Model-Based Trajectory planning Implementation and Intelligent Refinement.

MOIRA 2nd Public Technical Course

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MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

IEEE Robotics & Automation Society Spanish Chapter

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Index

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Introduction.

Use case: Railway transportation Systems.

Main trends at a global level

SUSTAINABLE

REDUCTION IN ENERGY COSTS

RELIABILITY AND LONGER LIFESPAN

Solutions

AUTOMATION

DIGITALIZATION

CYBERSECURITY

Therefore, **in recent years, efforts** have been made **to increase the degree of automation in current railway transportation systems**.

Grade of Automation (GoA)	Train Operation	Setting train in motion	Driving and Stopping	Door opening and closing	Operation in event of disruption
GoA 1	*ATP with driver		DRIVER		
GoA 2	*ATP and *ATO with driver				
GoA 3	Driverless train operation	AUTOMATIC			ATTENDANT
GoA 4	Driverless train operation				

In Europe, working on it from 2016 - 2019

In Europe, working on it from 2019 to today

*ATP – Automatic Train Protection system
*ATO – Automatic Train Operation system

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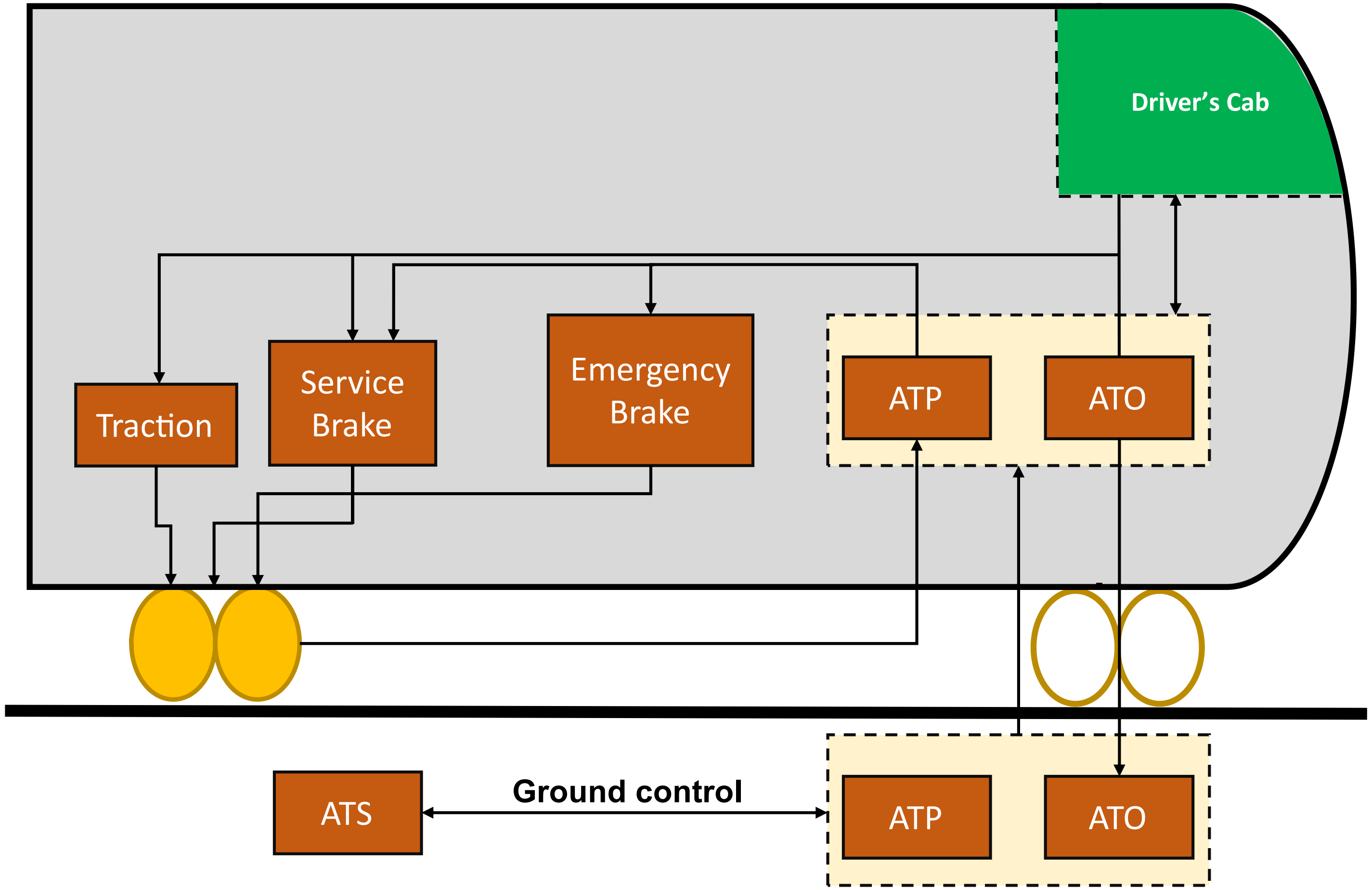
Introduction.

