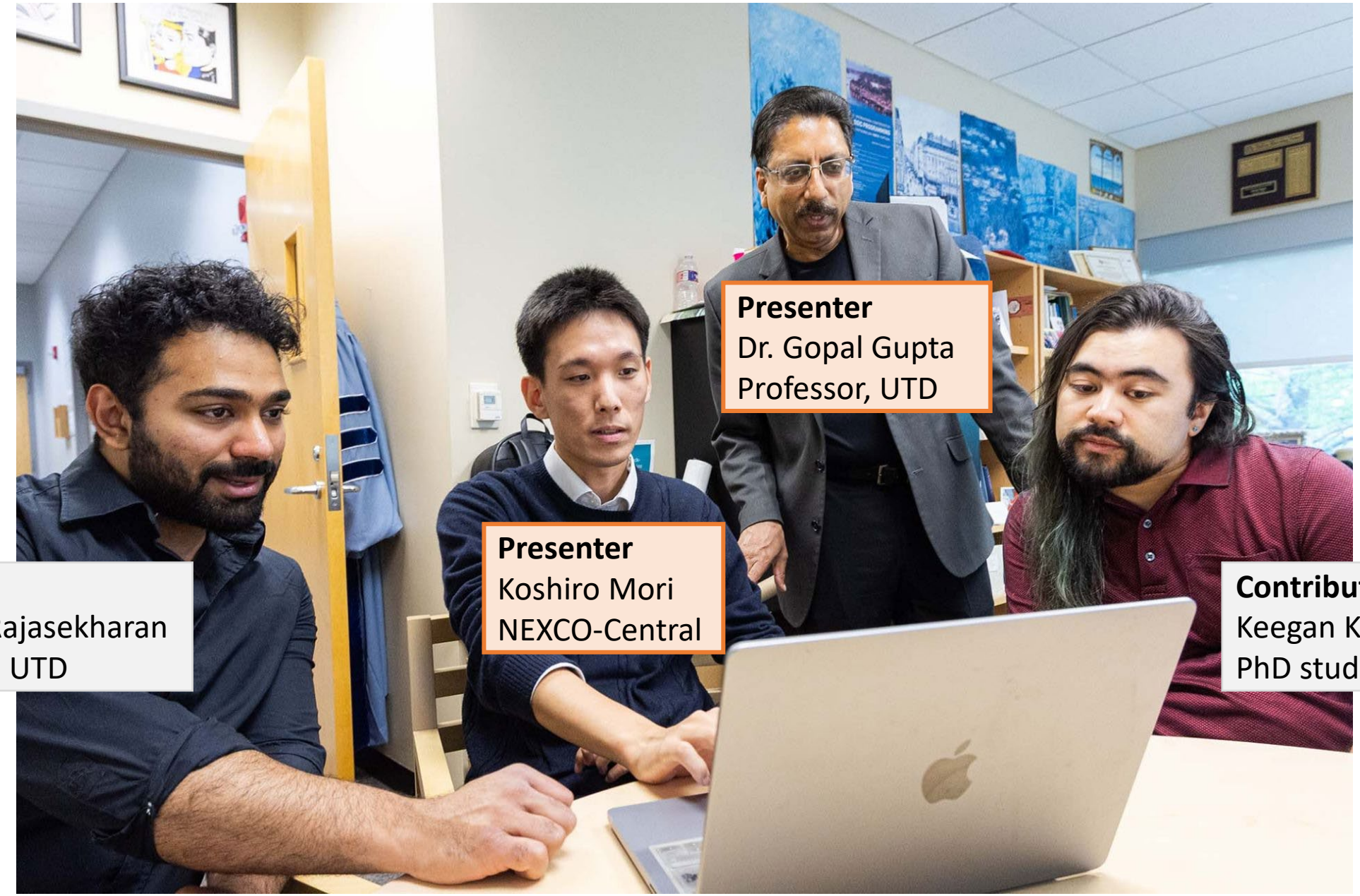
AI-Assisted Pavement Management and Explainable Budget Simulation for Public Works Planning

Nexco Central
and
Center for Applied AI and Machine Learning, UT Dallas

Agenda

1. *Introduction*
2. *AI Technology: A Brief Introduction*
3. *Smart Pavement Management Framework*
4. *Explainable Budget Simulation*
5. *Conclusion*

