THE ‘RECCEL’ TOOLBOX: A RESPONSE TO CARBON REDUCTION CHALLENGES IN THE UK CONSTRUCTION INDUSTRY

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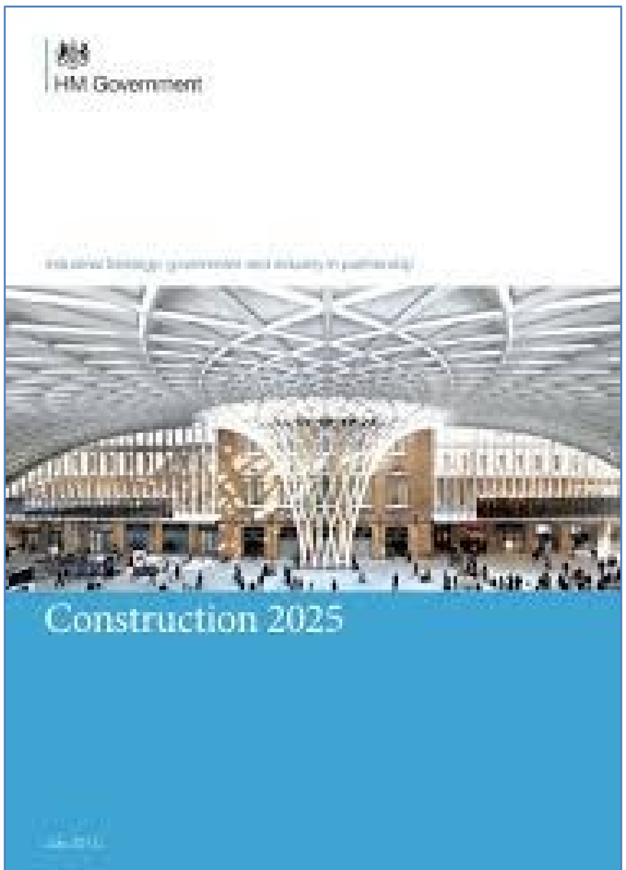
What's in the name?

ReCCEL =

Reducing Construction Carbon Emissions in Logistics



Innovate UK
Technology Strategy Board

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Who are we?

COSTAIN

UNIVERSITY OF EDINBURGH
Business School

cenex

LCV 2016
The Low Carbon Vehicle Event 2016
The UK's Premier Low Carbon Vehicle (Technology Showcasing & Networking) Event

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What are we looking at?

- Low carbon delivery on major infrastructure projects
- Focus on:
  - logistics aspects of project delivery
  - telematics/telemetry technologies and services
  - data supply chain: fragmented / disjointed

What are we doing?

- optimisation of

  - construction operations planning/execution

  - procurement decisions, featuring
    - low carbon HDVs
    - intelligent logistics tech

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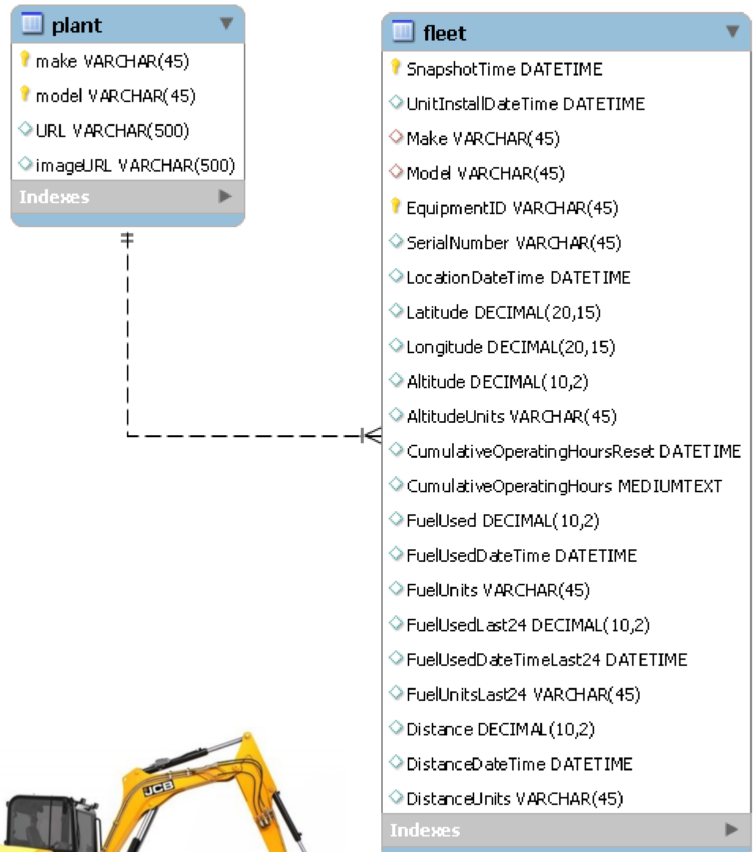
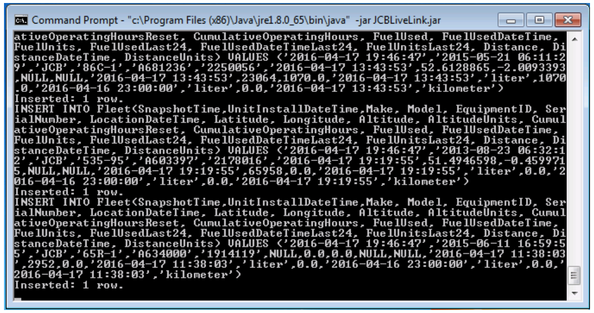
telematics (un)explained



