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GOBIERNO DE ESPAÑA · MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD · SECRETARÍA DE ESTADO DE INVESTIGACIÓN, DESARROLLO E INNOVACIÓN

PROJECT COOP

"COOPERATIVE FREEWAY DRIVING STRATEGIES IN A MIXED ENVIRONMENT WITH DRIVERLESS AND TRADITIONAL VEHICLES"

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1. The team and the project

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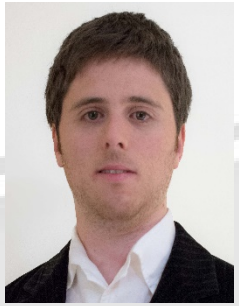

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Main researchers

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- ✓ Lines of research: traffic analysis and management, urban mobility, operations in transportation and logistics, car and bike-sharing, etc.
- ✓ Most of his investigations have lead to academic awards and Q1 papers
- ✓ Coordinator of the Master Program on Supply Chain, Transport and Mobility at the UPC
- ✓ Research stays: University of California-Berkeley, TØI - Institute of Transportation Economics, etc.

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- ✓ Professor Emeritus at the UPC since 2015.
- ✓ Lines of research: traffic modelling and planning, optimization and simulation, urban mobility, logistics, etc.
- ✓ Scientific developer of the modelling software Aimsun and co-founder of TSS-Traffic Simulation Systems.
- ✓ Scientific advisor of PTV.
- ✓ More than 100 papers and many national and european research projects

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PROJECT COOP: COOPERATIVE FREEWAY DRIVING STRATEGIES IN A MIXED ENVIRONMENT WITH DRIVERLESS AND TRADITIONAL VEHICLES

Financing:	Subdirección General de Proyectos de Investigación. Dirección General de Investigación Científica y Técnica. Ministerio de Economía y Competitividad (Spain)
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2. Introduction

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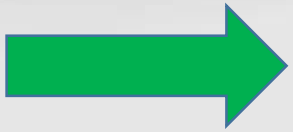
FOUR STARTING POINTS:

1. **Mobility is a by-product of the demand**

The number of trips will still increase in the Internet and Technology era

2. **Developed countries already have a modern and complete road network**



The solution for congestion lies in an appropriate traffic management

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3. **The introduction of autonomous (even highly automated) vehicles will be progressive**

→ **Traffic will be mixed for a long time**

4. **Are autonomous vehicles the solution for congestion? Safety and comfort are important goals but traffic efficiency should be kept in mind…**

→ **Impact on traffic flow should not be forgotten!!**

Bottlenecks?? **Another type of accidents??** **Pollution??**

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Autonomous* vehicles are designed with more conservative parameters than that of the drivers of traditional vehicles
(Diakaki, Papageorgiou, Papamichail, & Nikolos, 2015)

Example:

time-gap (interval) is usually 2 seconds in automated vehicles instead of the second (or less) typical of drivers

+ selfish decisions

Mass introduction of autonomous non-cooperative vehicles would lead to an important capacity reduction
(Ntousakis, Nikolos, & Papageorgiou, 2015)