Project Team



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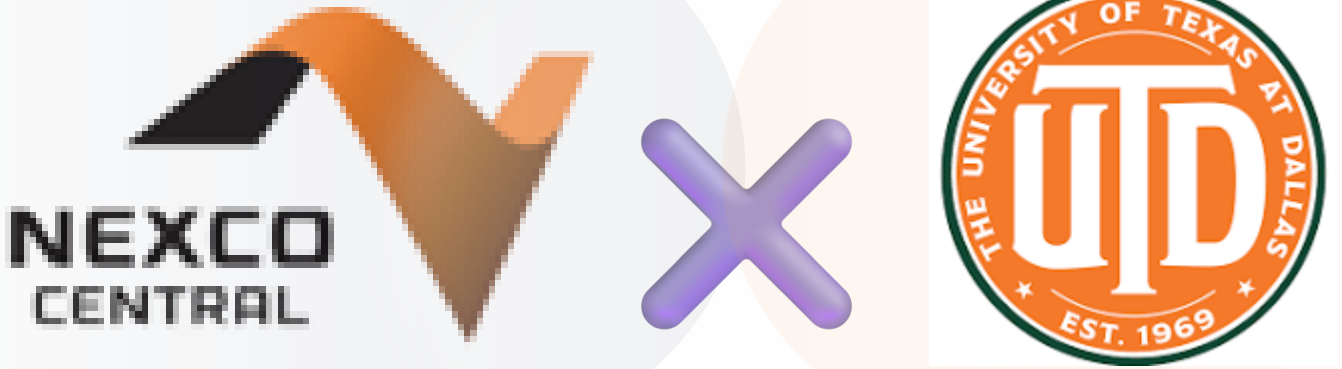
Research Collaboration



- *NEXCO-Central brings*
  - *AI-assisted pavement condition assessment (SPM)*
  - *insight into real road authority priorities and constraints*
- *UTD brings*
  - *AI and data analytics expertise*
  - *Explainable AI expertise*
  - *Decision-support framework development*

→ **Both entities see common benefits in this collaboration and improvements to *society*.**

Agenda

Artificial Intelligence: A Brief Introduction

- Intelligent reasoning by computers has been a goal of computer scientists ever since computers were first invented in the 1950s.
- Intelligence has two broad components:
  - Acquiring or learning knowledge (machine learning)
  - Applying knowledge that is learned (automated reasoning)

  \+ Vision, Speech Processing, Speech Generation, etc., etc.
- AI has been receiving a lot of attention lately:
  - Is AI == machine learning; Is AI == deep learning?
- Pendulum has swung the other way:
  - for the first 40-50 years, AI was equated to automated reasoning
  - more recently AI is equated to machine learning or deep learning (**predictive** ML)
  - Today: AI means LLMs or generative AI (**generative** ML)
- Research on both learning and reasoning started in the 50s.

AI Technologies

What is Predictive Machine Learning?:

- Given background knowledge, positive and negative examples of a concept (training data), goal of machine learning is to learn the general rule or function that captures that concept




+ bird + bird + bird - bird - bird

- Automatically learn the concept of what is a bird
- Supervised learning, unsupervised learning, reinforcement learning

What is Automated Reasoning?:

