Creating a Digital Twin of the VCI highway from inductive-loop data

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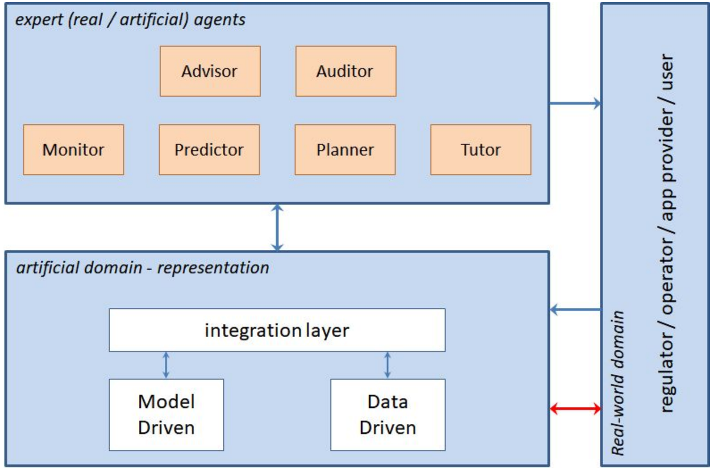
Context

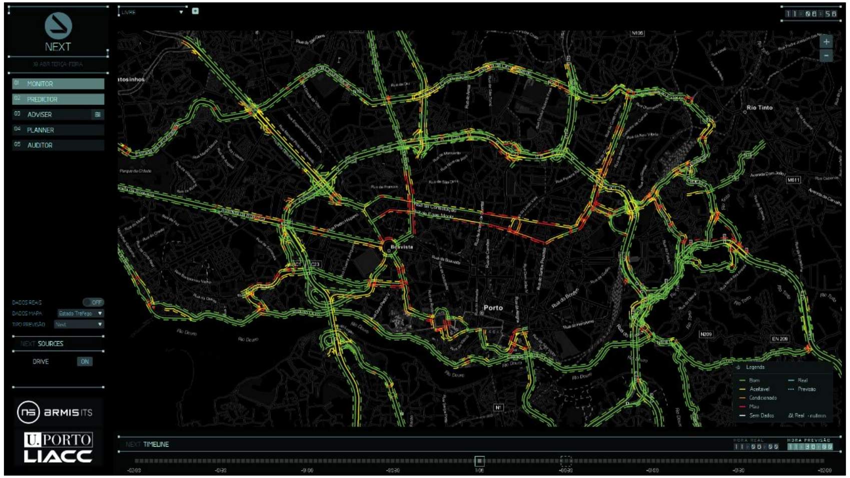
The **Via de Cintura Interna** (VCI) highway in Porto has been encountering issues, such as traffic congestion and accidents.

This work will be done in collaboration with the company ARMIS, namely with its Intelligent Transport Systems module.

ARMIS developed the platform *Next*, intended for monitoring, managing and planning urban networks through intelligent traffic control, which applies the concept of artificial transport systems.

Hereupon, this dissertation intends to improve this platform.





Problem

The primary goal of this work is the creation of a **Digital Twin** (DT) of the VCI highway.

ARMIS will provide direct access to data from inductive-loop detectors underneath the VCI pavement, which will be used to calibrate the digital model in real-time.

The problem with fixed detectors is their limited network coverage.

In regions without sensors, information is scarce or poor, making it difficult to precisely replicate the entire VCI network digitally.

Motivation

Integrating DTs in intelligent transportation helps increase decision-making execution, safety, and vehicle stability, beyond expediting smart and safe driving.

This dissertation intends to complement the *Next* platform with a VCI Digital Twin (DT).

This integration makes the system more reliable, reducing discrepancies between simulated and real values.

This study will be highly valuable for the ITS field and for spreading the notion of DT in this industry.

Goals

This dissertation has two primary goals:

- Development of a Digital Twin of the VCI highway
- Analysis of data generation techniques in places devoid of sensors

In order to achieve the goals indicated above, the following specific objectives need to be fulfilled:

- ➢ Study of the theme's relevant topics and presentation of its state-of-the-art;
- ➢ Scrutiny and processing of data from sensors;
- ➢ Development of a VCI Digital Twin using the microscopic traffic simulator SUMO;
- ➢ Model validation through comparison with sensor data;
- ➢ Data generation in highway locations devoid of sensors;
- ➢ Incorporation of produced data in the DT and respective validation.

In addition to generating a solid dissertation document, the developed work must be valuable to ARMIS.