Sampling rates:

- 5 min (JCB Livelink)
- 30 min (Komatsu Komtrax)
- …



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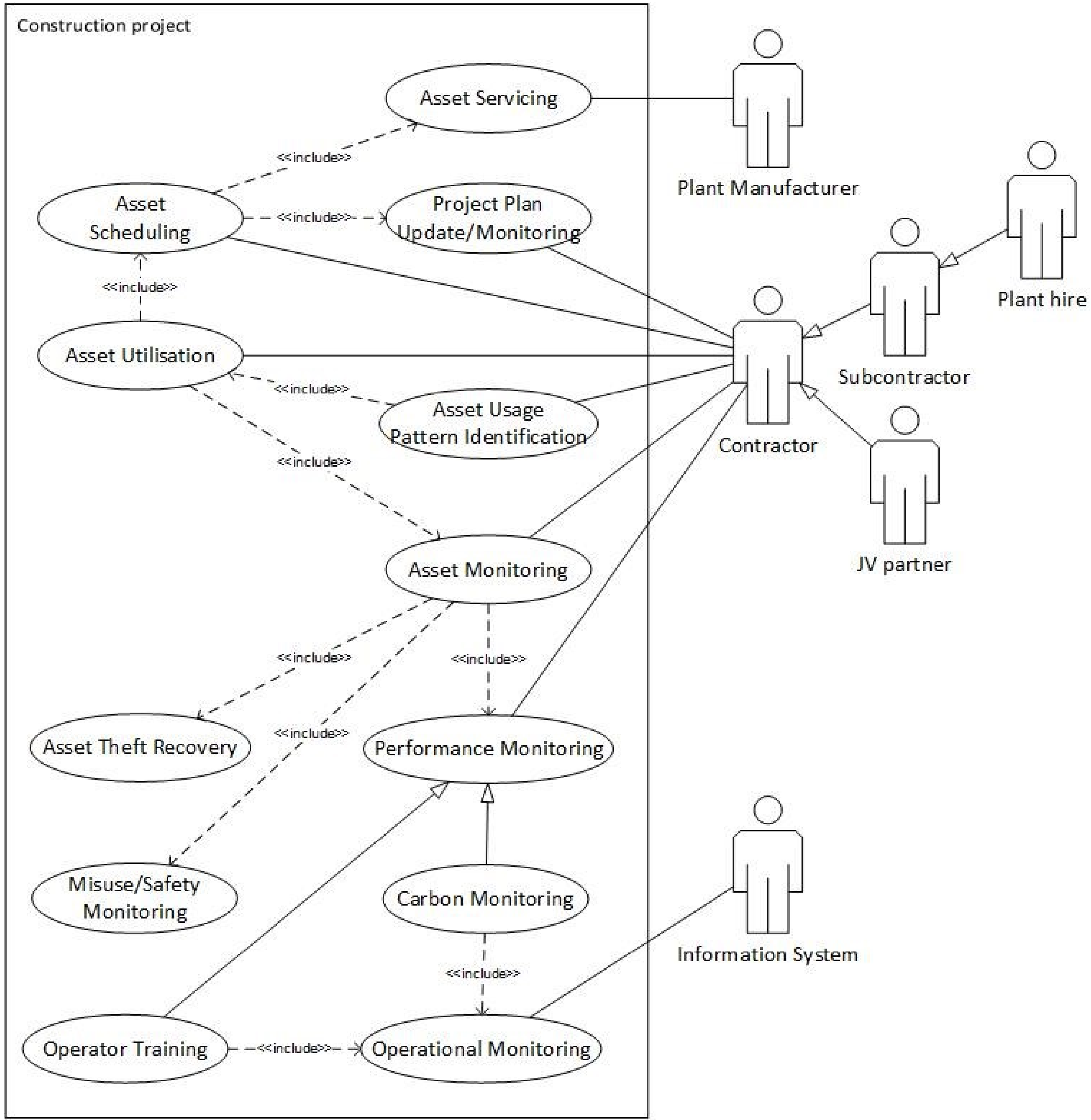
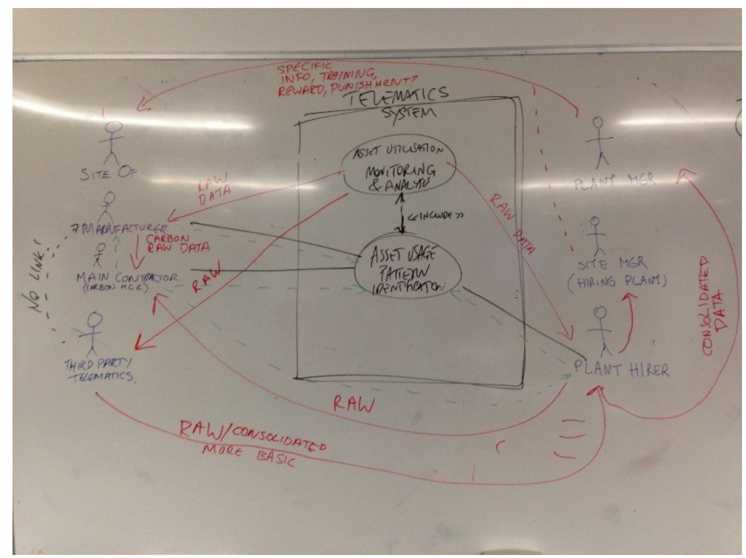
telematics (un)explained





