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DigiProximation:

Exploring the Practicalities of Digital Twinning

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The Workshop

- Starting with the aphorism that ‘All models are wrong, some are useful’ (Box, 1976, attrib.) John Beckford shares insights to the opportunities, challenges and practical issues with the idea of digital twins their utility and limitations. John offers a structure within which an Intelligent Nation can enhance utility and understanding by developing models which are ‘less wrong, more useful’ in recognising that they are not twins but digital approximations.

John Beckford

- Cybernetician and management scientist
- Board chair: https://risemutual.org/
- Non-executive director of https://www.fusion21.co.uk/ and https://www.corehaus.co.uk/
- Trustee of The Under 17 Car Club Charitable Trust and director of its subsidiary, U17 Drivers Pathfinder Limited
- President of the Cybernetics Society.
- PhD in Management Systems and Sciences from the University of Hull
- Fellow of the Cybernetics Society, the RSA and the IET
- Member of The Institute of Management Services.
- Visiting Professor in:
  - Department of Civil, Environmental and Geomatic Engineering at University College London.
  - Centre for Information Management, School of Business and Economics, Loughborough University
- Author: Intelligent Organisation (2020), Intelligent Nation (2021), Quality (2022)

DigiProximation

- The only true model of something is the thing itself
  - Ashby, 1950's
- All models are wrong, some are useful
  - Box, 1976
- A model is neither true nor false but more or less useful
  - Beer, 1985
- To be useful it must be persistent, evolving, adaptive (Beckford, 2021)
  - It will necessarily be 'self-approximating'
    - Autopoietic – Maturana and Varela, 1974
- "every good regulator of a system must be a model of that system".
    - Conant-Ashby Theorem, *Int. J. Systems Sci.*, 1970, vol **1**, No 2, pp. 89–97

DigiProximation Hypothesis

- We cannot conceive a model which will be ‘right’ from the outset……

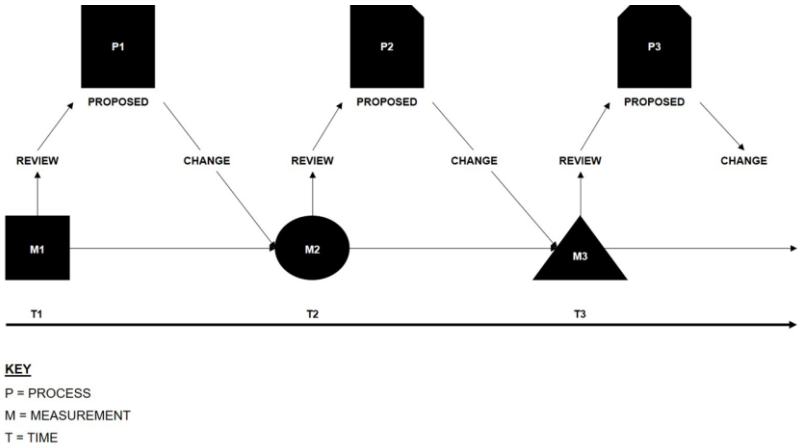
  we can conceive a model that learns to be more right over time – not necessarily in its data but in its assertions

DigiProximation

- A Digital Twin is not an end in itself
  - What is it for?
  - Purpose is a key determinant of the cost-benefit equation
  - Technology exists which enables
- It can be done:
  - But should it be done?
  - What is the cost?
  - What is the value?
    - Fridge Maintenance

