Artificial Intelligence for railway traffic planning and management: Preliminary Results and Next Steps

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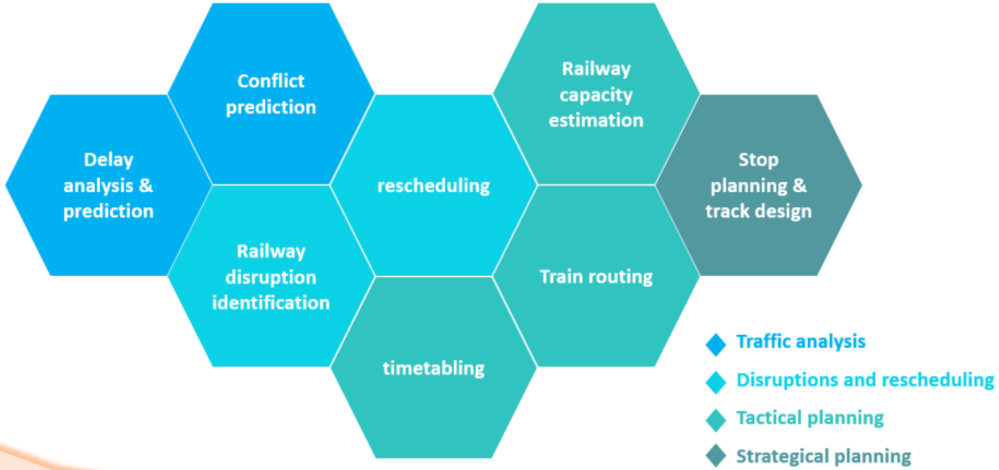
Presentation Outline

- *Research Process Overview*
- *Preliminary Results:*
  - *Hints From other Sectors*
  - *Transferability Analysis*
- *Next Steps and Case Studies:*
  - *Graph embedding-based Train Delay Prediction*
  - *Supervised-ML for Railway Disruption Identification*
  - *RL-based Train Timetable Rescheduling*

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

Deep-Neural Networks
Cognitive IoT
Explainable AI

Transport analysis/Traffic planning and management is a significant railway sub-domain that AI techniques have been heavily introduced in

Analysed Sectors

Transport-related

Clusters of Promising Applications

- Integrating heuristic searching strategies with deep neural networks for vehicle routing
- Alternative routes services/navigation for passengers based on Cognitive Internet of Things
- Attributing Primary and Secondary delays in Railway networks using Explainable AI

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”

Integrating heuristic searching strategies with deep neural networks for vehicle path planning

Derived from path planning/navigation for road network (Automotive)

Graph-based methods (e.g. critical link method, queuing theory) are popular among road vehicle path planning tasks.

Target Application (railway)

Discover the valid routes for a given origin-destination pair in the integrated network

Considered factors:
Total travelling time
Energy consumption
Passenger convenience
Capacity of chosen tracks

Rail car routing and path planning

Challenges

1) Previous studies focus on homogeneous railway network pathing without considering other types of networks

2) Conventional searching algorithms are not efficient for real-time routing

Approach

Heuristic searching strategies —Feed in→ **Deep neural Networks** —generate→ ***Vehicle navigation and path planning***

Widely investigated in the traditional path planning algorithms

The training data is optimal paths in a graph generated by a shortest path algorithm

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)				✓	

Alternative route services for passengers based on Cognitive-IoT

Borrowed from the travel route selection for individual passenger (Automotive)

Passengers may leave the vehicle at any of the intermediate station as they need, even transfer to another vehicle afterwards due to different destinations.

Target Application (railway)

The journey time distribution of any possible path can be estimated.

Challenges

1) Travelling behavior of the individual passenger is more difficult to be captured just adopting mathematical methods/heuristic search.
2) The general objects should have the capability of learning from outside and think independently.

Considered factors:
Total travelling fare
Travel time/comfort
Transfer difficulties
Travel convenience

Intelligent passenger route recommendation

CIoT framework for passenger navigation

Perception-action cycle → Massive data analytics → Semantic derivation and knowledge discovery → Intelligent decision-making → On-demand service provisioning

Bridge the physical world (physical objects, facility resources) and the social world(human demand of travelling, social behavior)

Transferability Table (TTable)

Dimension	Criterion	Criteria (qualitative/perceptive) Evaluation				
		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)		✓			

Attributing Primary and Secondary delays in Railway networks using Explainable AI

Challenge 1

XAI has not received practical attentions within the rail sector.