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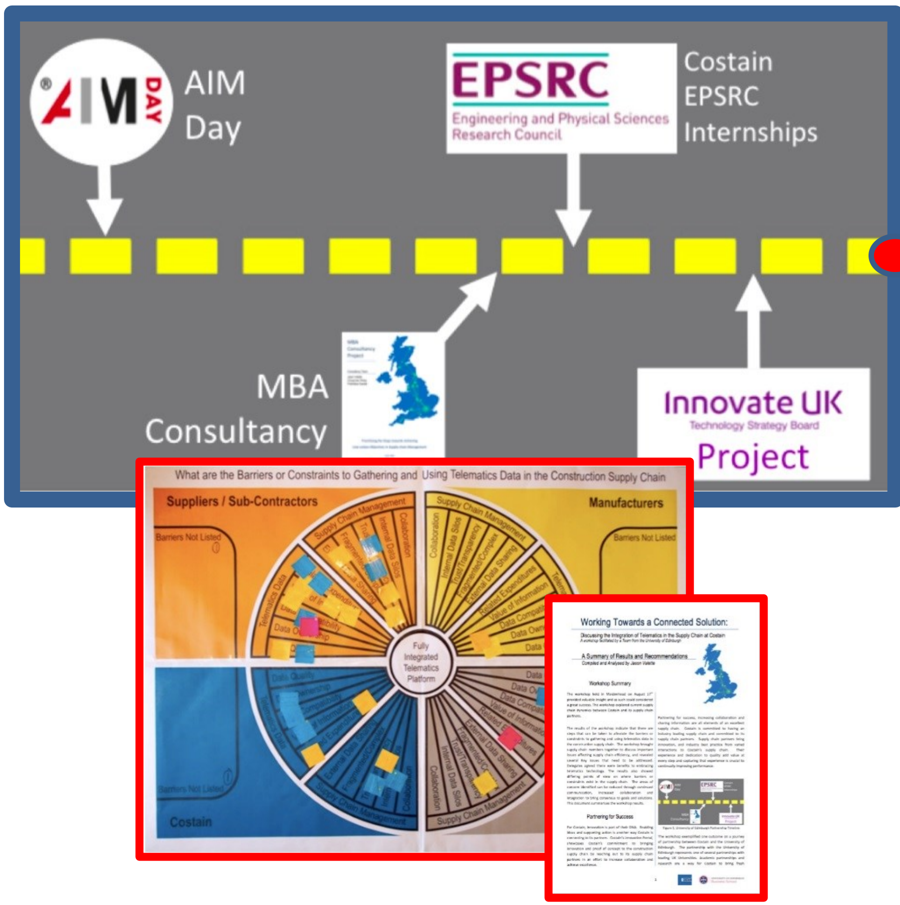
How big are the issues/opportunities?

