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Producing effective maintenance strategies to control railway risk

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Motivations

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- Complex and diverse portfolio of assets
  - Heterogeneity
  - Highly interconnected (dependencies)
  - Expensive to manage



- Many assets are safety critical


- Maintenance is vital to control the risk and maintain high levels of service

Motivations

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Need for an effective approach to asset management to run a **SAFE**, **RELIABLE** and **AFFORDABLE** railway

- Bespoke models to predict assets response to maintenance
- Whole-life / Whole-system approach
- Link asset maintenance to system performance and safety

Railway Asset Management Framework

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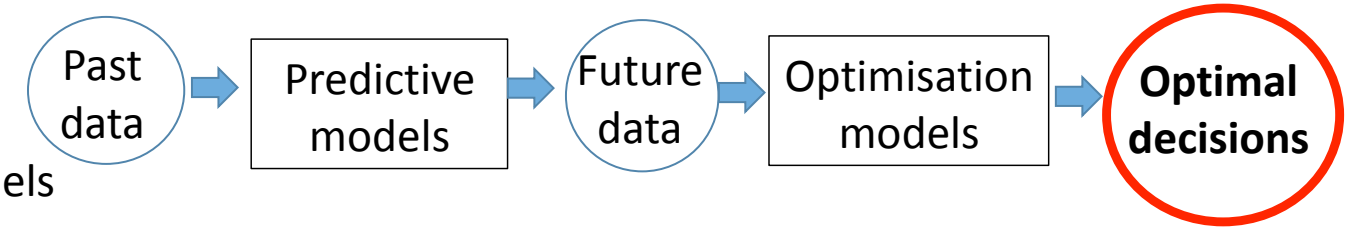
*Railway Asset Management Modelling Framework to support both **localised** and **systemic optimal decisions** on infrastructure maintenance*

Library of models

- Statistical models
- Predictive models
- Optimisation models



Decision levels

- Infrastructure: asset/section/route/network
- Planning stage: strategic/tactical/operational

Procedures to link models for whole-system representation and analysis

Predictive models

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- **Asset state models** to assess assets response to maintenance
- **Service provision model** to evaluate delays and journey cancellations
- **Risk and safety models** to evaluate risk and consequences of hazardous events

Enable prediction of **KPIs**

- Assets conditions
- Service reliability
- Safety
- Costs

Asset State Models

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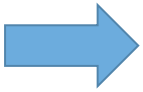
DEGRADATION AND FAILURE

&

INTERVENTION STRATEGIES:

- Inspection type and frequency
- Levels of degradation triggering intervention
- Components replacement prior to failure
  - •Condition
  - •Age
  - •Usage
- Opportunistic maintenance
- Renewal
- Enhancement
- Resources availability (equipment and personnel)



For **any asset management strategy** predict **distributions** of :

- Asset conditions
  - Failure modes probabilities
  - Duration of failed/degraded states
  - Future conditions (at any time)
- Asset availability
- Number of each intervention type
- Asset remaining life

ASSESS AND COMPARE DIFFERENT MAINTENANCE STRATEGIES TO SUPPORT DECISIONS

Common modelling technique: Petri nets

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- State-based
- Stochastic
- Simulation friendly
- Any distribution of failure times
  - Assets wear-out (increasing failure rate → early replacement option)
  - Dependency on past conditions/events
- Complex maintenance processes:
  - Servicing, inspection, replacement prior to failure (based on; condition, age, use), reactive repair, refurbishment, renewal
  - Condition and risk based inspection
- Concise structure compared to the credible alternatives
- Modularity (Easy linking to form the system model)
- Distribution of outputs rather than point estimates

Petri nets

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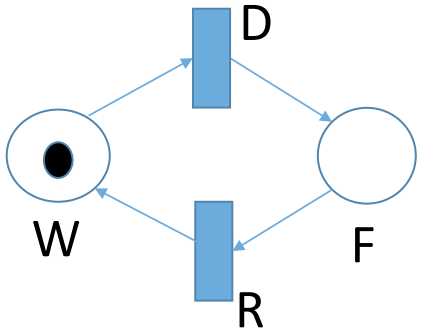
PLACE component state, physical condition, logical condition

