Driving the Future of Automatic Train Operation: A Focus on Intelligent Driving Algorithms

Roger Idrovo, Paul Zabalegui, Sergio Arana, Jaizki Mendizabal

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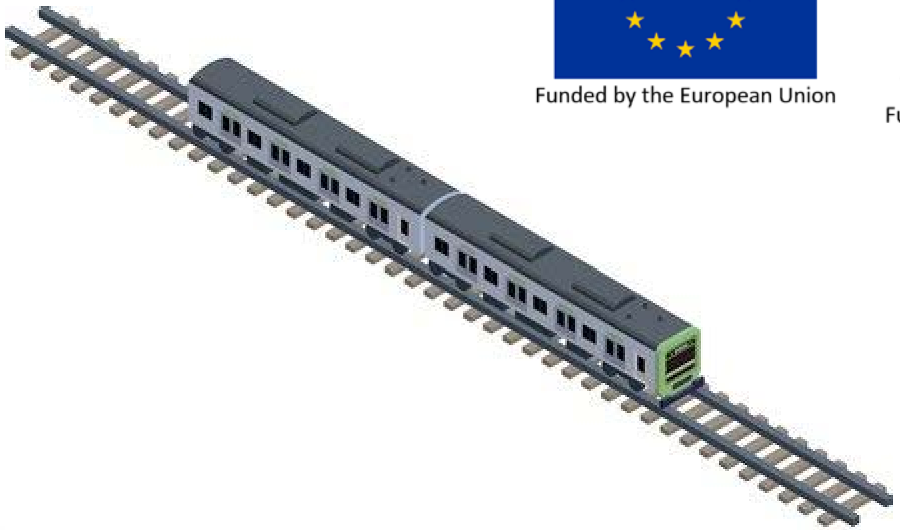

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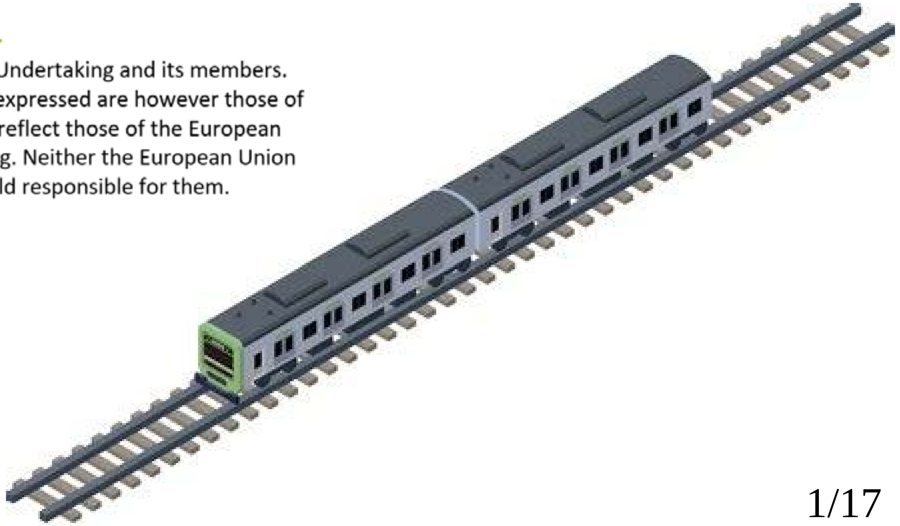

Outline

1. Introduction
2. ATO architecture for GoA 3/4
3. PhD research contribution: Smart algorithms for driving functions
4. Conclusions and future works

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Introduction

Promoted various initiatives

Fostering more **efficient** and **eco-friendly mobility** in rail networks.

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Creating an **efficient** and **high-capacity railway network** by eliminating obstacles to interoperability and incorporating **intelligent solutions** for the industry.

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seeks to **advance automation** in railways and leverage **digitalization** to make the **mobility smarter**, more **efficient**, and **greener**.

Introduction

The railway sector is constantly **innovating** and **harmonizing** smart solutions, products, and standards with the main objective of providing a more **efficient**, **cost-effective**, **secure**, **competitive**, and **reliable** mode of transportation.

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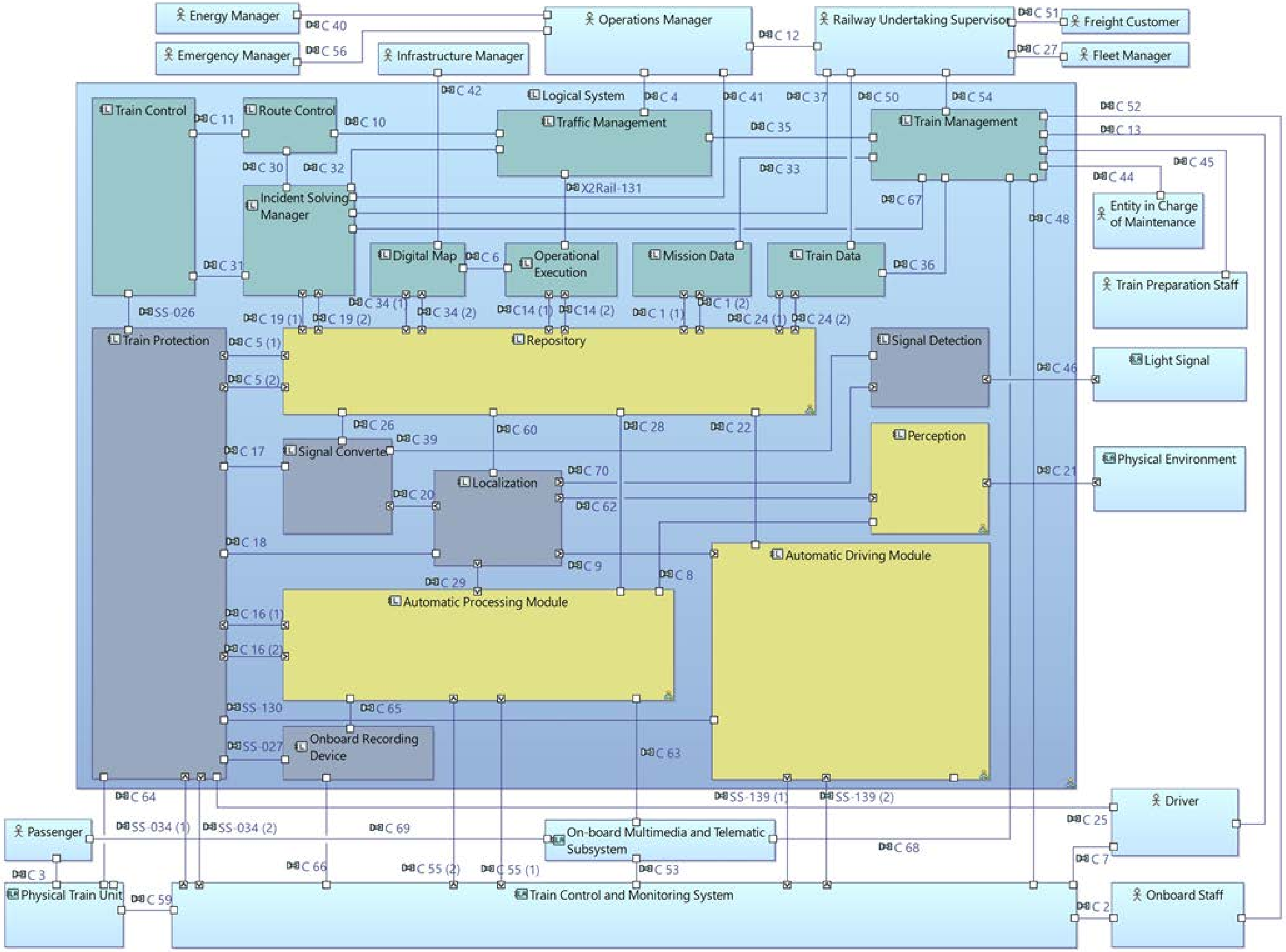
2. **ATO architecture for GoA 3/4**
3. PhD research contribution: Smart algorithms for driving functions
4. Conclusions and future works