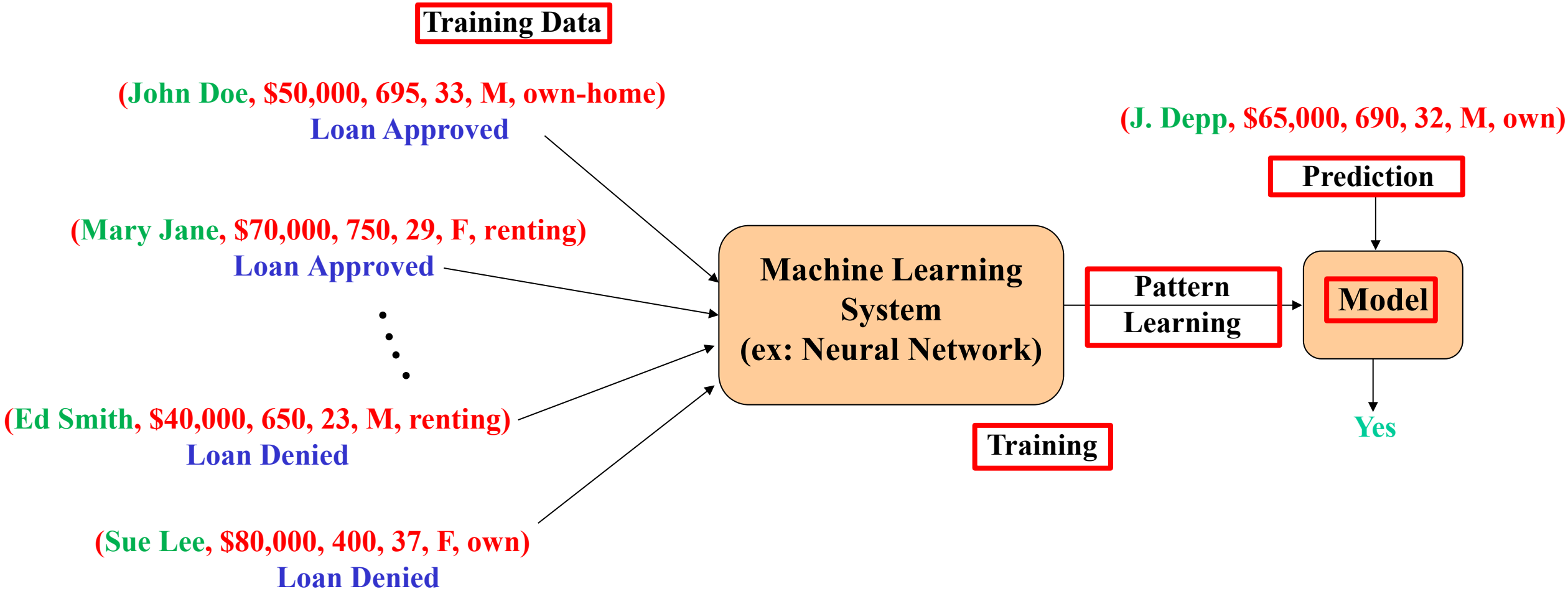
- Given pieces of information (axioms) deduce new knowledge