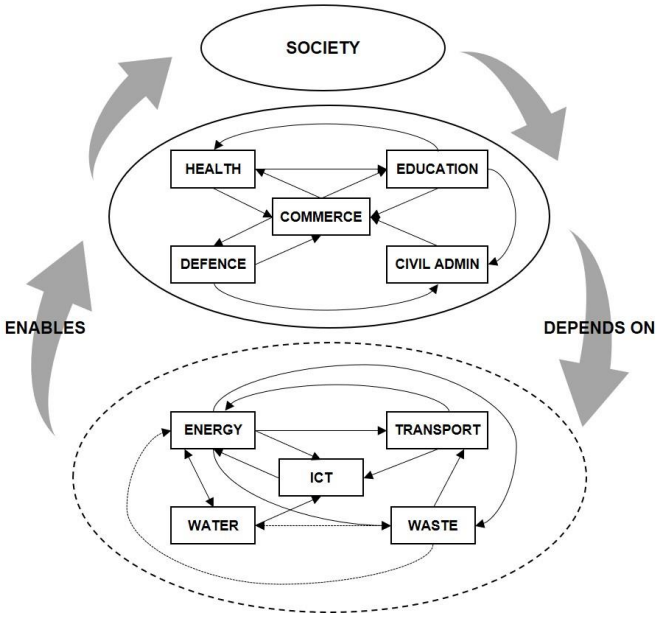
Challenges

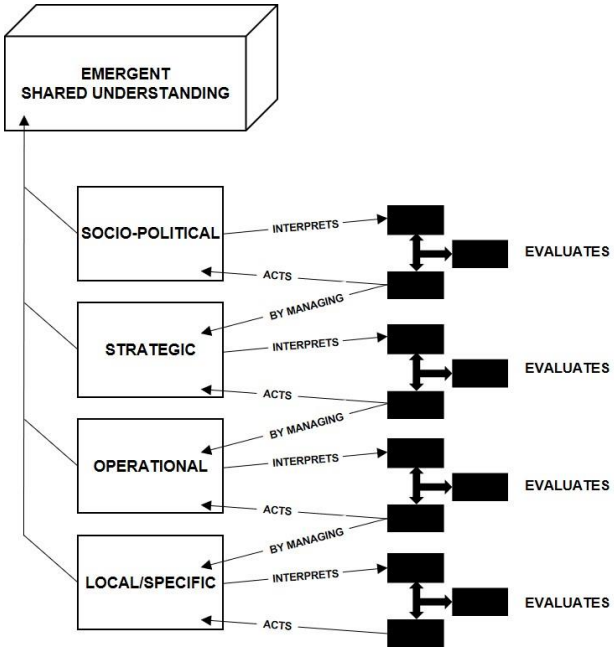
- Challenges
  - Accuracy
  - Rate of degradation of assets
  - Rate of maintenance, upgrade, replacement of assets
  - Change in materials and specifications
  - Shadows at the back of the Cave?
    - The model becomes the reality
- Clarity of scope
- Purpose
- Temporal and spatial scales?
- Resolution or granularity?
- Precision?
- Cost-Benefit?



The Perpetually Failing Problem Solving Engine (Beckford. 1993)

Of What?


SOCIETY
HEALTH
EDUCATION
COMMERCE
DEFENCE
CIVIL ADMIN
ENABLES
DEPENDS ON
ENERGY
TRANSPORT
ICT
WATER
WASTE


EMERGENT
SHARED UNDERSTANDING
SOCIO-POLITICAL
STRATEGIC
OPERATIONAL
LOCAL/SPECIFIC
INTERPRETS
ACTS
BY MANAGING
EVALUATES

Modelling

- We need to work backwards from the outcome we desire to the process that generates it and the inputs on which it depends.

Seasonally Agnostic Railway Model

- NR Scale and Scope:
  - 20000 miles of track (mainly twin)
  - Innumerable bridges and other structures
  - Thousands of vehicles
  - Over 100000 people
  - Millions of journeys
- What matters?
- The information that matters is about performance
  - Do people and packages get to destinations safely and timeously.

BECKFORD

Presentation to
Jim Natrass

Seasonally Agnostic Railway Model

Why do we need the Seasonally Agnostic Railway Model (SARM)?

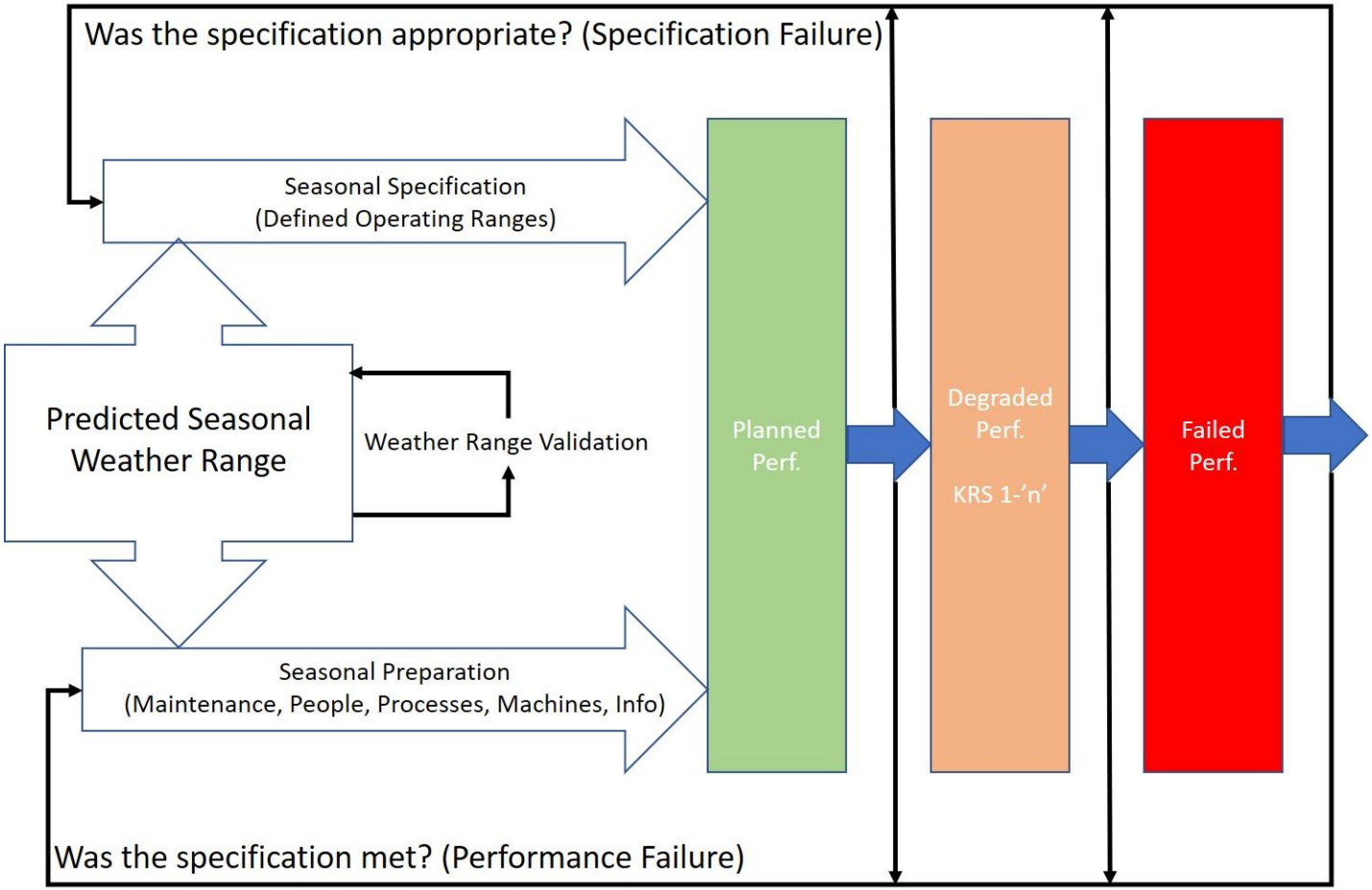
What will the SARM support?

