Agile Simulation in Planning and Operating London's Elizabeth line

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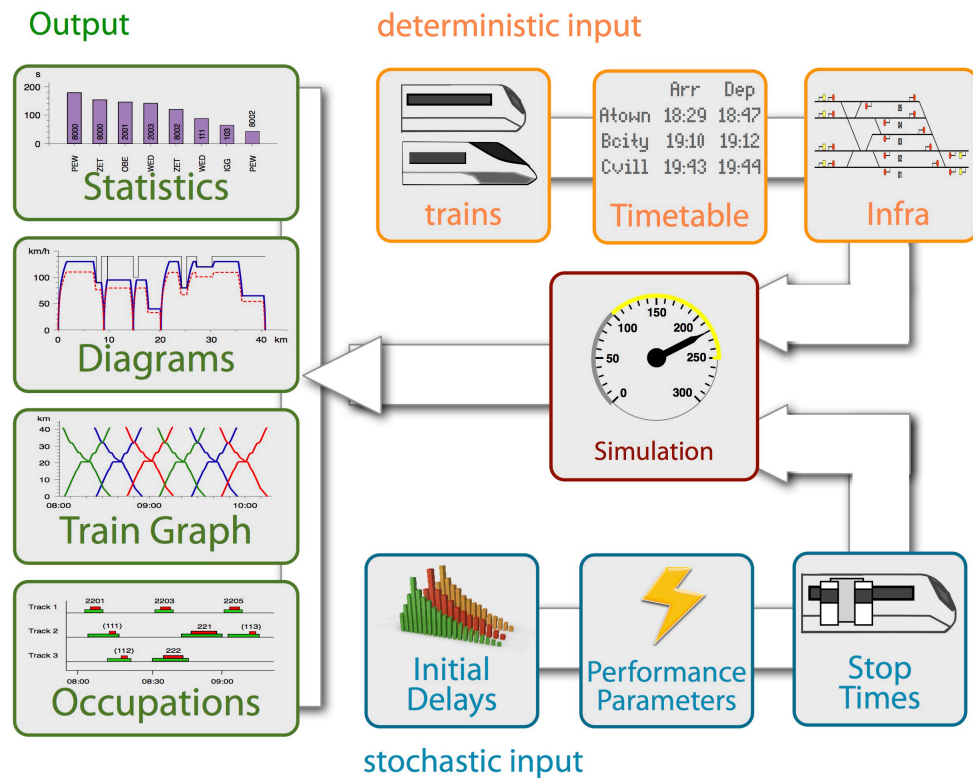
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Outline

1. Simulation and "Agile" Simulation
2. The Elizabeth line
3. Agile Simulation Benefits: Examples from the Elizabeth line
4. Conclusions

1. Synchronous Microscopic Simulation

Output

Statistics

Diagrams

Train Graph

Occupations

deterministic input

trains

	Arr	Dep
Atown	18:29	18:47
Bcity	19:10	19:12
Cvill	19:43	19:44

Timetable

Infra

Simulation

Initial Delays

Performance Parameters

Stop Times

stochastic input

Railway Simulation History

Single Train Run

+ All trains
  Lines
  Time Interval

Deterministic Sim.

+ Variability of operations
  Time (several days)

Stochastic Sim.

+ Real delay Distributions

Advanced Stochastic Sim.

✓ One train
✓ Verify run time

✓ Any computer

✓ All trains leave on time
✓ First check of timetable FEASIBILITY

✓ More computational power
✓ Network model
✓ Interface to import timetable data

✓ Stochastic departure and Stop time based on standard variability
✓ First check of timetable ROBUSTNESS

✓ More computational power
✓ Parallel computing? (Min50 runs)
✓ Driver behavior model
✓ Realistic delays

✓ Stochastic departure and Stop time based on REAL VARIABILITY
✓ HIGHEST ACCURACY
✓ Precise estimation of ROBUSTNESS and RELIABILITY

✓ Real delays
✓ Filter to remove secondary delays
✓ Parallel computing? (250 runs)

Why isn't simulation used more often?