Challenge 2

Knowledge representation & understanding from Big data is not friendly for those who have little expertise on AI tasks.

Target Application **(railway)**

Discerning different reasons for the occurrence of train delays.

In aviation, on the one hand…

Attributing different delays with particular (or a set of) reasons are tough and complex.

In aviation, on the other hand…

Train dispatchers want to know which flight builds up how much delay at which airport, for preventing more delays occur and propagate.

Transferability Table (TTable)

Dimension	Criterion	Very High	High	Medium	Low	Very Low
		Criteria (qualitative/perceptive) Evaluation				
Congruence	*Mission/aim/scope*		✓			
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	Domain Characteristics		✓			
Maturity	*AI Application*				✓	
	Automation		✓			
Implementability	*Technology*			✓		
	Sustainability (costs and effort)				✓	

Case Study Identification

Train Delay Prediction

Predicting unnecessary **waiting time** or **in-vehicle time** for passengers

- ❖ Decrease total travel time
- ❖ Improve passenger comfort & satisfaction

- ❖ Current studies are mainly stochastic-based models and statistical distribution model.
- ❖ Investigating delay propagation mechanism solely, without much consideration on the occurrence of disruptions

Disruption Attribution Analysis

Identifying adverse events and **learning** from operation logs/incident reports

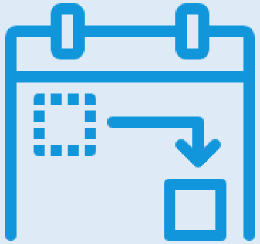
- ❖ Avoid the re-occurrence of potential accidents
- ❖ Promote reliability & quality

- ❖ Learning process affected by subjective judgements
- ❖ A plenty of accident cases are difficult to be acquired
- ❖ Randomly occurred disruptions would have different impacts on the railway network.

Smart Rescheduling

Developing a model to reschedule an existing timetable

- ❖ Minimizing the overall delay
- ❖ Utilizing the capacity of tracks/facilities effectively



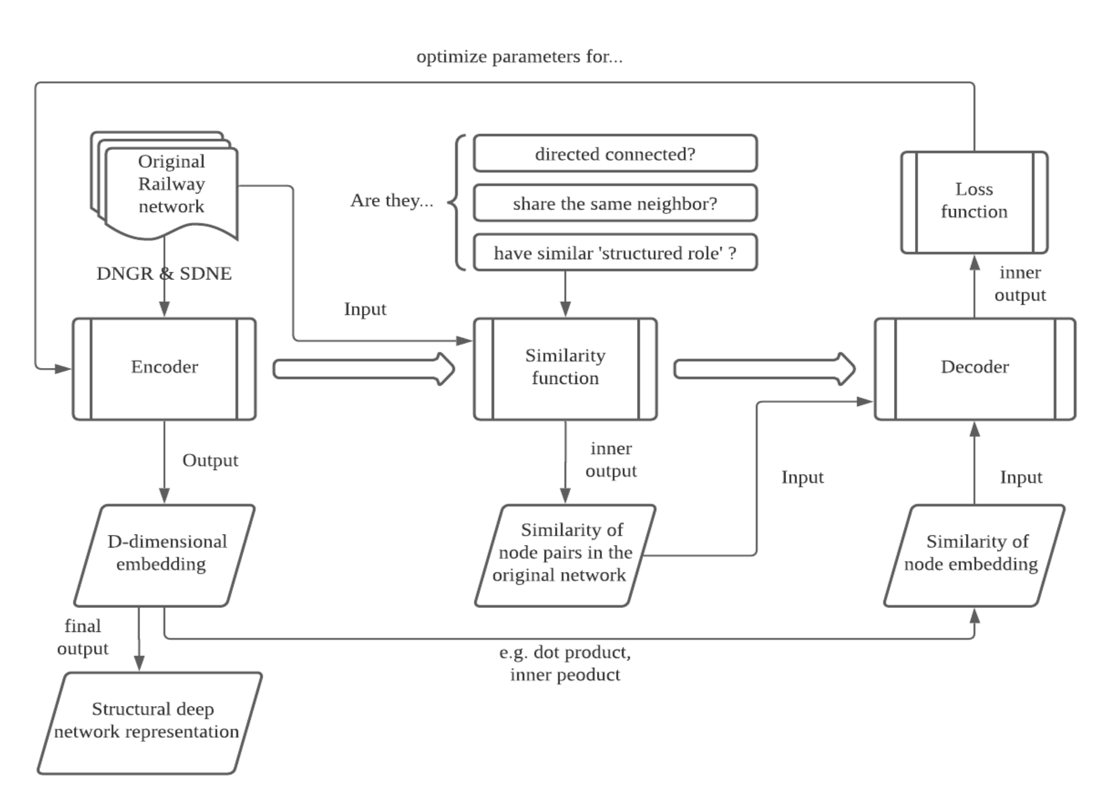
- ❖ Mathematical optimization process requires massive computational resources and time expenses
- ❖ Complexity of rescheduling problems make the feasible model difficult to be transferred.