Seasonally Agnostic Railway Model

- Purpose:
  - Seasonal perturbations in railway performance which appear to be weather related
  - Historically no connection between maintenance activity and rail performance
  - Can we develop a model that:
    - Improves resilience, i.e. enables predict and prevent rather than react and recover
    - Provides information for operational decision making around both operations and maintenance
    - Provides information to passengers to inform travel decisions
    - Enables learning and adaptation at multiple levels of consideration

- Arising from the fatal rail accident at Carmont in 2020
- Also a Case study undertaken for the Safer Complex Systems, Engineering X programme with Royal Academy of Engineering and Lloyds Register Foundation (Forthcoming, May 25th)

Seasonally Agnostic Railway Model



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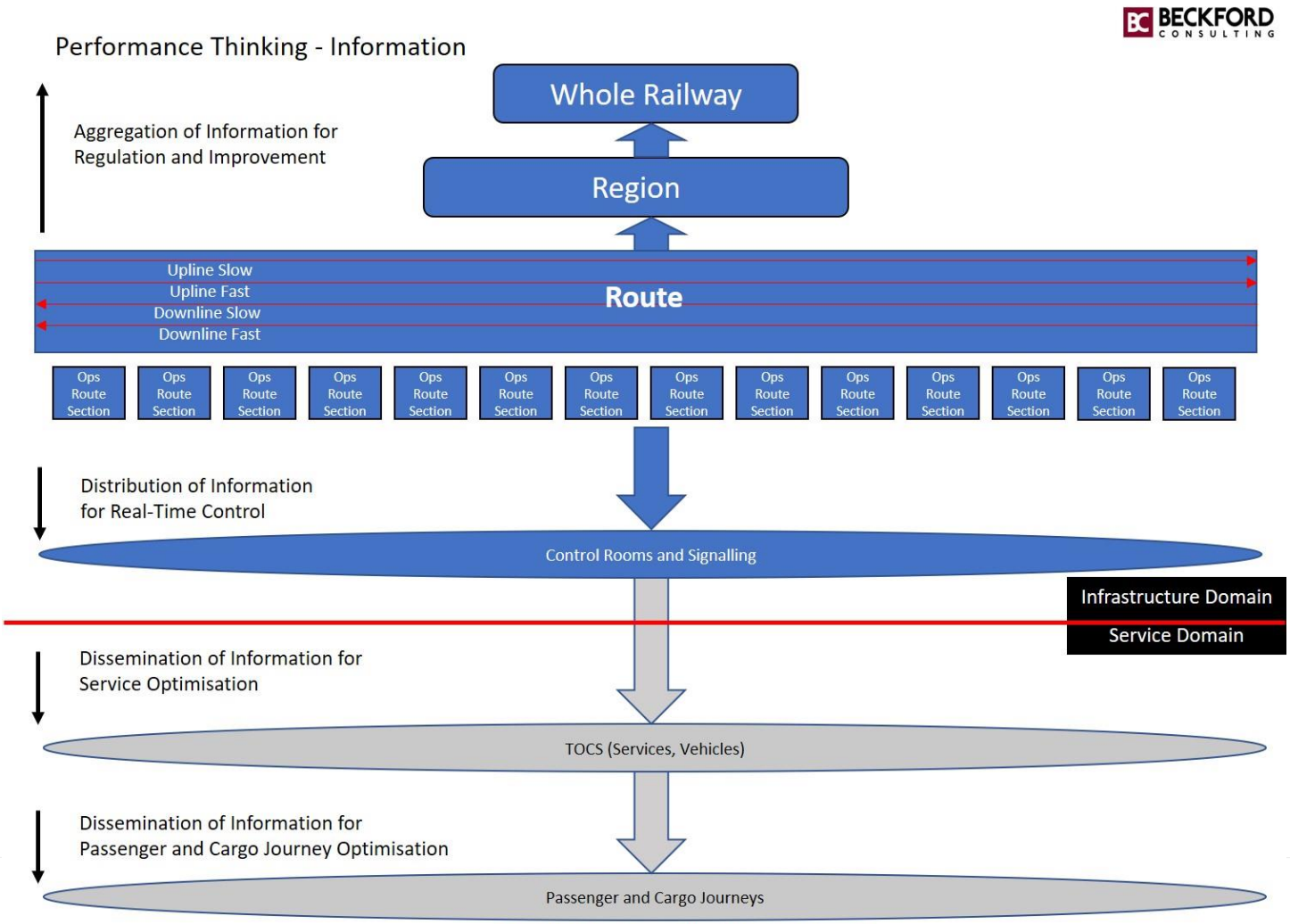
Seasonally Agnostic Railway Model