ATO architecture for GoA 3/4

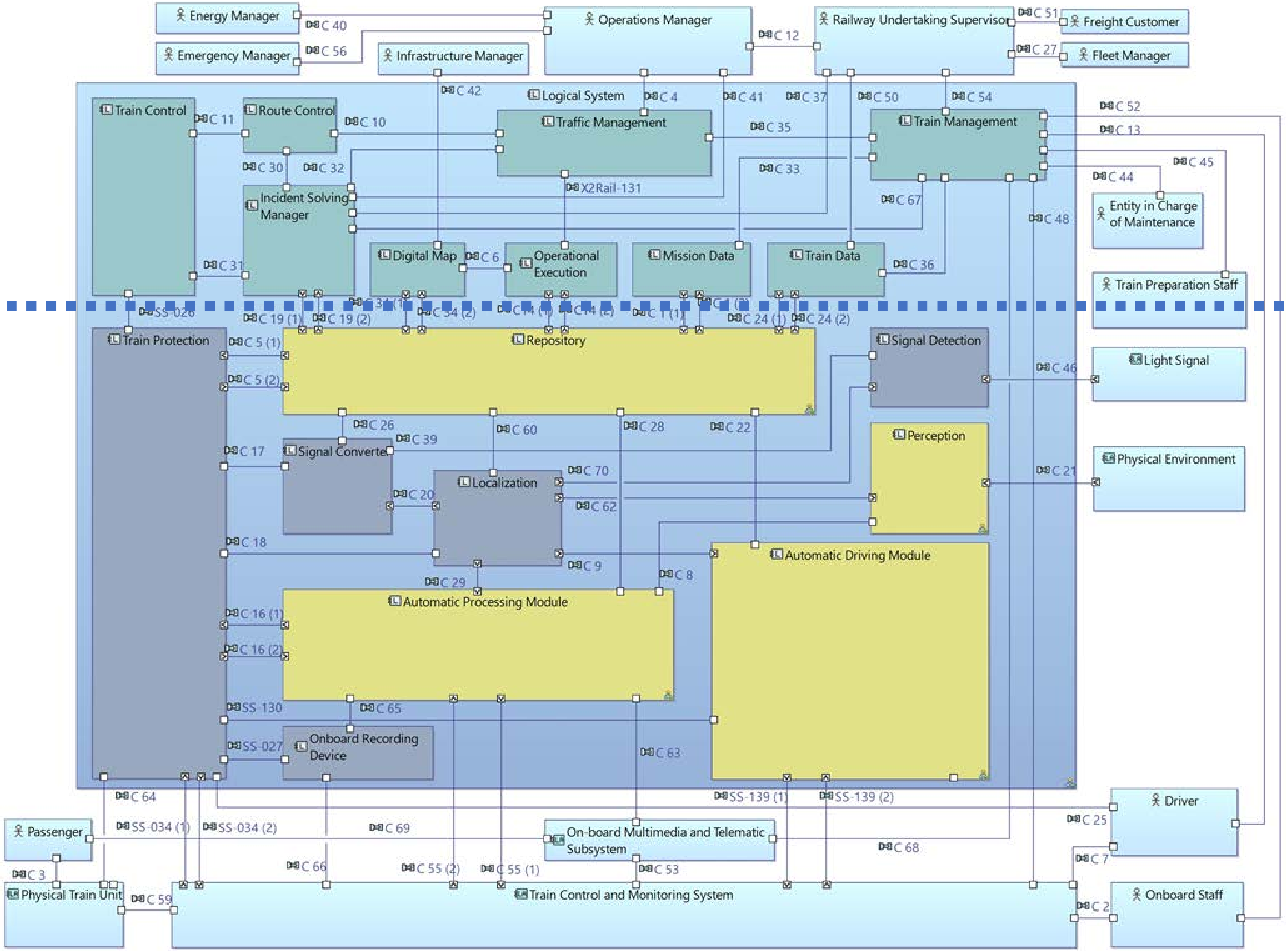


ATO architecture for GoA 3/4

X2RAIL 4

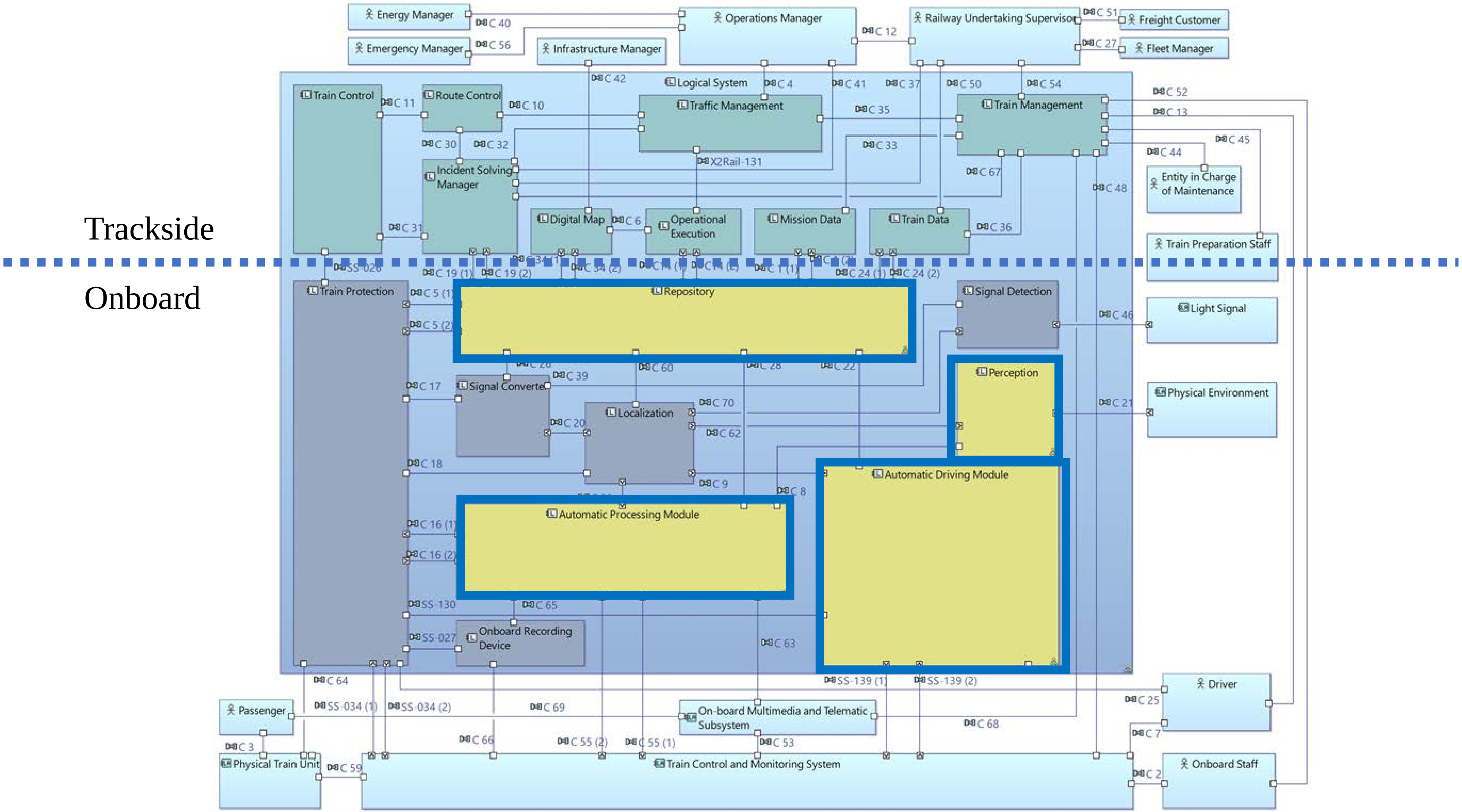
Trackside

Onboard



ATO architecture for GoA 3/4

X2RAIL 4



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3. **PhD research contribution: Smart algorithms for driving functions**
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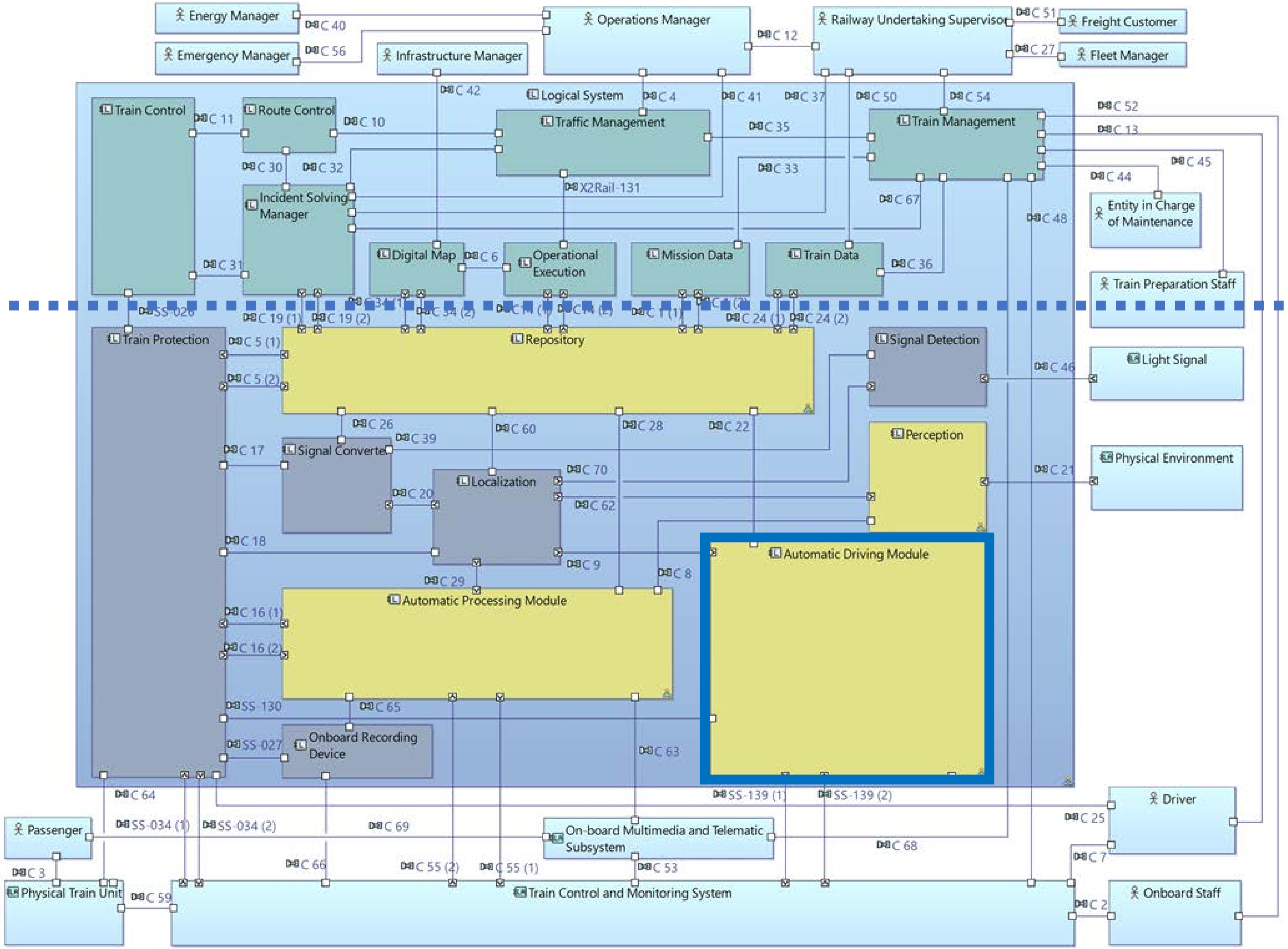
Smart algorithms for driving functions

Trackside

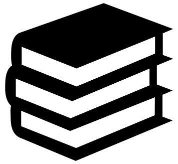
Onboard



Smart algorithms for driving functions

Overview of various smart algorithms

Smart algorithms for driving functions



Overview of various smart algorithms

Two critical functions of ATO:
- Optimizing speed profiles.
- Automatic tracking control.

