Intelligent Transportation Systems ITS - II

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Contents

ITS for Smart Mobility

Context

Traffic congestion on urban roads is a problem of great interest nowadays since it strongly affects security and pollution. Workfoce centralization, population and economic growth alongside with continuous urbanization are the main causes of traffic congestion. As cities strive to update/expand the current infrastructures the development of Information Technologies bring new possiblities as an alternative solution for transportation systems.

The current project aims to explore some of the new technologies used in the so called Intelligent Transportation Systems (ITS). They objective is to study to a certain level of detail some of the new traffic management systems that will conduct new ways of transportation in the XXI century. The general idea is based on the fact that information collected by sensors within traffic networks or in-vehicles sensors can collect information regarding the traffic condition, perform estimation of unknown traffic states and decide on specific actions to modify this state.

Projects

Specially, in this case the project will be focused in four main activities:

- **Trafic signal design:** This projects aims to study how to optimally deal with the design of light cycles to optimize the traffic performance. Based on information collected by infrastructure

Figure 1: New connected vehicles https://pixabay.com.

based sensors the traffic state can be determined and specific decisions in terms on green/red light times can be dynamically adapted.

- **Vehicle Platooning:** New in-vechicle sensors create situations in which vehicles may exchange information to improve traffic conditions. This project aims to study control algorithms implemented in the V2V (Vehicle-vehicle) communication layer that can be used to design traffic decisions.
- **Density reconstruction:** Sensors installed in traffic infrastructures provide information regarding the traffic state. Nevertheless the solution is not scalable to cover large cities due to the economical leverage required to deploy this technology. Algorithms to reconstruct traffic information may provide a promising future for accurately determine the traffic state of a city. The aim of this project is to study how multiple sources of information can be integrated to reconstruct traffic variables within a city.

General Objectives

- Identify new technologies implemented in the Intelligent Transporation Systems and investigate how these technologies are deployed in real systems.
- Define and determine adequate models that are suitable for deploying new ITS technologies.
- Develop specific solutions for ITS that can be tested under pre-defined scenarios.

Project information

Deliverables

The project is mainly composed in 3 phases.

1. **Problem identification & literature review:** This phases consists in:
    1. Identify particularly the problem under study, meaning the system to be controlled and the way it is assesed.
    2. Retrieve bibliographical information about the problem under study.
    3. Summarize the already proposed alternatives in the existing literature.

    The main objective of this phase is to understand what are the main challenges when solving the specific project under study and to present in general ways how this problem has been solved.
2. **Setting up a suitable model:** Once the problem has been identified the main objective is to precisely describe the traffic models that are suitable for the approach. For this phase the stages are divided as:
    1. Determine a specific traffic model that can be used for the corresponding situation
    2. Define the scenario in which the solution should be tested
    3. Pre establish parameters and requirements for the solution to be implemented.
3. **Experimental results:** Finally, the main objective is to perform a validation and solution for the problem under study. Several tools are provided for this purpose like micro/macro

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Reporting

In order to fullfill the requirements for each phase each group should provide a report as follows:

- *Report 1:* Summarizes the results of the 1. Problem identification & literature review and 2. Setting up a suitable model. (***Due date: January 9th, 2018***)
- *Report 2:* Summarizes the results of the phase 3.Experimental results (***Due date: January 23rd, 2019***)

Project 1: Signalized Traffic

The main objective of this project is to design *traffic light signal* controls in order to optimize particular traffic conditions. Traffic signals regularly pre-establish fixed values *red* or *green* for a particular intersection. In fact the behavior can be modeled as:

The relationship between the switched green/red time in a traffic light can be represented by a pulse signal (Figure 2). The red line in the figure represents the *duty cycle* which represents the fraction of time the light was in green (1) with respect to the total cycle time ($60s$). In this case, the main objective is to study traffic models that can model signalized intersections and design control laws.

Objectives

The main objective of this project is to:

1. Study the fundamental aspects of traffic signal control strategies.
2. Obtain and simulate a macroscopic traffic model for a urban network with traffic signals
3. Create and design control strategies applied via traffic signals in urban traffic networks.
4. Compare the behavior of fixed-time traffic signal polices and dynamic-time traffic signal polices.

Description

Task 1: Modeling

Check models for macroscopic networks: (Grandinetti, Canudas-de-wit, and Garin 2015), (Grandinetti, Garin, and Canudas-de-wit 2015),(Varaiya 2013). Determine the parameters required to model a road traffic network.