- *ref*: ES from UK HS2 Hybrid Bill
  - 7% of the total carbon emissions originated from the transport of materials
  - 57,000 tCO_2e (tons of total CO_2 equivalent) were produced by staff travelling to work

- turnover of UK construction industry $\cong$ £100bn/year
  - this equates to 7% of UK's added value
- global construction market to grow over 70% by 2025

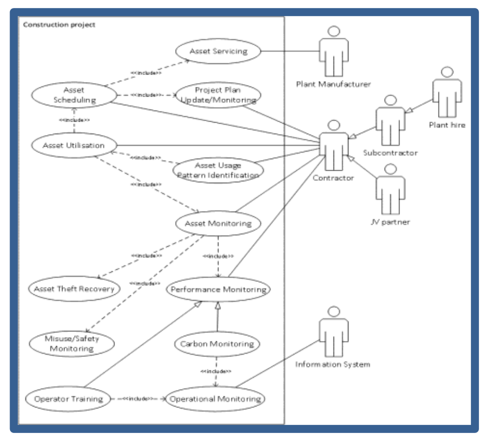
The ReCCEL journey, so far

prep/groundwork



1st Oct 15
2nd Nov 15
29th Jan 16
25th Feb 16
22nd Apr 16

ReCCEL use cases



ReCCEL toolbox development

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So … what's in the box, then?

Tool	Supply Chain Integration	
	Type	Level
Asset Monitoring Dashboard	Data	Single-site
Asset Routing/Refueling	Data + Process	Single-site
Asset Scheduling/Servicing	Data + Process	Multi-site

Tool	Actors	Sites
Asset Monitoring Dashboard	ATC	C610 Shieldhall Woolston
Asset Routing/Refueling	ATC	C610 A1+
Asset Scheduling / Servicing	Plant hire subcontractors ATC	C610

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Asset Monitoring Dashboard

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Mar 1 — 2016-03-01 10:00:00

Mar 23 — 2016-03-23 10:00:00

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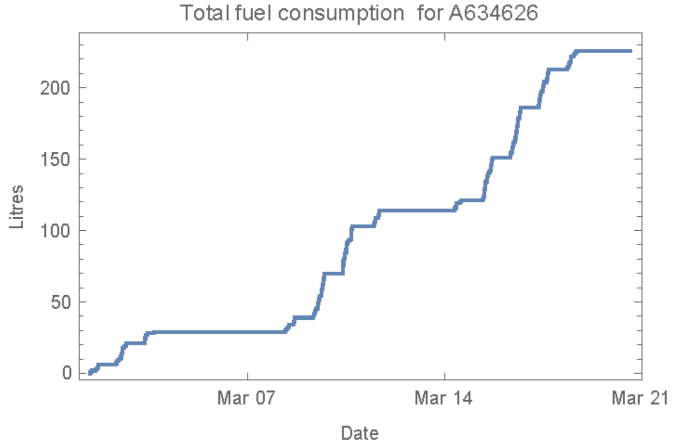
Out[40]= Compute plot

Out[41]=



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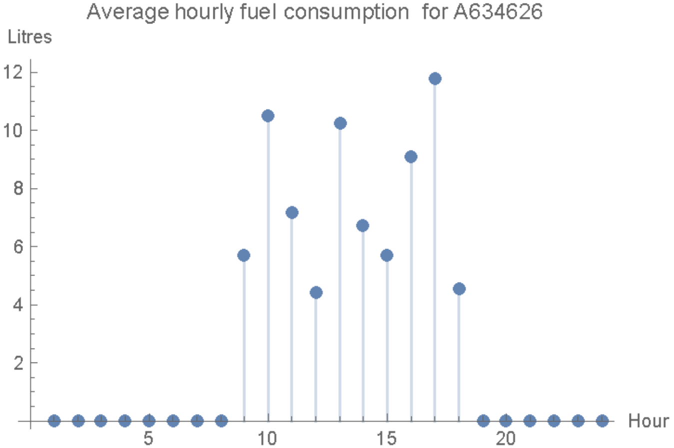