- **_Potential:_** Much more published on how optimisation _**could**_ improve railway performance – than true success stories. (Liebchen & Schülldorf 2019)

- **_Perception:_** Simulation is …

  - complicated …

  - takes too long …

  - results often unhelpful for improving real railway performance.

Railway Planning Process

Alternative Development

Revise

Simulation

Evaluation

Solution
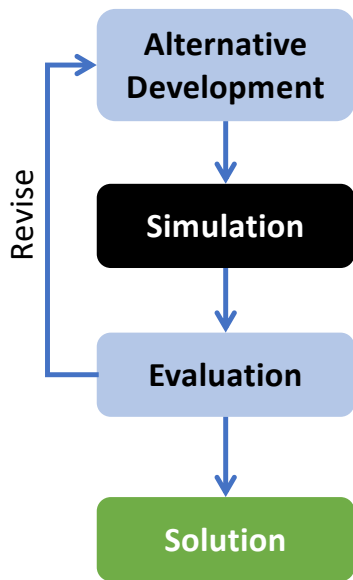
Traditional

Simulation is often …
- … a separate step
- … done by outside experts
- … using mysterious tools
- … for long term planning.

Simulation: Areas for Improvement

Weakness	Description
Model set-up time	*It takes too long to create models.*
Model error correction	*It takes too long to de-bug models.*
Large model running time	*It takes too long to run large network models.*
More complex strategic planning	*Risk of simulation failure in complex planning.*
Effective tactical planning	*Simulation too slow and un-targeted.*
Multi-parameter optimisation	*Simulation too slow and independent.*

Hansen, I., & Pachl, J. (Eds.) (2014). Railway timetabling and operations: Analysis, modelling, optimisation, simulation, performance, evaluation. Eurail press.

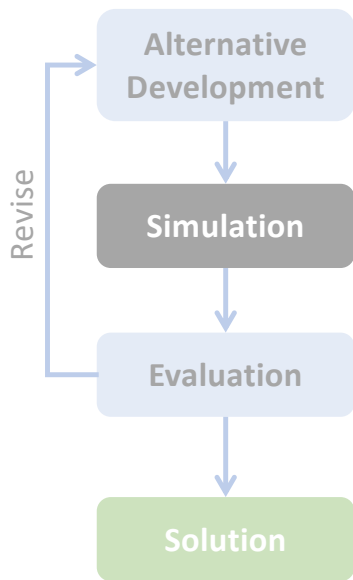# Simulation Improvements: 2023 Status

Weakness	Improvements	2023
Model set-up time	*Data management tools, visualisation*	
Model error correction	*Speed, visualisation*	
Large model running time	*Software designed for new hardware*	
More complex strategic planning	*Speed, memory, **collaboration***	
Effective tactical planning	*Speed, memory, **collaboration***	
Multi-parameter optimisation	*Speed, memory, **collaboration***	

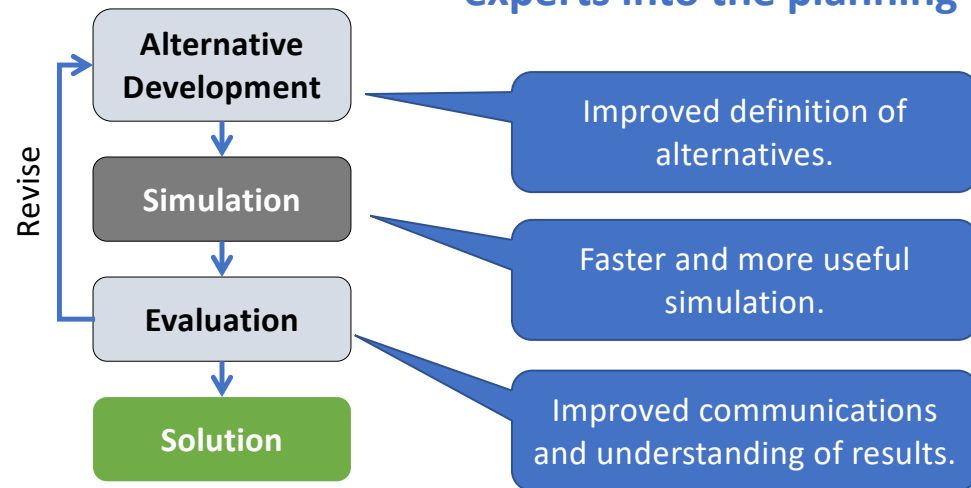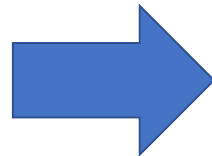# Improving Technology **+** Changing Processes

