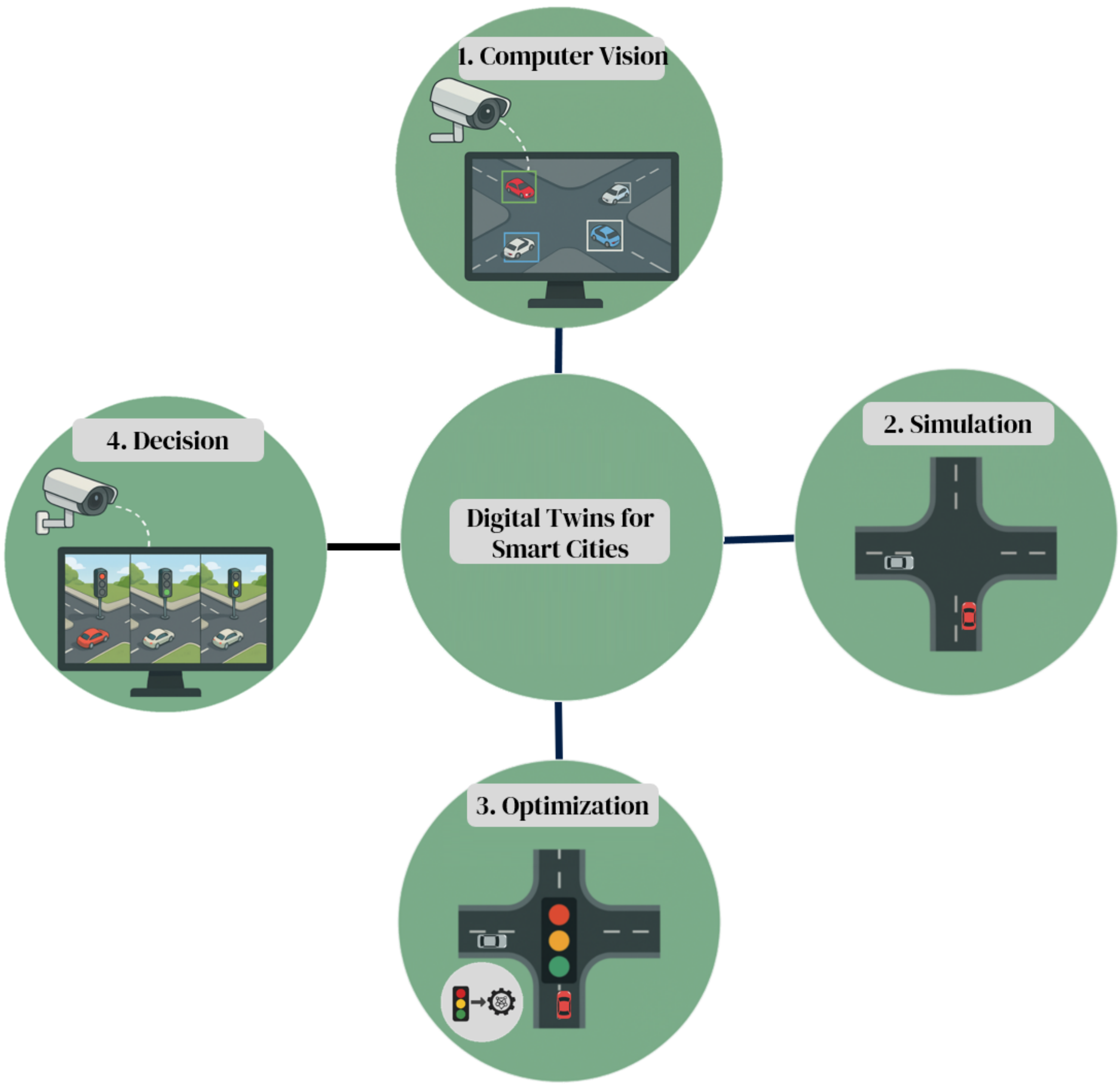
RoadwayVR Course Hub

RWR 4013 Digital Twins for Smart Cities

Course Outline – Fall Term (September - December 2026)

Instructor: Dr. Ahmad Mohammadi

Course Website: View Link



Course Overview

This 12-week course introduces digital twins for smart cities through a practical, project-based workflow aligned with four common layers/phases of a city digital twin:

1. Data Layer (Computer Vision): collect field traffic data from video (detection → tracking → counts/speeds).

2. Model Layer (Simulation): build a digital network and traffic model in SUMO (network → demand → signals).

3. Connection Layer (Optimization): integrate physical and virtual world and evaluate system performance using KPIs (delay, emission, level of service) and test scenarios (signal timings).