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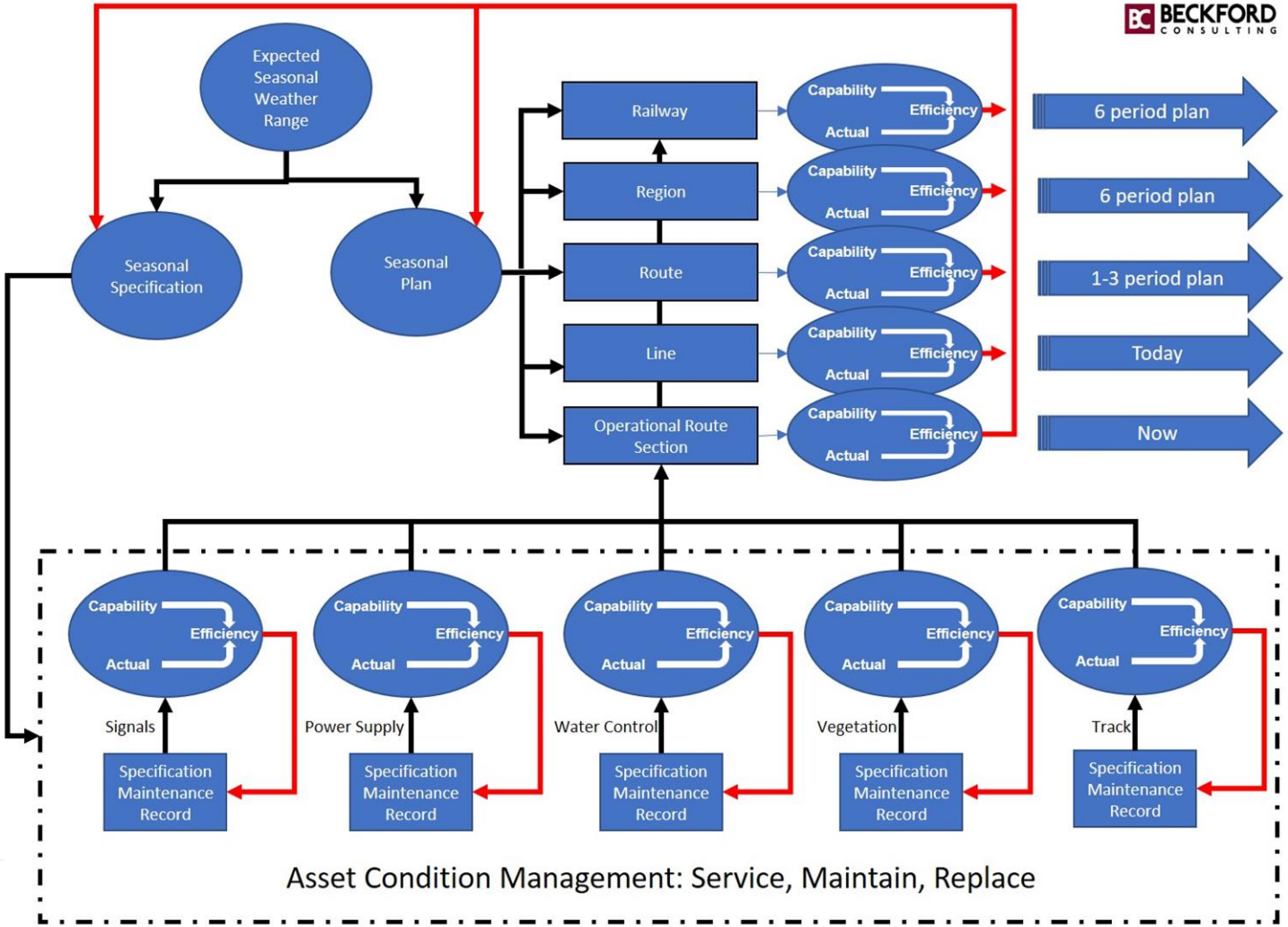
Seasonally Agnostic Railway Model