*Level 5 not yet

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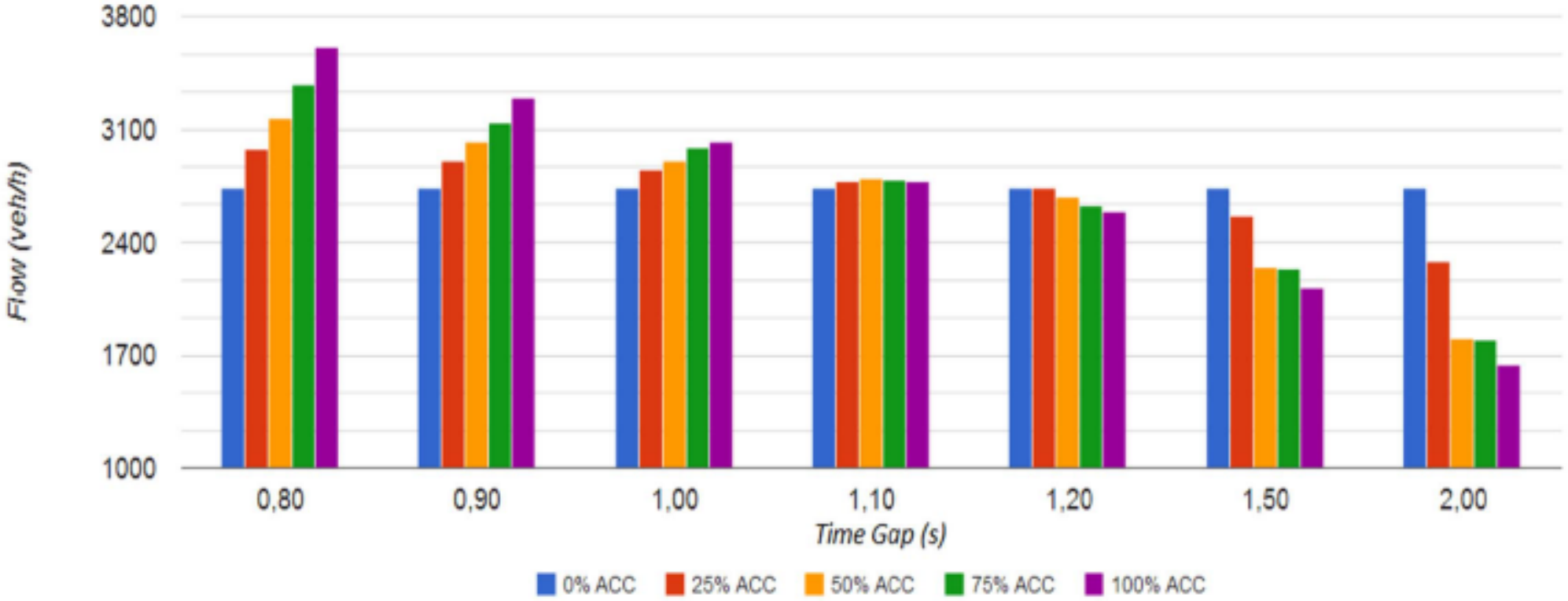
Influence of the introduction of ACC vehicles on the maximum flow per lane depending on their rate and on the time-gap



From: Ntousakis, I.A., Nikolos, I.K., Papageorgiou, M.: On microscopic modelling of adaptive cruise control systems. *4th Intern. Symposium of Transport Simulation (ISTS'14)*, 1-4 June 2014, Corsica, France. Published in *Transportation Research Procedia* 6 (2015), pp. 111-127.

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These disadvantages could be overcome by means of cooperative driving (specially platooning) and it would be even possible to improve the current situation

- ✓ **Both traditional and autonomous vehicles could benefit from cooperative driving**
- ✓ **The improvement would already be noteworthy with 30% "autonomous" vehicles**

(Guériau et al., 2016)

Cooperative vehicles stabilize traffic flow, specially because of the reduction of stop and go and shock waves
(Ntousakis, Nikolos und Papageorgiou, 2015)

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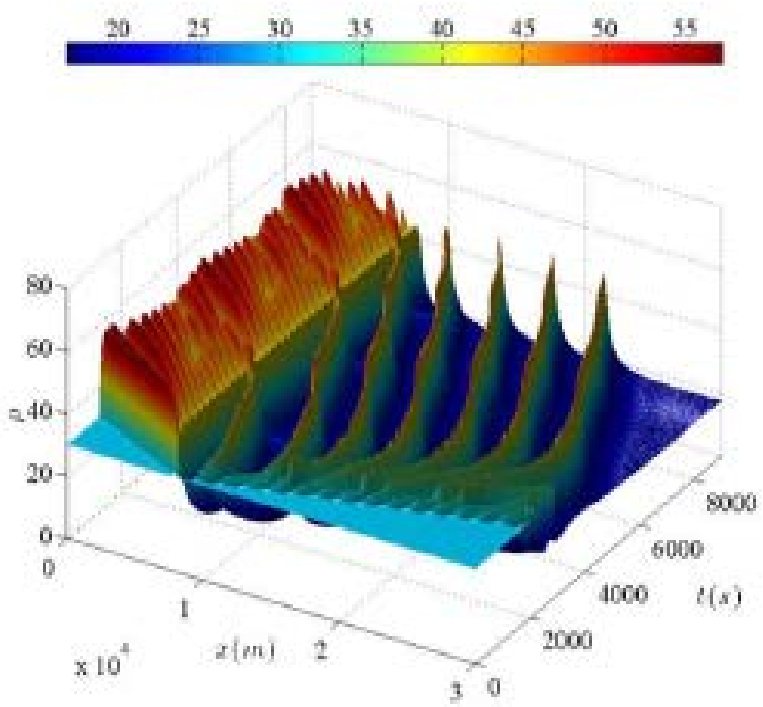
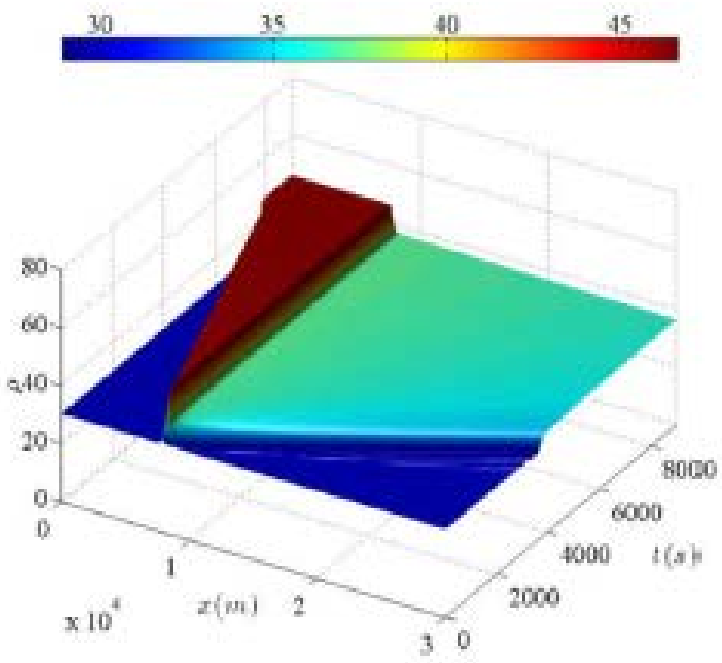
Space-time evolution of the density close to an on-ramp