All humans are mortal Socrates is a human

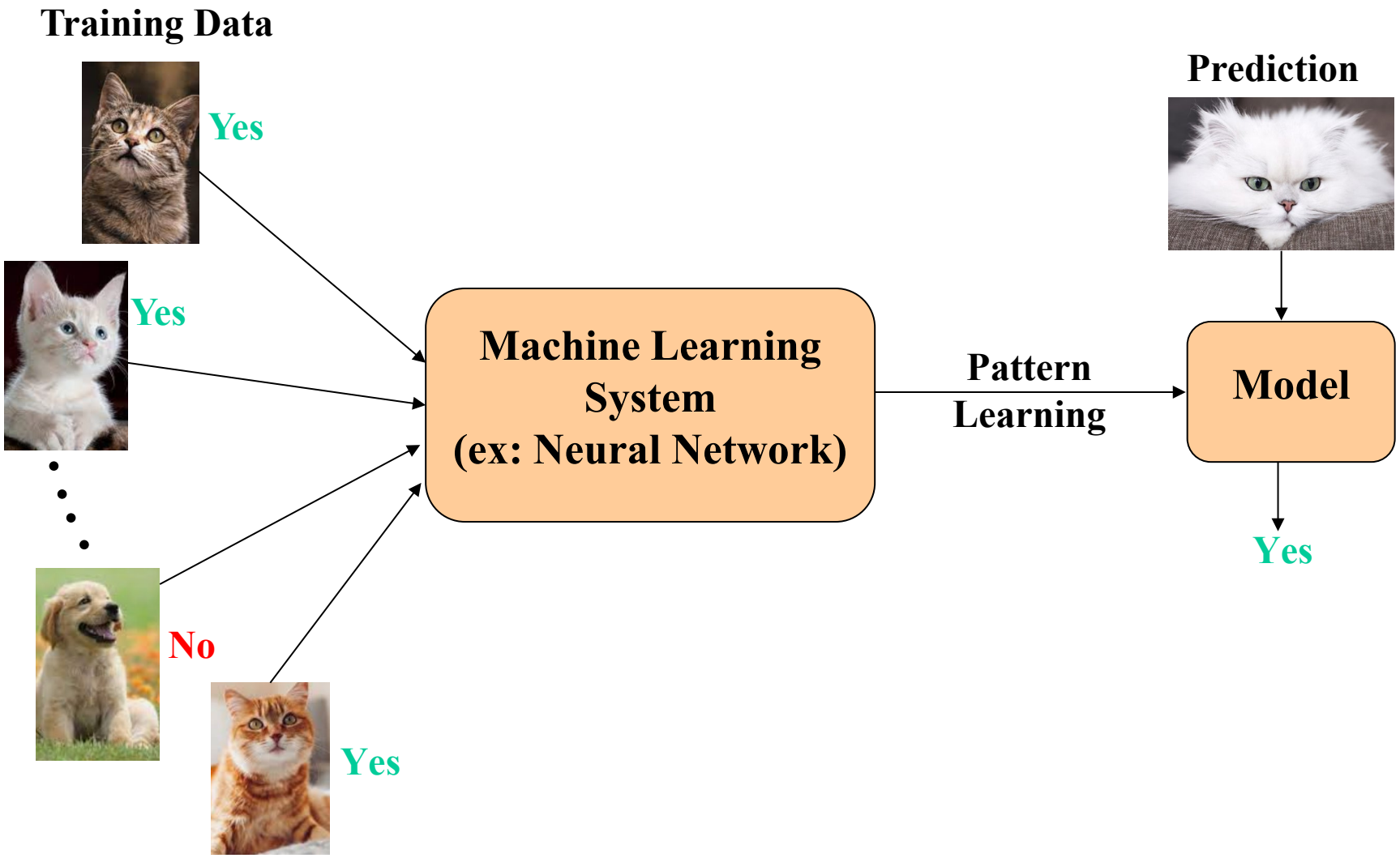
Conclude: Socrates is mortal

Predictive Machine Learning

- Driven by data: data has features and a label



Predictive Machine Learning




6
Πολίτες ΕΕ - ΕΟ
EU – EEA – CH National
Όλα τα Διαβατήρια
All Passports
7


6
5
4
Staff route

Generative ML/AI: Example-driven Search

- Two types of Machine Learning: **Predictive and Generative**
- **Predictive ML**: Given large amount of labeled data, learn the model, which will help us predict the label given a new data record
- **Generative AI**:
  - Datasets consist of large number of sequences of some type of tokens (words, moves, pixels)
  - Given a new partial sequence, use the example sequences to predict the next token
  - Basis of LLM and Generative AI technology
- Example: learning to play chess: learn the patterns of moves
  - Collect millions of chess games; each game is a sequence of moves of black and white pieces
  - To make a move, look at the last 5 moves
  - Find all game traces that contain this 5 moves sequence: say there are 1000 of them
  - Examine the move made after these 5 moves in these 1000 traces
  - Finally, choose the move that leads to a win most often

Generative Machine Learning

- LLMs: Dataset = all documents on the internet
- ChatGPT: Released Nov. 30, 2022; Extension of GPT-3, fine tuned through supervised learning and reinforcement learning using human trainers
  - Reached million users in 5 days; Still a superhot tech.
  - Generates text (poems, articles, essays)
  - Poem about the Marriott chain, its hospitality, etc. →

Marriott, a global dance of light,
A chain that spans both day and night.
From opulent towers to modest doors,
In every corner, a Marriott soars.

In bustling cities, where dreams ignite,
Or tranquil landscapes, bathed in quiet.
A haven for all, budget in hand,
Marriott beckons, across the land.

Service, a melody in each suite,
A promise kept, both warm and sweet.
For every traveler, a tailored grace,
Marriott's embrace in every space.

Worldwide whispers of service grand,
In Marriott's arms, we understand.
From lavish stays to modest retreats,
A symphony of choices, where joy repeats.