Context

Before implementing a real scenario in this phase we aim to describe the context of a virtual example. Consider the following traffic urban corridor which obeys a simplified version of the real arterial scenario.

The network of Figure 3 represents a regular corridor in a city like. The priority for this type of corridors is to maximize the priority of green time so the traffic does not get congested along the network. It is important to highlight that for the proposed network

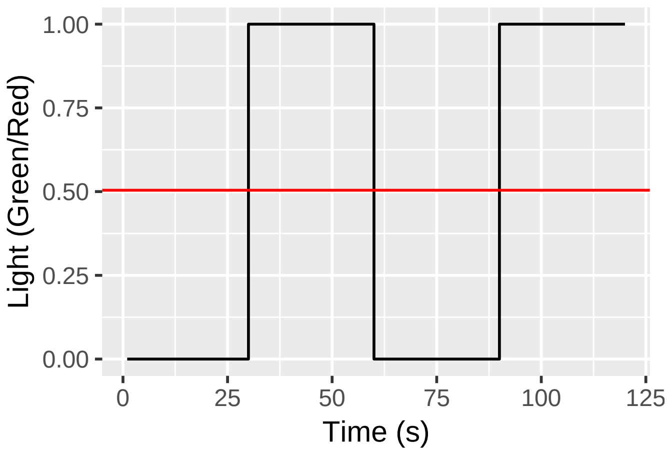

Figure 2: Traffic light signal example.

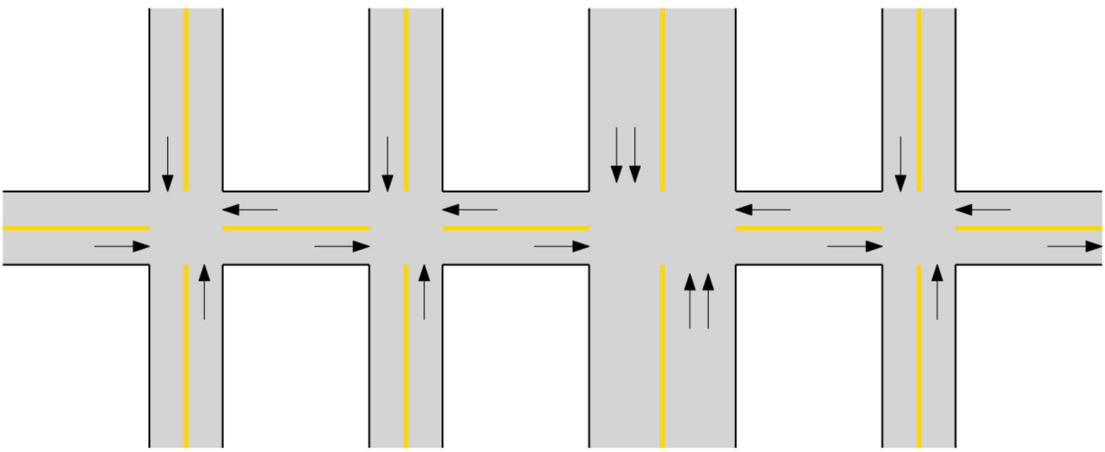

Figure 3: Example of traffic network.