Smart algorithms for driving functions

Overview of various smart algorithms

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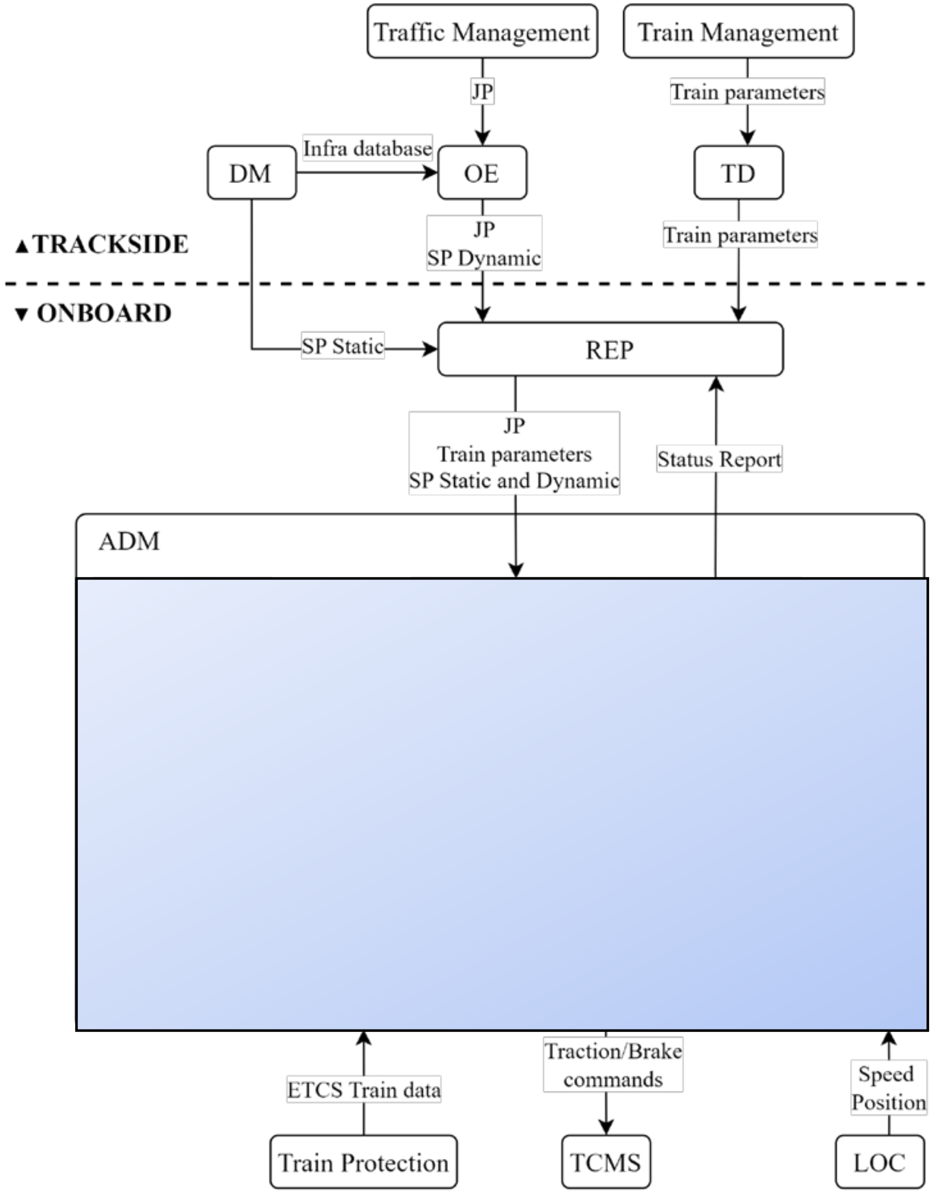
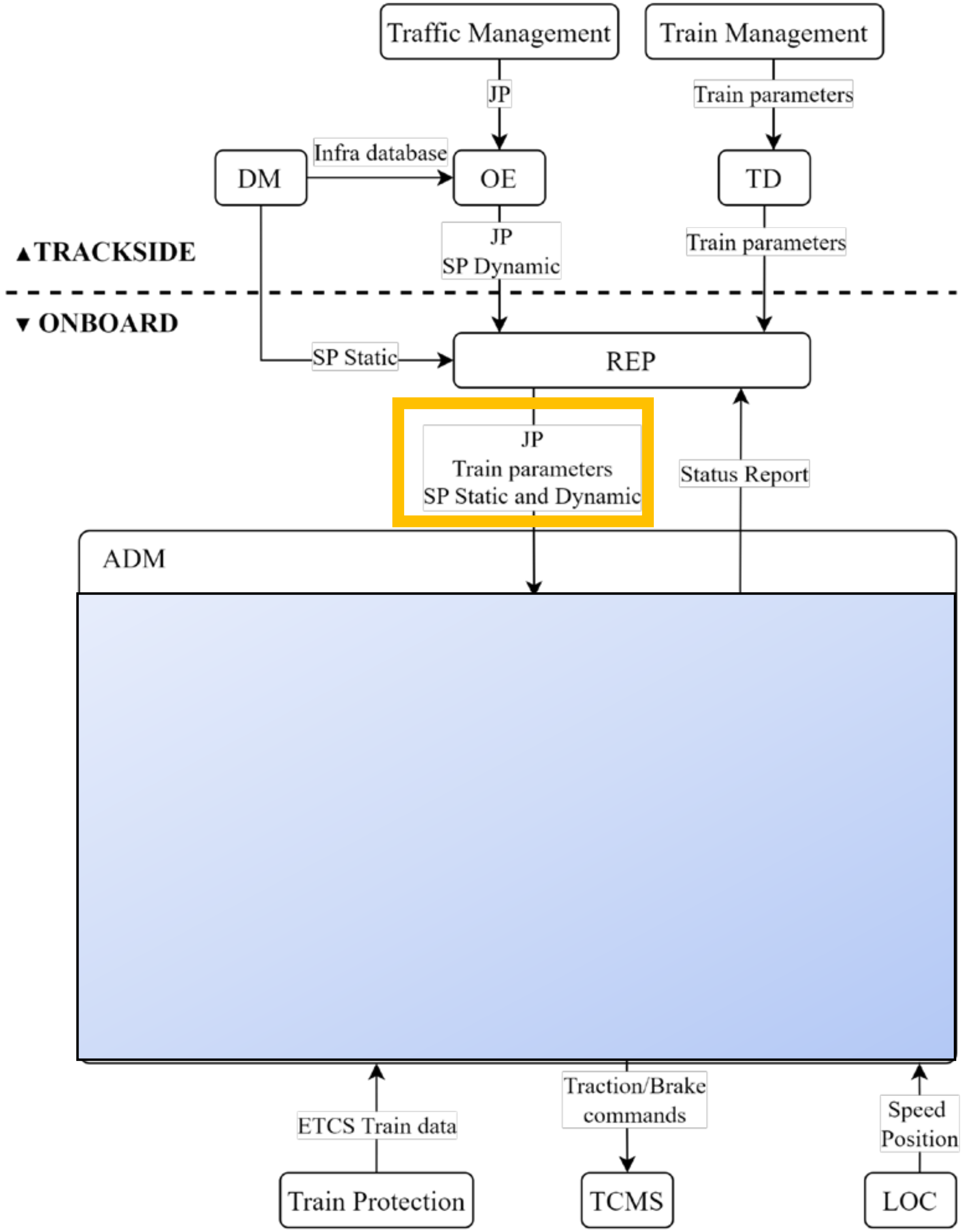
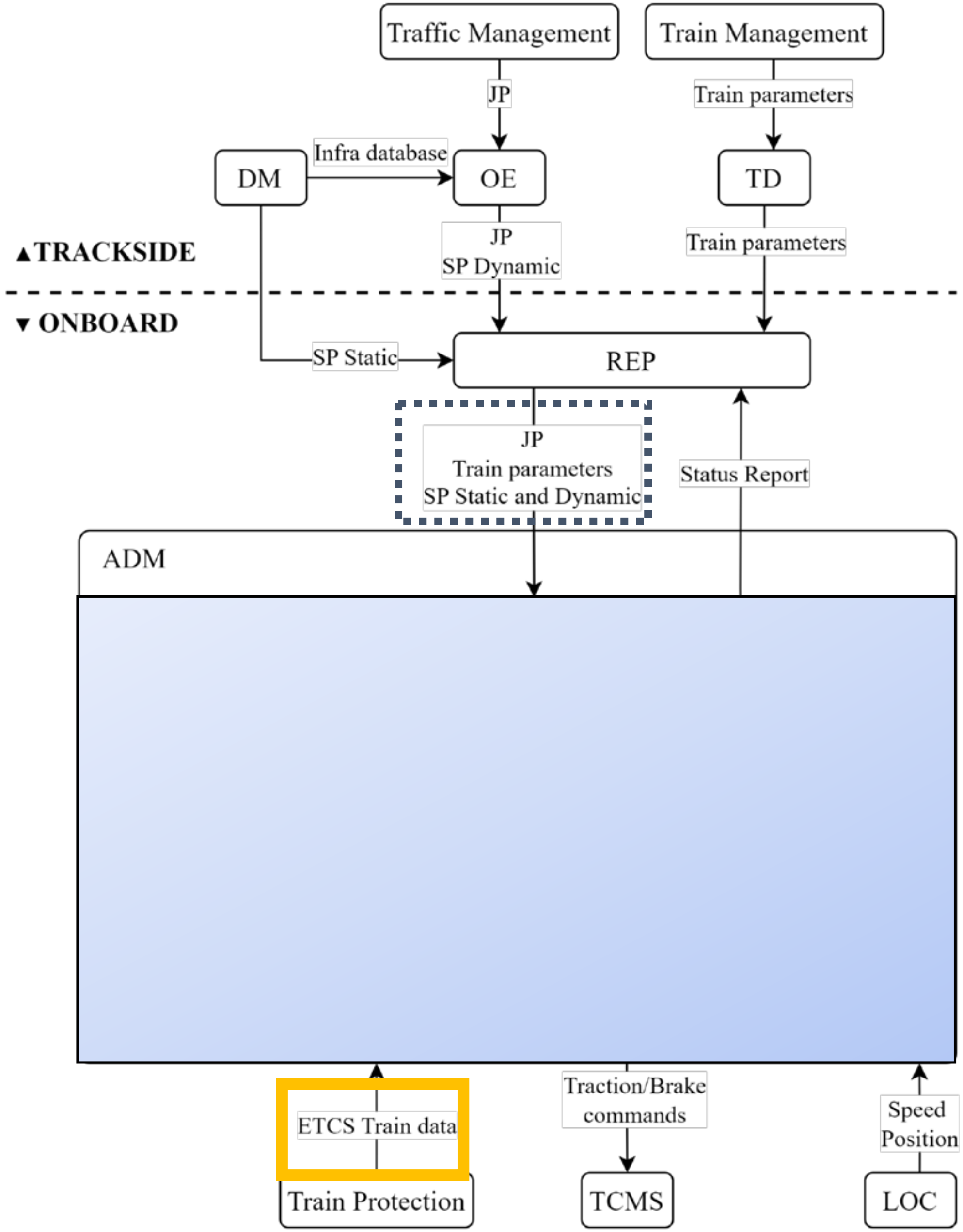
- Automatic tracking control.



