SETTING THE STAGE FOR FUTURE MOBILITY

« Aller vite… mais avec des aspects techniques solides »

Prof. Dr.-Ing. Marc ANTONI
Rail System Director
« Aller vite... mais avec des aspects techniques solides »

• Part 1 – Asset Management in general

• Part 2 – Modelling HSL Assets for Asset Management

• Part 3 – Safety & Security : Cyber issues
Part 1 – Asset Management in général
Standardisation: Complementarity within the EUAR-ESO-UIC trio
Regulation vs. Norms vs. Standards and requirements

**Process-related standards**

- Operation
- Maintenance
- Integration
- High speed
- Freight
- Asset Management
- Safety/Security
- Organisation

“Operator” responsible for the **system** and the **services**

**Product-related standards**

"Manufacturer" responsible for the **products**

- Products
- Sub-System
- Industrialisation

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**System vision**

**Asset Management**

or voluntary binding for the members
1 – Asset Management / Railways

A perfect coherent system vision:

- performance requirement for assets definition, the conditions of use and the work to be carried out
1 – Asset Management / Railways
A perfect coherent system vision:

Asset Management system
1 – Asset Management / Railways

Target MACRO-PROCESS for:

✓ PROSPECTIVE
✓ PRESCRIPTION
✓ OPERATIONAL
ASSET MANAGEMENT STRATEGIES
INTEGRATION OF TECHNICAL NEEDS

Network Objectives
Objectives by corridor

Measured network performances by subsystem « customer vision »

Asset Knowledge, Asset performances, Return of experiences

OPERATION STRATEGIES

Product policies, Technology policies
Design specification / maintenance / operation
Different investment & maintenance policies
Resource strategies

ASSET MANAGEMENT STRATEGIES

1 – Asset Management / Railways
1 – Asset Management / Railways
from digital to asset Management

Predictive maintenance goes through processing and cross-data. This is our number one challenge.
→ Part 2 for HSL

Conditional Maintenance
Based on statements or measures revealing a degradation

Preventative Maintenance
Based on calendar concepts or use units

Corrective maintenance

Model-based predictive maintenance and advanced data analysis
1 – Asset Management / Railways

ASSET MANAGEMENT
INTEGRATION OF WORK NEEDS

Operations Strategies

Network Objectives
- Objectives by axis

Measured network performances/
- Subsystem
  « customer vision

Product policies, Technology policies
- Design/maintenance/operating requirements

Differentiated Investment & Maintenance policies means strategies

State of the patrimony of the axis/corridors
- Emergences Asset Performances

ASSET MANAGEMENT STRATEGIES

Estimation of the maintenance needs and costs

- Customer vision
- Technology policies
- Design/maintenance/operating requirements

Refined means strategies

Commands Strategic axis:
- Circulable capacity
- Object works framed to achieve
- Performance schedule to be achieved
- Resource plans

Estimation of the maintenance needs and costs

Network Objectives
- Objectives by axis

Measured network performances/
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Refined means strategies

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Estimation of the maintenance needs and costs
2 – Asset Management /value-based approach

Contribution of a corridor or line to enhance the value of the network

The value of a line brought to the network can be expressed by different considerations:

• **Commercial performance** (performance from the customer's point of view): passenger traffic, freight traffic, travel time, Traffic flow, regularity, Incident recovery time…

• **Strategic performance** (functions provided by the line): contribution to the resilience of the network (alternative route function), contribution to the economy of the territory, contribution to the interoperability of the network, etc.