- Dall-E 3: A system that will produce art from a natural language prompt:
  - Egyptian painting: arguing over whose turn it is to take out trash

Large Language Models

- ChatGPT can produce text that reads like human-written text
- Quite remarkable!! How does it do it?
  - Given an (incomplete) sentence LLMs try to predict the next word that would reasonably fit
  - Reasonable fit: what someone may write after looking at billions of sentences
  - Consider the sentence: "*The best thing about AI is its ability to...";* predict what word will come what fraction of the time

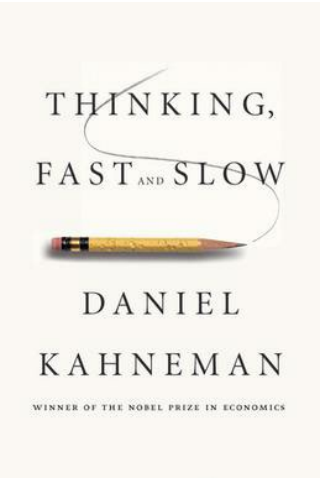
The best thing about AI is its ability to

learn	4.5%
predict	3.5%
make	3.2%
understand	3.1%
do	2.9%

  - LLMs may pick the highest probability word, but it does not always do so;
  - it may pick the 2nd best or the 3rd best word
  - How often to go to lower rank?: temperature parameter

Can LLMs do it all?

- Can machine learning & LLMs achieve AGI or ASI? Can LLMs be trustworthy?
  - **No.** They lack “awareness”, they don’t “know” what they know and what they don’t know
- machine learning == sensing == pattern recognition
  - (non-human) animals are much better at sensing
  - But lack advanced reasoning capabilities video
- Better reasoning capability means higher intelligence
- Two different ways in which brain processes thought: System 1 and System 2
  - Thinking Fast and Slow: Daniel Kahneman (Nobel Prize winner 2011)
  - System 1: intuitive, fast thinking: based on recognizing patterns using our senses
  - System 2: slow/deliberative thinking: based on (commonsense) reasoning
  - “Fast” thinking: obtain sensory input and use our instinct to draw conclusions
  - “Slow” thinking: complex reasoning that is **verifiable/explainable**
  - Automate System 1: ~ Machine Learning
  - Automate System 2: ~ Automated (Commonsense) Reasoning



Commonsense Reasoning

- How to overcome hallucinations of LLMs/GenAI?: Use reasoning as humans do
- Why do computers have trouble in reasoning while humans can reason about things effortlessly? (Human brain uses only 12-20 watts of power)
- Human-style reasoning (system 2) characteristics:
  - We *jump* to conclusions (draw conclusions) in absence of information

    Can't tell if it is cold outside. If I see no one wearing a jacket, it must be warm
  - And revise them if new information becomes available (default rules)

    those people outside are from Norway and can withstand more cold, my conclusion may not hold
  - We do not pursue a line of reasoning if it leads to global inconsistency (integrity constraints)

    One cannot sit and stand at the same time (inconsistency); a living person must breathe (invariant)
  - We can deal with multiple "possible worlds" simultaneously (assumption-based reasoning)

    For example, nemo the fish can talk in the cartoon world, but not in the real world
- Reasoning allows us to check consistency and completeness of observed world

CRUCIAL FOR TRUSTWORTHY, RELIABLE, & EXPLAINABLE AI

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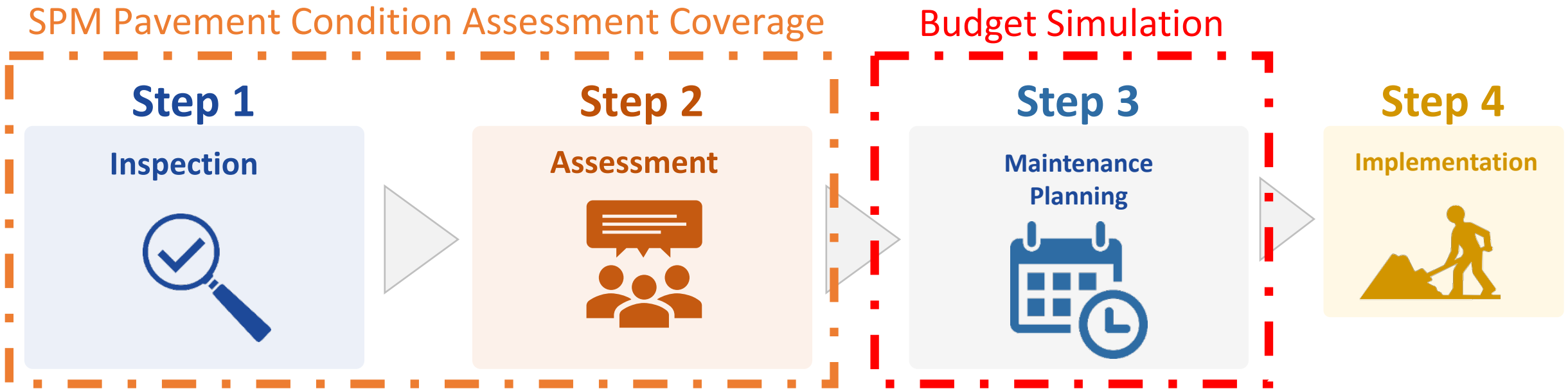
Smart Pavement Management: Overview