Asset Routing / Refuelling

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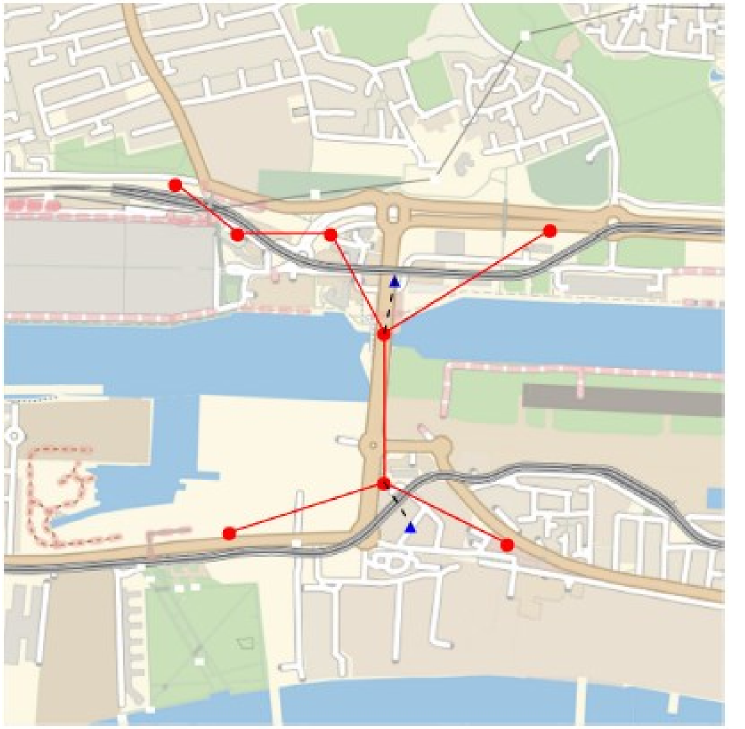
Asset Refuelling / Bowser Routing

- Single construction site
- Multiple assets (plant, fleet, generators)
- Single fuel type
- Network of relevant locations on site
- All feasible pathways connecting any two locations
- Discrete time, finite horizon
- Single bowser truck
- Single cistern, infinite capacity



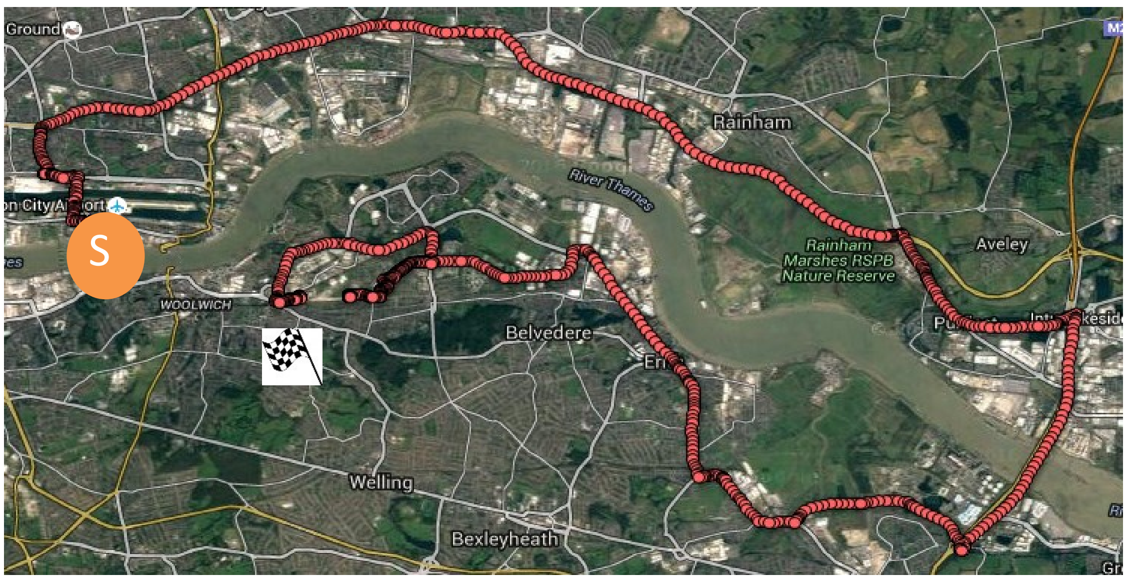
- Asset info, at any time *t*:
  - location
  - fuel consumption

Asset Refuelling / Bowser Routing

- Bowser moves b/w any two adjacent locations within a single time period
- Bowser does not go back to cistern if on its way to refuel an asset
- Refuelling an asset
  - takes negligible time
  - requires: bowser and asset in same location
- Time modelling: “large bucket”