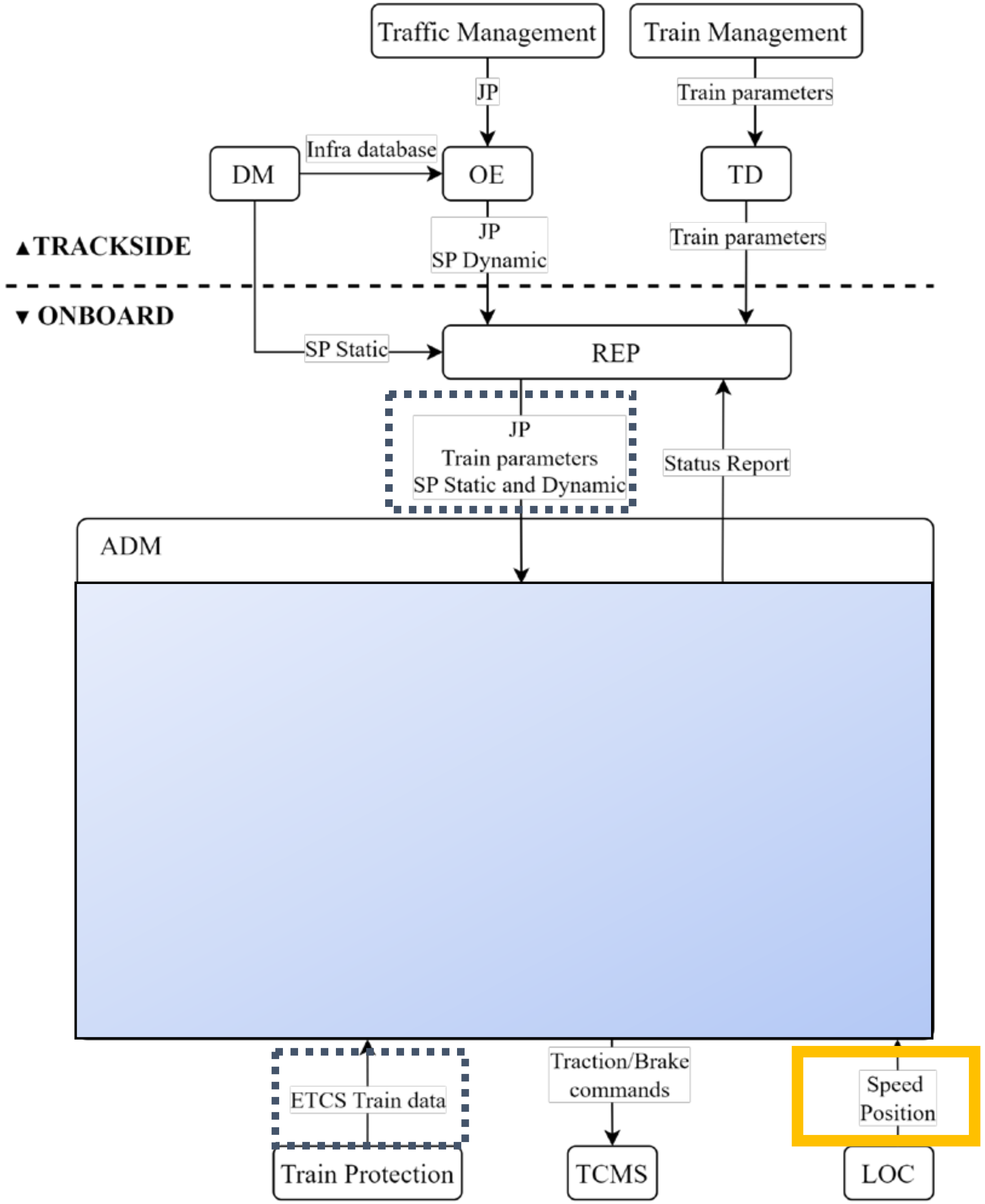
Smart algorithms for driving functions



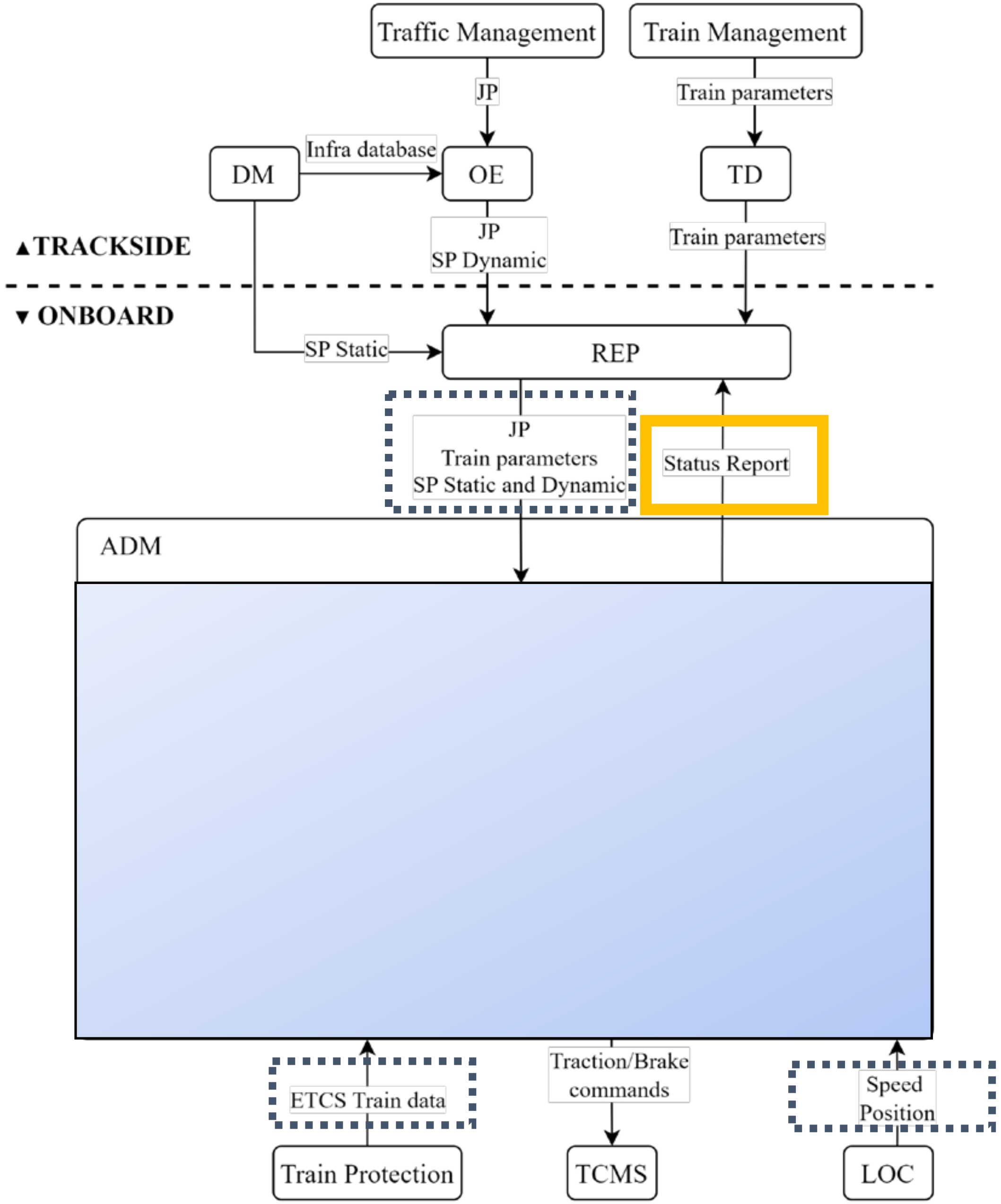
Smart algorithms for driving functions



Smart algorithms for driving functions