- ***Simulation technology:*** significant improvement … for example:
  - Simulation time in 2016:   14 hours for 30 runs
  - Simulation time in 2023:   1.5 hours for 250 runs

- ***How we use simulation:*** not so different … but,

  - ***Innovation theory:*** It's critical to _**change old processes**_ to take advantage of new technology … adding new technology to old processes isn't enough.

  - ***Tacit knowledge theory:*** Using new technology effectively often requires knowledge which is not known explicitly, even by experts, and which is difficult to explicitly transfer to other people.

Railway Planning Process

Agile Simulation …
… changes the railway planning *process* by embedding simulation experts into the planning team.

Traditional

- Alternative Development
- Simulation
- Evaluation
- Solution

Revise

Agile

- Alternative Development
- Simulation
- Evaluation
- Solution

Revise

Improved definition of alternatives.

Faster and more useful simulation.

Improved communications and understanding of results.

What's in a name?

Agile simulation ≠ new technology → new process for using simulation.

Noticed it after several years of successful collaboration.

Named "*agile simulation*" because similar to agile software development:

> *"a collaborative effort of self-organizing and cross-functional teams with their customer(s)/end user(s), adaptive planning, evolutionary development, early delivery, continual improvement, and flexible responses to changes in requirements, capacity, and understanding of the problems to be solved." (Beck, et al; 2001)*

Agile simulation advantages illustrated using Elizabeth line examples.

2. Elizabeth line

Elizabeth line Planning History

- 1943   Abercrombie Plan: included an East-West Railway Line for London
- 1974   London Rail Plan: first used term *Crossrail*
- 2001   London East West Study recommends detailed study
- 2005   Transport for London (TfL) and UK DoT create "Crossrail Ltd."
- 2009   Ground broken
- 2015   Tunnelling complete
- 2016   Renamed *Elizabeth line*
- 2022   Initial service through tunnel opens to passengers
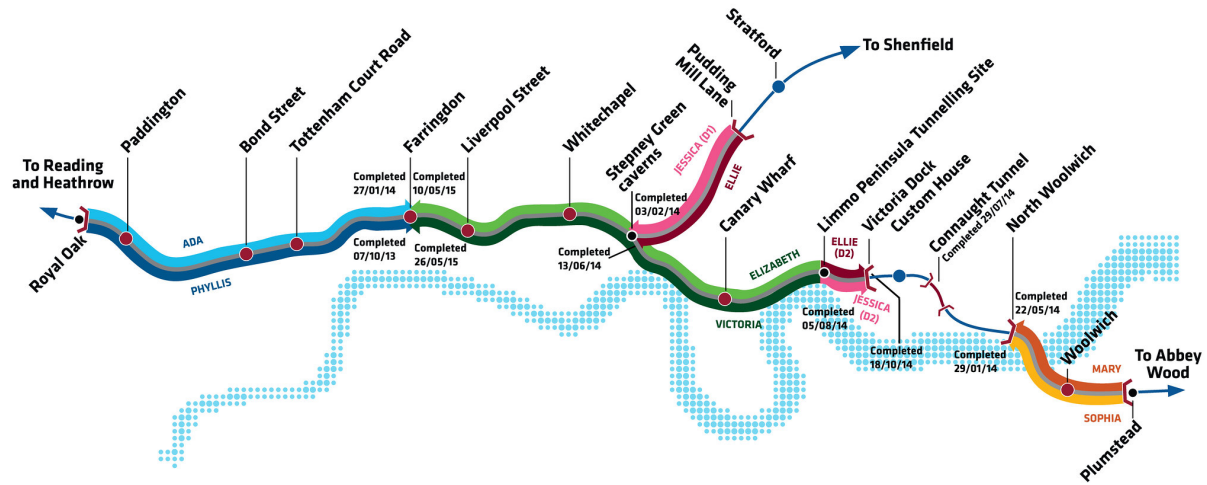
Schematic diagram of tunnelling plan showing eight tunnelling machines.