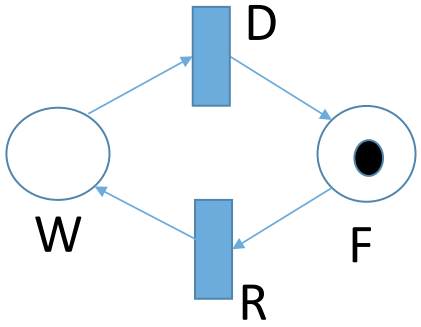
TRANSITION event: degradation, failure, repair (immediate, timed - deterministic and stochastic)

TOKEN (number of tokens in each place determine the state of the system at any time – **MARKING=SYSTEM STATE**)
Tokens are "consumed" and "produced" when events occur (transitions "fire") determining a new system state

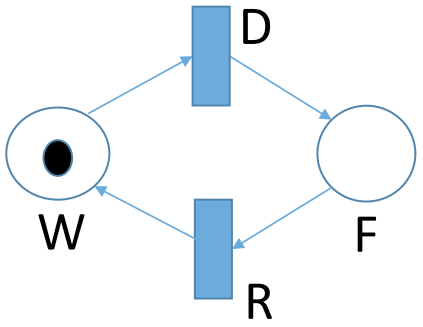
Initial working state



Failure occurs – transition D fires



Component is repaired – transition R fires



Track geometry maintenance model

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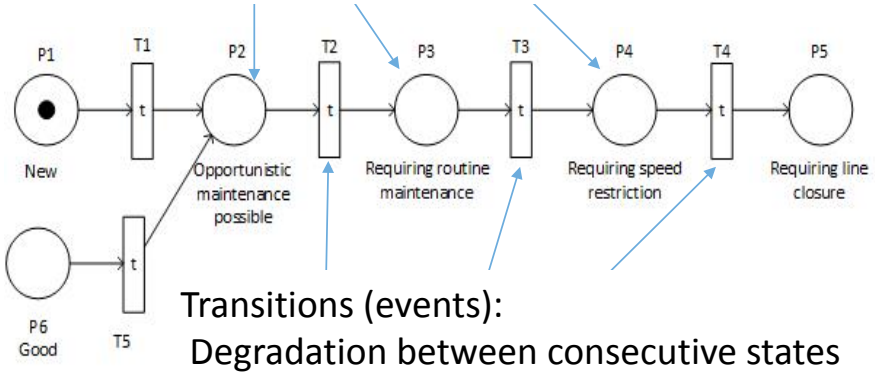
Places (conditions):
Progressive levels of degradation triggering different maintenance interventions



Transitions (events):
Degradation between consecutive states
(Any distribution of times to degrade)

- 4 degraded states
- Degraded state affecting **service** and **safety**:
  - speed restriction
  - line closure
- Weibull distribution of times to degrade
- Not as good-as new after maintenance

Track geometry maintenance model

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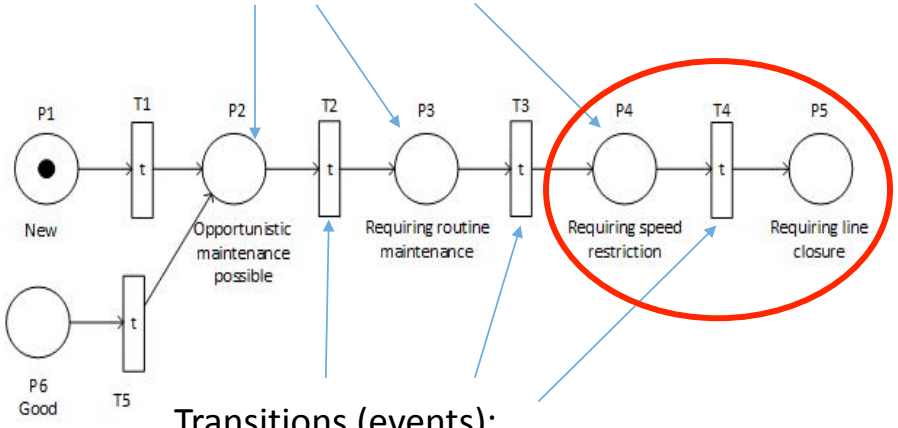
Progressive levels of degradation triggering different maintenance interventions