Smart algorithms for driving functions



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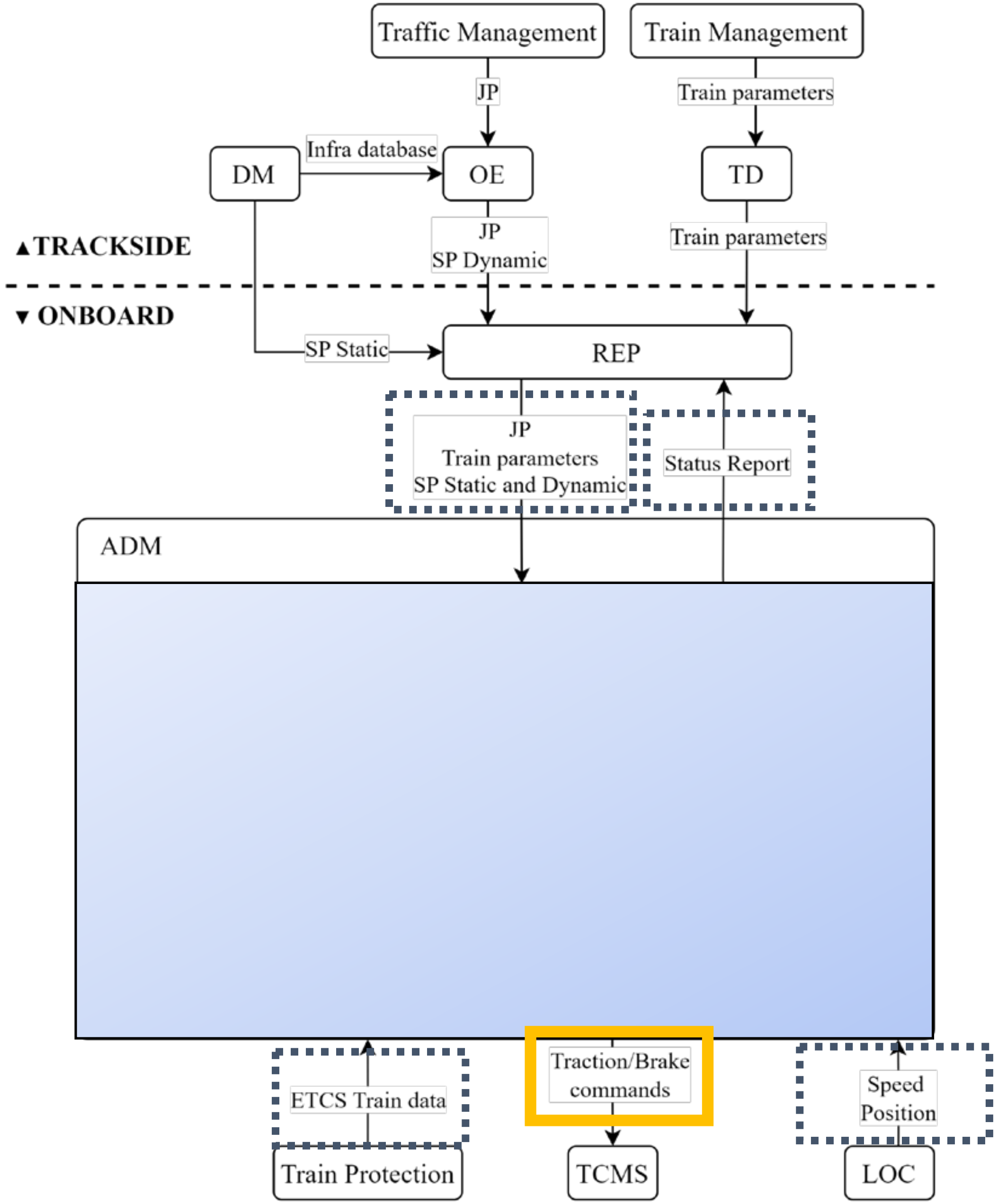
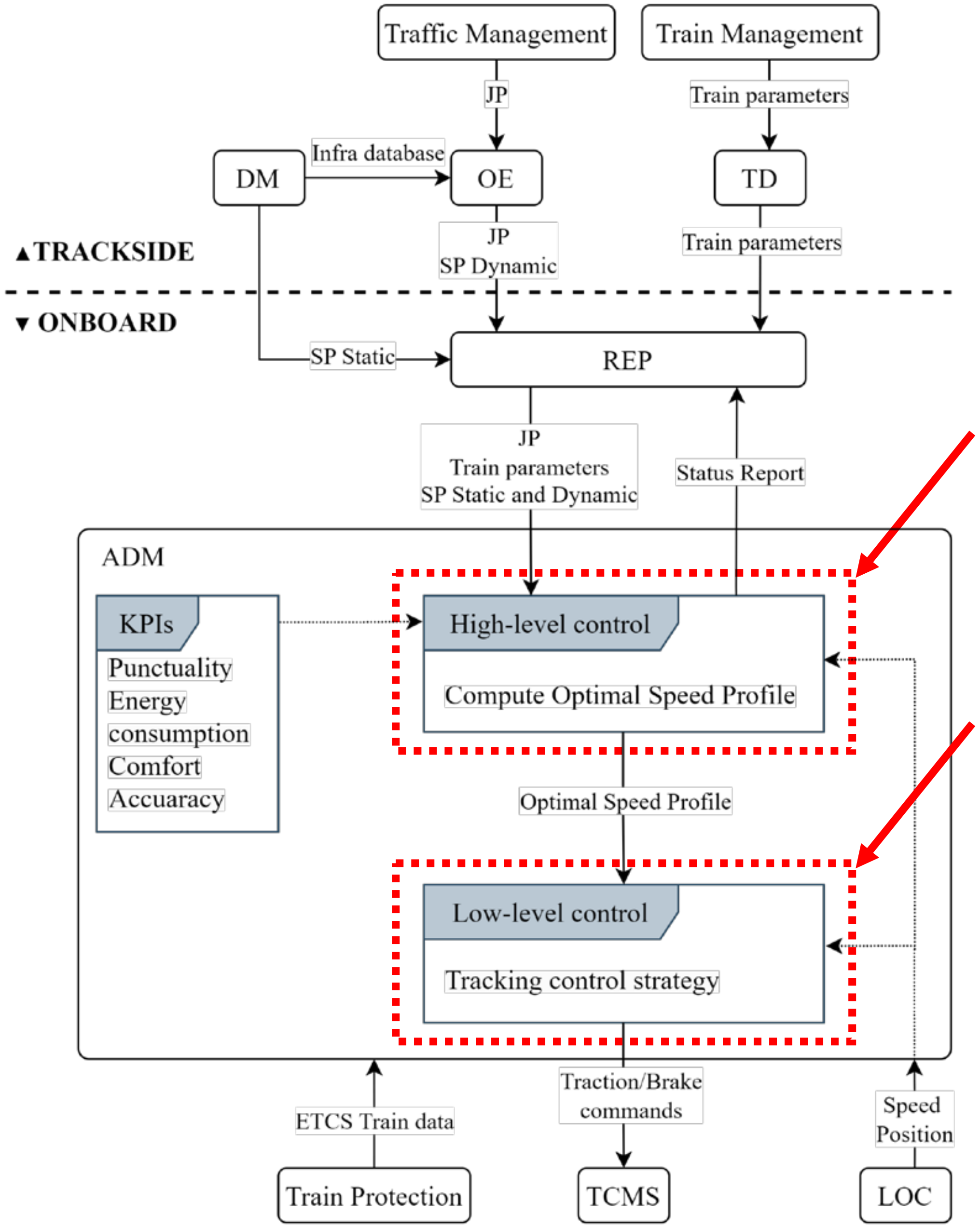