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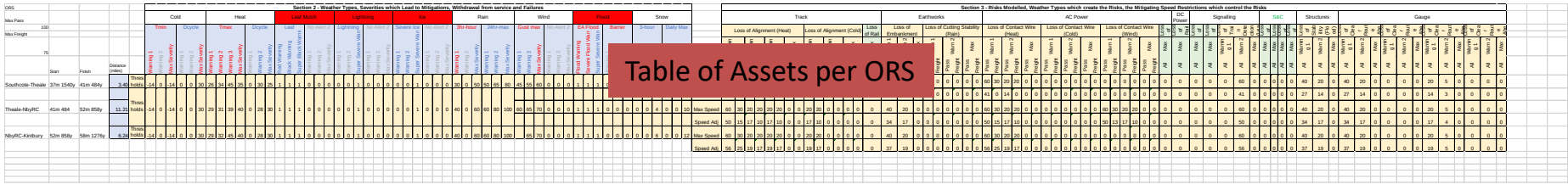
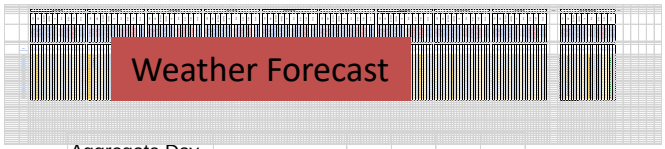
Seasonally Agnostic Railway Model





Aggregate Day

Highs, Lows, Max, Min, Cumulative

	Hot	Cold	Windy	Rain (mm)		Snow (inches)		
Range/Cum	33	12	48	Cumulative	71	Cum Inch	11	
Max	46	-10	72	3 Hr Max	60	3 Hr Max	8	
Min	13	22	24	1Hr Max	28	1 Hr Max	4	
03:00	13	-15	34	0	0		0	0
04:00	13	-15	34	0	0		0	0
05:00	13	-18	38	0	0		0	0
06:00	13	-20	42	4	4		0	0
07:00	13	-20	46	7	11		0	0
08:00	15	-21	49	28	39		0	0

Table of Extreme Weather

Train Timings for ORS's Southcote Jn to Kintbury 2 hour sample departing Reading 10.00 - 12.00 Exc Sat

Headcode		1C75	2K38	1C76	Freight	1K08	1C77	6V49	2K40	1C78	2Z50
Train type		XP	LP	XP		SFP	XP	Freight	LP	XP	LP
Time		09.37	10.12	10.04	10.08	10.07	10.35	07.47	11.12	11.04	11.54
From		Padd	Reading	Padd	Theale Ha	Padd	Padd	Northamp	Reading	Padd	Reading
To		Paignton	Newbury	Penzance	Whatley C	Bed					
	Mileage										
Reading depart	35.78	**10.02**	**10.12**	**10.29**							
Southcote Jn	37.62	10.04	10.15	10.31							
Theale	41.22	10.07	**10.19**	10.34	**10.37**						
Aldermaston	44.63	10.09	**10.23**	10.37	10.44	10.51	11.09	11.15	**11.23**	11.37	12.04
Midgham	46.59	10.11	**10.26**	10.38	10.49	10.52	11.10	11.17	**11.26**	11.38	12.05
Thatcham	49.45	10.13	**10.30**	10.40	10.52	**10.55**	11.12	11.20	**11.30**	11.40	**12.08**
Newbury Racecourse	52.31	10.14	**10.35**	10.42	10.55	11.00	11.14	11.23	**11.35**	11.42	**12.13**
Newbury	53.06	**10.16**	**10.38**	10.43	10.56	**11.03**	**11.15**	11.24	**11.38**	11.43	**12.17**
Kintbury	58.38	10.22		10.46	11.01	**11.09**	11.21	11.29		11.46	

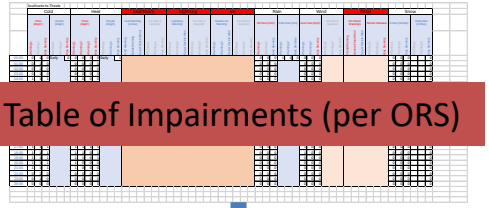
Up and Down Timetables

Train Timings for ORS's Kintbury to Southcote Jn 2 hour sample departing Reading 10.00 - 12.00 Exc Sat