• **Revenue**: tolls collected / train route
2 – Asset Management / value-based approach

Value structuration

- **National network rank 1**
  - Sustainable axes / Traffic increase or maintenance / Performance requirements / Important revenues
  - Decision on network priorities (performance contract)

- **National network rank 2**
  - Long-term axes / Traffic increase or maintenance / Performance requirement
  - Axes with uncertain traffic prospects or not guaranteeing certain economic criteria

- **Local lines**
  - Permanent lines / Increased traffic / Performance requirement
  - Long-term lines with stability or even reduction in traffic
  - Futureless lines

- **Optimal maintenance**
  - Renewals to ensure safety and increase performance requirements
  - Modernizations
  - New offers

- **Adapted maintenance**
  - Adapted maintenance (renewal / maintenance mix) to ensure safety & security to control performance or performance decline
  - Modernizations (subject to an economic model)

- **Limited maintenance for safety**
  - Adapted maintenance (renewal / maintenance mix) to ensure safety or renewals & developments if CPER financing
  - Maintenance or adapted renewal submitted to CPER to ensure safety & reduced performance
  - Maintenance adapted to ensure safety & lower performance

- **Futureless lines**
  - Maintenance or adapted renewal submitted to CPER to ensure safety & reduced performance

**Notes:**
- **1**
  - National network rank 1
- **2**
  - National network rank 2
- **ADAPTED MAINTENANCE**
  - Axes with low traffic / low traffic & decreasing
- **LIMITED MAINTENANCE FOR SAFETY**
  - Axes with uncertain traffic prospects or not guaranteeing certain economic criteria
- **OPTIMAL MAINTENANCE**
  - Sustainable axes / Traffic increase or maintenance / Performance requirements / Important revenues
  - Renewals to ensure safety and increase performance requirements
  - Modernizations
  - New offers
2 – Asset Management / value-based approach

Appropriate maintenance

GLOBAL RENEWAL

Global renewal scenario

Global renewal

Alternative maintenance scenarios

(mix Investment & maintenance)

Global renewal: one-time renewal

Light renewal: smooth renewal and minimization of performance degradation related to the asset safety

Safe renewal: smooth renewal of the line to protect against security risks
2 – Asset Management / value-based approach

Appropriate maintenance
Example with different maintenance scenarios

**SCENARIOS**

- Global regeneration (11 sites)
- Lightened regeneration (43 yards, 49 maintenance operations)
- Safety Regeneration (69 worksites, 75 maintenance operations)

Cumulative% of renewal units realized
## 2 – Asset Management / value-based approach

Appropriate maintenance / EXAMPLE: SOCIO-ECONOMIC issues – Relation with global renewal - Focus on key balance statement

<table>
<thead>
<tr>
<th>VAN actualisées à 4,5% en 2019 (M€)</th>
<th>Capacity Impact</th>
<th>CAPEX</th>
<th>OPEX</th>
<th>RU</th>
<th>IM</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variations</td>
<td>De 0,2 à 1,9</td>
<td>+/- 10%</td>
<td>De 1 à 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Regeneration 1</td>
<td>-16</td>
<td>+17</td>
<td>-19</td>
<td>-</td>
<td>~</td>
<td>-</td>
</tr>
<tr>
<td>Reduced Regeneration 2</td>
<td>+18</td>
<td>+16</td>
<td>-19</td>
<td>+</td>
<td>~</td>
<td>+</td>
</tr>
<tr>
<td>Reduced Regeneration 3</td>
<td>+2</td>
<td>-13</td>
<td>-19</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Reduced Regeneration 4</td>
<td>-12</td>
<td>+24</td>
<td>-19</td>
<td>-</td>
<td>+</td>
<td>~</td>
</tr>
<tr>
<td>Safety Regeneration</td>
<td>-21</td>
<td>+25</td>
<td>-24</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
</tbody>
</table>
3 – Towards a governance within an axis vision

Decision-making process in a railway axis vision

- Approval of the axis strategy
- Authorization to initiate an emergence
- Approval of completeness and consistency
- Approval of a programmatic scenario
- Approval of a strategic order
- Approval of a production order

DEVELOPMENT
OBJECTIVES/ AXE

EMERGENCE

PROGRAMMATIC

ORDER
DEVELOPMENT

PLANIFICATION

Stratégies d’axes

OPERATION

ASSET MANAGEMENT

Timetable Planification

Work planning by axis
Part 2 – Modeling HSL Assets for Asset Management
1 - Modelling for Infrastructure Management after conception engineering

Three steps (example for track):

3 – Tools for LCC calculation at the national or route levels, including environmental effects, track possession and unavailability costs…