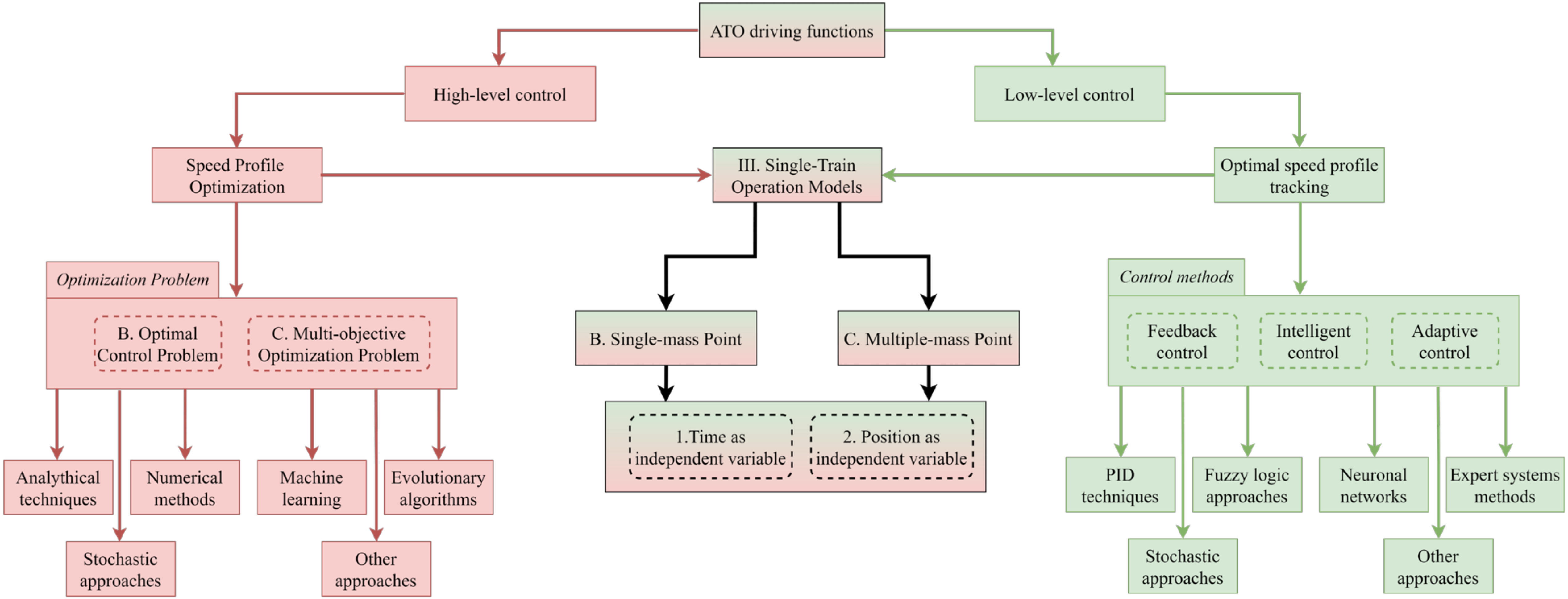
Smart algorithms for driving functions



Optimizing speed profiles

Automatic tracking control

Smart algorithms for driving functions



Smart algorithms for driving functions

ATO: Automatic Train Operation
DAS: Driver Advisory System
MOP: Multi-objective Optimization Problem
OCP: Optimal Control Problem
OSP: Optimal Speed Profile