Automatic train control system: Main structure.



The automatic train control system (ATC System), based on IEEE Std. 1475-2012, **is mainly defined as follows**:

- **ATP Subsystem** — Ensures safety by averting potential colisions and defines Speed limits along the track.
- **ATS Subsystem** — Monitors and Coordinates the movements of the entire train fleet within the railway network.
- **ATO Subsystem** — Based on the info from the ATS and ATP, the ATO, governs the Speed and Traction/braking of each train.

The ATO is what I'm developing

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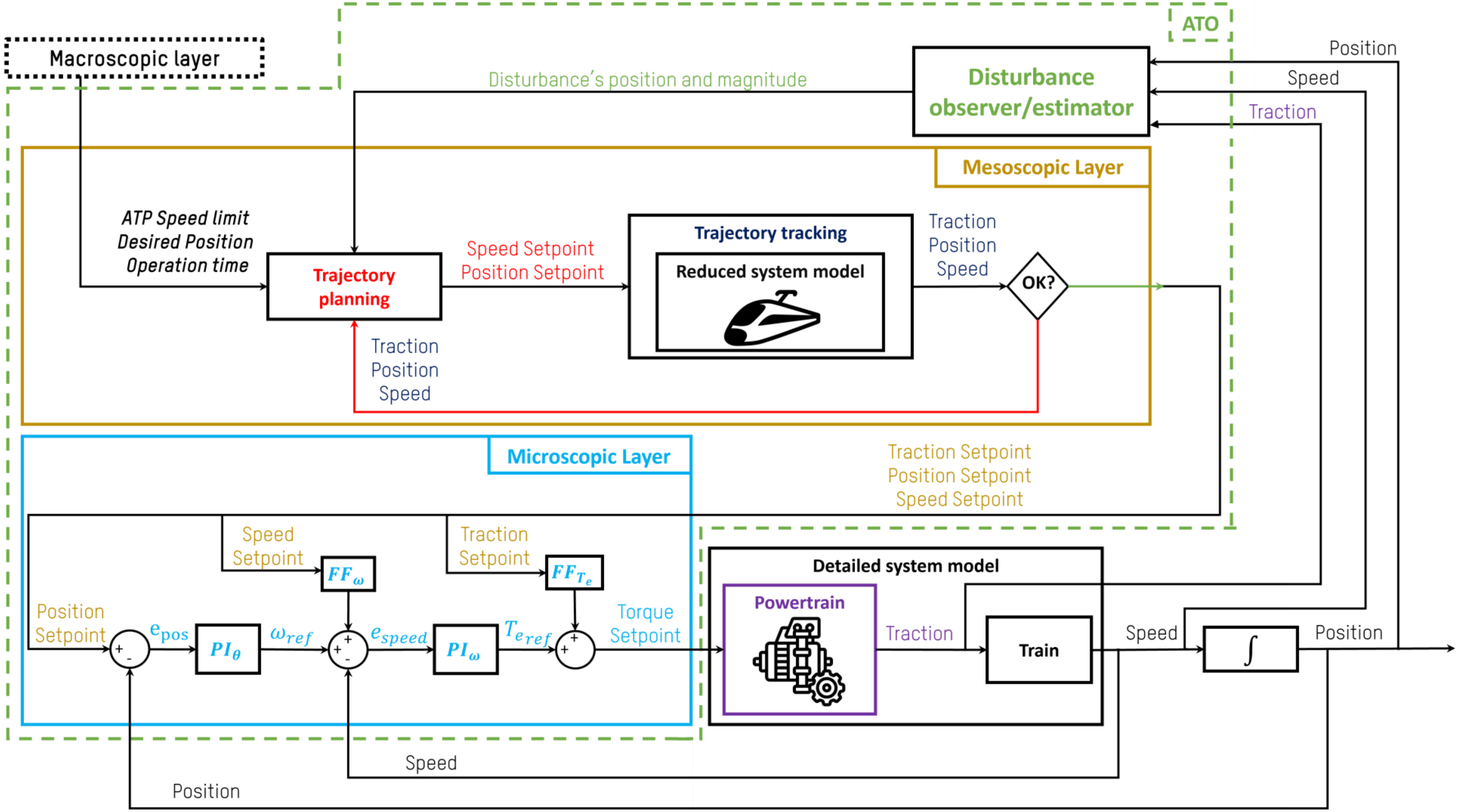
Introduction.

