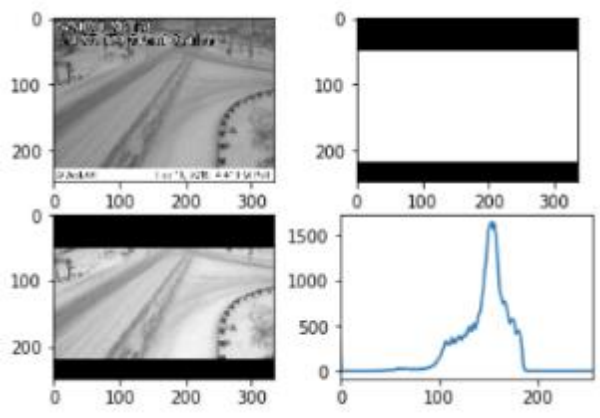
- Traffic volume detection and vehicle classification
  - Transfer learning
  - MobileNet pretrained on ImageNet and finetuned on MIO-TCD

	Car	Truck	Bus	Cyclist	Background
Car	91%	5%	2%	2%	0
Truck	6%	87%	4%	3%	0
Bus	1%	2%	96%	1%	0
Cyclist	2%	2%	1%	95%	0
Background	0	0	0	0	100%

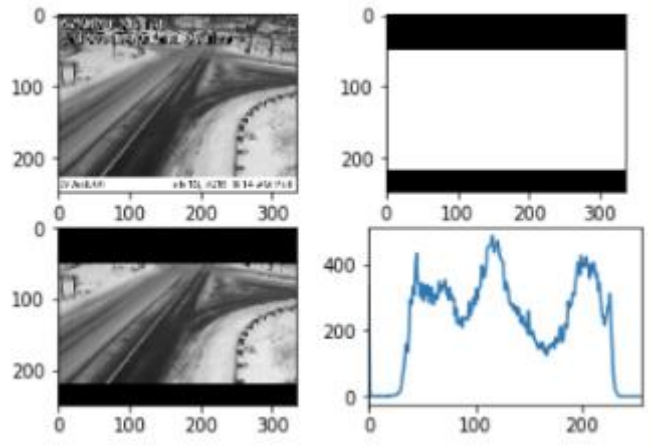
Edge-AI for Traffic Sensing

Road Surface Conditions Monitoring





	Dry	Snowy	Icy	Wet
Dry	**97.5%**	0.4%	0.7%	1.4%
Snowy	0.2%	**97.9%**	1.8%	0.1%
Icy	1.6%	1.6%	**93.6%**	3.2%
Wet	0.6%	1.7%	2.4%	**95.3%**