A day in the life of a bowser …

- Typical day of a bowser truck:
  - 2 long journeys and ca. 20 short journeys on-site.
- Example day: Tuesday 21/06/2016



47.6 km

1h 31min

avg speed 31.5 km/h

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Asset Refuelling / Bowser Routing

Parameter	
T	number of time periods;
A	number of assets;
N	number of nodes in the overlay network (i.e. $N = \|V\|$);
$d_{i,j}$	distance between node i and node j in the overlay network, if $i = j$, $d_{ij} = 0$;
$\delta_{i,j}$	a binary variable that is set to one if and only if it is possible to travel from node i to node j in one time period;
$l^a_{t,i}$	a binary variable that is set to one if an only if asset a is at node i during time period $t \in T$;
f^a_t	fuel consumption of asset a in time period $t \in T$ denoting the node in the overlay network;
F	total fuel consumption for all assets across all time periods;
c_a	tank capacity of asset a;
s_a	initial tank level of asset a;
c_b	bowser tank capacity;
s_b	initial bowser tank level;

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Asset Refuelling / Bowser Routing

Decision variable	
V_t^i	a binary variable that is set to one if and only if, at time t, the bowser is at node i;
$T_t^{i,j}$	an auxiliary binary variable that is set to one if and only if the bowser transits from node i to node j by the end of period t.
Q_t^a	the quantity of fuel delivered to asset a at time t;
B_t	the quantity of fuel transferred from the cistern to the bowser at time t.

A bilinear formulation

$$\min \sum_{t=2}^{T} \sum_{i=1}^{N} \sum_{j=1}^{N} V_{t-1}^{i} V_{t}^{j} d_{i,j} \qquad (1)$$

which captures the distance travelled by the bowser, which we aim to minimise.

We assume that the bowser is at node 1 (the cistern) at the beginning of the planning horizon

$$V_1^1 = 1. \qquad (2)$$

Fuel cannot be transferred from the cistern to the bowser unless the bowser is at node 1

$$B_t \leq V_t^1 C_b, \quad t = 1, \ldots, T. \qquad (3)$$

The following constraint enforces bowser capacity

$$s_b + \sum_{k=1}^{t} B_k - \sum_{k=1}^{t} \sum_{a=1}^{A} Q_k^a \leq C_b, \quad t = 1, \ldots, T. \qquad (4)$$

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A bilinear formulation

We next introduce inventory conservation constraints for the bowser

$$s_b + \sum_{k=1}^{t} B_k - \sum_{k=1}^{t} \sum_{a=1}^{A} Q_k^a \geq 0, \quad t = 1, \ldots, T. \tag{5}$$

We denote as F the total fuel consumption for all assets across all time periods and introduce the following constraints which ensure the bowser does not carry more fuel than needed

$$\sum_{k=1}^{T} B_k \leq \max(0, F - \sum_{a=1}^{A} s_a - s_b); \tag{6}$$

$$\sum_{k=1}^{T} \sum_{a=1}^{A} Q_k^a \leq s_b + \sum_{k=1}^{T} B_k. \tag{7}$$

A bilinear formulation

The following constraint captures the fact that at each point in time the bowser must be somewhere in the network

$$\sum_{i=1}^{N} V_t^i = 1, \quad t = 1, \ldots, T. \tag{8}$$

The bowser can transit from node i to node j only of these are connected,

$$\delta_{i,j} \geq V_{t-1}^i + V_t^j - 1, \quad t = 2, \ldots, T;\ i, j = 1, \ldots, N. \tag{9}$$

We introduce inventory conservation constraints for asset tanks

$$s_a + \sum_{k=1}^{t} (Q_k^a - f_t^a) \geq 0, \quad t = 1, \ldots, T;\ a = 1, \ldots, A. \tag{10}$$

$$s_a + \sum_{k=1}^{t} (Q_k^a - f_t^a) \leq c_a, \quad t = 1, \ldots, T;\ a = 1, \ldots, A. \tag{11}$$

A bilinear formulation

The following constraint states that an asset can be refuelled only if it is located at the same node in which the bowser is found at a given time period