Automatic train control system: Used framework.



Notes:

- In the **first year as a PhD Student**, **just** the **mesoscopic layer** was developed. (1 Conference article and 1 Q1 Under review)
- At the **beginning of my second year as a PhD Student**, the **microscopic layer** has been developed (1 Conference article)
- **Some weeks ago**, we removed some info provided by the macro layer (Disturbances), and we developed the **Disturbance observer/estimator**. (Writing 1 Q1)

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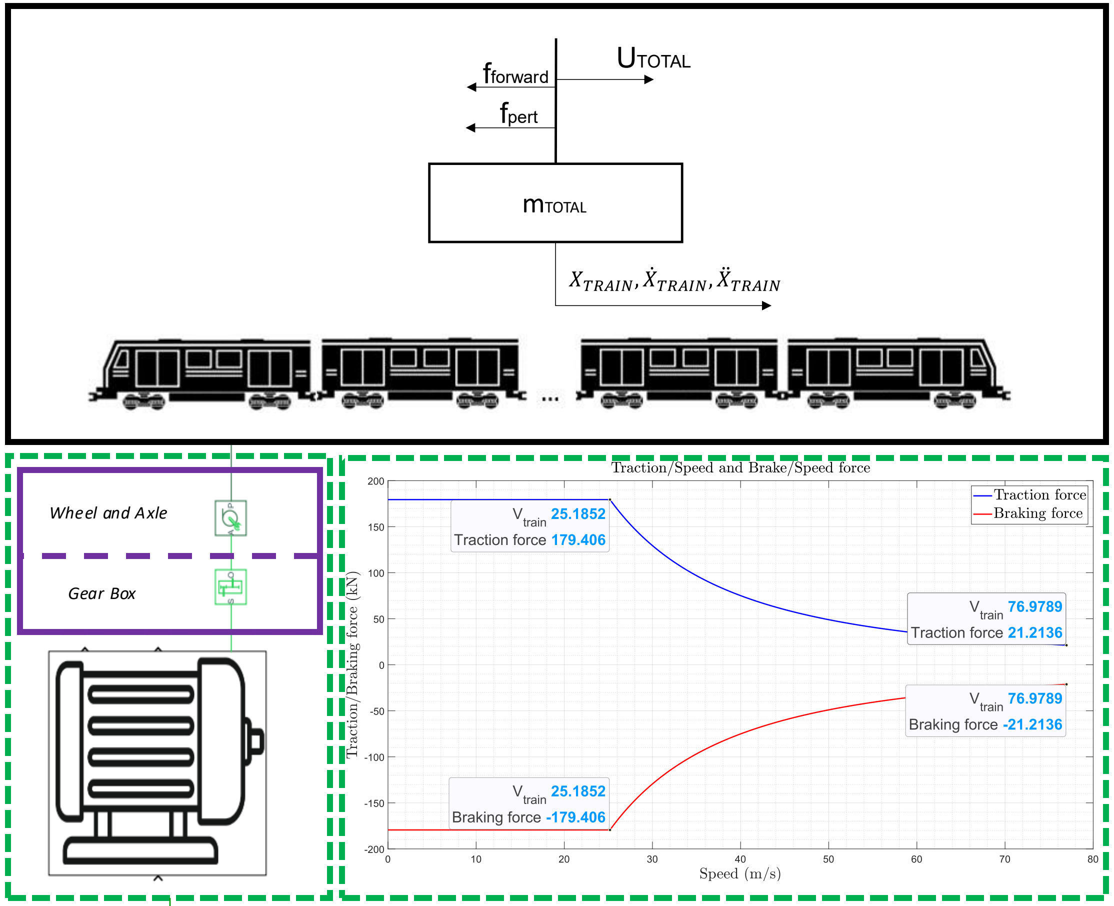
Modeling and development.