Edge-AI for Environment Sensing

Camera View Dehaze for Visibility Detection

Original Image

Scattering Map

De-hazed Image

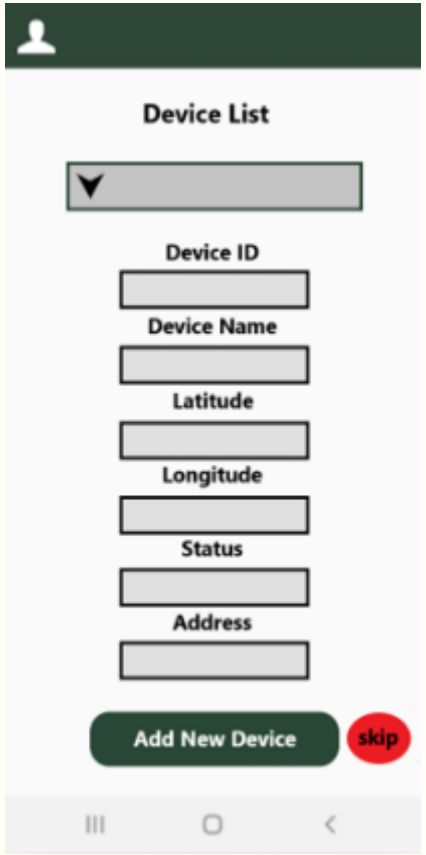
Edge-AI for Environment Sensing

Visibility Detection

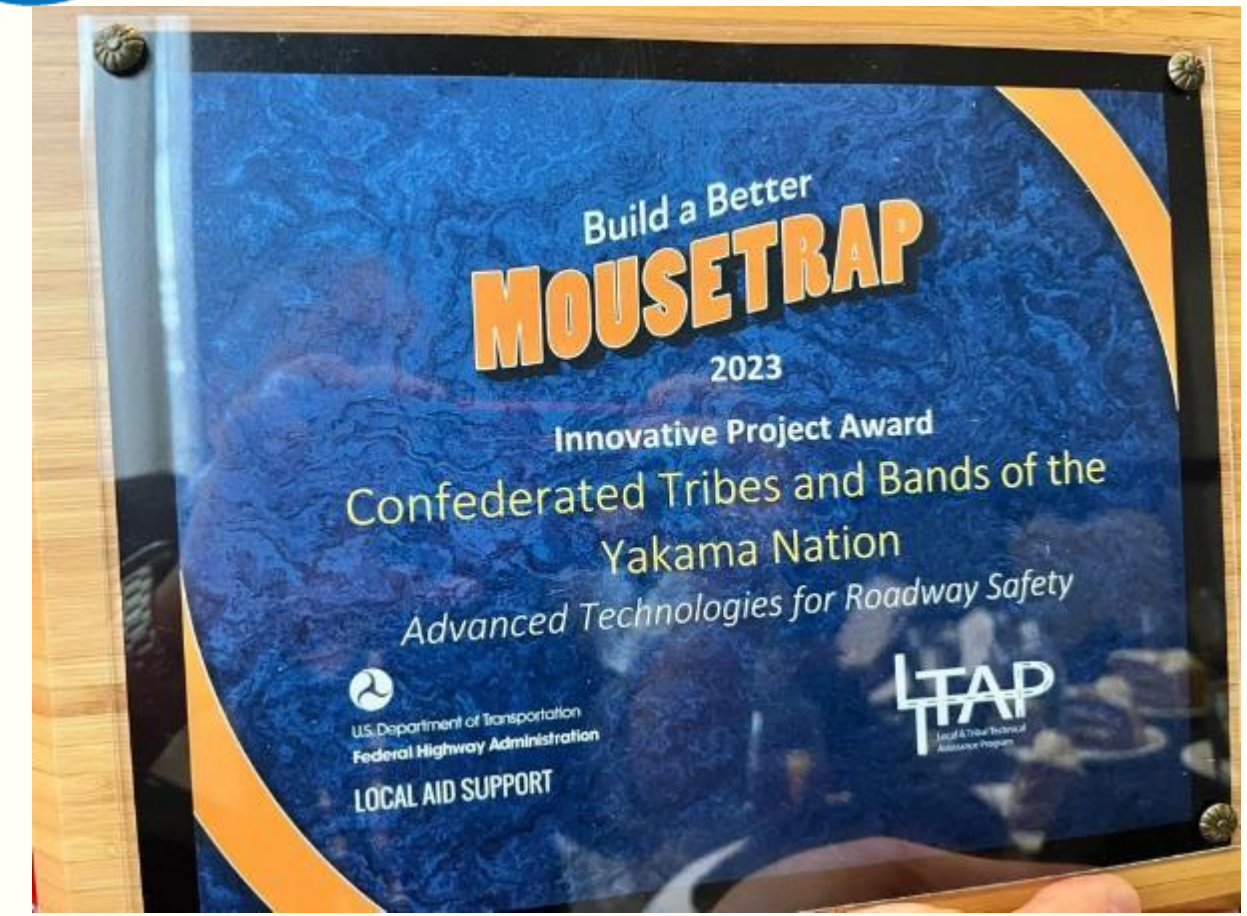
Threshold / Visibility	$\pm 5\%$	$\pm 10\%$	$\pm 20\%$
$V_s < 500$ m	85.29%	89.14%	93.18%
$500\text{m} \leq V_s < 1000$ m	88.17%	90.25%	95.42%
$1000\text{m} \leq V_s < 2000$ m	90.36%	93.22%	97.03%
$V_s \geq 2000$ m	91.23%	95.78%	98.75%
Overall	89.27%	92.15%	96.61%

Edge AI for Highway Monitoring

Mobile App for device management, real-time data collection, event detection & warning.



Pilot Application in Yakama Nation



This pilot project received the FHWA 2023 Build a Better Mousetrap Innovative Project Award!