Her Majesty Queen Elizabeth II and HRH Prince Edward Earl of Wessex visit Paddington Elizabeth line station – 17 May 2022.

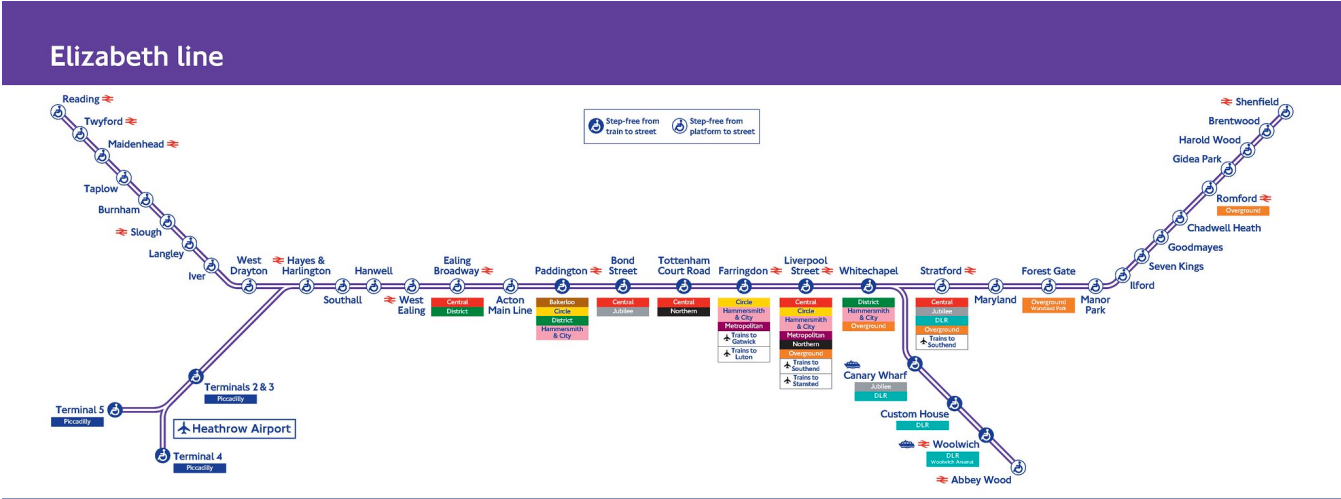**The Elizabeth line's stations are designed for efficient, safe and comfortable railway service.**

Model 345 series trains used on the Elizabeth line.

Opening Day: Elizabeth line customers using the new railway.

3. Advantages of Agile Simulation

Five examples from the Elizabeth line planning and operations

Agile simulation is fast and accurate

Bid Preparation Process

- Complexity: dense service of surface lines operating on shared track + tunnel.
- Timing: multi-stage operations plan.
- Payments: Intricate incentive-penalty framework for compensation.

Simulation Requirements

- Strict submission deadlines = need for speed.
- Incentive-penalty compensation scheme = need for accuracy.
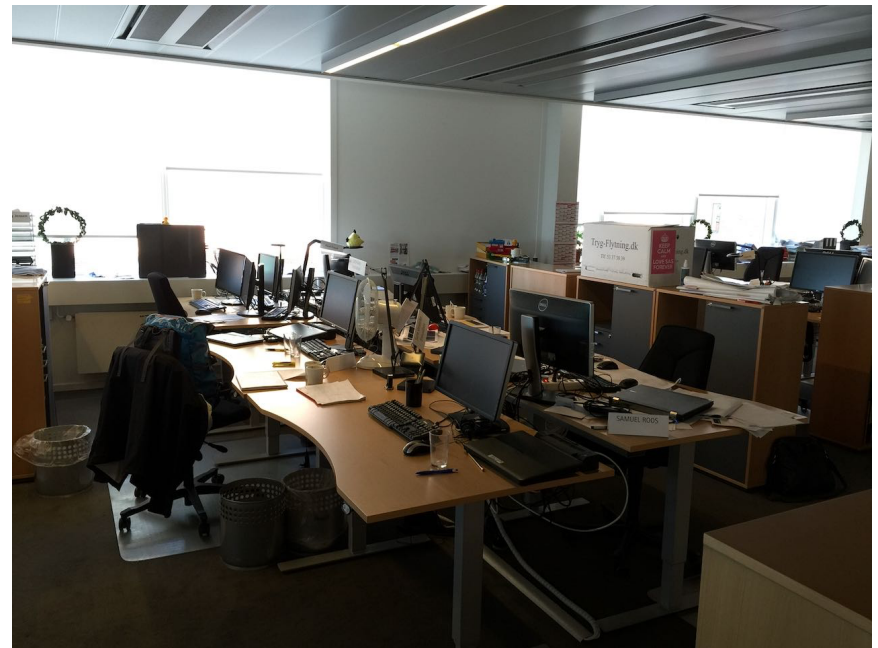
Agile simulation facilitates stakeholder consensus