Headcode		Freight	2T10	2K31	Freight	1A76	2K33	1A77	1A78	1K15
Train type			LP	LP		XP	LP	XP	XP	SFP
Time		05.23	09.43	10.06	07.12	06.05	11.06	08.35	07.10	11.40
From		Tytherington	Bedwyn	Newbury	Merehead	Penzance	Newbury	Plymouth	Penzance	Bedwyn
To		Appleford	Newbury	Reading	Acton	Padd	Reading	Padd	Padd	Padd
	38	9.48	**9.53**		10.03	10.38		11.17	11.39	**11.5**
	06	10.01	**10.04**	**10.06**	10.16	10.43	**11.06**	**11.23**	**11.44**	**11.57**
	31	10.02		**10.08**	10.17	10.44	**11.08**	11.24	11.45	**12.00**
Thatcham	49.45	10.06		**10.12**	10.21	10.45	**11.11**	11.26	11.46	**12.04**
Midgham	46.59	10.09		**10.16**	10.24	10.46	**11.16**	11.27	11.48	12.07
Aldermast	44.63	10.12		**10.19**	10.27	10.47	**11.19**	11.28	11.50	12.09
Theale	41.22	10.16		**10.24**	10.32	10.49	**11.23**	11.30	11.53	**12.11**
Southcote	37.62	10.2		10.29	10.38	10.53	11.30	11.34	11.57	12.15
Reading a	35.78	10.26		**10.35**	10.44	**10.58**	**11.36**	**11.38**	**12.00**	**12.22**

Table of Products

W1	Minutes									W1								
Delay ORS1	-2.9	-3.9	-2.9		-3.9	-2.9		-3.9	-2.9	Delay ORS1	-3.9		-4.1	-6.0	-4.0	-7.0	-4.0	-4.0	-4.0
Delay ORS2	-6.8	-15.8	-7.8	-17.3	-12.3	-6.8	-10.8	-15.8	-7.8	Delay ORS2	-14.8	0.2	-17.8	-15.8	-5.8	-16.8	-6.8	-8.8	-13.8
DelayORS3	-7.9	-2.9	-3.9	-5.7	-8						-12.9	-10.9	0.1	-12.9	-4.9	0.1	-5.9	-4.9	-6.9
Cum. Delay	-17.6	-22.6	-14.6	-23.0	-24						-31.6	-10.7	-21.8	-34.7	-14.7	-23.7	-16.7	-17.7	-24.7
W2																			
Delay ORS1	-5.9	-7.9	-5.9	0.1	-7						-7.9	0.1	-9.1	-11.9	-7.9	-13.9	-7.9	-7.9	-7.9
Delay ORS2	-13.1	-31.1	-15.1	-34.6	-24						-29.1	0.9	-35.1	-31.1	-11.1	-33.1	-13.1	-17.1	-27.1
DelayORS3	-15.6	-5.6	-7.6	-11.4	-17.2	-13.2	-11.2	-5.2	-7.2	DelayORS3	-25.6	-21.6	0.4	-25.6	-9.6	0.4	-11.6	-9.6	-13.6
Cum. Delay	-34.9	-44.5	-28.5	-45.9	-49.7	-32.2	-35.3	-44.2	-28.2	Cum. Delay	-62.5	-20.6	-43.7	-68.6	-28.6	-46.6	-32.6	-34.6	-48.6
W3										W3									
Delay ORS1	-8.6	-11.6	-8.6	0.3	-11.6	-8.6	-5.7	-11.6	-8.6	Delay ORS1	-11.6	0.3	-46.2	-53.7	-119.8	-53.2	-103.8	-82.4	-55.7
Delay ORS2	-19.4	-46.4	-22.4	-51.9	-36.9	-19.4	-31.4	-46.4	-22.4	Delay ORS2	-43.4	1.6	-52.4	-46.4	-16.4	-49.4	-19.4	-25.4	-40.4
DelayORS3	-23.2	-8.2	-11.2	-17.1	-25.9	-19.9	-16.9	-7.9	-10.9	DelayORS3	-38.2	-32.2	0.8	-38.2	-14.2	0.8	-17.2	-14.2	-20.2
Cum. Delay	-51.3	-66.3	-42.3	-68.7	-74.4	-48.0	-54.0	-66.0	-42.0	Cum. Delay	-93.3	-30.3	-97.8	-138.4	-150.4	-101.9	-140.4	-122.1	-116.4



Weather	Hot	Cold	Windy	Rain	Rain(Cum)	Snow	Snow(Cum)
Switch	0	0	0	1	1	0	0
09:00	0	0	0	0	60	0	0
10:00	0	0	0	0	32	0	0
11:00	0	0	0	0	7	0	0
12:00	0	0	0	0	0	0	0

Train Timings for ORS's Southcote Jn to Kintbury 2 hour sample departing Reading 10.00 - 12.00 Exc Sat