Highway Safety Improvement

Image source: https://www.thedrive.com/news/44961/50-car-pileup-in-pennsylvania-kills-at-least-five-in-whiteout-conditions

AI Applications in Transportation

- Successful AI applications needs domain knowledge

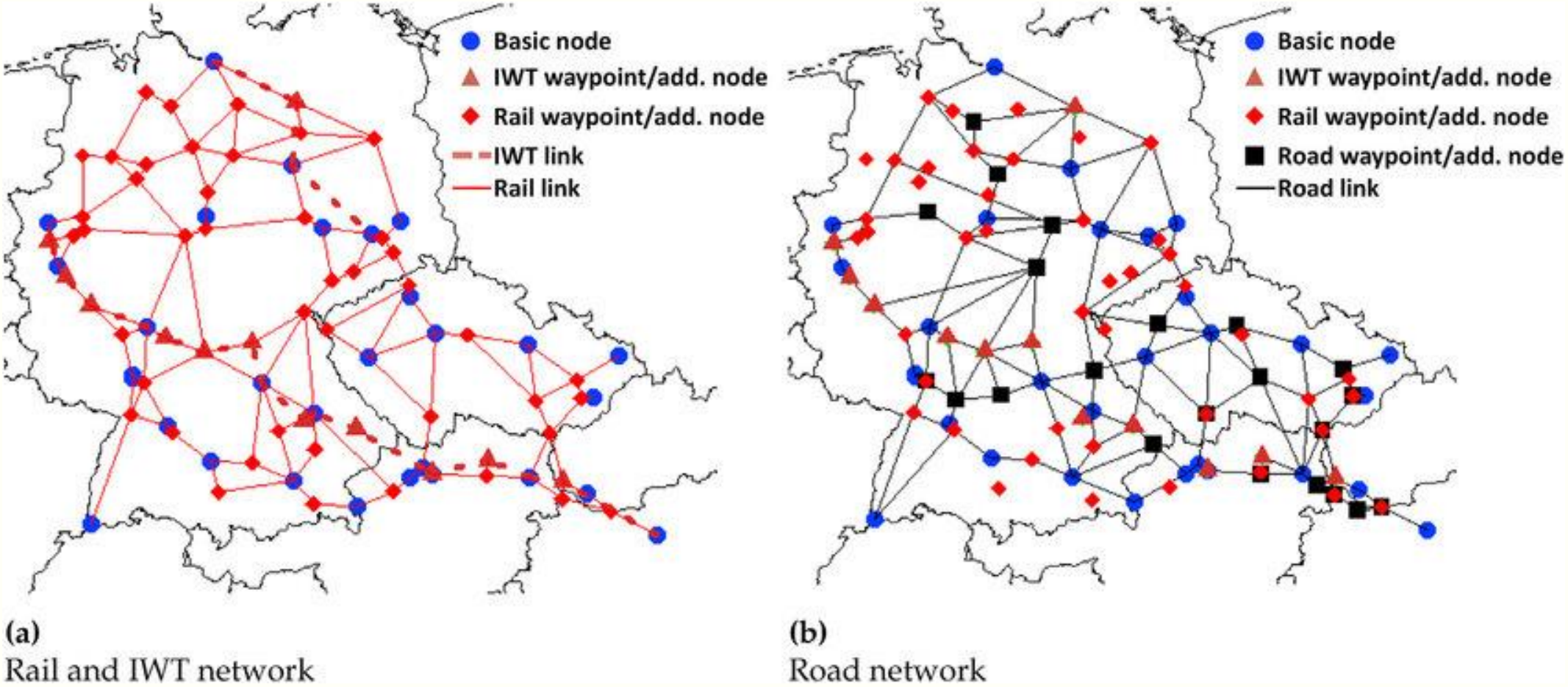


Image source: https://www.researchgate.net/figure/Transportation-network-with-nodes-and-network-links_fig4_346440166

Edge Computing for ATUs

- At some point in the day, everyone is a pedestrian. Walking accounts for about **11%** of all trips. Unfortunately, pedestrian injuries and fatalities remain high. In 2021, **7,388** pedestrians were killed – a **13%** increase from 2020 – and more than **60,000** pedestrians were injured nationwide (source: NHTSA).

