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Stepping towards digital and automatic rail operation with EURail-FP2-R2DATO: a systemic approach

Joseph MANSOUR SALAMÉ, Jean-Baptiste SIMONNET , Bastian SIMONI, Sana DEBBECH
SNCF Réseau (Paris, France), SNCF Holding (Paris, France), ALSTOM Group (Paris, France)

A systemic approach can help to design & deploy DATO. A collective and practical path is at hand.

CONTEXT AND MOTIVATION

Why DATO?

- Growing demand, ageing infrastructure, climate constraints → need for automation.
- DATO integrates heterogeneous and emerging technologies (FRMCS, automation functions, sensing, data platforms).
- Challenge: deploy these innovations **within diverse legacy systems** across Europe.
- Goal of the project: Design the **simplest architecture** enabling scalable, interoperable and progressive integration of DATO within the EU-Rail ecosystem.

SYSTEMIC & THEORETICAL FOUNDATIONS

System of Systems (SoS) lens:

- Rail = autonomous but interconnected subsystems (infrastructure, onboard, operations, digital platforms).
- Complexity arises from **connectivity, diversity, emergence**.

Criterion	System	System of Systems (SoS)
Autonomy	Granted by the system	Exercised by the sub-systems to achieve the system objective
Belonging	System components do not choose themselves	Each sub-system belongs to a cost-benefit analysis
Connectivity	Minimal connectivity between components	Myriads of connections between sub-systems
Diversity	Minimal diversity	Achieved with autonomy, belonging, and connectivity
Emergence	Foreseen and tested	Need for the detection and elimination of bad behaviors

Systemic exploration (Le Moigne):

- A structured method based on four axes:
  - **Ontological** – What is the system?
  - **Teleological** – What is its purpose?
  - **Functional** – What functions must it deliver?
  - **Genetic** – How does it evolve?

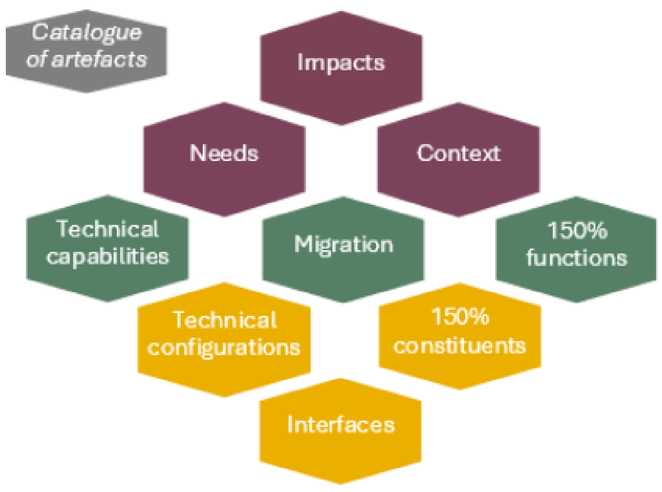
Why systemic?

- To align expectations, reduce inconsistencies, and structure architectural choices in a fragmented, multi-actor environment.

Why look at concepts and knowledge?

- Concept and knowledge can be partitioned and linked.
- Conceptual description embedded in the architecture can be the foundation for continuous exploration.
- Knowledge referenced in the architecture helps to secure migration.

DIFFERENT VIEWS TO DESIGN DATO

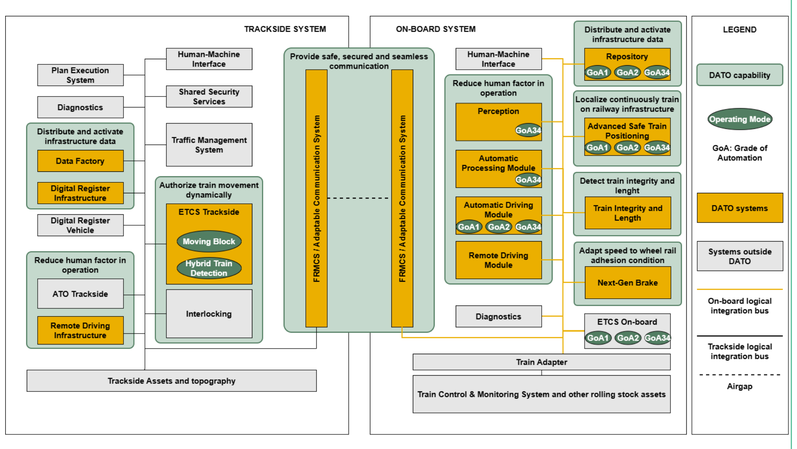


•Design a simple, complete, resilient architecture that integrates with legacy systems while enabling progressive migration and data governance across the European rail value chain.

ARCHITECTURE WORK ALONG LE MOIGNE'S FOUR AXES

Ontological Axis – Defining the system of interest

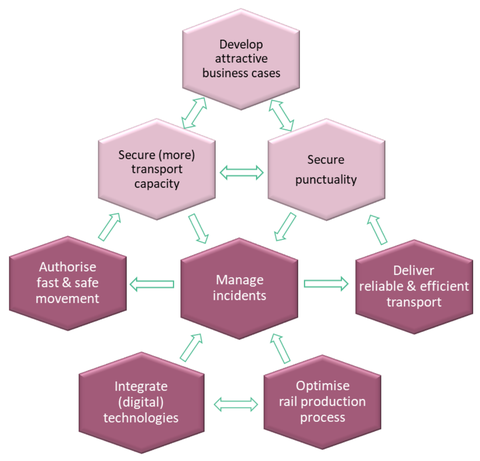
- FP2-R2DATO modelled as a **rail SoS** combining trackside, onboard, operations and digital platforms.
- Multi-view architecture (operational, functional, constituent, technical).
- Shared artefact catalogue: actors, capabilities, functions, constituents, interfaces.