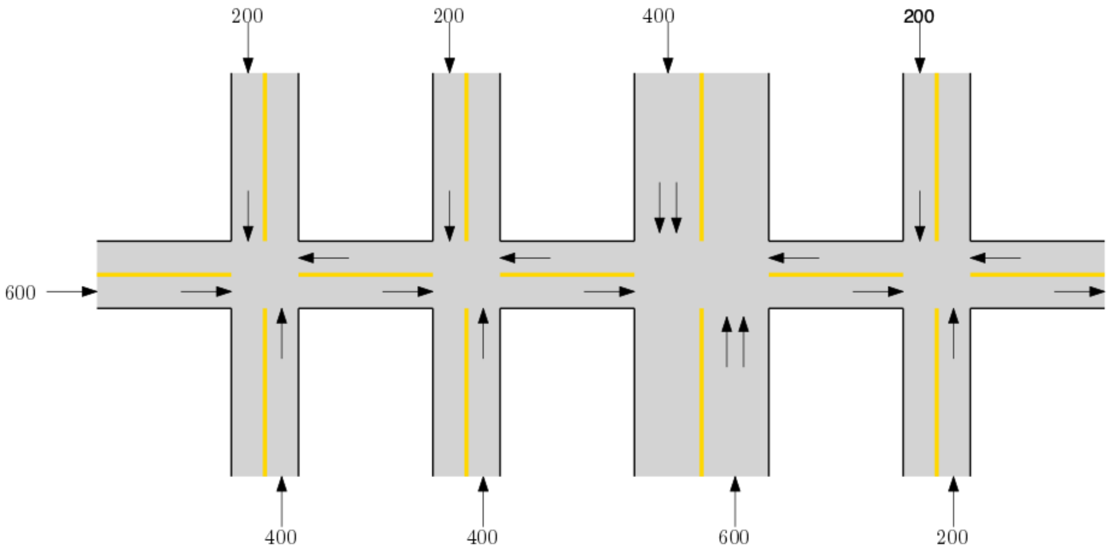

Figure 4: Demand profiles for a specified scenario.

Questions

- Based on a literature review, determine current existing traffic models for signalized traffic networks.
- For the network in Figure 3, build a macroscopic signalized traffic model.
- Determine the *signalized/averaged* traffic model for the case where lights are installed along each intersection of the corridor. For those roads in which direction is not explicitly defined, consider the direction of a regular intersection.

Expected outcomes

- Present a brief summary of the existing current models for signalized traffic networks. At same time highlight the key features of these models and the remaining difficulties. Consider including references for the presented models.
- Based on (Grandinetti, Canudas-de-wit, and Garin 2015) obtain a model for the signalized network of Figure 3 and the parameters required model this corridor.
- Define the set of parameters for the traffic network, notably those related to the fundamental diagram as well as the traffic light signal timings. Consider a fixed setup of this parameters for the moment and overall explain the reason of the choice.

Task 2: Simulation

Dynamic simulation of open loop traffic networks. For this task be sure to review already implemented simulations available at Link. Get familiar with the code here developed before you enter into details of implementation.

Context

Based on the model established in the **Task 1** and considering a family of specific parameters, perform a simulation for a constant demand value of demand in veh/hr as specified in the Figure4.

Questions

- Simulate and obtain density plots of the dynamic the behaviour when the *duty cyle* of lights is similar for all the traffic lights. 50%
- Does the current values create a congestion in the proposed network?
- How can the performance of the network be improved? Create a second set of parameters for the traffic lights *duty cycle*
- For the existing model and according to (Grandinetti, Canudas-de-wit, and Garin 2015) obtain the two different *density* and *flow* dynamic profiles between a *switched* signalized traffic model and an *averaged* traffic model

Expected outcomes

- Present the dynamic profiles for density on each one of the roads under different setups of traffic lights. The dynamic profiles should specify density per road in time
- Provide comparisons between different traffic signalized models and an analysis on how this error evolves according to different values of demand.
- Specify a second set of parameters for *duty cycle* that could improve the performance of the network with respect to the 50% case. Justify the reason of your choice and verify in results the desired behavior.

Task 3: Control strategy

For this task we aim to consider the *duty cycle* as a control input variable to regulate the flow within the traffic network. In this case take into account that the decision variable needs somehow to be determined dynamically via a control algorithm.

Context

For the Figure 2 the average value can be found as:

$$\bar{u} = \frac{1}{T}\int_0^T u(\tau)d\tau \tag{1}$$

As it is illustrated in (Grandinetti, Garin, and Canudas-de-wit 2015), in Eq. (1) is easier to design a value for $\bar{u}$ rather than u due to its binary character.

Questions

- Explain and construct a block diagram illustrating the control of the road traffic network via traffic signals
- Design and present an algorithm that takes decisions for the traffic signals based on the state of the network. How would you construct the value of u based on the congestion state of the network.
- Perform simulations of the system under a preestablished manual control and compare it to a situation where the control depends on the congestion state of the network.

Expected outcomes

- Present a comparison between the traffic network with signalized control and without signalized control.
- Apply the controller over different versions of the model notably *averaged* and *switched*
- Compare the open loop situation with the closed loop situation and provide conclussions on the control performance.

Task 4: Performance evaluation

Finally in order to compare it is important to determine indicators than can be designed in order to compare the effects of introducing an automated control strategy.