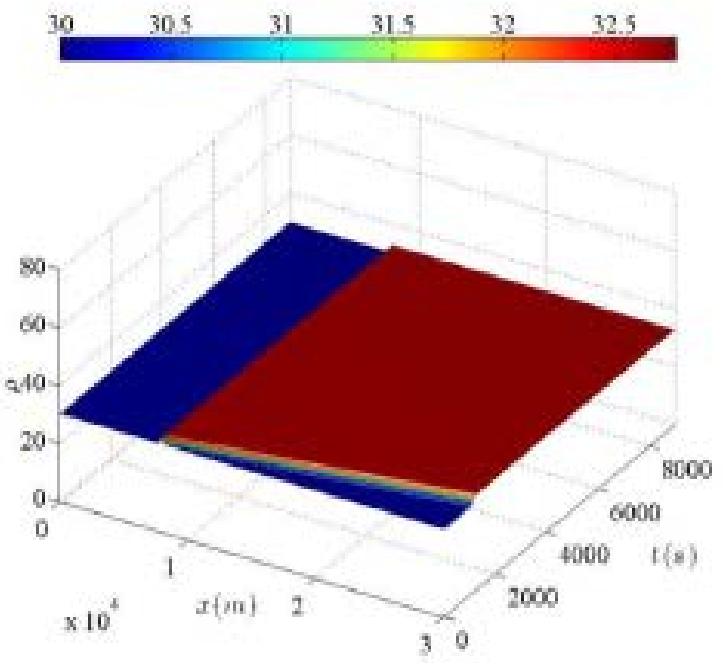
Traditional vehicles



ACC vehicles



CACC vehicles



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Platoons of autonomous vehicles are a suitable strategy for improving traffic efficiency

Vehicles can drive with very small intervals and high speeds while mantaining safety levels

Efficiency will depend on:

- ✓ **Platoon composition**
- ✓ **Platoon speed**
- ✓ **Time interval, etc.**

A lot of doubts and challenges:

- ✓ **Mixed composition?**
- ✓ **Length?**
- ✓ **What about the different technologies used by car companies?**
- ✓ **What must be taken into account at special points such as on-ramps, off-ramps or weaving segments?, etc.**

3. Goals

Main goals

1. **Analysis of the consequences of the introduction of autonomous vehicles in traffic streams**
   - In different boundary conditions related to (e.g.) the rate of each vehicle type, the characteristics of the infrastructure, the cooperative driving mode, etc.
2. **Study of the possible contribution of autonomous vehicles to the major objectives of traffic management**
   - Efficiency, safety and sustainability
3. **Adaptation of the current traffic management strategies to a mixed environment**
   - With traditional and autonomous vehicles
   - Design of new specific strategies??