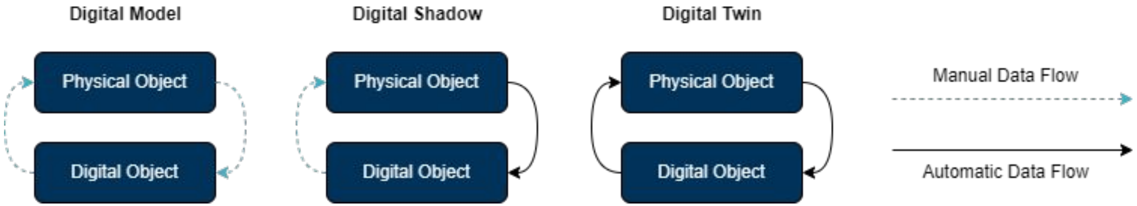
State of the art: Definition of Digital Twin

The meaning of this term has varied over time to reflect new applications. Due to the ever-changing definitions, there is a degree of uncertainty around the terminology, making it challenging to describe. The promising future of this technology requires a more definitive definition.

[1] conducts an exhaustive systematic literature review on Digital Twins, seeking to narrow down the meaning of this concept, defining it as follows:

“A set of adaptive models that emulate the behaviour of a physical system in a virtual system getting real-time data to update itself along its life cycle. The digital twin replicates the physical system to predict failures and opportunities for change, prescribe real-time actions for optimizing and/or mitigating unexpected events by observing and evaluating the operating profile system.”

The uncertainties about this term result in some fallacies by some authors. [2] presents three definitions that help identify the general misconceptions in the literature:



[1] Semeraro, Concetta, Mario Lezoche, Hervé Panetto, e Michele Dassisti. «Digital Twin Paradigm: A Systematic Literature Review». *Computers in Industry* 130 (1 de setembro de 2021): 103469.
[2] Fuller, Aidan, Zhong Fan, Charles Day, e Chris Barlow. «Digital Twin: Enabling Technologies, Challenges and Open Research». *IEEE Access* 8 (2020): 108952–71.

State of the art: Challenges of Digital Twins

DTs coexist alongside AI and IoT technology, resulting in shared difficulties. The most significant challenges of this technology are:

- The limitations of the present IT infrastructure;
- The need for high-quality noise-free data from a continuous, uninterrupted stream;
- Privacy and security issues;
- Trust difficulties;
- High expectations of this tool;
- Absence of a standardised modelling methodology;
- Ensuring that information relating to domain use is conveyed to each development and functional level of DT modelling.

State of the art: Data Sources

DTs must perceive the current state of the physical entity by collecting the surrounding environmental information and communicating it in real time to the virtual model system.

[3] grouped available data into three broad types:

- **Static observations:** real-time information obtained in fixed locations in the network, e.g. from induction loops or surveillance systems;
- **Route observations:** usually obtained from GPS-enabled vehicles, smartphones or traffic operators;
- **Global observations:** usually obtained from a secondary source, like weather reports or special events.

When incorporating this information into the system, its uncertainty may also require assessment, especially when using data from unreliable sources like smartphone usage.

It is important to emphasize that this work will be based on static observations.

[3] Barros, Joaquim, Miguel Araujo, e Rosaldo J. F. Rossetti. «Short-term real-time traffic prediction methods: A survey». *International Conference on Models and Technologies for Intelligent Transportation Systems*, 2015.

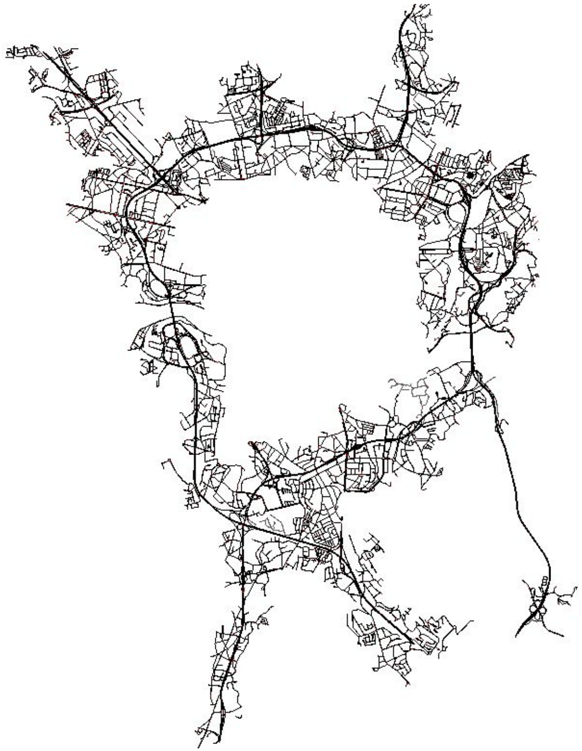
Methodology (I) - Map Cleaning

A descriptive model of the VCI is already being constructed, and it will be incorporated into the DT.