Staged Opening Plan

- RFP specified 9 operating stages.
- Construction delays significantly impacted planned schedule.
- Stakeholder consensus required to move forward with each stage.

Simulation Requirements

- Clear communications between stakeholders and simulators.
- Credibility of simulation results enhanced by trust gained with embedded simulation experts being part of the team.
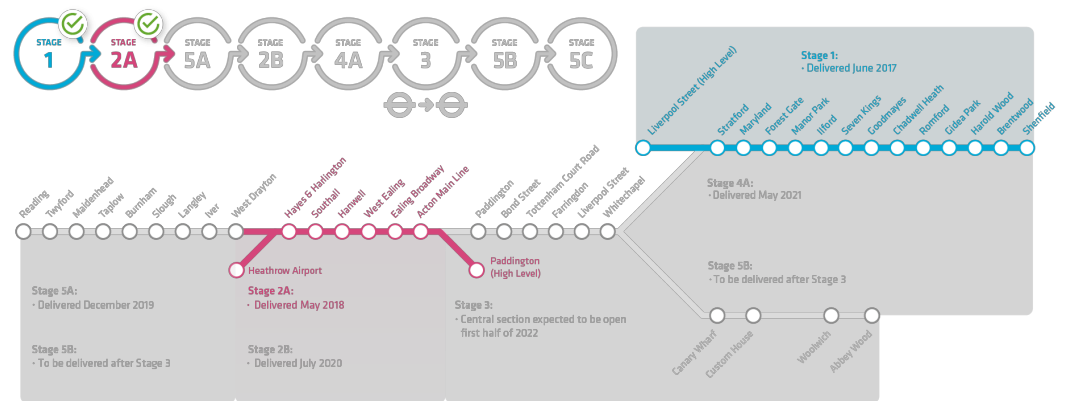
Stage 2A
Elizabeth line Staged Operating Plan

Agile simulation supports efficient construction

Liverpool St. Station Platform Lengthening

- Remove 1 platform and lengthen 4 others to accommodate new vehicles.
- Tunnel delays meant Elizabeth line trains still using surface station.
- Simulation shows original TT unsatisfactory.