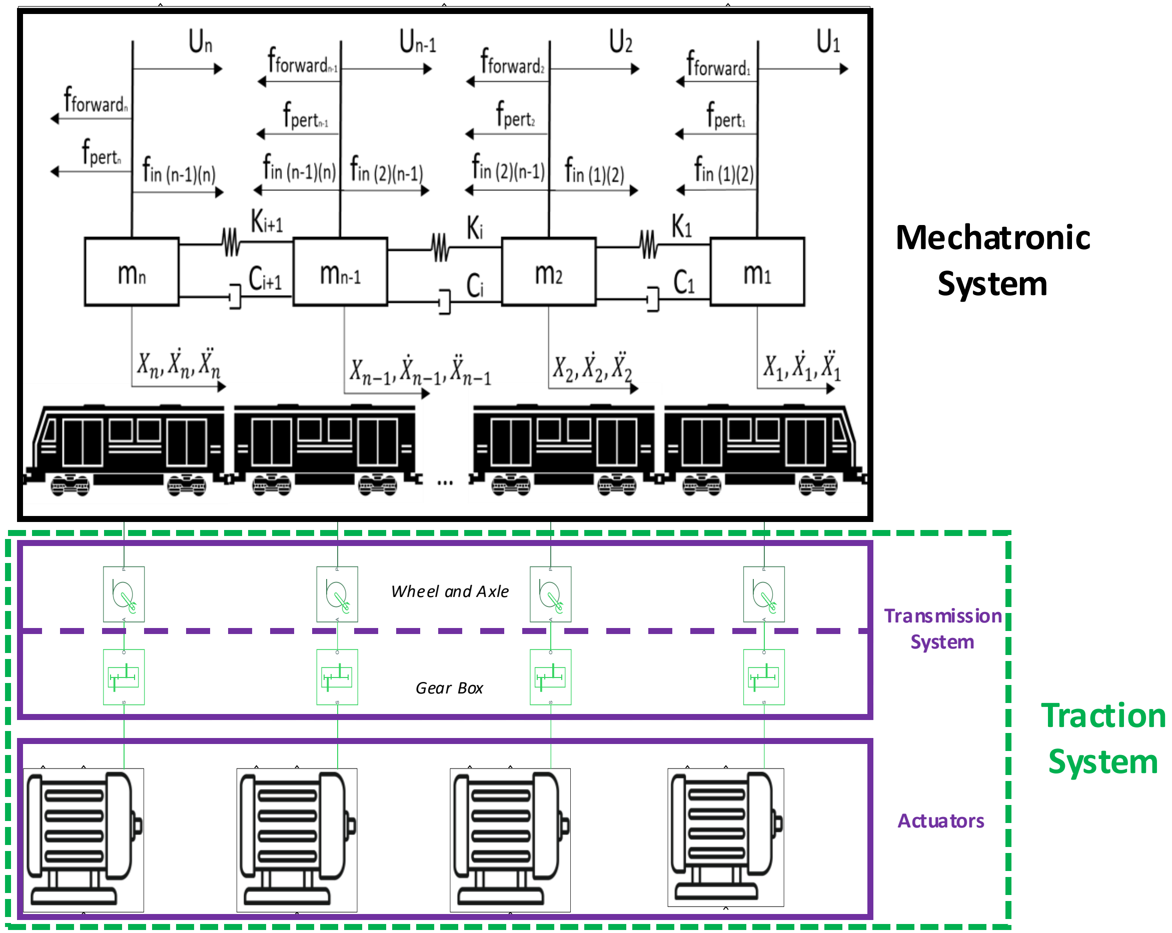
Simplified and detailed models.

The **simplified model** is **used** in the meso layer **for planning** purposes:



Modeling of the reduced Traction system, using the ideal Traction/braking curves

The **detailed model** is **used for** the **simulation** of the ATO Subsystem:



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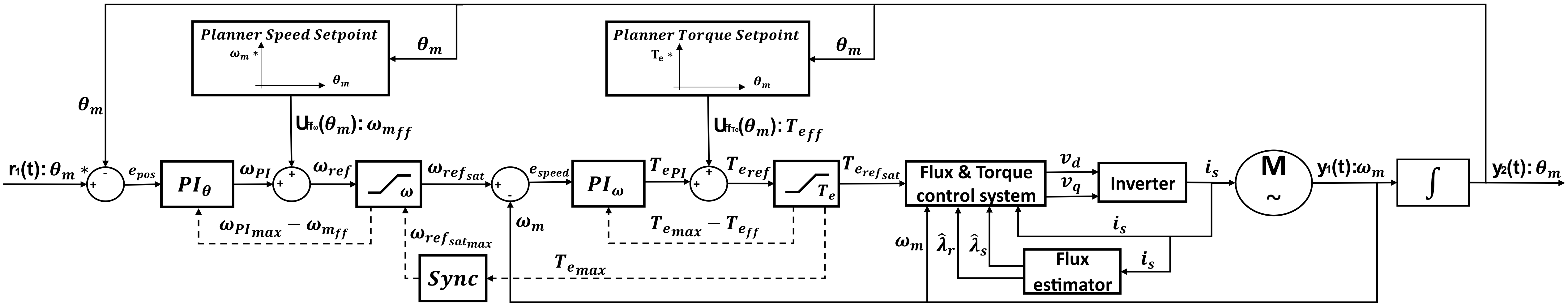
Modeling and development.