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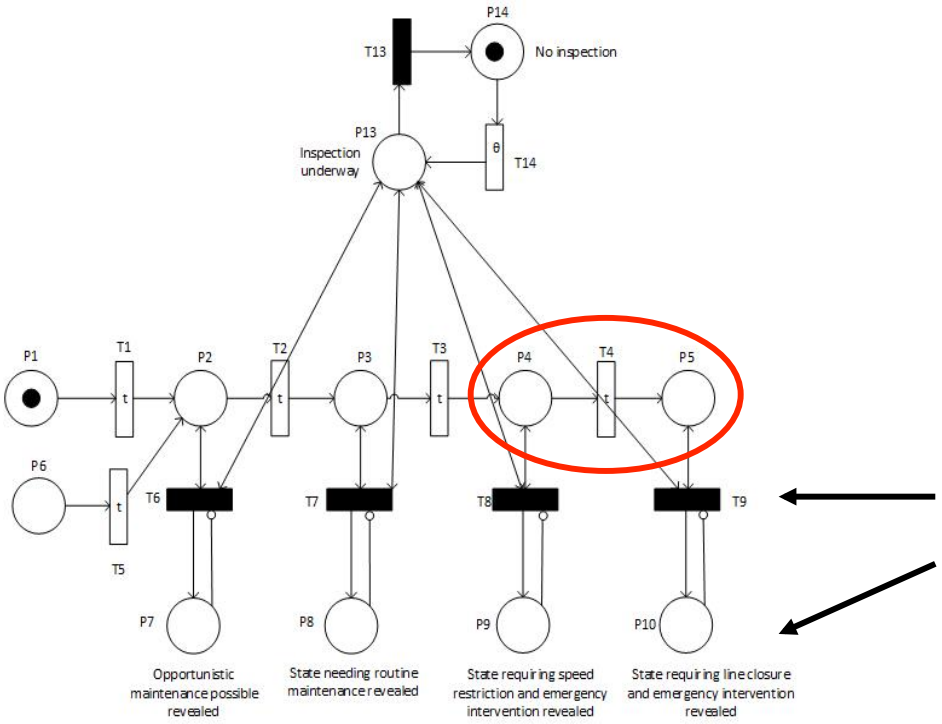

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- **Periodic inspection**
- **Current states revealed**

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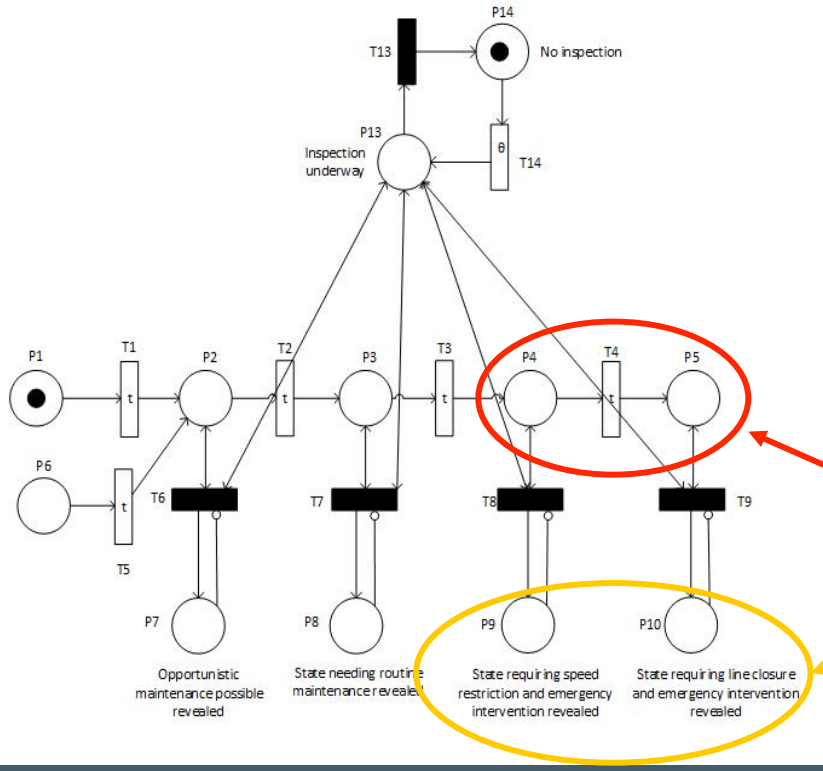