2 – Tools for the estimation of maintenance needs of the track (with different renewal strategies)

1 – Work of the deterioration and failure laws of each the track components
After 30 years of operations and 650MT with V300, more than ¾ of rails of LN1 are original. The last rails were replaced in 2018…
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

• **Failure laws of rails**:  
  - lifespan of the rails on a ballasted HSL is about 400MT with 3% of cumulative defects, 700MT with 6%  
  - the parameters of these laws are sensitive to track topology and aggressiveness of the rolling stock

The failure rate can grow more quickly if the rolling stock has an important rate of “slippage” (20% for some materials)
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

- Failure laws of aluminothermy welding:
  - Lifespan of a weld on ballasted HSL is about 400MT with 3% of cumulative defects [even without preventive grinding]
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

- **Failure laws of manganese or movable frogs:**
  - lifespan of these components is longer on wooden sleepers than on concrete ones
  - the parameters of these laws are sensitive to the aggressiveness of the rolling stock
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

- **Failure laws of manganese or movable frogs:**
  - lifespan of these components is longer on wooden sleepers than on concrete ones
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1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

- **Failure laws of switch half switch set:**
  - Lifespan of these components is longer on wood sleepers than on concrete ones.
  - The parameters of these laws are sensitive to the aggressiveness of the rolling stock and the hardness of the track.
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

- **Geometry degradation laws:**
  - lifespan of the ballast, without sand-gravel mix bitumen or PAD, is approximately 25 years on HSL (>300)
  - this lifespan will be much higher with sand-gravel mix bitumen and/or PAD
  - maintenance needs follow Cochet-Maumy laws

\[
\text{Im}(N) = k \times 0.8 \times \delta \times \left( a + b \times \left( 2^{\frac{N}{5}} - 1 \right) \right)
\]

The parameters of these laws depend on grinding, the type of **rolling stock**, etc.
Step 1: Lifespan of the components (ballasted HSL)

The nature of the under layer has a significant influence on track lifespan and HSL geometry → specific Cochet-Maumy parameters.
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

Some under sleeper PAD have an influence on track lifespan and HSL geometry ⇒ specific Cochet-Maumy parameters
1 - Modelling for Infrastructure Management after conception engineering

Step 1: Lifespan of the components (ballasted HSL)

Some under sleeper PAD have an influence on track lifespan and HSL geometry ⇒ specific Cochet-Maumy parameters

Average of longitudinal levelling
1 - Modelling for Infrastructure Management after conception engineering

Step 2: Estimation of maintenance needs (ballasted HSL)

Tools for estimation of track maintenance needs (EBM):

Principe / ballasted track:

1 – Cyclical or programmed operations:
   Fixed charges determined by the standards for track surveillance, programmed maintenance, structure…

2 – Preventive conditioned maintenance:
   - Levelling maintenance charges: Interventions conditioned by the information coming from track surveillance. Probabilistic estimation of the intervention needs for a specific route, for a UIC group of routes…
   - Asset replacement charges: Interventions conditioned by asset defect detection… Probabilistic estimation of the failure laws of each asset
1 - Modelling for Infrastructure Management after conception engineering

Step 2: Estimation of maintenance needs (ballasted HSL)
Example of estimation of maintenance needs for the French network

Switches & Crossing UIC 1 to 6

[Graph showing maintenance needs estimation with scenario lines for different years and millions of euros.]
1 - Modelling for Infrastructure Management after conception engineering

Step 2: Estimation of maintenance needs (ballasted HSL)
Example of estimation of maintenance needs for the French network

Switches & Crossing UIC 1 to 6  Normal Track UIC 1 to 6
1 - Modelling for Infrastructure Management after conception engineering

Step 3: LCC calculations (ballasted and unballasted HSL)
HSL ballasted track (UIC group3)
1 - Modelling for Infrastructure Management after conception engineering

Step 3: LCC calculations (ballasted and unballasted HSL)

HSL ballasted track (UIC group3)
1 - Modelling for Infrastructure Management after conception engineering

Step 3: LCC calculations (ballasted and unballasted HSL)

Slab track

ΣInvest / T
ΣMaintenance / T

HSL300 - UIC3 - current track without switches
1 - Modelling for Infrastructure Management after conception engineering

Step 3: LCC calculations (ballasted and unballasted HSL)

Slab track

HSL300 - UIC3 - current track without switches
Thanks to its experience of component and sub-system behaviour, IMs can:

→ specify and optimise new components to facilitate maintenance, taking into account usage, environment, specific quality targets,…

→ optimise the dimension of spare parts and the corresponding maintenance organisation.