71 MIN

A PEDESTRIAN WAS KILLED EVERY 71 MINUTES IN TRAFFIC CRASHES IN 2021.

Edge-AI for VRU Data Collection

Pedestrian Detection + Tracking

Edge-AI for VRU Data Collection

Diverse Pedestrian Groups Sensing

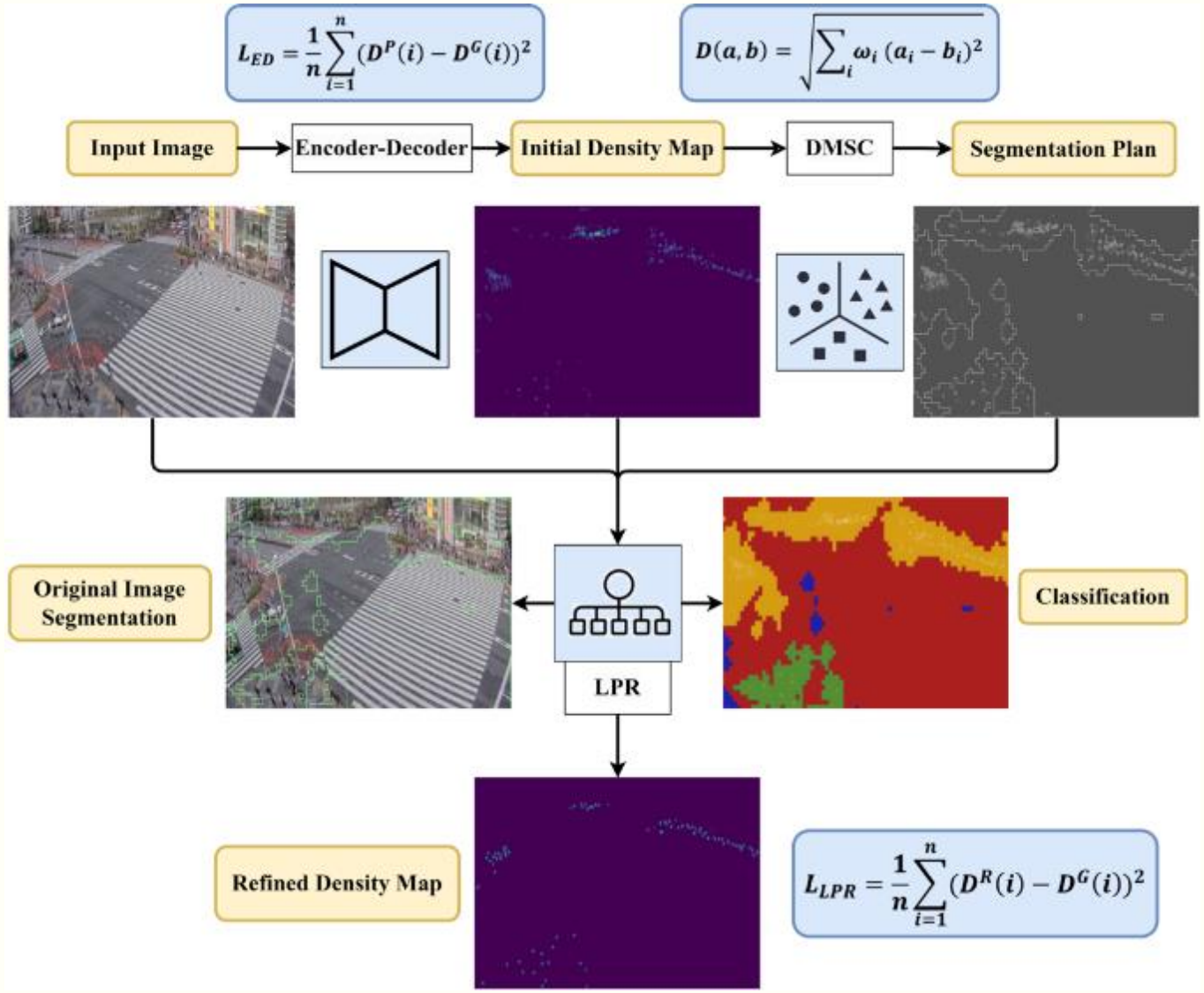
YOLO V4 Object Detection Model

Our Pedestrian Sensing Method
(Object Detection + Density Detection)