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Specific objectives

1. State of the art and technological review
2. Macroscopic modelling of platoons
3. Mesoscopic simulation
4. Proposal of ad hoc traffic management strategies
5. Evaluation of the strategies in the mesoscopic simulator
6. Main conclusions

There is one work package aimed at each objective

4. Work packages and planning

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Planning

WORK PACKAGES		2017				2018				2019			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	State of the art and technological review												
2	Macroscopic modelling of platoons												
3	Mesoscopisc simulation												
4	Ad hoc traffic management strategies												
5	Evaluation of the strategies in the simulator												
6	Main conclusions												

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Work package 1: State of the art and technological review

- **Latest technical achievements in the field of autonomous vehicles:**
  - ✓ Specially those related to their integration in cooperative systems like V2V and V2I
  - ✓ Technologies applied on-board and/or in the infrastructure (mainly freeways)
- **Short-term expected progress**
- **Worldwide research on the dynamic management of these new traffic streams**
- **Current analytical modelling of mixed systems**
  - ✓ With autonomous and traditional vehicles
  - ✓ Additionally with platoons
  - ✓ Both microscopic and macroscopic
- **Opinions about COOP and its hypotheses. Similar or related projects. Synergy.**

1.1.2017 – 30.9.2018

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Work package 2: Macroscopic modelling of platoons

- **Traffic flow macroscopic analysis:**
  - ✓ Understanding of the interactions in the platoon and between the platoon and the traditional vehicles
  - ✓ Average parameters in predetermined time intervals
  - ✓ Phenomenon conceptualization ⟹ representative parameters

More practical

- **Modification of the classic Theory of Traffic Flow:**
  - ✓ Modified **"Kinematic Wave Theory"** ⟹ **valid for a single vehicle type**
  - ✓ Combination with the Theory of **" Slugs and rabbits"** (Daganzo, 1999 and Muñoz und Daganzo, 2002)
- **Possible moving bottlenecks:**
  - ✓ Effect of a platoon of heavy vehicles with slow speed
  - ✓ Effect of the traditional vehicles in front of a platoon of light vehicles

Optimization of the platoon features depending on the traffic situation

1) **Modelling in free flow**

2) **Modifications and additions for congestion**

   - ✓ **Recurrent congestion**
   - ✓ **Active and moving bottlenecks**

3) **Special attention close to on-ramps or off-ramps** → **Lane changes**

1.1.2017 – 31.3.2018

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Work package 3: Mesoscopic simulation

Macroscopic analysis of each lane

- ✓ **Above all macroscopic variables**
- ✓ **A couple of necessary microscopic variables to be able to define the platoons**
- ✓ **Mixed environment with traditional and autonomous vehicles**

A microscopic analysis would require too many parameters

An empirical calibration would not be possible nowadays

Looking for a robust and straightforward model

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- **Matlab???**
- **Possibly a modified version of the Cell Transmission Model (Daganzo, 1955)**
  - ✓ **Robust and straightforward finite difference method**
  - ✓ **The nodes' model must be modified**
  - ✓ **The flows' transmission model is valid**
- **Calibration will be based on the results of WP2**

1.10.2017 – 31.12.2018

TREN (microscopic)

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Work package 4: Ad hoc traffic management strategies

Mixed traffic streams optimization in real time

1.10.2018 – 30.6.2018

A lot of related questions

Technical challenges

- **Can heavy and light vehicles form a platoon??**
- **Will be current strategies valid?**
- **Should special measures be taken close to e.g. weaving segments?**
- **Should platoons (and where appropriate single autonomous vehicles) drive in an exclusive lane??**

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Should platoons (and where appropriate single autonomous vehicles) drive in an exclusive lane??

The major contribution of platoons to an efficient traffic would take place if they would drive in an exclusive lane, at high speed and with small intervals/gaps

BUT:

- ✓ **Only with high rate of autonomous vehicles and high demand**
- ✓ **Underutilization of the ability of cooperative vehicles to stabilize traffic streams (Ntousakis, Nikolos and Papageorgiou, 2015)**
- ✓ **Probably necessary with severe congestion → shared with e.g. HOV??**