Teleological Axis — Purpose & Value of DATO

Expectations towards DATO can be articulated across three levels:

- Level 1, **Strategic issues** regarding passengers and freight forwarder: Reduce costs; Increase transport capacity; and Secure punctuality
- Level 2, **Business issues** regarding direct stakeholders: All stakeholders aim to increase the usage intensity of their assets. Infrastructure managers aim to supply more resilient network capacity; Rail undertakings aim to offer attractive transport services; and Suppliers aim to deliver new systems and technologies
- Level 3, **Technical issues**: Authorize fast and safe movement [A]; Optimize rail production process [B]; Deliver reliable and efficient transport [C]; Integrate digital technologies [D]; and Manage incidents [E].



Functional Axis — From Needs to Capabilities

- Use cases mapped to **DATO capabilities** and then to **technical issues.**
- Emphasis on **interfaces and data exchanges** → core levers for interoperability.
- Traceability maintained across needs → capabilities → functions → constituents.

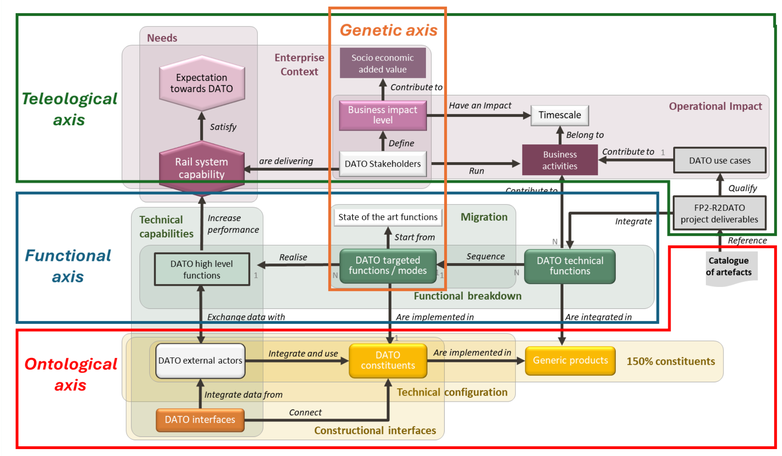
Identified DATO capability	Technical issues				
	[A]	[B]	[C]	[D]	[E]
Reduce human factor in operation		X	X	X	X
Authorize train movement dynamically	X	X		X	X
Adapt speed to wheel rail adhesion condition	X		X	X	
Localize continuously train on railway infrastructure	X		X	X	X
Detect train integrity and length	X			X	X
Provide safe secured and seamless communication	X	X	X	X	X
Provide safe and secure digital modular platform				X	
Distribute and activate infrastructure data	X	X	X	X	X

Genetic Axis — Evolution & Migration

- Multiple technical configurations of DATO identified.
- Progressive migration strategy: manage dependencies, enable upgrade paths, reduce integration risks.
- Data is a driver of transformation: improved worker support & passenger service.
- Architecture treated as a **living artefact**, refined through iterative workshops.

A FRAMEWORK TO SUPPORT DESIGN & DEPLOYMENT

Align on the essential concepts needed to integrate heterogeneous solutions within a complex environment; the systemic axes help maintain coherence while preserving a global view.



LESSONS LEARNED

- Systemic exploration enables alignment across **heterogeneous WPs.**
- Multi-view architecture improves **consistency and integrability**.
- Focusing on **interfaces & data** is essential to manage SoS complexity.
- Simplicity must be a **design objective**, not an afterthought.

Enablers for successful deployment

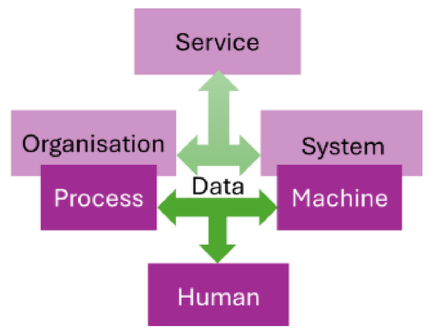
- Clear allocation of functions & responsibilities.
- Standardised data models & interfaces aligned with **FRMCS, ERTMS, EU-Rail System Pillar**.
- Migration roadmaps tailored to national contexts.
- Continuous alignment between architecture, governance, and socio-economic goals.

Future explorations

- Refining interface definitions for implementation-level specifications.
- Extending the metamodel to degraded modes, cross-border flows & edge cases.
- Monitoring emergent behaviour and resilience under stress conditions.
- Quantifying socio-economic impacts of architectural choices.
- Deepening links between systemic modelling and V&V (simulation, pilots).

CONCLUSION

Need to align approach on the integration of technology & digital components but also take into account organisational structures and operational processes to secure qualitative services
➔ find common understanding on the cooperative challenges inherent to complex SoS environments.



Added value of systemic exploration:

- ➢ Enable human centred approach to focus on the data truly needed to meet expectations with less costs, efforts and risks
- ➢ Align on desirable concepts and shared knowledge needed for value creation across heterogeneous and evolving systems.
- ➢ Secure convergent data structures and formats for an executive system of system design.

Contact Information

Jean-Baptiste SIMONNET

Address
Tel: +33 6 20 40 88 89
Email: jean-baptiste.simonnet@sncf.fr
Web: rail-research.europa.eu/rail-projects/fp2-r2dato/