Context

Indicators for traffic networks are regularly expressed in terms of the state of the network, for example the *Service of Demand* (SoD) measured in terms of flow:

$$SOD = \int_0^T \sum_{r \in R} f_r(\tau) d\tau \tag{2}$$

Or the *Total Travel Distance* (TTD) measured in terms of the density

$$TTD = \int_0^T \sum_{r \in R} \rho_r(\tau) d\tau \tag{3}$$

Questions

- What does the aforementioned indicators represent?
- Measure the indicators over the traffic network with a manual setup of traffic signals *open-loop* vs a controlled setup of traffic signals *closed-loop*.

Expected outcomes

- Report indicators for both cases and conclude about the results.
- Provide recomendations on how to design u for the corridor

Sources

For more details on how to deploy traffic simulations and traffic models please check:

- Traffic Macrosimulator - Github
- For traffic models check (Grandinetti, Canudas-de-wit, and Garin 2015) available Link and (Grandinetti, Garin, and Canudas-de-wit 2015) available at Link

Project 2: Vehicle Platooning

The main objective of this project is to design a controller for a platoon of vehicles in order to optimize the traffic flow and reduce the fuel consumption. A platoon of vehicles can be seen as:

The objective illustrated in Figure 5 is to control the *headway space* between two single vehicles in a formation of multiple vehicles. This project is inspired in works presented on (Duret, Wang, and Ladino 2019a), (Wang et al. 2014) but more information about platoons can be found at (Ali, Garcia, and Martinet 2015).

Objectives

The main objective of this project is to:

1. Study and understand the fundamental problem of string stability.
2. Obtain and create a dynamic model for vehicle platoons and asociate its parameters with traffic theory.
3. Create and design a control strategy for the headway space and analyze its behavior.
4. Compare and analyze the behavior of parameter setups for variations of the proposed control strategy

Description

Task 1: Platoon modeling

Consider the dynamical model presented in (Duret, Wang, and Ladino 2019a), (Turri, Besselink, and Johansson 2017) where the problem of truck platooning is detailed.

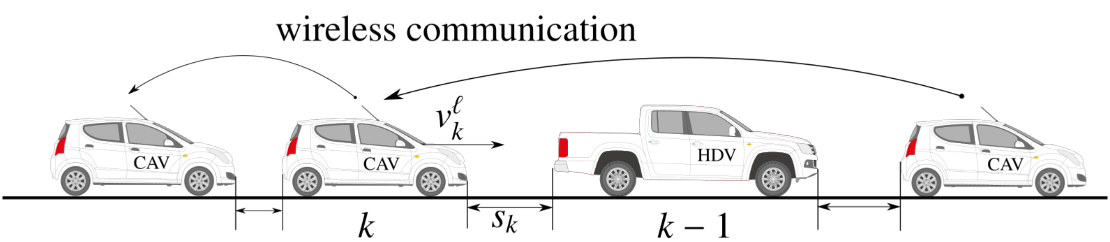

Figure 5: Example of a vehicle platoon.

Context

In general the platoon problem is a *dynamic control problem* where the objective is to regulate or mantain the value of a specific variable within the system at a desired level. In order to produce this regulation a *controller* is requrired and in most of the cases cases there is always a way to express the dynamical model in the following form:

$$\dot{x}(t) = f(x(t), u(t)) \tag{4}$$

where $x(t), u(t)$ correspond to the state vector, and the control vector of the system. In general a system describing this behavior is called *dynamic* system. In case of platoon the state vector represents all the variables that contain *minimum* information to represent the system like, vehicle position, speed, or headway space. The control vector correspond to the variables that are inputs to the systems, e.g. acceleration when modifying the state of a vehicle.

Questions

- What are the main goals of platoon strategies, and how they can improve the traffic in future?
- Create a model for a platoon of 4 vehicles that considers a simple dynamic model of 2nd order and a 3rd order one. **Note: Consider for this case a model in which no drag is present within the model.**. This model can be written as in (4) where the stability can be analyzed.
- Which could be the traffic parameters in this kind of models?

Expected outcomes

- Present a brief summary on the motivations to create vehicle platoons and the main existing models that can be developed for this purpose.
- Based on the work of (Duret, Wang, and Ladino 2019a), (Wang et al. 2014) determine writedown the state equations for a platoon model of 4 vehicles of *2nd order* and *3rd order.*
- Determine the stability properties of the model. Stability properties are associated to the location of zeros and poles of the transfer function of the model or eigen values of the matrix See more

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Task 2: Open loop simulation

Context

One of the first studies in terms of analyzing the properties of a dynamical system is the dynamical response of the system. This response can be characterized by the step response of the system to a specific control input.