Simulation Requirements

- Stochastic simulation of possible delays and recovery plans.
- Integrated TT and construction planning with contractor (= 20% cost saving).
- Stakeholders especially sensitive due to negative tunnel delay publicity.
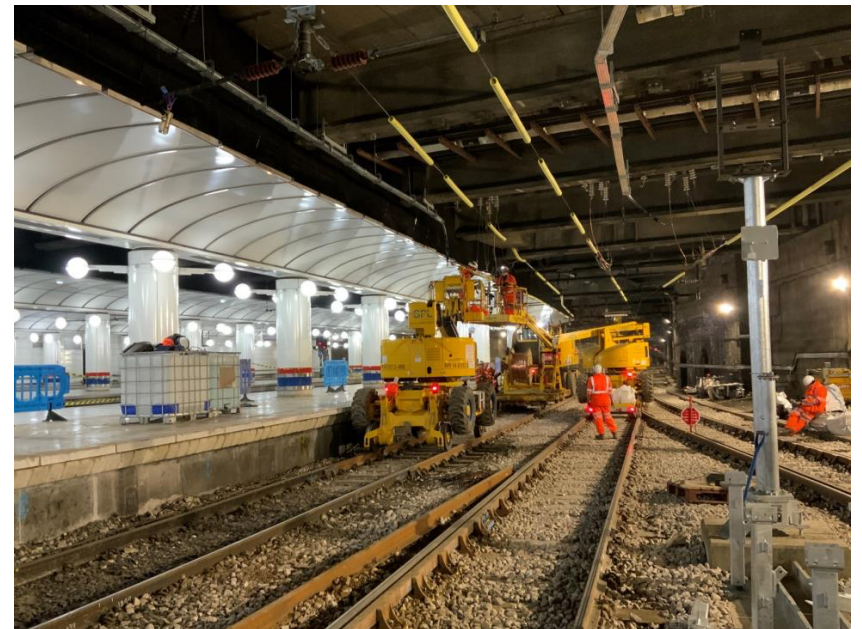
Agile simulation inspires model improvements

Early Implementation of End-to-End Service

- Central tunnel opened: 24 May 2022.
- Service operating well (97% punctuality).
- Should full service be introduced early?

Simulation Requirements

- Stochastic simulation using "three-railway" service data.
- Simulation shows TT unsatisfactory.
- New vehicle function "auto-reverse" added to simulation model and used in acceptable reduced timetable.


"Three Railway" Operations
Elizabeth line – Summer 2022
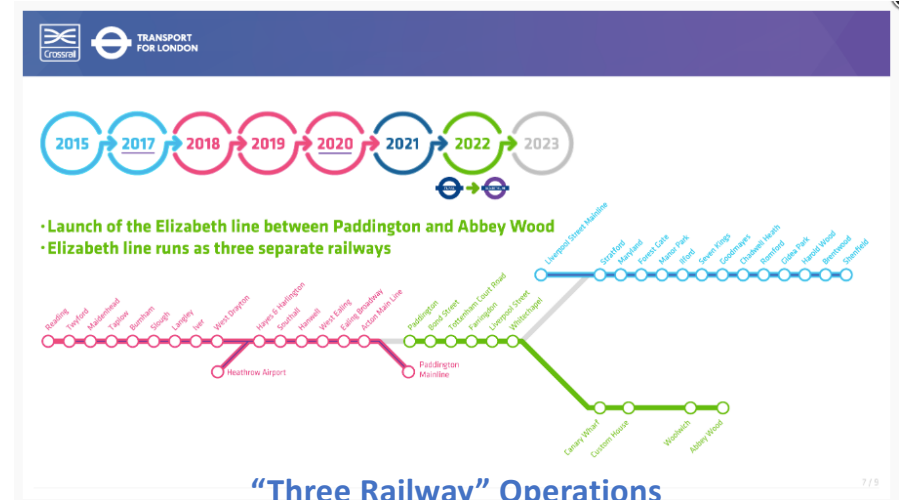
Agile simulation encourages operating improvements

Shenfield Line Timetable Improvement Study

- Busy Shenfield – Liverpool Street line.
- Access to expert and model led team to ask:
- Could service be improved to reduce delays?