Development of the control system: Control scheme

Using the **info provided by the mesoscopic layer** after the planning process, **the following control scheme has been designed**:



- The **control scheme** used is a **cascade position control** system → **Speed inner loop and position outer loop**.
- **Two feedforward** actions are used, **based on the position of the system**
- **Saturations for each loop** have been **implemented** based on the speed limits and based on the actuator's physical capacity.
- **An anti-windup method** has been developed **based on the synchronization between both control loops**.

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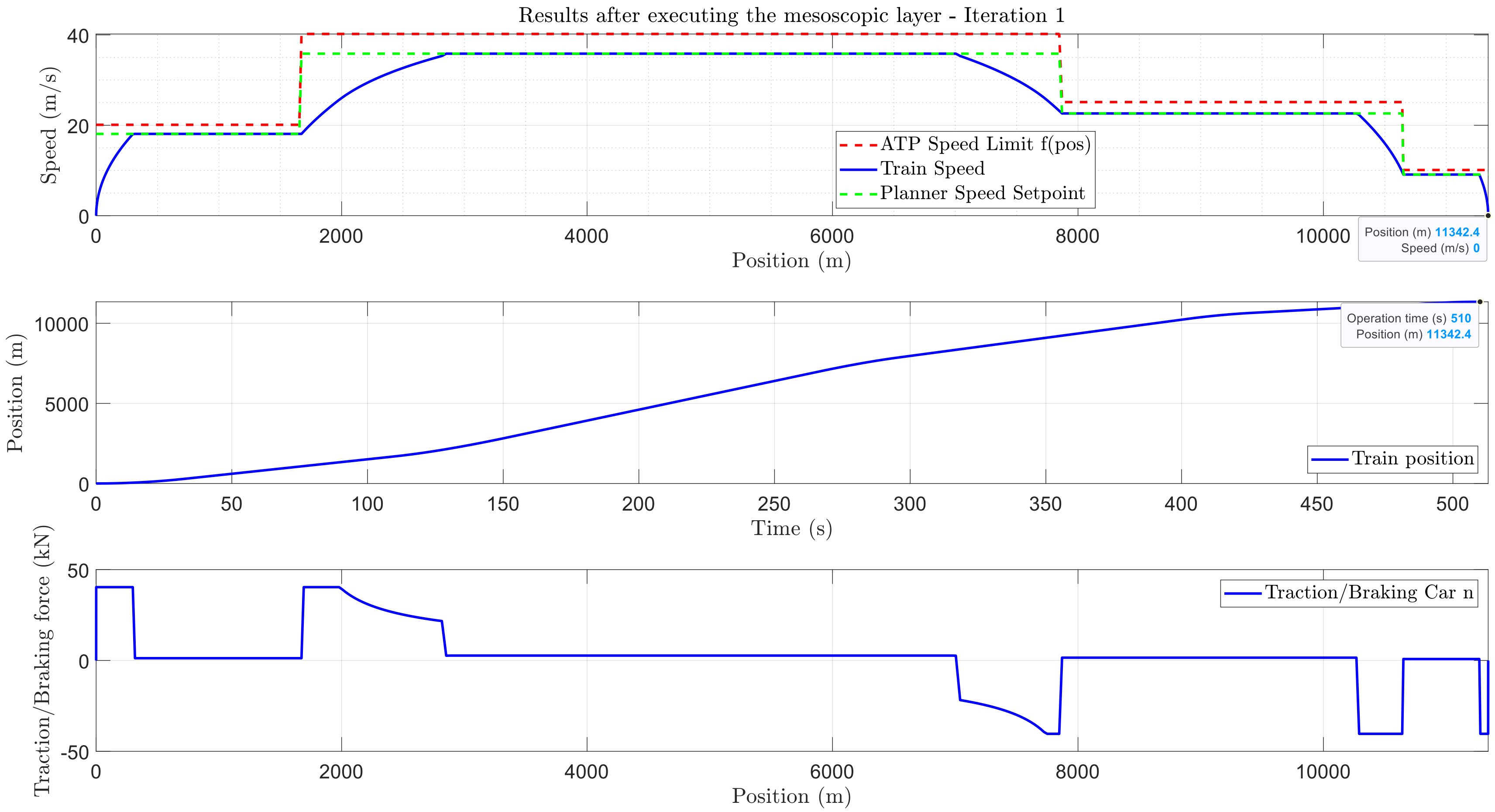
Modeling and development.

