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Artificial Intelligence for Predictive Maintenance and Defect Detection: Preliminary Results and Next Steps

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Presentation Outline

- *Research Process Overview*
- *Preliminary Results:*
  - *Hints From other Sectors*
  - *Transferability Analysis*
- *Next Steps and Case Studies:*
  - *Smart Maintenance at Level Crossings*
  - *Digital Twins for Railway Stations*

Research Process Overview

Taxonomy and State-of-the-Art of AI in Railway

Definition of Application Areas and Relevant Railway Problems

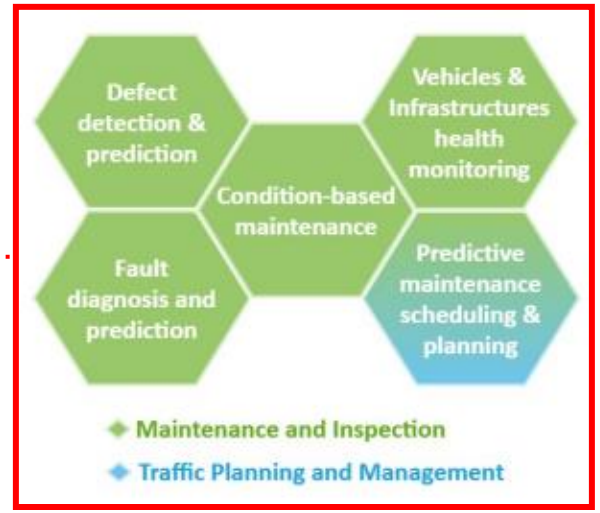
Case Study Identification

Transferability Analysis

Proofs-of-Concept Development

Roadmaps Identification

Digital Twins
IoT Devices
Autonomous UAVs
Cloud Computing



Maintenance and Inspection is the most investigated railway sub-domain

Analysed Sectors

Transport

Non-Transport

Promising Research Directions

- Structural Health Monitoring based on Autonomous UAVs
- Vehicle Health Monitoring based on Cloud Computing
- Fault Diagnosis and Prognosis based on Digital Twins and IoT
- Motion-based RUL Estimation through Non-intrusive Sensors

Qualitative Framework for Transferability

Dimension	Description	Criterion	Description
Congruence	the adherence between the AI application intended to be transferred in the source domain and its counterpart in the target domain.	**Mission/Aim/Scope**	the adherence of the AI application that is intended to be transferred to the mission, aims, and scope in the target domain.
		Previous Experience	the previous experience, i.e. the research/developing status of an AI application in the source domain.
		Failure Severity	the gap that exists in terms of unpleasant consequences between a valuation error in the source domain and a valuation error in the target domain.
Significance	the benefits that the AI application may bring in the target domain if successfully transferred, regardless of its maturity.	**Potential Effectiveness**	how much effective could be the AI application if successfully transferred.
		Impact	the positive impacts that the AI application would have in the target domain in successfully transferred
Similarity	the similarities between the specific goal of the AI application in the source and target domains and between the characteristics of the two domains	**Goal**	the similarities between the specific goal of the AI application in the source and target domains.
		Domain Characteristics	how different are the target and source domains in terms of their peculiarities.
Maturity	the advancement of the AI application in the target domain.	**AI Application**	the grade of maturity that the AI application has achieved in the target domain in terms of its research/developing status.
		Automation	the grade of automation that can be associated to an AI application in the source domain.
Implementability	the effort and costs needed to implement the AI application in the target domain considering the required technologies, skills and the possibility to maintain the application over time.	**Technology**	whether the technology in the target domain is mature enough to accommodate the AI application or further improvement are needed.
		Sustainability (costs and effort)	the costs and effort needed to maintain the transferred AI application in the target domain over time.

Fixed

Variable

Qualitatively scored from “very low” to “very high”

Structural Health Monitoring based on Autonomous UAVs

In Physical Infrastructure Monitoring (Critical Infrastructures)

Autonomous UAVs to collect structural images of concrete buildings (indoor) and bridges

Technology

Autonomous UAVs

+

AI-based Approach

Image-based Defect Detection

Widely investigated within the rail sector

Possible Target Application

Full Automated Assets Health Monitoring
(Assets: rail tracks and catenary systems)

While Avoiding Traffic Disruption

Some Challenges

- Integrate UAVs in the railway communication system
- Failures could heavily affect safety