Main Author	Ref.	System	Speed Profile Optimization Model					
			Method	KPI	Main constraints	OSP Type	Real-world track data	Algorithm
Cao	[65]	ATO	MOP	K_{EC}, K_P, K_C	Dynamic constraints, control forces, limited speed and warning speed curves.	Off-line	✓	RRGA
Zhong	[77]	ATO	OCP - MPC	K_{EC}	Dynamic constraints, punctuality, fluctuating track gradients, TSR, control forces and speed limits.	On-line	✓	PM
Goverde	[78]	ATO	OCP	K_{EC} / RT	Dynamic constraints, control forces, fixed and varying speed limits and gradient.	Off-line	-	PM
He	[79]	ATO	OCP - MILP	K_{EC}	Dynamic constraints, control forces, traffic lights, comfort, line conditions, and speed limits.	Off-line	-	Optimizer Software
Bin	[80]	ATO	OCP	K_{EC}	Dynamic constraints, neutral sections, comfort, double-speed limits.	Off-line	✓	DP
Ning	[81]	ATO	RL	K_{EC}, K_P	Varying gradients, ATP speed supervision profile, scheduled/reschedule various running times and speed limits	On-line	✓	DDPG
Wang	[82]	ATO	MOP	K_{EC}, K_P, K_C, K_{SA}	Dynamic constraints, control forces, speed limits.	Real-time	✓	IMOA
Wang	[83]	ATO	MOP	K_{EC}, K_P, K_C	Dynamic constraints, control forces, speed limits.	Real-time	✓	ISSO
Cao	[84]	ATO	OCP - MILP	K_{EC}, K_C	Sectionalized tunnel, neutral zone, riding comfort, and speed restrictions	Off-line	✓	Optimizer Software
Barruffo	[85]	ATO	OCP	K_{EC}	Punctuality, safety, comfort, dynamic constraints, ETCS intervention, speed and position limits.	Real-time	✓	NMPC
Fernández	[86]	DAS	MOP	K_{EC}, RoD, RT	Dynamic constraints, control forces, punctuality, comfort, dynamic constraints	On-line	✓	DNSGA
Fernández	[87]	DAS	MOP	K_{EC}, RT	Dynamic constraints, control forces, speed limits, control forces, comfort	On-line	✓	DMOPSO
Lin	[90]	ATO	RL	K_{EC}, K_P, K_{SA}	Dynamic constraints, control forces and speed limits.	Off-line	✓	ITO
Xiao	[91]	DAS	OCP	K_{EC}	Punctuality, control forces, movement authority, and temporary speed limits.	Real-ime	✓	PMP+ LMM
Bai	[92]	DAS	MOP	K_{EC}, K_P, DS	Dynamic constraints, control forces, overspeed protection, boundary conditions for kinetic energy	Off-line	-	QP
Li	[93]	DAS	MOP	K_{EC}, K_P, DS	Dynamic constraints, control forces, overspeed protection, boundary conditions for kinetic energy	Off-line	-	QP
Zhang	[94]	ATO	OCP - QCMIP	K_{EC}	Dynamic constraints, punctuality, steadiness, pneumatic brake, control forces and speed limits.	Off-line	✓	Optimizer Software
Zhou	[95]	ATO	MOP	K_{EC}, RT	ETCS intervention, dynamic constraints precision stop, comfort.	On-line	✓	Adaptative GA

Smart algorithms for driving functions

Main Author	Ref.	System
Cao	[65]	ATO
Zhong	[77]	ATO
Goverde	[78]	ATO
He	[79]	ATO
Bin	[80]	ATO
Ning	[81]	ATO
Wang	[82]	ATO
Wang	[83]	ATO
Cao	[84]	ATO
Barruffo	[85]	ATO
Fernández	[86]	DAS
Fernández	[87]	DAS
Lin	[90]	ATO
Xiao	[91]	DAS
Bai	[92]	DAS
Li	[93]	DAS
Zhang	[94]	ATO
Zhou	[95]	ATO

- The majority of the studies **concentrate** on formulating an OSP for **ATO** systems, while a smaller portion is directed towards the **DAS**, which generates an OSP for the driver to track during train operation.

Smart algorithms for driving functions

Main Author	Ref.	System	Method	KPI
Cao	[65]	ATO	MOP	K_{EC}, K_P, K_C
Zhong	[77]	ATO	OCP - MPC	K_{EC}
Goverde	[78]	ATO	OCP	K_{EC} / RT
He	[79]	ATO	OCP - MILP	K_{EC}
Bin	[80]	ATO	OCP	K_{EC}
Ning	[81]	ATO	RL	K_{EC}, K_P
Wang	[82]	ATO	MOP	K_{EC}, K_P, K_C, K_{SA}
Wang	[83]	ATO	MOP	K_{EC}, K_P, K_C
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Fernández	[87]	DAS	MOP	K_{EC}, RT
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Bai	[92]	DAS	MOP	K_{EC}, K_P, DS
Li	[93]	DAS	MOP	K_{EC}, K_P, DS
Zhang	[94]	ATO	OCP - QCMIP	K_{EC}
Zhou	[95]	ATO	MOP	K_{EC}, RT

- The **OCP** typically involves **minimizing** or **maximizing** a **cost function**, with the **KEC** indicator frequently used in most scientific articles.

- The **MOP** involves identifying the **optimal solution** values for several **desired objectives**. Typically, the **KEC**, **KP**, **KSA**, and **KC** indicators are considered in this method.

Smart algorithms for driving functions

Main Author	Ref.	System	Algorithm
Cao	[65]	ATO	RRGA
Zhong	[77]	ATO	PM
Goverde	[78]	ATO	PM
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Bai	[92]	DAS	QP
Li	[93]	DAS	QP
Zhang	[94]	ATO	Optimizer Software
Zhou	[95]	ATO	Adaptative GA

- **Numerical** and **heuristic algorithms** have **emerged** as the most commonly used **optimization techniques**

- **Machine learning** have garnered **increasing attention** in the field of **automatic train operation**.

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4. **Conclusions**

Conclusions

- ✓ This work provides an **analysis** and **comparison** of **ATO high-level control solutions**, and introducing **a novel ATO architecture based on GoA 3/4** from the X2Rail-4 project.

- ✓ This research categorized the existing **single-train operation models** into two groups:

    - **Single-point mass models** that consider a **train** as a **single mass point** for simpler calculation of forces acting on the train.

    - **Multi-point mass models** that divide a **train** into **multiple point masses** for a more detailed understanding of the forces acting on different sections of the train.

- ✓ **Numerical** and **genetic algorithms** have emerged as the **most commonly** used **optimization techniques.**

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THANK YOU!

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Smart algorithms for driving functions

Details From Selected Studies on Single-Point and Multi-Point Models.

Main author	Ref.	Train Model	Independent variable	Dependent variable	Control variable u_{max}	Control variable u_{min}	$F_{B-pneu.}$	$F_{B-regen.}$	W_B	W_A f_g	W_A f_{curv}	W_A f_t	Railway System
Cao	[65]	SPM	Position	Time Speed	✓	✓	-	-	✓	✓	-	-	Metro Train
Zhong	[77]				✓	✓	-	✓	✓	✓	-	-	HST
Goverde	[78]				✓	Const.	-	-	✓	✓	-	-	Intercity Sprinter
He	[79]				✓	✓	-	-	✓	✓	✓	-	Tram
Bin	[80]				✓	✓	✓	-	✓	✓	-	-	HST
Ning	[81]				✓	✓	-	✓	✓	✓	✓	✓	HST
Wang	[82]				✓	✓	-	-	✓	✓	✓	-	Metro Train
Wang	[83]				✓	✓	-	-	-	✓	-	-	Metro Train
Cao	[84]			Time Energy	✓	Const.	-	-	✓	✓	✓	✓	HST
Barruffo	[85]		Time	Position Speed	✓	✓	-	-	✓	✓	✓	-	HST
Fernández	[86]				✓	✓	✓	✓	✓	✓	-	-	HST
Fernández	[87]				✓	✓	✓	✓	✓	✓	-	-	HST
Lin	[90]	MPM	Position	Time Speed	✓	✓	✓	✓	✓	✓	✓	-	Freight Train
Xiao	[91]				✓	✓	-	-	✓	✓	-	-	HST
Li	[92]			Time Energy	✓	✓	✓	✓	✓	✓	✓	-	Freight Train
Bai	[93]				✓	✓	✓	✓	✓	✓	✓	-	HHT
Zhang	[94]		Time	Position Speed	✓	✓	✓	✓	✓	✓	✓	-	HHT
Zhou	[95]				✓	✓	✓	✓	✓	✓	✓	✓	HHT