Development of the control system: Results

After executing the meso layer's planning algorithm (1st iteration), the following setpoints are generated to the micro layer:



Track conditions:

- Required **operation time: 510 seconds**
- **Desired position**: 11342.4 m = **11,3424 Km**
- **Red** line: ATP **Speed limit**
- There are some **unknown disturbances.**

Planning output specifications:

- Planning time ≈ 1.2 s
- Error ≈ 0.24 µs
- Any disturbance taken into account

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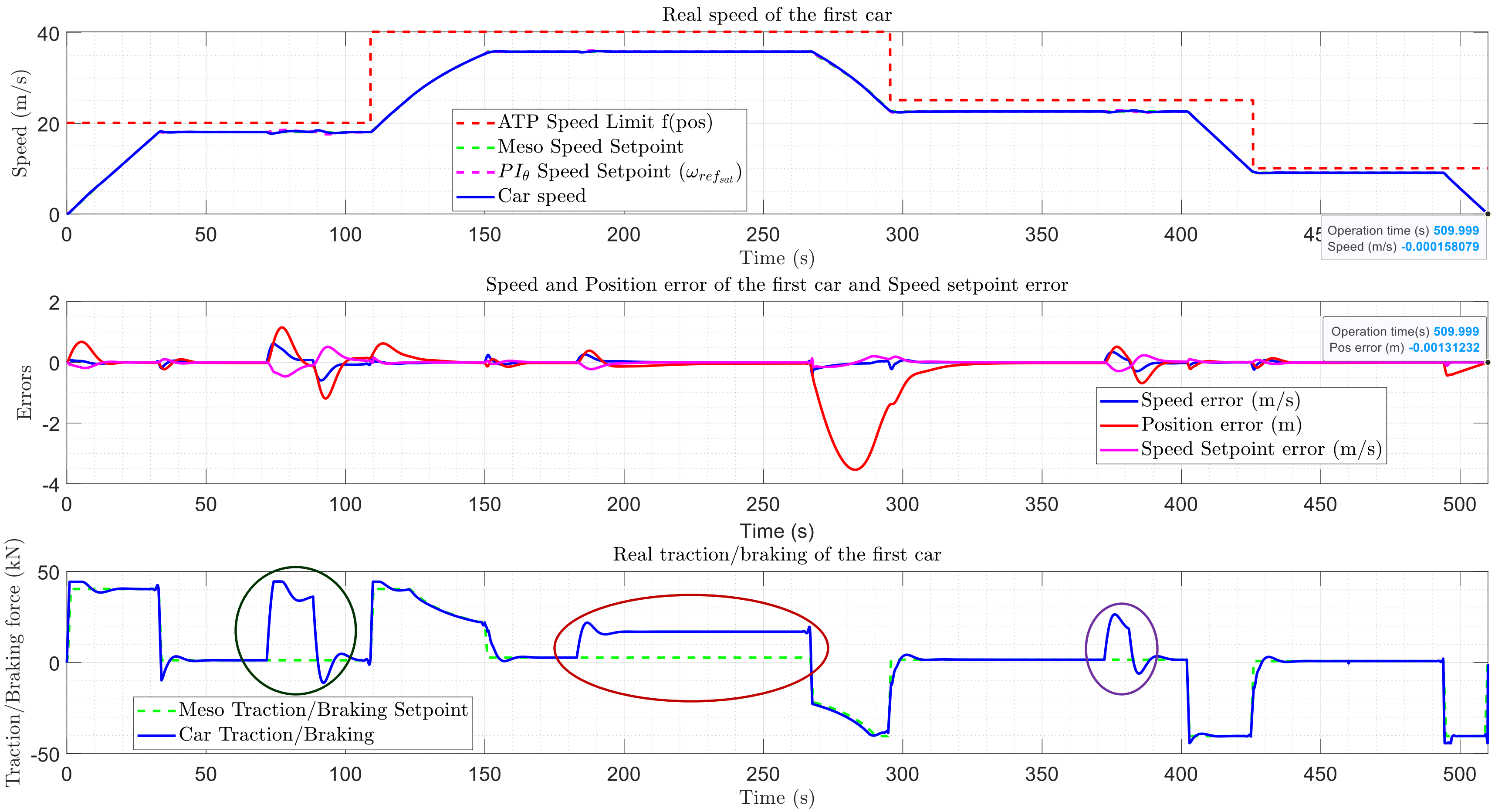
Modeling and development.