The first step is to obtain a representation of the VCI vehicular network. For this, a highway map was obtained from OpenStreetMap, proceeding with the conversion into a SUMO network.
However, the representation also contained unnecessary information, which could harm the model's behaviour.

Thus, the map was cleaned, following the steps below:

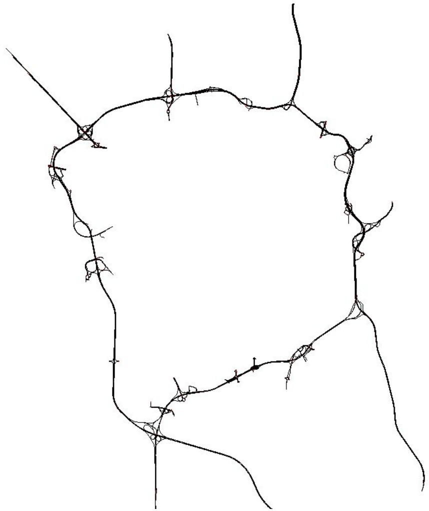
1. Use **netconvert** script to remove unnecessary lanes (train, pedestrian, etc.);
2. Remove non-VCI roads from the map using NETedit;
3. Use once again **netconvert** script with argument **--remove-edges.isolated true** to remove dangling nodes and isolated edges;



Methodology (II) - Creating the OD matrix

An OD matrix denotes a map's possible origin/destination points. An automatic way of recognising these points is needed, implemented as follows:

1. Created a new version of the map where only the VCI roads remain.
2. Created a script that analyses every node of the map:
   a. It is an entry node if it contains at least one outgoing edge but no incoming.
   b. It is an exit node if it contains at least one incoming edge but no outgoing.



The edges exiting the VCI are the **destination edges**, and the edges entering the VCI are the **origin edges.** In total, there were 858 origin/destination pairs.

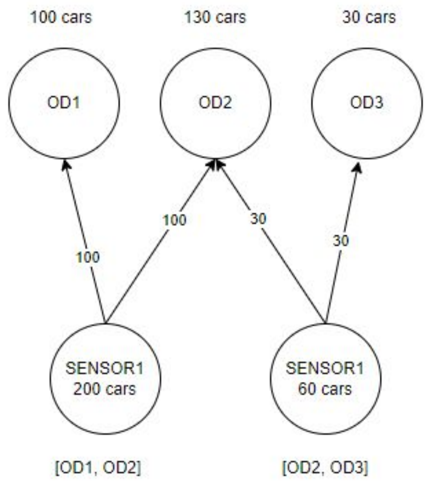
Methodology (III) - Preparing the simulation

Each OD pair is assigned a given number of vehicles, which will trace their route based on that origin and destination.

The next step involves defining a maximum case that would serve as a starting point for the optimisation. Each sensor has a specific number of routes that pass through it. With this, and knowing the total volume of cars that pass by each sensor in a given time, it is possible to equally distribute this value by the several OD pairs whose routes pass through that sensor.

After this, we can define scenarios based on the percentage of cars leaving each OD. For instance, scenarios where 25%, 50%, 75% and 100% of that initial number of cars are present.

The flow resulting from each scenario will now have to be compared to the actual flow.



Methodology (IV) - Calibrating the model

To obtain the data from the simulation, it is necessary to add sensors to SUMO based on the positions of the inductive-loop detectors.

In real life, a single sensor measures traffic in both directions. In the simulation, a sensor is needed for each lane. Therefore, it was necessary to carry out further processing to group these data in both directions to compare them.