Semi-autonomous UAVs
Partially manoeuvred by human operators while autonomously inspecting assets

Transferability Table (TTable)

		Criteria (qualitative/perceptive) Evaluation				
Dimension	**Criterion**	**Very High**	**High**	**Medium**	**Low**	**Very Low**
Congruence	*Mission/aim/scope*	✓				
	Previous Experience			✓		
	Failure Severity			✓		
Significance	*Potential Effectiveness*	✓				
	Impact	✓				
Similarity	*Goal*			✓		
	Domain Characteristics			✓		
Maturity	*AI Application*		✓			
	Automation		✓			
Implementability	*Technology*			✓		
	Sustainability (costs and effort)		✓			

Fault Diagnosis and Prognosis based on Digital Twins and IoT

Digital Twins have been investigated in different sectors to address very different problems

In Machinery

Rotating Machinery Remaining Useful Life (RUL) Estimation

In Manufacturing

Manufacturing Processes Optimization

In Avionics

Gas Exchange Optimization in Aircraft Engines

Technology

Digital Twin

+

AI-based Approach

Regression-oriented Approaches

Adopt (and possibly re-use) non-intrusive sensors

Some Challenges related to IoT Sensors

- Expensive and time-consuming
- Probable re-approval process in safety-critical scenarios

Transferability Table (TTable)

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	Previous Experience		✓			
	Failure Severity			✓		
Significance	*Potential Effectiveness*		✓			
	Impact	✓				
Similarity	*Goal*		✓			
	Domain Characteristics			✓		
Maturity	*AI Application*				✓	
	Automation			✓		
Implementability	*Technology*			✓		
	Sustainability (costs and effort)			✓		

Motion-based RUL Estimation through Non-intrusive Sensors

Goal

Estimate the Remaining Useful Life by leveraging non-intrusive Sensors (e.g., cameras)

In Manufacturing and Machinery

Estimation of the Time to Failure (TTF) of bearings or cutting wheels

Approach

Degradation images were modelled as a spatiotemporal process

If considering moving objects (e.g., Level Crossing Barriers)

Needs

Estimate the RUL basing on the motion path of the barrier over adjacent frames, and not on its visible defects (e.g., scratches)

No relevant studies were found in this direction

Computer Vision Approaches based on Deep Learning
(to extract movement-related features)

+

AI approaches to analyze temporal dependencies (e.g., RNN)
(to compute the RUL estimation)

Transferability Table (TTable)

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Significance	*Potential Effectiveness*	✓				
	Impact	✓				
Similarity	*Goal*				✓	
	Domain Characteristics			✓		
Maturity	*AI Application*					✓
	Automation			✓		
Implementability	*Technology*		✓			
	Sustainability (costs and effort)	✓				

Case Study Identification

RAILS's Objective

Define roadmaps for the integration of AI applications in the rail sector by developing proofs-of-concept in order to understand:

- ❖To what extent it is convenient to introduce AI approaches
- ❖Which AI approach could represent the most suitable solution
- ❖How challenges may be overcome

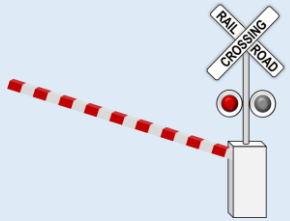
Identification of Case Studies

The Case Studies identification process has been performed in parallel with the Transferability Analysis. A Case Study had to met at least two of the following aspects:

- ❖Relevance in respect to the state-of-the-art
- ❖Support or Suggestion from the Advisory Board
- ❖Possible transferability along with the identified directions

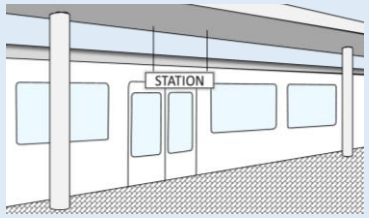
Selected Case Studies

Smart Maintenance at Level Crossings



- ❖ Level Crossing is one of the most interesting scenarios given its relevance in terms of safety concerns.
- ❖ This would allow us to investigate further along some transferability directions.

Digital Twins for Railway Stations Monitoring



- ❖ Railway Stations represent the junction point between passengers and rolling stock.
- ❖ Digital Twins could allow for a visualisable and analysable model to efficiently analyse station facilities and platforms.