For the case of a platoon vehicle the input in *open* loop are the accelerations of all vehicles. It seems logical that if a vehicle modifies its speed from a specific value the space between two vehicles. We are going to verify this behavior at simulation level.

Questions

- Which is the response of spacing of all vehicles when an impulse of deceleration of amplitude $u = 0.1 m/s^2$ is performed over the second vehicle? *

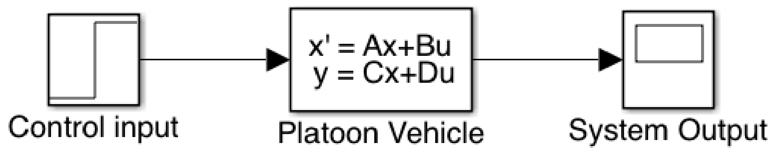


Figure 6: Open loop system.

- Are there any differences between the spacings when applying the decceleration over a *2nd order* model or a *3rd order model*?
- Consider the *time engine* constant in the *3rd order* model. What is the effect of this vale in the dynamic acceleration/ decceleration of the system?

Expected outcomes

- Create a simulation of the *2nd /3rd order* platoon vehicle models in which the inputs are the accelerations of all vehicles and the outcomes are the headway spaces, and speeds of each vehicle.
- Retrieve the dynamic response of the headway space for the 2nd order/ 3rd order for an impulse of $u = 0.1 m/s^2$
- Obtain the trajectories in space and time for the platoon of 4 vehicles.

Task 3: Vehicle platoon control

Context

In order to control the system a feedback loop should be introduced in terms of accelerations of vehicles as shown in the Figure 7

Whithin the Figure 7 the main objective is to create a closed loop that provides information in order to take the decision. These strategies have been already studied in literature. (Wang et al. 2014), (Ali, Garcia, and Martinet 2015).

Questions

- Based on the control strategy proposed in (Wang et al. 2014). Which is one of the possibles control structures that can be used for these systems?
- Define and justify some specific values for the proportional integral control parameters.

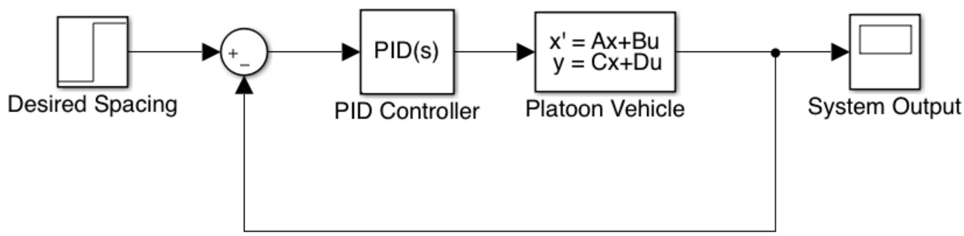


Figure 7: Closed loop system.

- Set the desire spacing of the system to a specific value of $10m$ for all vehicles, then test a change in the headway space of $5m$ for one of the vehicles. What do you see as a different behavior?

Expected outcomes

- Provide the dynamical response of the open-loop (headway space/speed) system, (all headway spacings/ speed profiles) to a change in decceleration of $0.1m/s^2$, applied over 1s.

- Provide the dynamical response of the closed-loop (headway space/speed) system, (all headway spacings/ speed profiles) to a change in spacing of $5m$.
- Compare the situations and conclude about the implementation of control systems on vehicle automatization. What are the benefits of implementing this type of algorithms?

Task 4: Performance evaluation

Context

In order to provide a final evaluation it is important to measure the dynamical performance of the control strategy. This dynamical response can be measured as in 8.

Questions

- Measure the dynamical response, setting time, rise time for the controller operated on the 2nd order model and 3rd order model. What can you conclude about the dynamical step response?
- Provide a variation of parameters in the contoller provided. How the parameters may affect the stability of the model?

Expected outcomes

- Provide an analysis from values obtained of simulations of the same control for multiple models (2nd/3rd order).
- Construct and determine the effects of modifying control parameters when they are applied to multiple models.