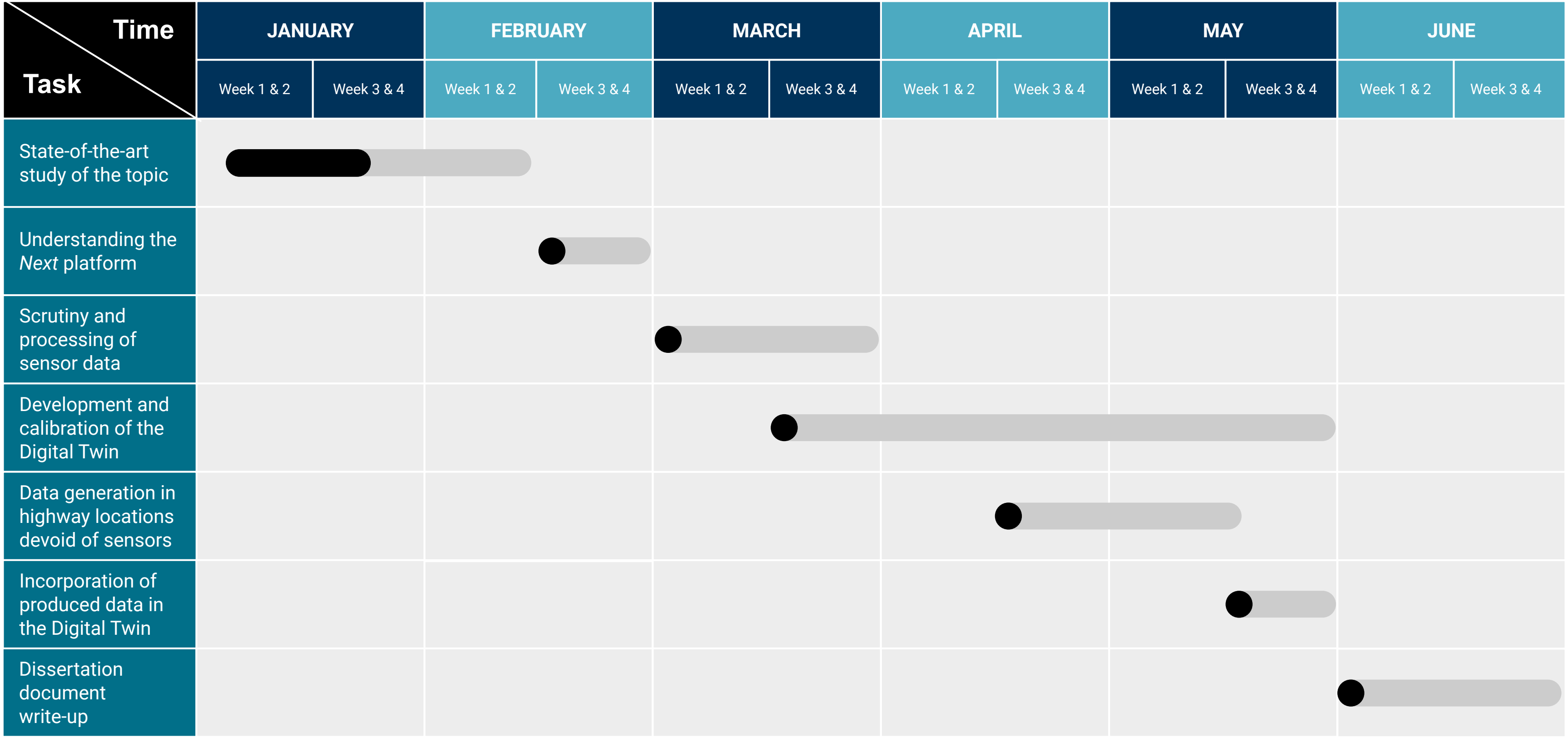
Inductive-loop detectors provide several metrics, like the total volume of cars that entered and left the sensor road during the observation, the arithmetic average speed and the harmonic average speed.

We can calculate an error to compare the real and simulated data. The smaller this error is, the closer our model is to the actual behaviour of the VCI highway. A reasonable option is the mean absolute error since this measure is less sensitive to outliers, which are very frequent in inductive loop data detectors, due to the difficulty of obtaining accurate and noise-free data from the sensors. This error is given by:

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n}$$

n = number of observations;
y = real sensor values;
x = SUMO sensor values;
e = difference between both values.

Work Plan


Time
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JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
Week 1 & 2
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State-of-the-art study of the topic
Understanding the *Next* platform
Scrutiny and processing of sensor data
Development and calibration of the Digital Twin
Data generation in highway locations devoid of sensors
Incorporation of produced data in the Digital Twin
Dissertation document write-up

SWOT Analysis

S — Strengths

- ARMIS interest
- Practical application
- Scientific and modern nature
- Considerable amount of sensors along VCI

W — Weaknesses

- Only one type of data source
- DT only concerns the VCI highway
- Missing or poor data in regions devoid of sensors

O — Opportunities

- Modernization of traffic control systems
- Introduction of DT concept in ITS
- Improvements in speed and quality of data collection

T — Threats

- Difficulties in obtaining accurate data
- Hard understanding of the *Next* platform
- Non-compliance with established deadlines

SMART Analysis

S	M	A	R	T
SPECIFIC	**MEASURABLE**	**ACHIEVABLE**	**RELEVANT**	**TIME BOUND**
Build a reliable Digital Twin for the VCI highway, carefully addressing locations without sensors.	Obtain a negligible error, both in model calibration and in the generation of synthetic data.	Validate the Digital Twin by using real-time data provided by ARMIS.	Besides ARMIS interest, it will contribute to the promotion of the term Digital Twin in ITS.	Complete Digital Twin development and incorporation of synthetic traffic data by June.