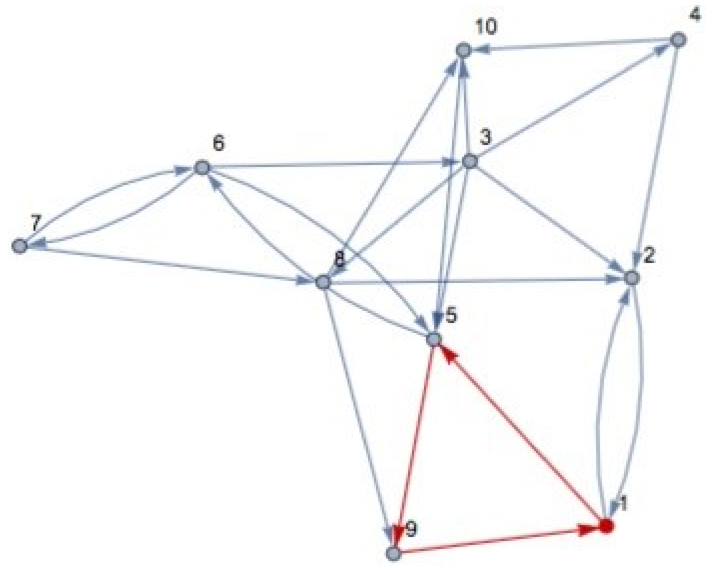
$$Q_k^a \leq c_a \sum_{i=1}^{N} V_t^i l_{t,i}^a, \quad t = 1, \ldots, T; \; a = 1, \ldots, A. \tag{12}$$

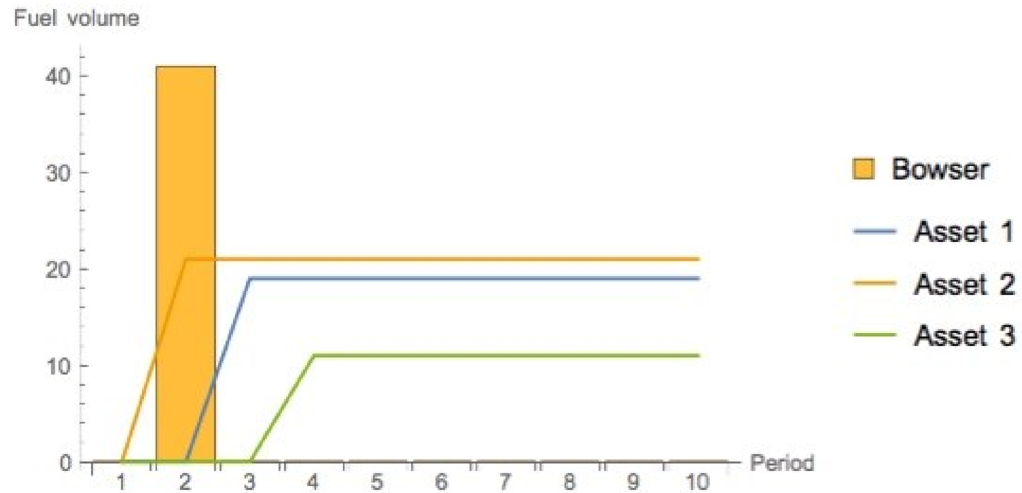
$$Q_k^a \leq \max\left(0, \sum_{k=1}^{T} f_k^a - s_a - \sum_{k=1}^{t-1} Q_k^a\right), \quad t = 1, \ldots, T; \; a = 1, \ldots, A; \; i = 1, \ldots, N. \tag{13}$$

Finally, we impose the following safety restriction: the bowser should only remain stationary at the cistern node

$$V_{t-1}^i + V_t^i \leq 1, \quad t = 2, \ldots, T; \; i = 2, \ldots, N. \tag{14}$$

Bilinear formulation: example





- Working example:
  - 3 assets
  - 10 nodes
  - 10 periods
- IBM ILOG CPLEX Opt Studio, v 12.6
- Solves in 0.8 s

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MILP reformulation

$$\min \sum_{t=2}^{T} \sum_{i=1}^{N} \sum_{j=1}^{N} T_{t-1}^{i,j} d_{i,j}. \tag{15}$$

The following channeling constraint links variables $T_t^{i,j}$ and variables V_t^i,

$$T_{t-1}^{i,j} \geq V_{t-1}^{i} + V_t^{j} - 1, \quad t = 2, \ldots, T;\ i, j = 1, \ldots, N. \tag{16}$$