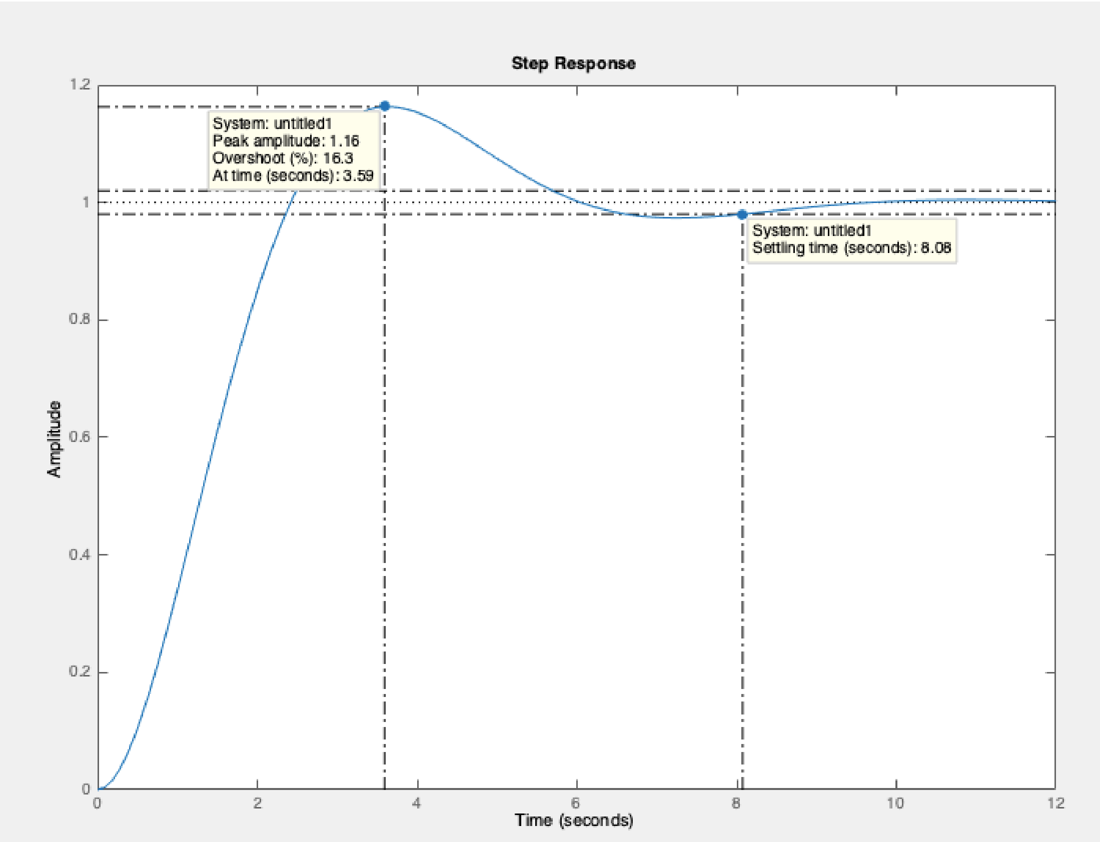


Figure 8: Typical dynamical response for a 2nd order model

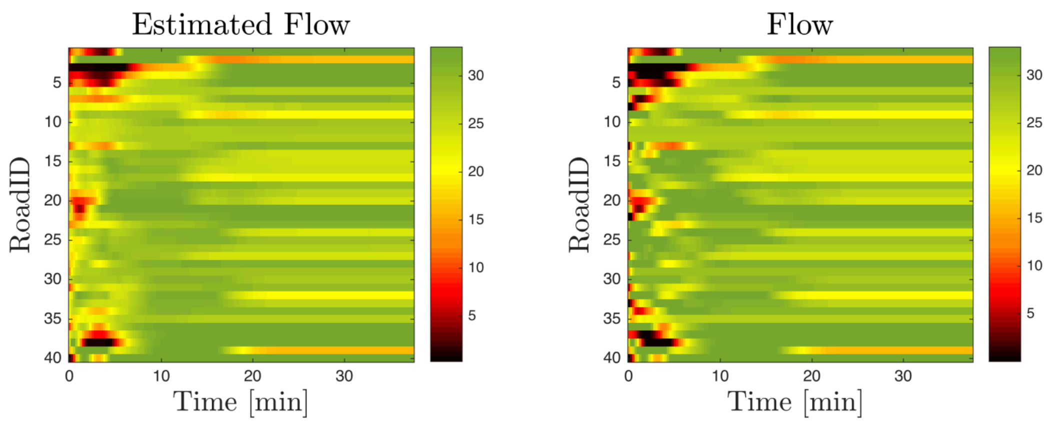
Sources

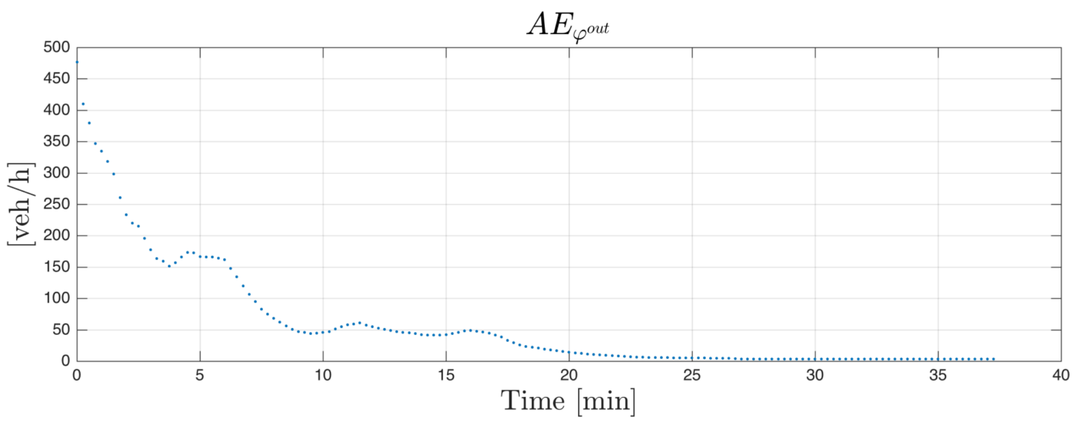
For more details on how to deploy traffic simulations and traffic models please check:

- Simulation results - Github
- Check (Duret, Wang, and Ladino 2019b) available Link

Project 3: Density Reconstruction

The state of congestion of a city is one of the critical. This project aims to study the reconstruction of traffic variables from different type of sources. For more information the detail of this work can be found at (Lovisari, Canudas-de-wit, and Kibangou 2016), (Ladino et al. 2018).





In this approach in particular, the reconstruction of density will be based on multiple hypothesys.

- There exist multiple sources of traffic information such as *Floating Car Data (FCD)* or *Magnetic Loop Data (MLD)*, the nature of these two measurements is different. While FCD can be collected easily and almost every where in the traffic network, it is not really representative of the congestion state due to the penetration rate. Its counter part MLD is accurate when determining the amount of vehicles circulating at specific spots, but extending this mechanism of measurement to the whole network is expensive.