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- Periodic inspection
- Current states revealed:
  - **Unrevealed need for SR and LC (safety)**
  - **Revealed need for SR and LC (service)**

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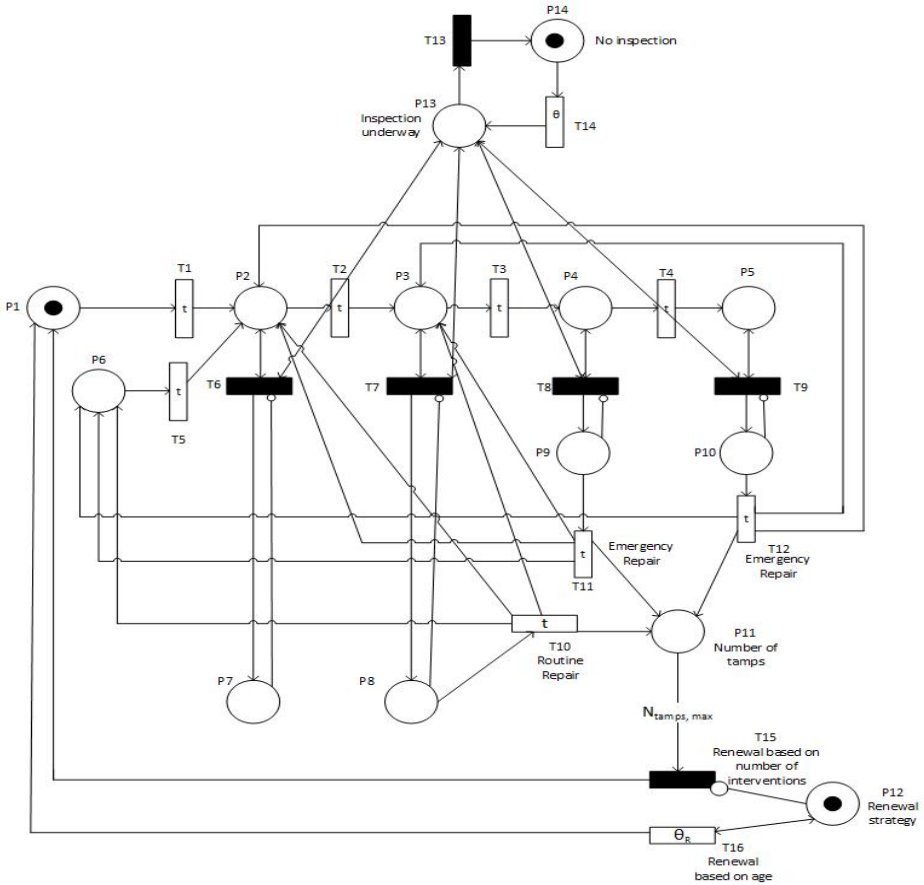

- 4 degraded states
- Weibull distribution of times to degrade
- Not as good-as new after maintenance
- Periodic inspection
  - Unrevealed need for SR and LC (safety)
  - Revealed need for SR and LC (service)
- **Revealed states trigger maintenance**
- **Maintenance effectiveness**
- **Side-effect of tamping**
- **Renewal strategies (e.g. age, past maintenance)**

Track geometry maintenance application

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What do we use it for? To investigate asset response to maintenance.

Table 1 SD threshold values for each degraded state

SD_{op}	SD_{rm}	SD_{sr}	SD_{lc}
opportunistic maintenance is possible (associated to place P2)	routine maintenance is required (associated to place P3)	SR and emergency repair required (associated to place P4)	LC and immediate repair required (associated to place P5)
1.5	1.8	2.5	3.5

Table 2 Weibull parameters associated to each stochastic transition representing degradation

T1		T2		T3		T4		T5	
β	η	β	η	β	η	β	η	β	η
1.5	600	1.5	500	1.6	370	1.7	280	1.8	740

Table *3* Maintenance strategies.