	Headcode		1C75	2K38	1C76	Freight	1K08	1C77	6V49	2K40	1C78	Down 2Z50
	Train type		XP	LP	XP		SFP	XP	Freight	LP	XP	LP
	Time		09.37	10.12	10.04	10.08	10.07	10.35	07.47	11.12	11.04	11.54
	From										Padd	Reading
	To	Mil							y	Plymouth		Newbury
	Reading depart								12	**11.29**		**11.54**
ORS1	Southcote Jn								15	11.31		11.56
	Theale								19	11.34		**12.00**
	Impact			0.00	0.00	0.00	**-3.75**	999				
ORS2	Aldermaston	44.63	10.09	**10.23**	10.37	10.44	10.51	11.09	11.15	**11.23**	11.37	12.04
	Midgham	46.59	10.11	**10.26**	10.38	10.49	10.52	11.10	11.17	**11.26**	11.38	12.05
	Thatcham	49.45	10.13	**10.30**	10.40	10.52	**10.55**	11.12	11.20	**11.30**	11.40	**12.08**
	Newbury Racecourse	52.31	10.14	**10.35**	10.42	10.55	11.00	11.14	11.23	**11.35**	11.42	**12.13**
	Impact		0.00	0.00	0.00	0.00						
ORS3	Newbury	53.06	**10.16**	**10.38**	10.43	10.56	**11.03**	**11.15**	11.24	**11.38**	11.43	**12.17**
	Kintbury	58.38	10.22		10.46	11.01	**11.09**	11.21	11.29		11.46	
	Impact		0.00	0.00	0.00	0.00						

Timetable with Impacts

Inner Workings

Seasonally Agnostic Railway Model

			Weather	Hot	Cold	Windy	Rain	Rain(Cum)	Snow	Snow(Cum)		
			Switch	0	0	0	1	1	0	0		
			09:00	0	0	0	0	60	0	0		
			10:00	0	0	0	0	32	0	0		
			11:00	0	0	0	0	7	0	0		
			12:00	0	0	0	0	0	0	0		
	Train Timings for ORS's Southcote Jn to Kintbury 2 hour sample departing Reading 10.00 - 12.00 Exc Sat											Down
	Headcode		1C75	2K38	1C76	Freight	1K08	1C77	6V49	2K40	1C78	2Z50
	Train type		XP	LP	XP		SFP	XP	Freight	LP	XP	LP
	Time		09.37	10.12	10.04	10.08	'10.07	10.35	07.47	11.12	11.04	11.54
	From		Padd	Reading	Padd	Theale Ha	Padd	Padd	Northamp	Reading	Padd	Reading
	To	Miles	Paignton	Newbury	Penzance	Whatley C	Bedwyn	Exeter	Whatley C	Newbury	Plymouth	Newbury
	Reading depart	35.78	**10.02**	**10.12**	**10.29**		**10.40**	**11.01**	**11.04**	**11.12**	**11.29**	**11.54**
ORS1	Southcote Jn	37.62	10.04	10.15	10.31		10.43	11.04	11.09	11.15	11.31	11.56
	Theale	41.22	10.07	**10.19**	10.34	**10.37**	**10.47**	11.07	11.12	**11.19**	11.34	**12.00**
	Impact		0.00	0.00	0.00	0.00	**-3.75**	999				
ORS2	Aldermaston	44.63	10.09	**10.23**	10.37	10.44	10.51	11.09	11.15	**11.23**	11.37	12.04
	Midgham	46.59	10.11	**10.26**	10.38	10.49	10.52	11.10	11.17	**11.26**	11.38	12.05
	Thatcham	49.45	10.13	**10.30**	10.40	10.52	**10.55**	11.12	11.20	**11.30**	11.40	**12.08**
	Newbury Racecourse	52.31	10.14	**10.35**	10.42	10.55	11.00	11.14	11.23	**11.35**	11.42	**12.13**
	Impact		0.00	0.00	0.00	0.00						
ORS3	Newbury	53.06	**10.16**	**10.38**	10.43	10.56	**11.03**	**11.15**	11.24	**11.38**	11.43	**12.17**
	Kintbury	58.38	10.22		10.46	11.01	**11.09**	11.21	11.29		11.46	
	Impact		0.00	0.00	0.00	0.00						