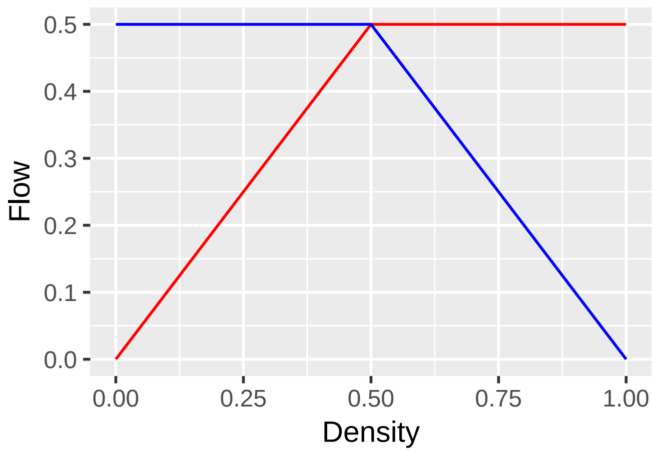


Figure 9: Demand/Supply Principle.

- The use of models like the LWR model may be useful for providing extra information to retrieve the congestion state of the network.

Objectives

The main objective of this project is to:

1. Study the LWR model and in particular its network counter part.
2. Obtain and simulate a macroscopic traffic model for a urban network.
3. Create and design an estimator in order to retrieve the state of the network based on heterogenous measurements.
4. Compare the behavior and performance of the estimator under multiple situations.

Description

Task 1: Modeling

Consider reading (Daganzo 1994) to understand the first basic principles and (Ladino et al. 2018) for more details about the network problem.

Context

In order to reconstruct the traffic models for this project it is important to understand the principle of demand supply prescribed in the *Cell Transmission Model (CTM)* (Daganzo 1994) and its extensions to the network case (Ladino et al. 2018).