Strategy	Inspection period (T14)	Mean time to perform routine maintenance (T10)		Mean time to perform maintenance from speed restriction (T11)		Mean time to perform immediate repair (T12)	
	θ(days)	μ(days)	$\sigma^2(days^2)$	μ(days)	$\sigma^2(days^2)$	μ(days)	$\sigma^2(days^2)$
1	15	20	5	5	1	1	0.1
2	15	20	5	10	2	1	0.1
3	15	30	5	5	1	1	0.1
4	15	30	5	10	2	1	0.1
5	15	40	10	5	1	1	0.1
6	15	40	10	10	2	1	0.1
7	120	20	5	5	1	1	0.1
8	120	20	5	10	2	1	0.1
9	120	30	5	5	1	1	0.1
10	120	30	5	10	2	1	0.1
11	120	40	10	5	1	1	0.1
12	120	40	10	10	2	1	0.1

Track geometry maintenance results

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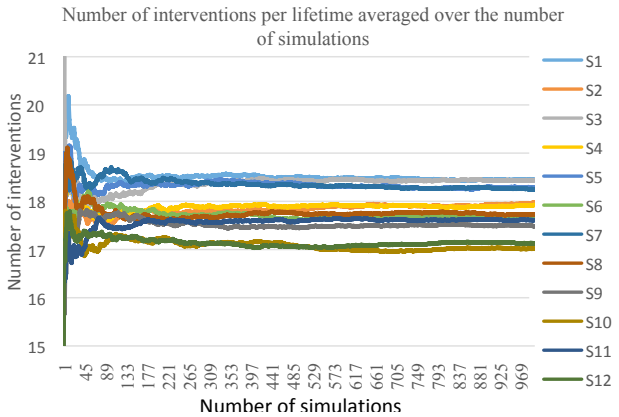

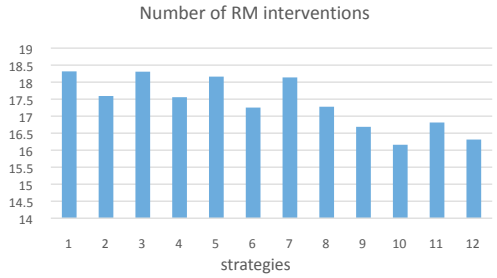

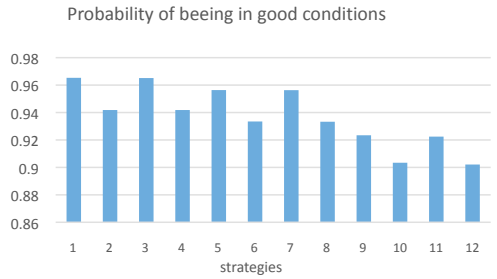

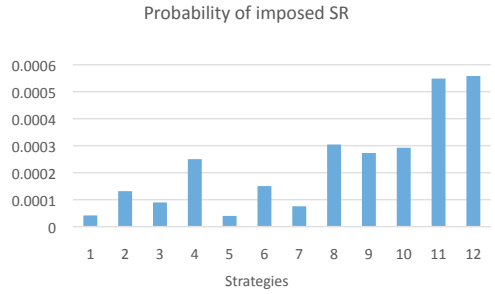

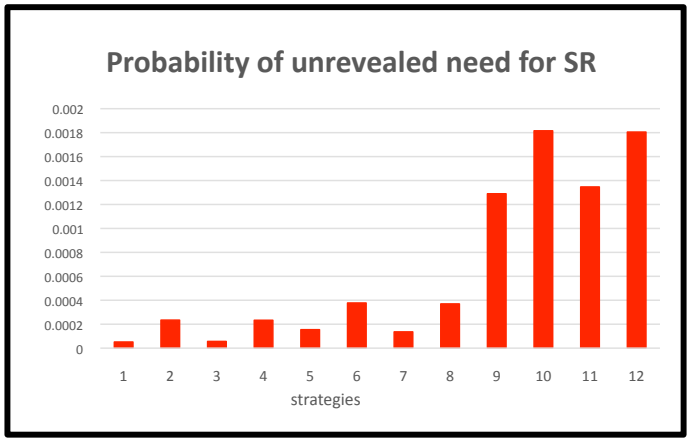

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Conclusions and future work

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- Need for a systematic approach to railway asset management:
  Railway Asset Management Modelling Framework
- Asset state models to predict asset response to maintenance
- Modelling technique: Petri net
- Results (failure modes probabilities) are input to service and safety models thus enabling to link maintenance to system performance and safety

Future work
- Continue populating the framework…..