The following examples come from signalling:
- choice of failure laws,
- architecture choice for critical computerised system.
2 - Modelling for Infrastructure Management before conception engineering

Modeling methods: renewal density for successive replaced components

Without system ageing

• The renewal density gives the replacements due to failure at time $t$:

$$h(t) = \sum_{n=1}^{\infty} -[(1-F(t))']^n$$

where * denotes the convolution.

• The integral of this function gives the number of expected replacements before time $t$.

![Graph showing the renewal density for successive replaced components over time.](image)
Modeling methods: renewal density for successive replaced components

With system aging

- We can include the ageing of the system (or effects of repairs) by using a factor $K$

\[ \eta_n = \eta_0 \cdot K \]

at the $n^{th}$ replacement.
- This translates the fact that even a new component has a reduced lifetime if it is introduced into an ageing system.

Reduced time $tr$

\[ \text{beta} = 3.4 \]

$K = 0.75$
2 - Modelling for Infrastructure Management before conception engineering

Modeling methods: renewal density for successive replaced components

- **Maintenance expenses**: \( Y(t) = c_i(t) + c_u \cdot n \cdot h(t) \)
  - \( c_i \): current costs
  - \( c_u \): replacement costs for one component
  - \( n \): number of components
  - \( h(t) \): renewal density

- Expected global maintenance expenses (including renewal) per year:

\[
C(T)/T = \left[ X + \sum_{t=0}^{T-1} \int_{t}^{t+1} Y(t) \right] / T
\]

With \( X \): renewal costs

\( E(T) \)

\( \text{To with } K=1 \)
2 - Modelling for Infrastructure Management before conception engineering

Modeling methods: renewal density for successive replaced components

- **Maintenance expenses:** \( Y(t) = c_i(t) + c_u \cdot n \cdot h(t) \)
  - \( c_i \): current costs
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  - \( n \): number of components
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- Expected global maintenance expenses (including renewal) per year:

\[
\frac{C(T)}{T} = \left[ X + \sum_{t=0}^{T-1} \int_{t}^{t+1} Y(t) \right] / T
\]

With \( X \): renewal costs

\( E(T) \)

\( To \) with \( K=0.8 \)
Modeling methods: renewal density for successive replaced components

Design choices could have a huge impact on a maintenance strategy and on the chances of reaching the right quality level (availability, security, safety…) with the economic target value.

The terms of the requirements have to be chosen taking into consideration the context of use and the economic and organizational targets… which are not known by suppliers.
2 - Modelling for Infrastructure Management before conception engineering

Architecture choice for a critical computerized system

**Classical architecture**
- Without independence between System and Functional SW

**Proposed architecture**
- With distinction between HW & System SW and the functional SW

![Diagram showing input, output, mixed functional and basis softwares, probabilistic safety, hardware, and interface.](image-url)
2 - Modelling for Infrastructure Management before conception engineering

Architecture choice for a critical computerized system

Classical architecture
- Without independence between System and Functional SW

Proposed architecture
- With distinction between HW & System SW and the functional SW

Input (TOR or communications in the railway context)

Output (TOR or communications in the railway context)

Mixed functional and basis Softwares

Probabilistic safety

Hardware

N of P architecture of the real time computerised system – SIL4 development

Application of formal methods impossible
2 - Modelling for Infrastructure Management before conception engineering

Architecture choice for a critical computerized system

**Classical architecture**
- Without independence between System and Functional SW

**Proposed architecture**
- With distinction between HW&System SW and the functional SW

Functionalities (interpretable and deterministic model as Petri nets with fixed writing and interpretation rules)