Edge Computing for ATUs

System Design:

- Encoder-decoder (ED)
- Density Map Segmentation & Clustering (DMSC)
- Local Patch Refinement (LPR)



People's Opinions Are Different

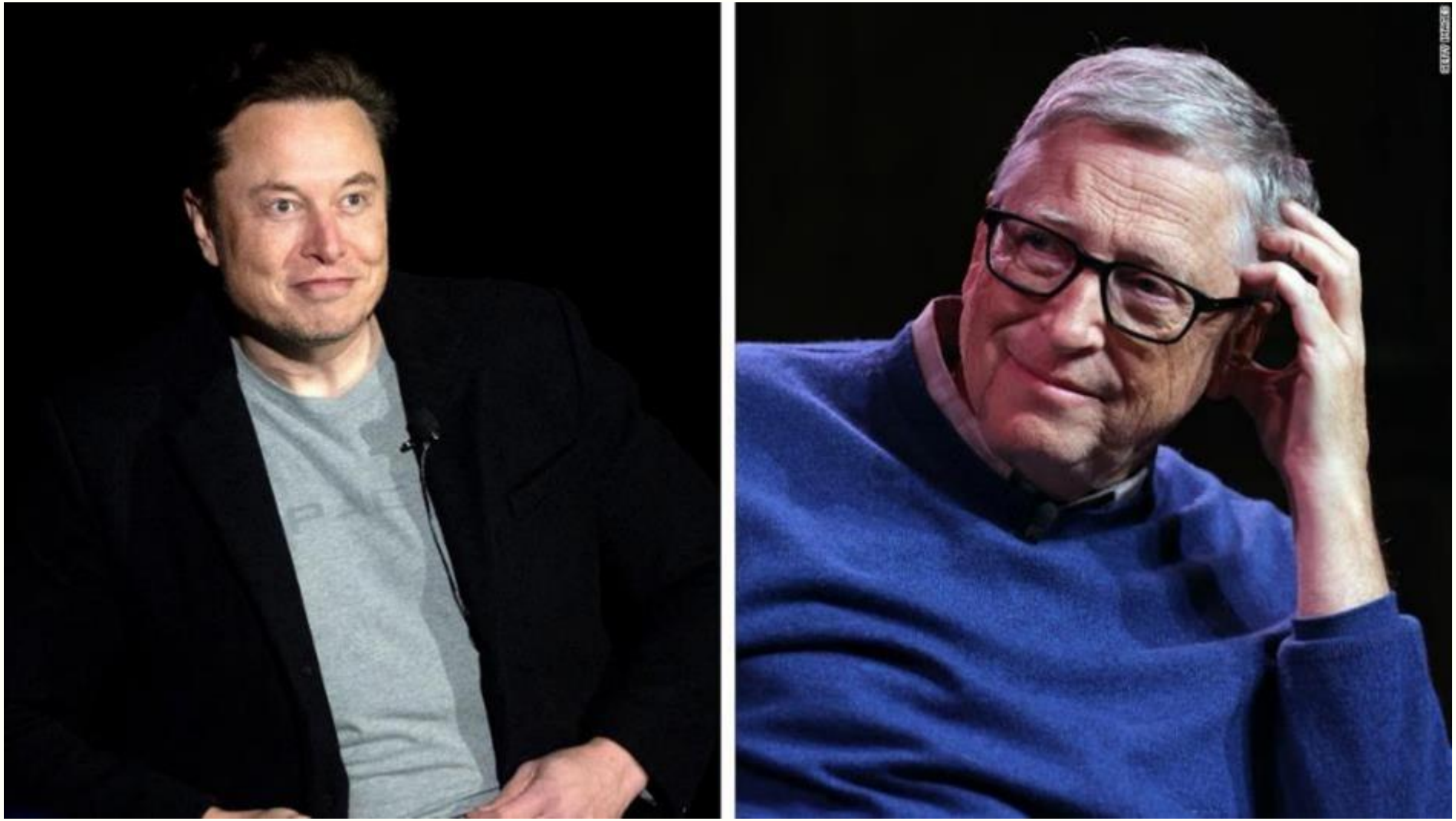


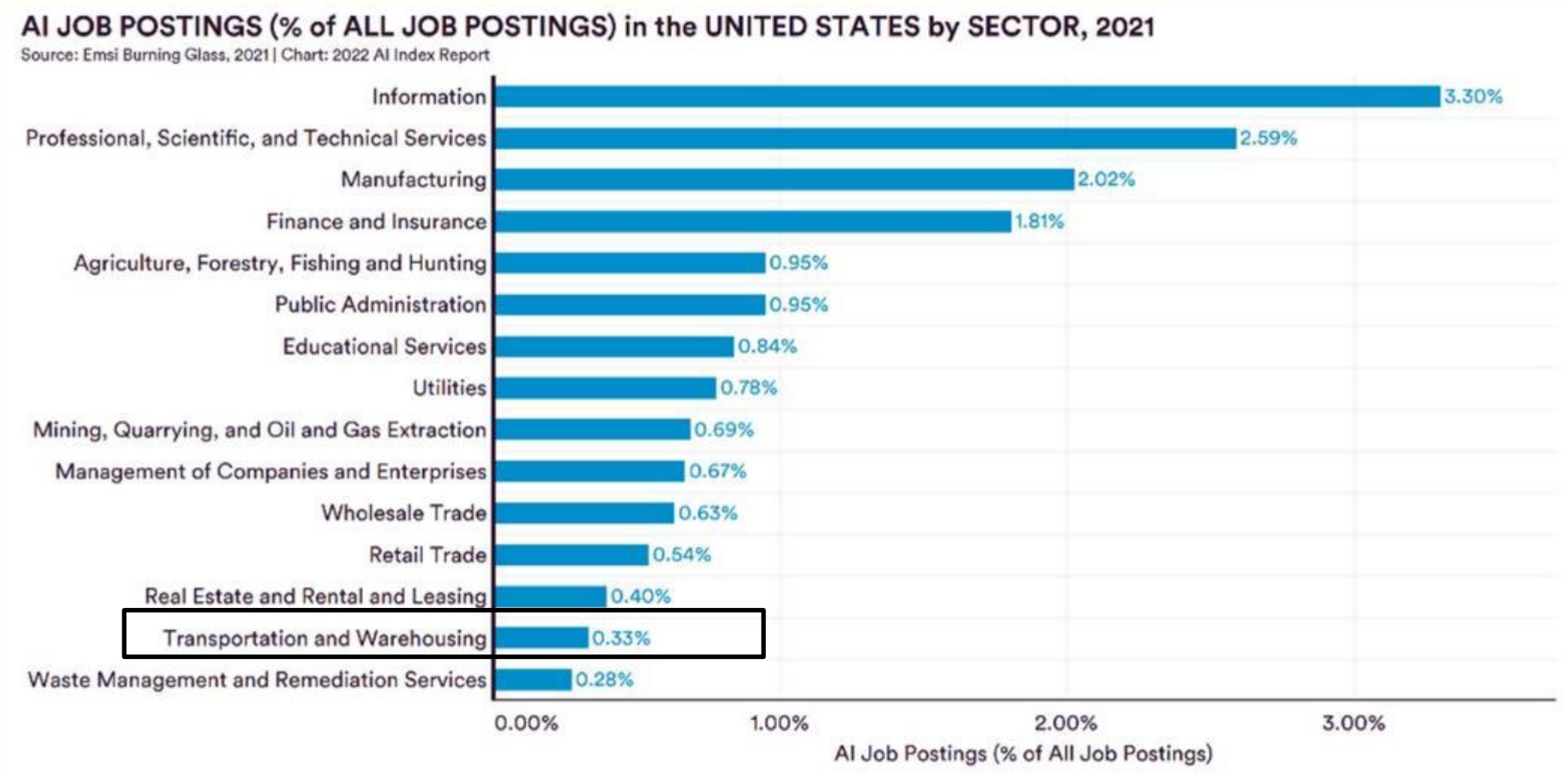
Image source: https://cdn.cnn.com/cnnnext/dam/assets/220505130714-elon-musk-bill-gates-super-169.jpg

Government Has a Role to Play

President Joe Biden issued an executive order on AI that many experts say is a significant step forward on Nov. 2, 2023