Simulation Requirements

- Delay cause identification using passenger arrival data (Oyster).
- Stochastic simulation.
- Solution implemented → 2.9% punctuality improvement (AM period).
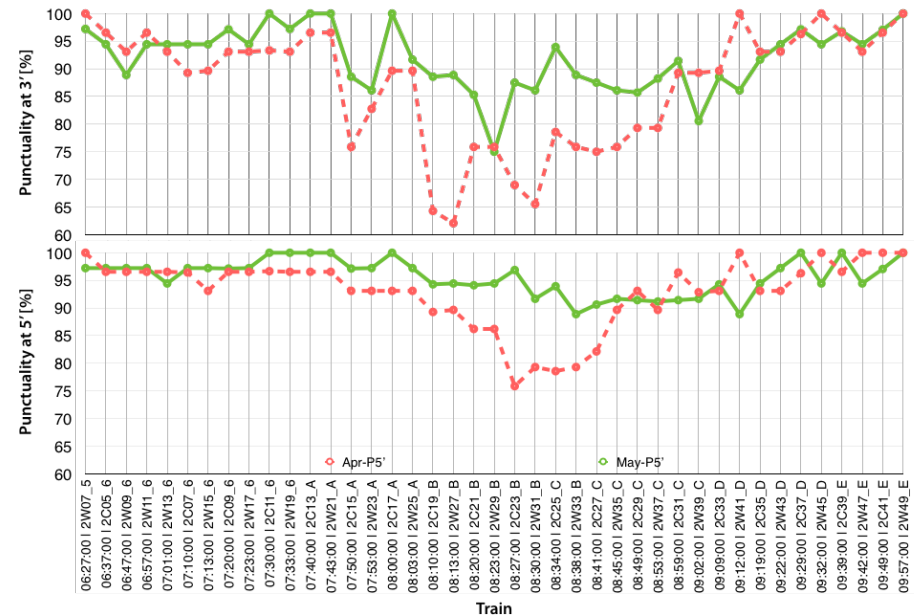
Medeossi G., Nash A., 2020. Reducing Delays on High-Density Railway lines: London–Shenfield Case Study. TRR 2674.
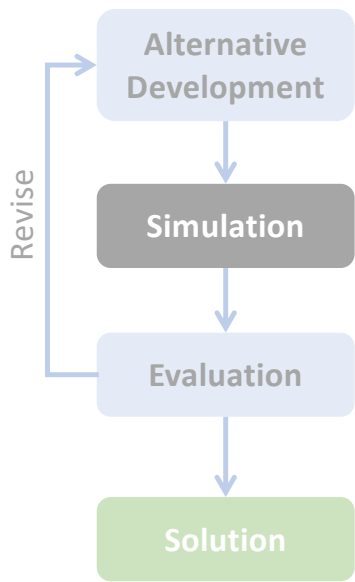
4. Conclusions: Agile simulation …

- Helps railways take advantage of significantly improved hardware and software, including multi-objective optimisation and integration with other models (e.g., energy saving, multi-modal coordination).

- = integrating simulation more fully into the planning process.

- = more complex strategic planning & more types of tactical planning.

- = especially useful for solving many of today's key railway challenges such as quickly increasing capacity and service quality.
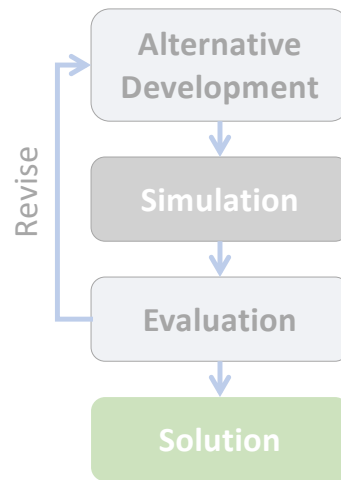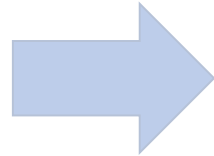
Agile Simulation is based on Soft Skills

- *Communications*

- *Relationships*
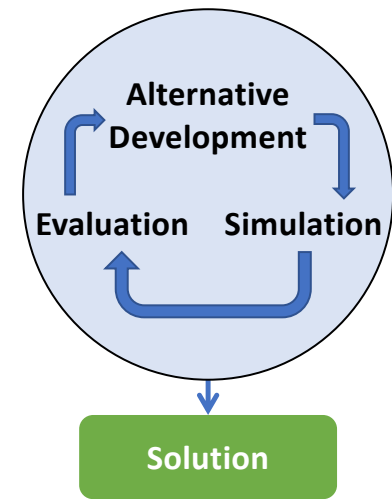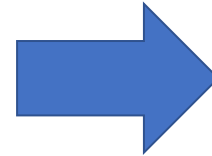
- *Trust*

- *Understanding*

Railway Planning Process

Traditional

Alternative Development → Simulation → Evaluation → Solution (Revise loop)

Agile

Alternative Development → Simulation → Evaluation → Solution (Revise loop)

Integrated

Alternative Development · Simulation · Evaluation (cyclic) → Solution

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Thanks for your attention!

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