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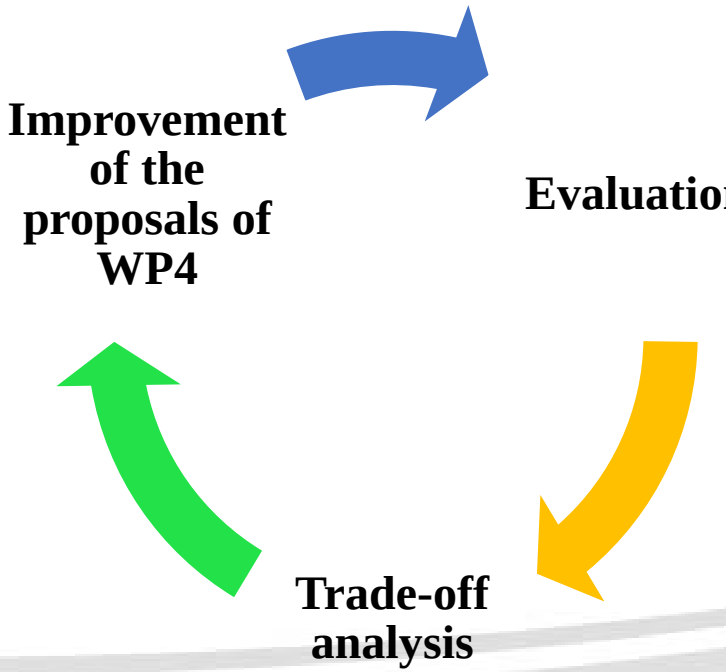
Work package 5: Evaluation of traffic management strategies in the mesoscopic simulator



- **Each strategy will be evaluated in different boundary conditions:**
  - ✓ **With different demands :**

Data from the "Highway Lab" at the B23 freeway towards Barcelona

  - ✓ **With special events (e.g. accidents, bad weather, etc.)**

- **Evaluation:**
  - ✓ **Goodness of the model**
  - ✓ **Should other macro/microscopic parameters be taken into account??**

1.10.2018 – 30.9.2018

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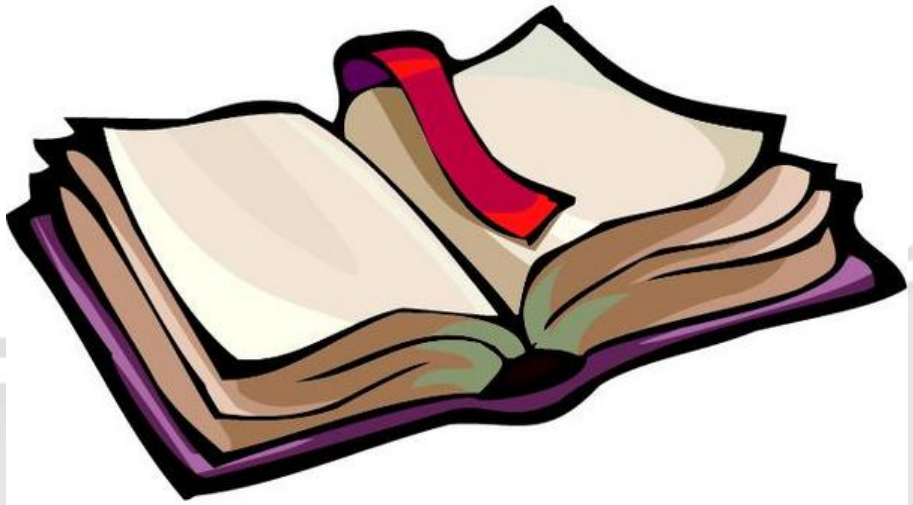
Work package 6: Main conclusions

- **Analysis and deductions**
- **Definition of future lines of research**

1.7.2019 – 31.12.2019



MANUAL:

✓ With a trade-off for each strategy

✓ Easy and practical (application-oriented)

ADDITIONALLY

✓ Report with a methodology to apply the strategies in a real case

5. Discussion

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The former and…

Our hypotheses to support the simulation:

1. **Autonomous vehicles of 3-5 level**

→ **They can form a platoon**

2. **The platoon drives in free flow at a speed v_p**

→ $V_p < V_{max}$ and $V_p < V_{maxvh}$

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3. **Platoons drive in the median lane**