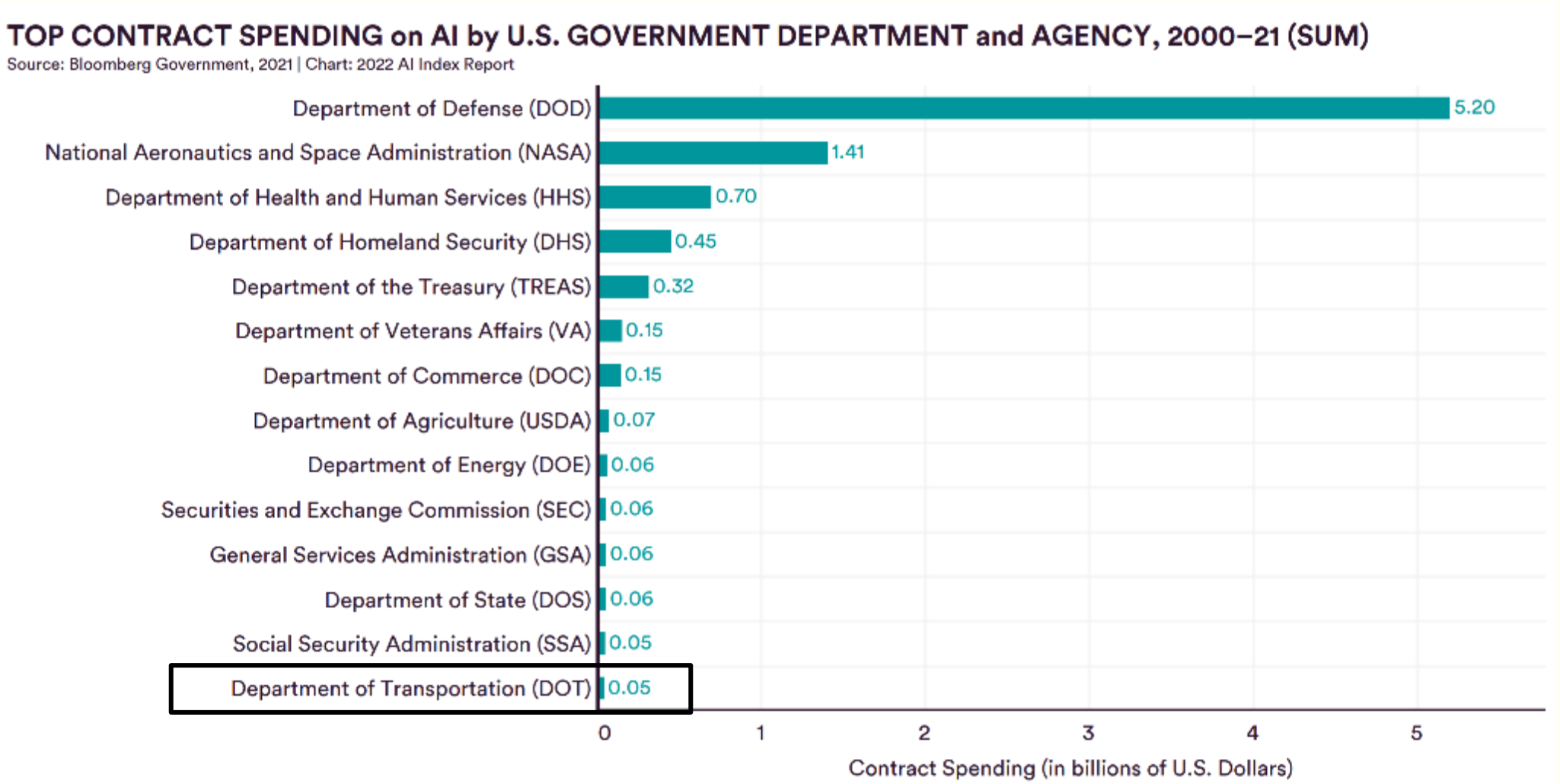
- Civil Rights
- Data Usage and Privacy
- Regulation on AI-Generated Products
- Etc.