4. Service Layer (Decision): choose the most effective scenario and communicate findings through a written project report, a presentation and a project showcase (demo video + website).

Teaching Philosophy

This course is designed using Universal Design for Learning (UDL) principles to ensure all students can access, engage with, and demonstrate understanding of traffic simulation concepts. The course provides:

- **Multiple means of representation:** Presenting the same concepts through text (lecture slides), hands-on (hands-on slides) formats, visual (video tutorial) and self-paced resources (website) to ensure students can access and understand key concepts through approaches that match their learning needs.
- **Multiple means of engagement:** Providing two support channels including Office Hours and Community Learning Platform. These support channels are designed to reduce barriers, accommodate varied learning contexts, and maintain motivation through accessible and timely assistance.
- **Multiple means of expression:** Providing students with opportunities to demonstrate learning through six complementary assessment structure: class participation and discussion, transportation news brief presentations, weekly in-class deliverables, weekly assignments, paper-based midterm with written reasoning, and the design project with professional deliverables (technical report, presentation).

Course Learning Outcomes

By the end of this course, students will be able to:

1. Develop foundational knowledge in digital twins for smart cities, including computer vision, traffic simulation, optimization, and visualization for transportation planning.
2. Collect and process real-world traffic data from video using object detection and tracking to produce counts and speed estimates.
3. Build digital road networks and traffic demand models using open-source tools (SUMO, QGIS) and standard modeling practices.
4. Test and compare transportation scenarios (e.g., signal timing alternatives) and evaluate performance using key metrics (delay, emissions, level of service).
5. Diagnose model mismatches between the physical and digital worlds, propose calibration actions, and justify validation decisions using evidence.

6. Communicate technical findings to diverse audiences through professional reports, visualizations, presentations, and a project showcase (demo video + website).

12 -Week Course Structure

Week	Topic (Lecture + Hands-on)	Materials
1	**Introduction to Digital Twins for Smart Cities** **Lecture:** What is a Smart City? What is a Digital Twin? The 4 Stages of a Digital Twin; Course syllabus overview (in one shot); Course learning outcomes; **Hands-on:** Fundamentals of computer vision; What is an image? Pixel data; Resolution; What are videos? Convolutional Neural Networks (CNNs); What is convolution?	Lecture Slides Hands-on Slides Video Tutorial
2	**Computer Vision I (Object Detection)** **Lecture:** Neural networks; Convolutional Neural Networks (CNNs); The 3 stages of a CNN; The 6 steps of object detection using a CNN; Step 1: Study area and video recording; Step 2: Frame extraction & dataset creation; Step 3: Image annotation & class definition. **Hands-on:** Step 4: Dataset partitioning (train/validation/test); Step 5: YOLO Trainer; Step 6: Understanding the results.	Lecture Slides Hands-on Slides Video Tutorial
3	**Computer Vision II (Object Tracking)** **Lecture:** Object detection vs. object tracking; Bird's-eye view (homography); Multi-object tracking (ByteTrack); Supervision (Roboflow); SimJamComputerVision; Object detection and tracking using SimJamCV. **Hands-on:** Real-world data collection to support planning projects; Lakeview Village Redevelopment Project; Example observed traffic counts; Turning movements and turning-movement counts table; Object detection and tracking using SimJamCV.	Lecture Slides Hands-on Slides Video Tutorial
4	**Introduction to Traffic Simulation** **Lecture:** What is traffic simulation?; purpose of traffic simulation; examples of traffic simulation studies; simulation of urban mobility (SUMO); road network development; vehicle characteristics; vehicle dynamics; car-following and lane-changing models **Hands-on:** Install simulation of urban mobility (SUMO); set up SUMO environment variables; install Notepad++; SUMO files and user interface; create a simple network with traffic flow; add opposite traffic flow; intersection—unsignalized; intersection—signalized.	Lecture Slides Hands-on Slides Video Tutorial
5	**Digital Road Network Modelling with GIS** **Lecture:** What is spatial data?; what is GIS and the seven steps of GIS?; GIS as a foundation for traffic simulation; GIS software types; desktop GIS comparison; GIS data layers for simulation; network elements required for simulation **Hands-on:** Network modelling with GIS; GIS software; download and install QGIS software (open source and free); map services; imagery map and georeferencing; import a GIS map into simulation.	Lecture Slides Hands-on Slides Video Tutorial
6	**Digital Road Network Development** **Lecture:** Edge vs. junction; Junction types; Download materials and import a GIS map into simulation (NetEdit); Create a road network on top of a GIS map. **Hands-on:** Lane connections; Right of way; Traffic signals; Traffic flows (demand).	Lecture Slides Hands-on Slides Video Tutorial
7	**Simulation Calibration** **Lecture:** Accurate road network development; Accurate traffic signal timing; Traffic movement calibration; Traffic volume calibration; Traffic speed calibration. **Hands-on:** Traffic movement/volume/speed calibration.	Lecture Slides Hands-on Slides Video Tutorial
8	**Midterm (Paper-Based): Physical vs. Digital World Reasoning** **In-class assessment (no computer):** A paper-based exam including fundamental concepts and printed figures/tables from computer vision (object detection results,	