Input (TOR or communications in the railway context)

Output (TOR or communications in the railway context)

Software supporting the execution of the functionalities

Hardware

N of P architecture(s) of the real time computerised system – SIL4 development

Application of formal validation methods
2 - Modelling for Infrastructure Management before conception engineering

Step 3: LCC calculations (Critical IT system with and without formal interface between HW and functional SW)

- **Case 1**: without formal interface between HW and functional SW
2 - Modelling for Infrastructure Management before conception engineering

Step 3: LCC calculations (Critical IT system with and without formal interface between HW and functional SW)
- **Case 1**: without formal interface between HW and functional SW
Case 2: with a formal interface between HW and functional SW
2 - Modelling for Infrastructure Management before conception engineering

Step 3: LCC calculations (Critical IT system with and without formal interface between HW and functional SW)

- **Case 2**: with a formal interface between HW and functional SW
Part 3 – Safety & Security: Cyber issues
1 - Safety and cybersecurity issues

Safety and cybersecurity issues have become a concern for UIC in recent years (in the different functional “layers” of the rail system)

Different levels of fragility in rail services have been identified:

- Information systems in relation to the customer
- Traffic management information systems, contracts, customs information, rolling stock and infrastructure maintenance information
- Critical operating systems

= Business AND Systems
1 - Safety and cybersecurity issues

Following a pathfinder project called ARGUS, implemented in cooperation with the COLPOFER group (OSJD) and well-known industrial players such as Cyclus, Splunk, Airbus, APSYS and others, UIC has created its first Guidelines for Cyber-Security in Railways.
2 – Cyber risk: myth or reality?

We are currently in:
- A world engaged in digital warfare at economic and/or military level
- An interconnected and open digital world

This world represents a paradigm shift for the railways

- Railways are one of the priority targets of certain actors

- Today, railways use digital technologies and architectures that are particularly vulnerable to potential attack (internal or external)
2 – Cyber risk: myth or reality?

Railways have become stuck in a position of denial about the emergence and growth of risks related to cyber attacks, for many reasons:

1. Consequences of attacks vs. determinism of preventive costs
2. “Service provider” vs. “technical mastery of systems”
3. Transition from white box systems, or functional white box to black box vision
4. Not taking safety or cyber risks into account in security studies (application of CSM, obtaining AMEC...)

Cyber risk: myth or reality?
2 – Cyber risk: myth or reality?

From the Internet: possible takeover of station information systems, automatic vending machines (ransom requests to regain control)

Immobilisation of rolling stock in operation by unauthorised radio connection (links intended for remote maintenance, etc.)

A “man in the network” can cause a fire, field elements in unsafe conditions, change the functionality of certain signal boxes, etc.

Intrusion tests performed by IMs or RUs demonstrate the weaknesses in certain systems, existence of plausible attack scenarios, etc.

The list is not exhaustive, especially since some actors “map” the networks of friendly/hostile countries...
Cyber risk is therefore a reality that can have a direct impact on rail traffic availability and safety.

We have experienced and will continue to experience a decline in the security levels of our critical infrastructure with the transition to digital. There are dangers that threaten us:

- **Russia and former USSR**: Hostile cyber attack/attack on behalf of industries or lobbies
- **China**: Peaceful attacks on industrial knowledge and illegal information gathering
- **Terrorist and/or extremist organisations**

Three major dangers
3 - Technological developments that threaten our systems

The evolution of technologies and modernism (technical and managerial) expose our systems to attack. Such developments include:

1. The emergence and uncontrolled spread of "railway clouds", cloud computing, IoTs, including for critical signalling systems

2. IoTs generally have only one common password to a series of products, registered in Hard internally, without the user being able to dynamically and frequently change it

3. Digital systems and networks (existing or future) that are poorly designed in terms of safety and security cannot subsequently be secured in practice
3 - Technological developments that threaten our systems