Development of the control system: Results

After using the setpoints in the micro layer's torque control system, the systems response (1st iteration):



Conclusions:

- The train **reaches** the **desired position** in the **required operation time**.
- However, **the applied traction and the planned** one are **different**.
- This **happens because** there are **some disturbances over the road**.
- **Thanks to** the tuned **control scheme**, the errors generated by the disturbances **are removed**.
- To reduce positioning errors during the operation, **a replanning must be done.**

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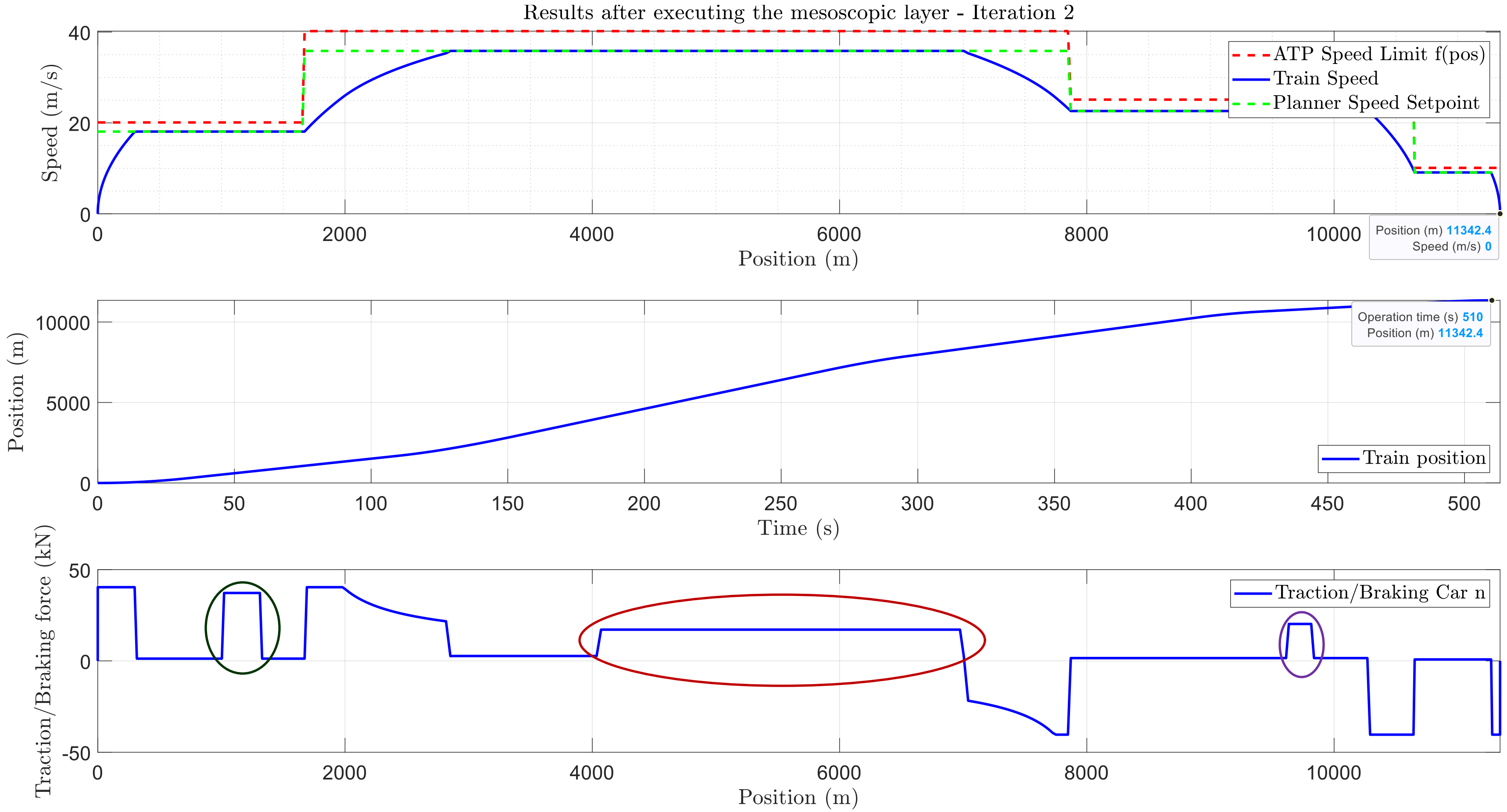
Modeling and development.

Development of the control system: Results

After the execution of the disturbance observer/estimation, the meso layer's planning algorithm is executed again (2nd iteration):



Planning output specifications:

- Planning time ≈ 1.5 s
- Error ≈ 0.24 µs
- **Three** disturbances taken into account.