Within the Figure (Ladino et al. 2018) the *red* curve represnets the *demand* of a link and the *blue* curve represents the *supply* of the link. The main objective is to model the fixed capacity of the flow. In this approach the blue line is determined by information *downstream* the network while the red line is determined by information *upstream*.

Questions

- Which is the actual model of

Expected outcomes

Task 2: Simulation

Context

Questions

Expected outcomes

Task 3: Estimation algorithm

Context

Questions

Expected outcomes

Task 4: Estimation performance

Context

Questions

Expected outcomes

```
plot(cars)  # a scatterplot
```

$$f\left(k\right) = \binom{n}{k} p^k\left(1-p\right)^{n-k} \tag{5}$$

In (5)

Below is an `align` environment (7):

```
\begin{align}
g(X_{n}) &= g(\theta)+g'({\tilde{\theta}})(X_{n}-\theta) \notag \\
\sqrt{n}[g(X_{n})-g(\theta)] &= g'\left({\tilde{\theta}}\right)
  \sqrt{n}[X_{n}-\theta ] (\#eq:align)
\end{align}
```

$$\begin{align}
g(X_{n}) &= g(\theta)+g'({\tilde{\theta}})(X_{n}-\theta) \tag{6} \\
\sqrt{n}[g(X_{n})-g(\theta)] &= g'\left({\tilde{\theta}}\right)\sqrt{n}[X_{n}-\theta] \tag{7}
\end{align}$$

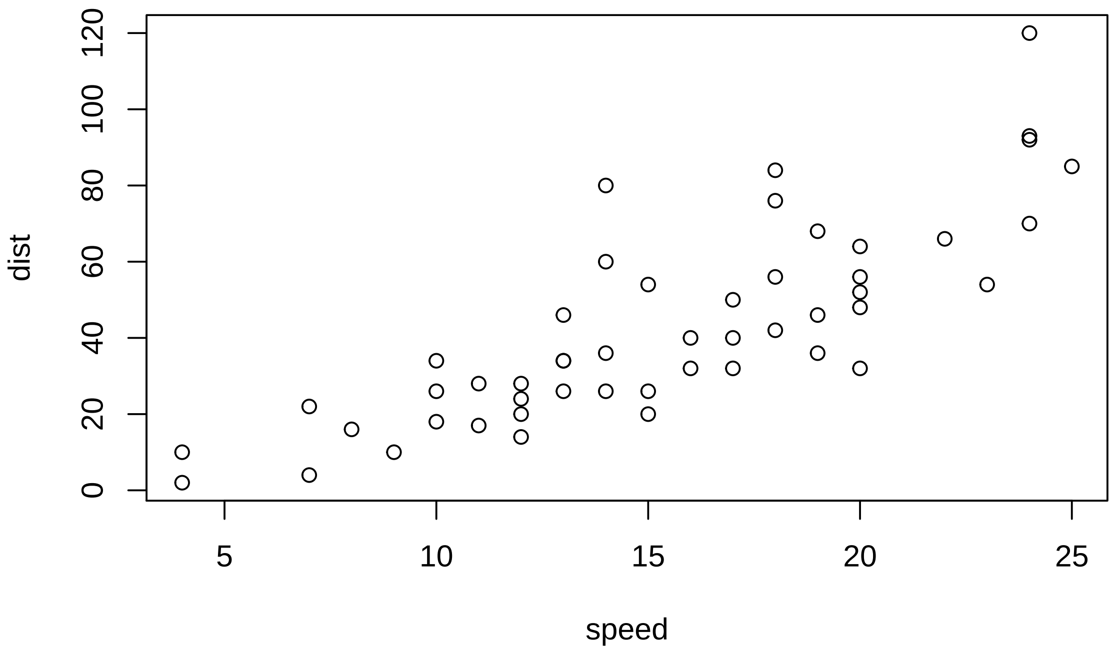


Figure 10: A scatterplot of the data `cars` using **base** R graphics.

Sources

For more details on the project please check:

- Simulation results - Github
- Check (Ladino et al. 2018) available at Link and (Lovisari, Canudas-de-wit, and Kibangou 2016) available at Link

Ali, Alan, Gaetan Garcia, and Philippe Martinet. 2015. "The flatbed platoon towing model for safe and dense platooning on highways." *IEEE Intelligent Transportation Systems Magazine* 7 (1): 58–68. https://doi.org/10.1109/MITS.2014.2328670.

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