4. Modern systems are highly centralised, which makes them vulnerable to an attack

5. Modern systems are not developed with the use of functional modelling or formal methods and use cost, hardware, OS and "general public" protocols

6. The consequences of a targeted attack are far greater than those that could possibly be expected for attacks on older systems
4 - Taking cyber threats into account in system design rules and related security studies

- Identification of security strategy levels
- Real independence of networks with different levels of cybersecurity and business consequences
- Gateways between networks with protocol breach
- Functional white box modelling of systems and their means of communication
- Systems development with the use of formal methods
- Useful resilience through independent and non-digital technological means
- Deployment of all radio communications in the railway sector > FRMCS
For safety demonstrations (application of Common Safety Methods):

- **Formalise** choices in security files in terms of acceptability of cyber consequences, types of network subset where certain systems can be deployed, etc.
- **Identify** the physical protective measures that must be associated with them (demonstration assumptions)
- **Identify** the rules of design, implementation, system integration that must be implemented (demonstration assumptions)
- **Consider**, in addition to ER related to human and organisational factors or aspects of technical failure, ER possibly related to external attacks by malicious third parties
- >Requires implementation of three types of measures (depending on the identified need):
  - Peripheral defence,
  - Defence in depth,
  - Endogenous defence (for SIL4 systems) and identify means of continuous verification of proper implementation and operation
- **Identify** (the nature of) the intrusion tests that will have to be performed regularly and on which railway subassembly (assumption of the demonstration)
5 - Taking cyber risks into account in IMs’ and RUs’ asset management processes

The railways (RUs and IMs) are responsible for traffic safety; they must define and are responsible for the SMS (Safety Management System - more appropriately called “SSMS” (Safety and Security Management System)).

Network strategy

Asset Management system
Including Security and « Cyber security »

Requirement analysis

Production
5 - Taking cyber risks into account in IMs’ and RUs’ asset management processes

A perfect coherent system vision → including Security and Cyber security:
5 - Taking cyber risks into account in IMs’ and RUs’ asset management processes

Network objectives
- Objectives by axis

Measured network performances/subsystem
- "Customer vision"

Product policies, technology policies
- Design/maintenance/operating requirements

Differentiated investment and maintenance policies

Status of patrimony of the axis/corridors
- Emergence asset performances

ASSET MANAGEMENT STRATEGIES

OPERATION STRATEGIES

Commands - strategic axis in terms of:
- Traffic capacity
- Works to be achieved
- Performance schedule to be achieved
- Resource plans

Estimation of maintenance needs

Network objectives

Objectives by axis

Measured network performances/subsystem
- "Customer vision"

Product policies, technology policies
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ASSET MANAGEMENT STRATEGIES

OPERATION STRATEGIES

Commands - strategic axis in terms of:
- Traffic capacity
- Works to be achieved
- Performance schedule to be achieved
- Resource plans

Estimation of maintenance needs
6 - UIC's work in this area will intensify in 2019

- Development of the FRMCS system (in collaboration with 3GPP, ETSI, suppliers...)
- Specialised cyber exchange platform: - telecoms and/or specialist manufacturers - standardisation bodies - railways
- UIC Railway Application Guide - Asset Management through ISO 55001
- Projects: APRA and OSJD
- Publication of new IRSs
- Sustainable development
6 - UIC's work in this area will intensify in 2019

• 2018 exploratory group conclusion: need for a practical approach

• Development of three axes:
  – Definition of priorities: critical systems/safety
  – Participation in existing ad hoc telecoms work groups (ETSI, 3GPP, GSMA, etc.)
  – Cooperation with a group of specialised industrial companies already active in providing sound solutions to other industries (airborne, energy, etc.)

• Registration in ad hoc telecoms work groups (H1)

• Identification/enrollment of 1st group of industrial companies (H1)

• Initial vision for possible technical solutions (end 2019)

Complementary to other initiatives (processes, normative rules, etc.)
Stay in touch with UIC!

www.uic.org

#UICrail

Prof. Dr. Marc Antoni
Rail System Director
UIC Rail System Department

antoni@uic.org

Thank you for your kind attention!