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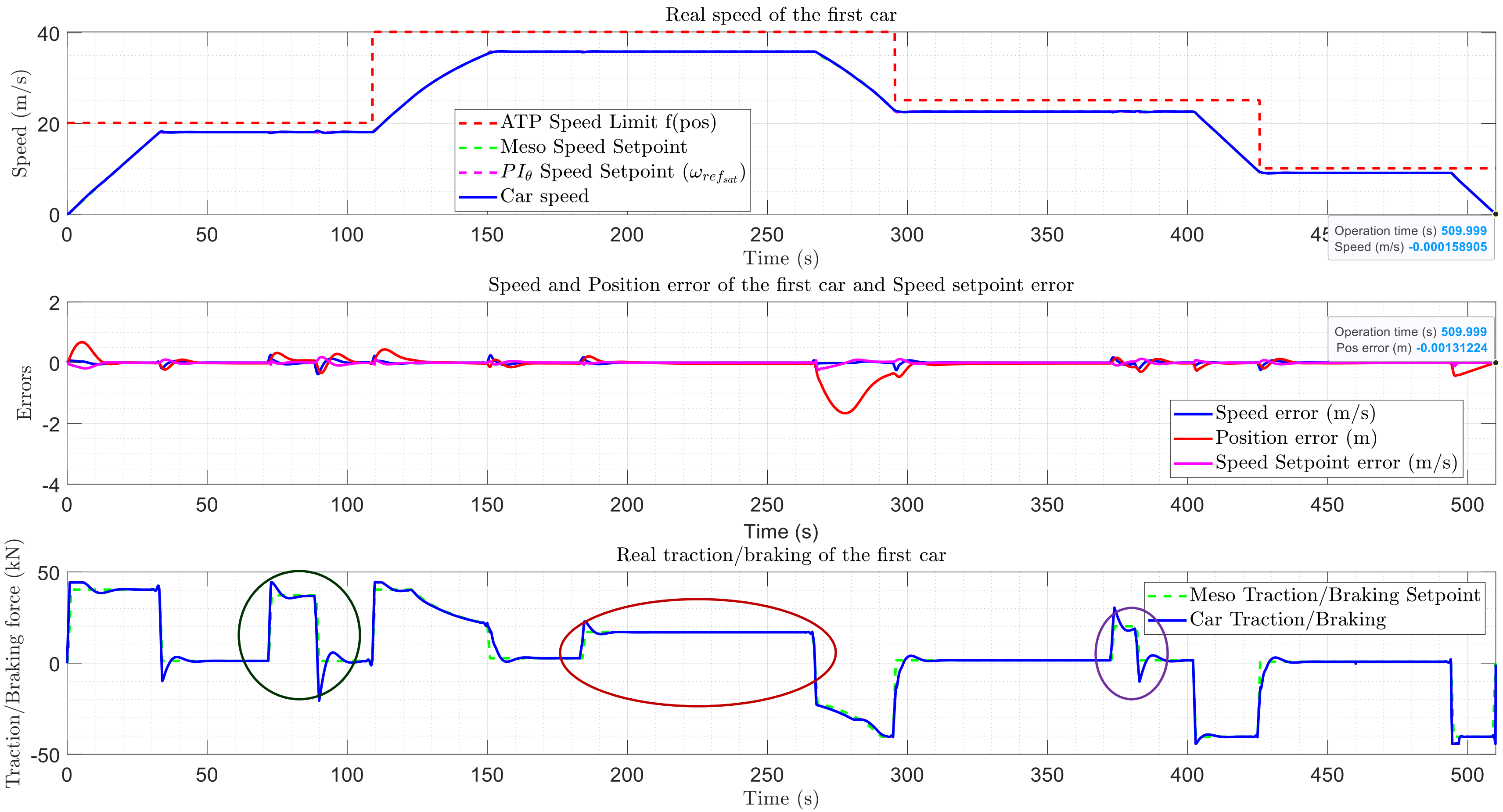
Modeling and development.

Development of the control system: Results

After using the new setpoints in the micro layer's torque control system, the systems final response (2nd iteration):



Conclusions:

- **The train also reaches** the **desired position** in the **required operation time**.
- However, the **applied traction and** the **planned matched.**
- This way, **the controllers don't have to overwork** with respect to the results in the 1st iteration.
- The **positioning errors** during the operation are **notably reduced**.

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Conclusions and future directions.

Conclusions and future directions.

Main conclusions

The **planning algorithm** allows for **agile planning.**

The **control scheme ensures** that the **control objectives** are **met.**

The **developed framework allows** the **simulation** of the train's autonomous operation **correctly**.

Thus, **paving the way** for the **future implementation** of **intelligent control techniques.**

Future directions

Uncertainties will be added to the detailed model, **leading to the improvement of the ATO subsystem.**

The entire **ATO will be run iteratively**, with a shorter prediction time, **generating more accurate run-time control commands**, thus creating a **predictive/iterative algorithm.**

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¡THANK YOU VERY MUCH!

ESKERRIK ASKO!

¡MUCHAS GRACIAS!

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