Huge Potential for AI & Transportation



https://aiindex.stanford.edu/wp-content/uploads/2022/03/2022-AI-Index-Report_Master.pdf

Huge Potential for AI & Transportation



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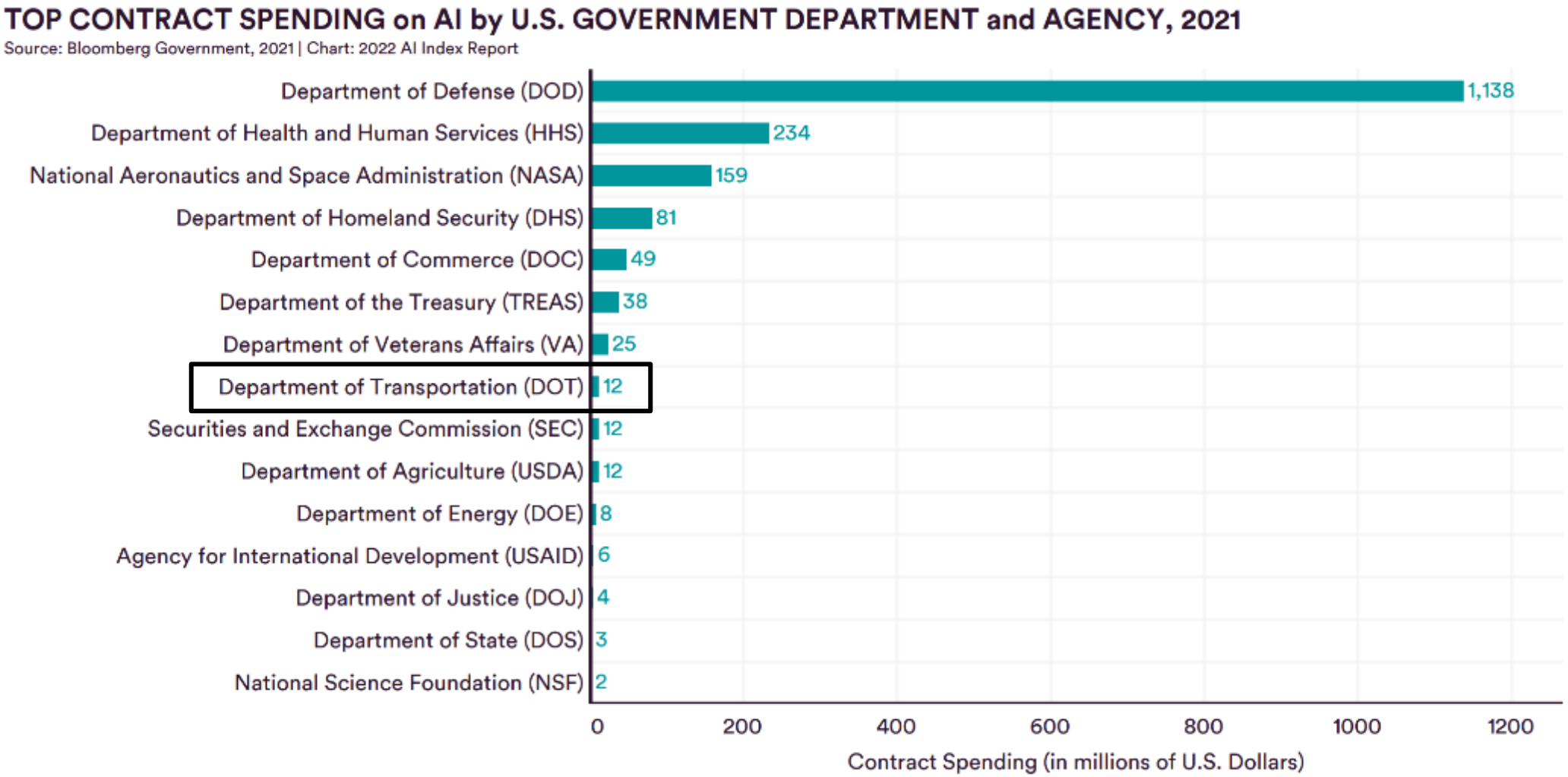
Huge Potential for AI & Transportation



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Thanks for Your Attention!

Let us work together for a safer, greener, more efficient, and more equitable future transportation system!

Yinhai Wang's contact Info: Email: yinhai@uw.edu Tel: (206) 616-2696