Graph embedding-based Train Delay Prediction

Goal

Predict the average delay level of a specific period in the future based on the historical delay data of multiple periods.

Process (SDNE framework)



Highlights

- **Firstly attempt to integrate a graph embedding module into the framework of spatial-temporal railway network.**
- **Geographical dependencies of delays between different stations can be preserved and the essential knowledge of the network is useful for the downstream prediction/rescheduling tasks.**
- **Considering interactions between rail network elements and the hidden correlations between them.**
- **Yield the best performance with 84.8% accuracy on primary delay prediction on train services.**

Supervised-ML for Railway Disruption Identification

Goal

Estimate the possibility of occurrence for various disruptions at each individual station during each time period.

Challenges

- **Insufficient empirical disruption observations available for each location and time slot**
- **The format of incident reports is different from other statistics of railway systems (i.e. timetables, traffic flows, passenger demands)**

**image from https://www.networkrail.co.uk/*

Approaches

Supervised machine learning model:

Logistic regression, MLP, KNN, and Random Forest

+

Incorporating the specific characteristics of each station and the features of time/season/weather, temperature and track status, etc.

→ The frequency of occurrence for different kinds of disruptions

RL-based Train Timetable Rescheduling

Goal

Efficiently reschedule existing train timetable affected by disruptions or potential delays, with the aiming of minimizing the overall delay for each train service.

Challenges

- ❖ Currently, the proposed solutions, such as exact optimization algorithms, expert-knowledge methods have their own advantages and shortcomings.
- ❖ Most AI-related algorithms are difficult to be understood and explained. (black-box models, e.g. NN, MLP)

Process

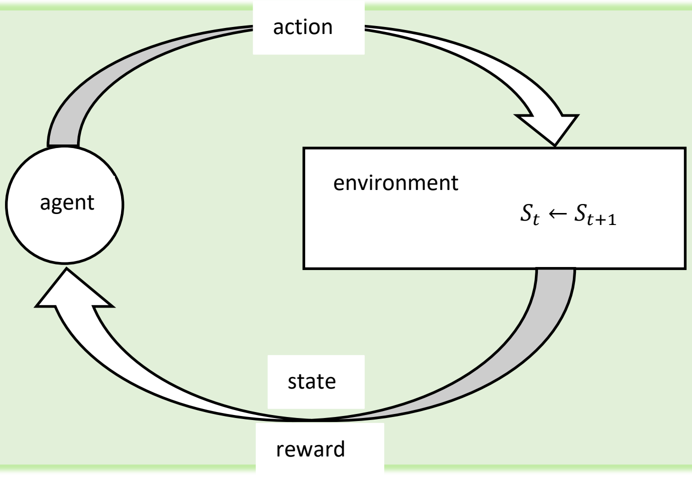
- ❖ Developing a discrete event simulator
- ❖ Defining the components for the reinforcement learning model, includes:

    Agents

    State-action pairs

    Objective function

    Reward function



Thank you for your attention!

RAILS

Roadmaps
for AI
Integration
in raiL Sector