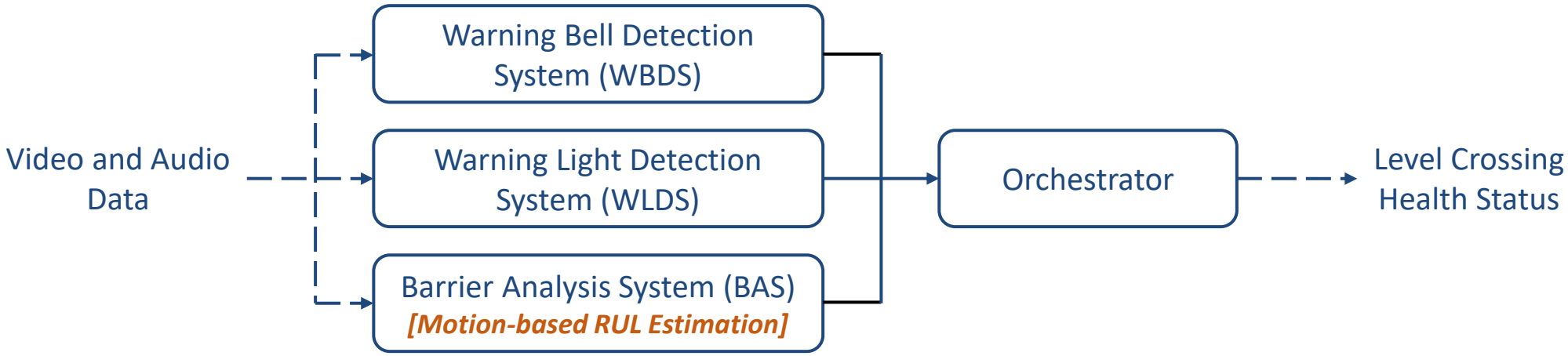
Smart Maintenance at Level Crossings

Goal

Investigate the potentials of AI in combination with non-intrusive sensors (cameras and microphones) to assess Level Crossings Health Status

AI Approaches

Classification Algorithms and Computer Vision Approaches based on Deep Learning

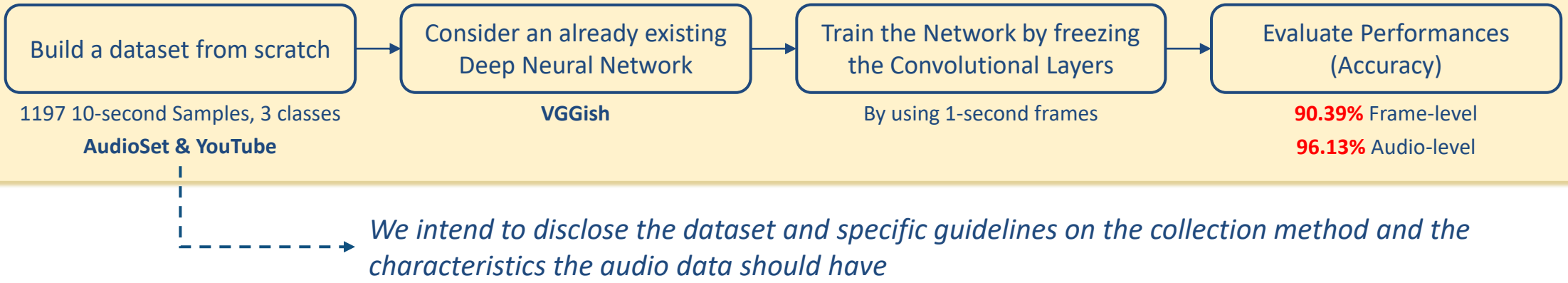


Preliminary Results on Level Crossings: WBDS

Goal

- **Assess the potentials of Transfer Learning to cope with the lack of publicly available datasets**
- **Build a dataset that could be used as benchmark**

Process



We also performed a *systematic review** with the aim of gathering as many publicly available dataset as possible that could be used as benchmarks or facilitate the work of future researchers who intend to address railway-related topics through AI approaches

** Pappaterra, M.J.; Flammini, F.; Vittorini, V.; Bešinović, N., "A Systematic Review of Artificial Intelligence Public Datasets for Railway Applications". Infrastructures 2021, 6, 136. https://doi.org/10.3390/infrastructures6100136*

Thank you for your attention!

https://rails-project.eu/

RAILS S2R Project

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https://www.researchgate.net/project/RAILS-Roadmaps-for-AI-integration-in-the-raiL-Sector-EU-Horizon-2020-Shift2Rail-JU