	object tracking results) and simulation (volumes/speeds, SUMO snapshots, and mismatch plots). Students will: • Answer conceptual questions on digital twins and smart cities concepts. • Answer conceptual questions on real-world data collection using computer vision, object detection, and object tracking. • Answer short conceptual questions on digital-world traffic simulation, including the purpose of traffic simulation and digital road network modelling with GIS. • Interpret outputs and identify likely sources of mismatch (computer vision vs. simulation). • Propose specific calibration actions (what to change and why).	
9	**Optimization** **Lecture:** Common types of intersection control; identify the types of intersection control; traffic light history; traffic signal technology; traffic signal planning; types of signal control; signal phasing; case studies in traffic signal planning. **Hands-on:** Functional and physical areas of an intersection; key performance indicators (KPIs); from delay to level of service (LOS); optimization.	Lecture Slides Hands-on Slides Video Tutorial
10	**Decision I (Communication & Presentation)** **Lecture:** Select best signal timing strategy (result interpretation: KPIs; result interpretation: signal timing); create a professional presentation (visualization of results; presentation preparation). **Hands-on:** Video demonstration.	Lecture Slides Hands-on Slides Video Tutorial
11	**Decision II (Write a Formal Technical Report)** **Lecture:** Structure; study goal and objectives; writing tips (formatting); writing tips (writing style & clarity); writing tips (referencing). **Hands-on:** Final project website + demo video + screenshots + KPI tables/plots; final project presentations.	Lecture Slides Hands-on Slides Video Tutorial
12	**Presentation Week** **Lecture:** Student presentations. **Hands-on:** Student presentations.	Lecture Slides Hands-on Slides Video Tutorial

Course Assessment

Activity	Type	Frequency	Weight	What It Evaluates
Class participation	Participation	Weekly	5%	Active engagement, peer learning, professional communication
In-class deliverables	Progressive	Weekly	15%	Technical skills application, immediate feedback on modeling
Transportation News Brief presentation	Communication	Once per student	10%	Ability to analyze current events and present to peers
Assignments	Practice	Throughout term	10%	Concept reinforcement, preparation for midterm
Midterm examination (paper-based)	Summative	Week 8	25%	Conceptual understanding, calibration reasoning without software
Design project	Applied Project	Cumulative	35%	End-to-end planning workflow, professional deliverables

Optional Course Materials

1. University of California, Berkeley. Course Materials [CS180/280A: Intro to computer vision and computational photography] (Fall 2025): https://cal-cs180.github.io/fa25/

2. Wunderlich, K., Vasudevan, M., & Wang, P. (2019). Traffic analysis toolbox (FHWA-HOP-18-036). FHWA. Access: https://ops.fhwa.dot.gov/publications/fhwahop18036/fhwahop18036.pdf

3. Tao, F., Zhang, M., & Nee, A. Y. C. (2019). Digital twin driven smart manufacturing. Academic press.

Prerequisites

No prior computer vision or traffic simulation experience required. Students should have:

- Basic understanding of transportation concepts (traffic flow, intersections, signals)
- Comfort with software installation and learning new tools
- Willingness to engage with technical material

Recommended background: Urban planning, Transportation planning or related field. Students from other disciplines (policy, design, data science) are welcome with instructor permission.

Student Support and Accessibility

Office Hours: By appointment via email (AhmadMohammadi1441@gmail.com) - flexible scheduling available to accommodate work/study commitments. Virtual meetings available.

Discord Community: Join our course Discord (https://discord.gg/8kPaECVzJY) for:

- Continuous support for Q&A (24-hour response time)
- Peer learning and study groups
- Archived resources and troubleshooting tips
- Community support outside scheduled hours

Accessibility: Students requiring accommodations should contact [Accessibility Services office] as early as possible. Course materials are provided in multiple formats (slides, videos, hands-on) to support diverse learning needs.

Technical Support: All required software (SUMO, QGIS) is free and open-source. Installation tutorials and troubleshooting guides provided.