Interface for Demo Purposes only

Seasonally Agnostic Railway Model

			Weather	Hot	Cold	Windy	Rain	Rain(Cum)	Snow	Snow(Cum)		
			Switch	0	0	0	1	1	0	0		
			09:00	0	0	0	0	60	0	0		
			10:00	0	0	0	0	32	0	0		
			11:00	0	0	0	0	7	0	0		
										0		
	Train Timing											Down
	Headcode										1C78	2Z50
	Train type										XP	LP
	Time									2	11.04	11.54
	From									ling	Padd	Reading
	To									bury	Plymouth	Newbury
	Reading dep									**11.12**	**11.29**	**11.54**
ORS1	Southcote Jr									11.15	11.31	11.56
	Theale									**11.19**	11.34	**12.00**
	Impact		0.00	0.00	0.00	0.00	**-3.75**	999				
ORS2	Aldermaston	44.63	10.09	**10.23**	10.37	10.44	10.51	11.09	11.15	**11.23**	11.37	12.04
	Midgham	46.59	10.11	**10.26**	10.38	10.49	10.52	11.10	11.17	**11.26**	11.38	12.05
	Thatcham	49.45	10.13	**10.30**	10.40	10.52	**10.55**	11.12	11.20	**11.30**	11.40	**12.08**
	Newbury Racecourse	52.31	10.14	**10.35**	10.42	10.55	11.00	11.14	11.23	**11.35**	11.42	**12.13**
	Impact		0.00	0.00	0.00	0.00						
ORS3	Newbury	53.06	**10.16**	**10.38**	10.43	10.56	**11.03**	**11.15**	11.24	**11.38**	11.43	**12.17**
	Kintbury	58.38	10.22		10.46	11.01	**11.09**	11.21	11.29		11.46	
	Impact		0.00	0.00	0.00	0.00						

Four questions:

1: What are the weather parameters at ‘time’?

2: Do those parameters exceed a performance threshold?

3: Is there a train service affected by that exceedance?

4: How many minutes delay will be imparted to the service?

Interface for Demo Purposes only

Challenges 2

- Availability and accuracy of asset data:
  - As designed
  - As installed
  - As maintained
  - Operating Specifications (i.e. min and max operating temperatures etc)
  - Undocumented Assets (e.g. earthworks composition not well understood)
  - Layers
    - Working at level of ‘key functionality’
    - Internally estimated 120 levels of asset in hierarchy
  - Geolocation of some assets not easily attainable
  - Adjacent environments not included in asset base

Modelling Challenges

- Scale of Railway
  - 20000 miles of track
  - Mainly twinned
  - Bi-Directional
- Scale of Model
  - 3 homeostats per ORS, 34000 data points per ORS, 36000 interacting ORSs
- Underlying knowledge (at least):
  - Systemic Modelling
  - Cybernetics (complex, dynamic, adaptive systems)
  - Information Theory
  - Engineering
  - Governance

Impact

- Effect of weather on services at varying temporal and spatial levels
- Understand impact of seasonal planning/maintenance
- Pre-empt service failure and alert passengers to potential delays
- Evaluate (££) the potential effects of alternative maintenance/renewal strategies
- Assess the service impact of climate changes and support development of risk mitigations

Impact

- Current experimental capability:
  - By weather event, Rain/Wind/Snow/Heat
    - Effects on individual assets
    - Delays arising at ORS
    - Delays arising at service level
    - Which weather events cause what delays (quantified) as a result of impact on which asset
- By Asset:
  - Which weather causes disruption when
  - What is ‘most likely to fail’ asset under what conditions
  - Do (particular) combinations of above exacerbate?
- Asset Frailty
  - Do assets outside maintenance cycle limits fail more often?
- The Value of preventing a Delay minute (£75/minute)
  - How much does it cost to prevent a delay minute?
  - when does it become cost effective?

Research Arising

(3 PhD Studentships)

- Core is Informational Cybernetics
  - Making Reliable Decisions using Unreliable Data
  - Developing and Applying ML/AI to a large scale predictive model
    - Drawing on proprietary work of Beckford & Dudley
  - Developing Organisational Adaptation Capability
    - Development, Implementation and Distribution
      - Inc. Cultural challenges and changes

Next Steps

- Twin models:
  - One addressing the issues of asset data accuracy and availability
  - One addressing the machine learning/artificial intelligence elements
- Extending:
  - From 3 * ORS to line of route
  - Including mobile assets
- Testing:
  - Evaluating accuracy using historic incident data
- Evolving:
  - Already presented to Client, Industry and Government
  - Now exploring additional requirements, potential for rail industry ‘Digital Platform’

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Presentation to
Jim Natrass

Seasonally Agnostic Railway Model

Why do we need the Seasonally Agnostic Railway Model (SARM)?

What will the SARM support?

DigiProximation

- Let us be ‘less wrong, more useful’ by:
  - Starting with an appreciation of the rationale for the model, the purpose to be fulfilled driven by understanding:
    - What do we wish to do with it?
    - What decisions do we wish to take using it?
  - Resolving:
    - Scope, Accuracy, Scale, Time, Value (Cost-Benefit)
  - Addressing:
    - R&D activities
    - Model Development Trajectory
    - Operational and Simulation Capability
  - Being:
    - Systemic not mechanistic in our mindset
    - Humble enough to understand and accept the limitations of what can be done
    - Arrogant (or confident) enough to keep pushing the boundaries of capability
    - Sensible enough to not let the model get in the way of the reality!
- Let us build a model that develops ‘rightness’ for itself

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DigiProximation:

Exploring the Practicalities of Digital Twinning

Dr. John Beckford

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Thank You

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