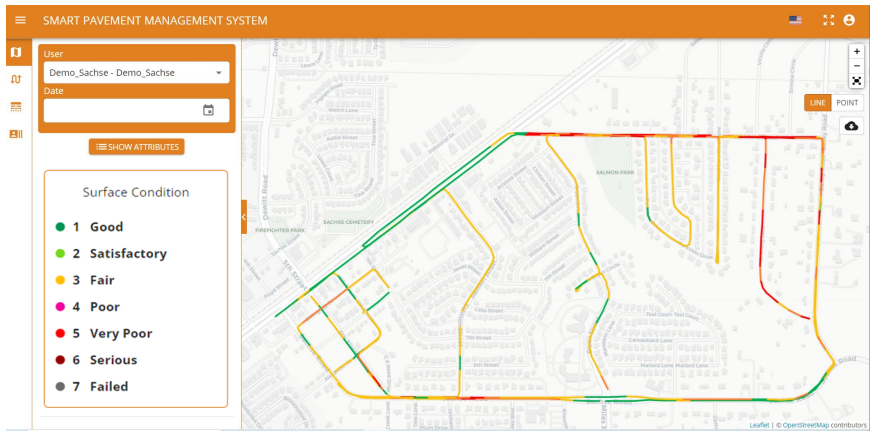
➞ **SPM provides a pavement condition rating. Based on the rating, *the newly developed simulation module supports data-driven maintenance planning by generating recommendations for budget allocation.***

Overview of Smart Pavement Management (SPM)

Smart Pavement Management (SPM): Predictive and Generative ML in Action

A tool to take a snapshot of pavement condition.

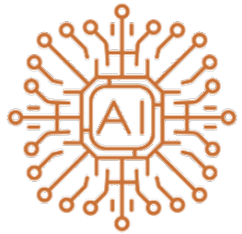
Technology Overview



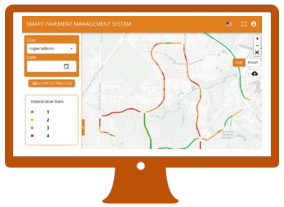
Product Demo

- **SPM provides a 7-tiered pavement condition rating with map display, verified by in-house engineers, that allows for timely, cost-effective analysis.**