→ Far away from on-ramps and off-ramps

4. **With free flow traditional vehicles can use the median lane too**

→ Mixed traffic stream of autonomous and traditional vehicles

→ Utilization of their ability to stabilize traffic flows

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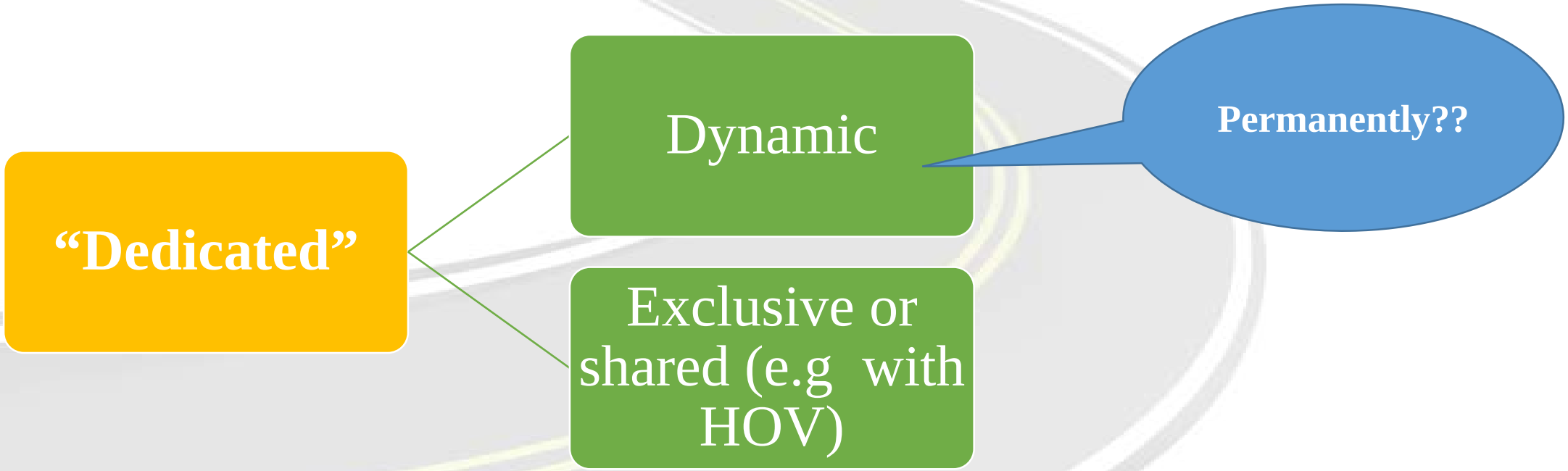
5. Traditional vehicles can not use the median lane in congestion

It must be "dedicated" to platoons



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6. Platoon formation: if vehicle B wants to belong to a platoon....

i. …it drives to the median lane

ii. It looks for other vehicles in “pairing”-mode and asks for connection

- These vehicles can not be too far (no more than 2-4 regular spacings)

  ⟹ Look ahead distance

iii. When vehicle A (the leader) has accepted the connection…

- … vehicle B (the follower) accelerates to perform it ($V_p < V_{max}$ und $V_p < V_{maxvh}$)
- As soon as vehicle A has accepted the connection with vehicle B, it is neither allowed to accelerate nor to connect with other vehicles ahead ⟹ “Hold” mode

iv. A platoon does not split out to accept vehicles that come from other lanes in the middle

⟹ shock waves could appear!

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7. Splitting from a platoon: if vehicle A wants to leave a platoon...

i. …it revokes the “pairing” and drives away

ii. If vehicle A was the leader, vehicle B (right behind) takes on the leadership

8. Should platoons have a length limit??

9. Should a platoon drive in the right lane if it is made up of heavy vehicles?

And additionally …

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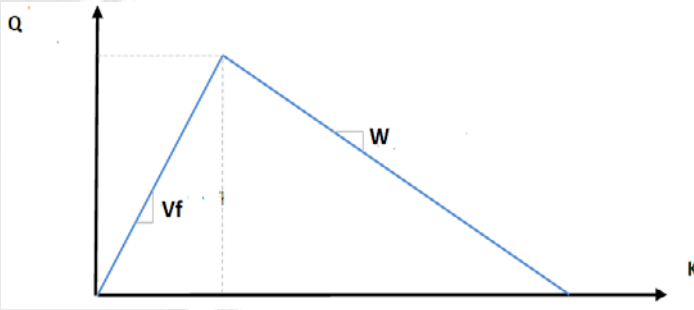
For the macro-level:

1. **We would like to find the following relationships:**

   i. **Between the rate of autonomous vehicles and the probability (or frequency) of platoon formation**

   ii. **Between the rate of autonomous vehicles and the average length of the platoons**

2. **How does a triangular fundamental diagram change depending on platoons‘ frequency and length?**



3. **Autonomous vehicles that either belong to or look for a platoon behave like “slugs“**

(according to Daganzo, 1999 and Muñoz and Daganzo, 2002)

Thank you very much for your attention

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