Constraint 9 can be replaced by the following constraints

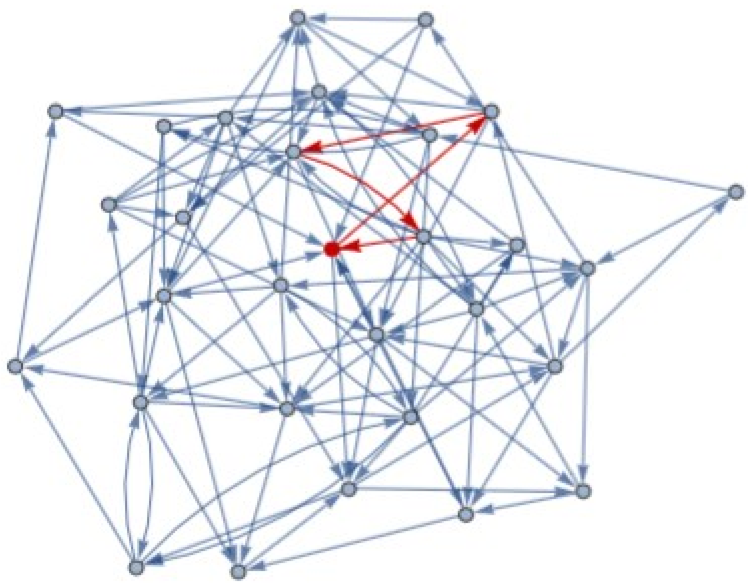
$$\sum_{j=1}^{N} T_t^{i,j} \delta_{i,j} = V_t^i, \quad t = 1, \ldots, T-1;\ i = 1, \ldots, N. \tag{17}$$

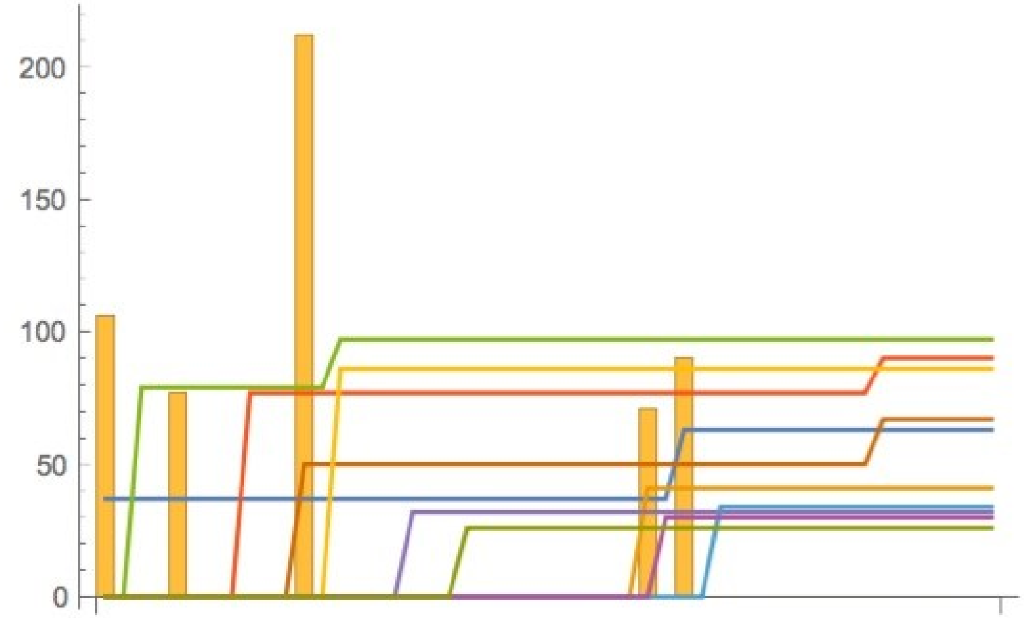
$$\sum_{j=1}^{N} T_t^{i,j} = V_t^i, \quad t = 1, \ldots, T-1;\ i = 1, \ldots, N. \tag{18}$$

Finally, the safety restriction can be rephrased as follows

$$T_t^{i,i} = 0, \quad t = 2, \ldots, T;\ i = 2, \ldots, N. \tag{19}$$

MILP reformulation: example





- Working example:
  - 10 assets
  - 30 nodes
  - 50 periods
- IBM ILOG CPLEX Opt Studio, v 12.6
- Solves in 190 s

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Sprinkling

Optimal routing of sprinkling vehicles in construction operations

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July 6, 2016

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Take-away messages?

- Data Integration from source to decision making point
  - 7.8% improvements on costs with respect to naïve policies – more to come as we move on

- Barriers to implementation
  - granularity of telematics data
  - consistency in implementing AEMP standard
  - contracts!

- JSDP library http://gwr3n.github.io/jsdp/

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