Easy Data Collection



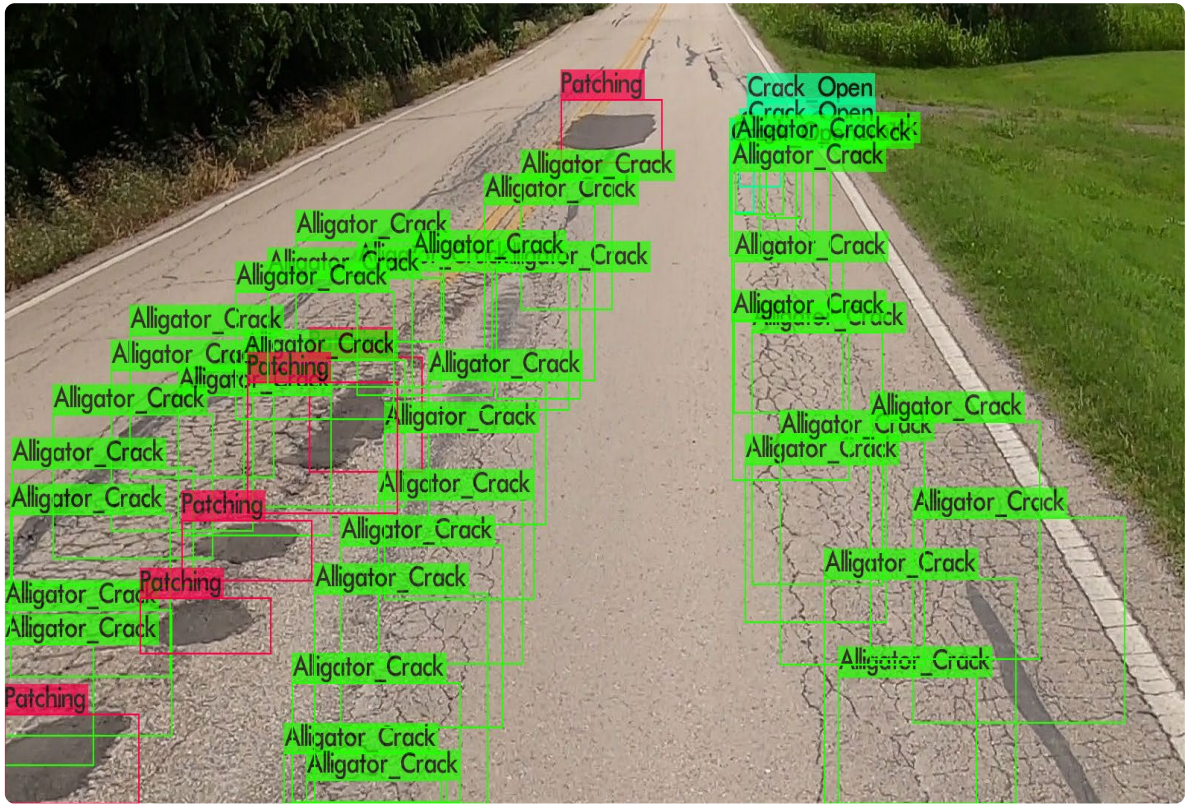
Data Processing with AI and Engineers



Results via Internet

NEXCO's Technology

- Our AI automatically detects pavement distresses and converts them into quantitative condition ratings.



Distress	Alligator Crack	Patching
Number of Rectangles	30	6

100

0

Rating	
1	Good
2	Satisfactory
3	Fair
4	Poor
5	Very Poor
6	Serious
7	Failed

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Project Goal

- The goal of this project was to mimic engineers' manual process in maintenance planning
- Uses commonsense reasoning technology

As - Is

Manually determine repair segments

- Difficult to balance the budget across the network
- Repair decisions depend on planner judgment
- Limited transparency into why a segment was selected

To - Be

Budget Simulation

- Budget systematically allocated across the network
- Repair decisions follow consistent rules
- Clear selection reasons are provided.

Implementation

➢ The budget simulation system distributes available budgets across road categories and recommends repair segments through data-driven prioritization

Input

- Pavement Condition
- Road Attributes
- Available Budget

Budget Simulation

Output

- Optimized Budget Allocation
- Repair Prioritization
- Basis for Recommendations

How Budget Simulation Works

➢ Ensures fair budget distribution while improving repair efficiency.

Step 01

Allocates Budget Across Categories

Calculate budget allocation ratios based on road type, zone type, district composition, or user-defined priorities.

Step 02

Groups Nearby Repair Candidates

Group nearby repair candidates to improve construction efficiency and reduce mobilization effort.

Step 03

Prioritizes Larger Repair Clusters

Fund larger repair clusters first to maximize repair efficiency within each budget category

Step 04

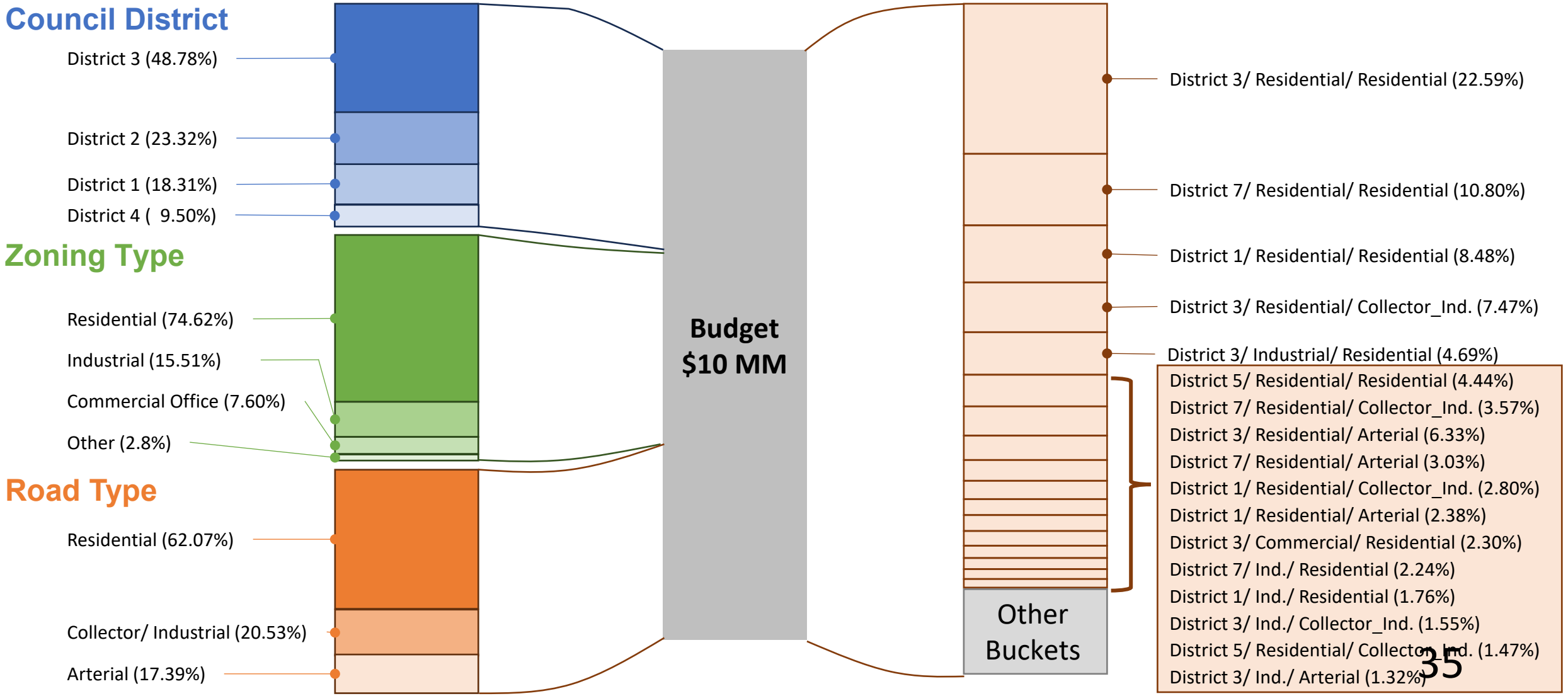
Provides Recommended Segments for Repair

Generate the list of selected segments and provide clear reasons for selection.

Budget Allocation Algorithm

Calculate the distribution of Rating 4 and 5 sections in the three factors

Spread the budget based on the distribution and the cluster analysis



Explainable Repair Recommendations

❑ The system also provides the reason why a segment has not been selected to be repair

VideoDate	Street	7-tier	cluster_id(no. segments)	repair_status	explanation
3/27/2023	Street A	4	CID 8(165 segs)	TRUE	
3/27/2023	Street B	1		FALSE	Segment rating is not in the input rating set.
3/27/2023	Street C	4	CID 127(66 segs)	FALSE	Cluster is too expensive to repair for the initial budget allocated.
3/27/2023	Street D	4	CID 123(37 segs)	FALSE	Cluster priority is too low.
3/27/2023	Street E	4	CID 157(60 segs)	FALSE	Cluster is not selected for repair.
3/27/2023	Street F	4	CID 141(2 segs)	FALSE	Cluster size is less than the minimum cluster size.

➢ Detail of the Explanation

#	Value	Situation
1	Segment rating is not in the input rating set.	The segment is outside the planning target. (In this example, targets are rating 4 and 5)
2	Cluster is too expensive to repair for the initial budget allocated.	The allocated budget is not sufficient to cover the cluster
3	Cluster priority is too low.	The average condition is better than other clusters to be repaired.
4	Cluster size is less than the minimum cluster size.	The segments are scattered and not adequate to be repaired individually.
5	Cluster is not selected for repair.	Other reasons.

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Conclusion

01	**AI technology has many shades: Learning and Reasoning** Automated reasoning essential for reliable, trustworthy, & explainable applications of AI
02	**Pavement management can be automated with AI technology** Both machine learning as well as automated reasoning technology can be applied
03	**Pavement condition can be automatically assessed using AI** Predictive and generative machine learning technology plays a crucial role
04	**Budget optimally allocated under practical constraints using AI** Automated reasoning technology plays a crucial role

Thank you

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