



# ASPECT 2019 ///

Institution of Railway Signal Engineers | Delft University of Technology | IRSE Nederland

Rail's particular challenge with resilience:  
shifting from controlled complicatedness  
to working with complexity

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**VicTrack**



# Resilience engineering is based on complex systems thinking

- 1. The system as designed is not the same thing as the real system**
- 2. As modern cities get larger and technology advances, our systems become more tightly coupled and interdependent**
  - Making us more vulnerable to multi-system shocks / stressors**
    - And making resilience more important**

Art: Stephen Wiltshire  
Tokyo panorama



# Two different philosophical views: Complicated (vs. complex)

A system can be centrally planned, controlled and tracked

Behaviour is predictable and repeatable

Component properties are key to controlling the system behaviour



Parts/people are interchangeable

The more standardised the components, the better it works

The goal is a stable, working system

# Two different philosophical views: Complex (vs. complicated)

No agent in the system controls the system, or can understand or usefully predict behaviour

History matters: behaviour evolves over time

Interactions and relationships matter



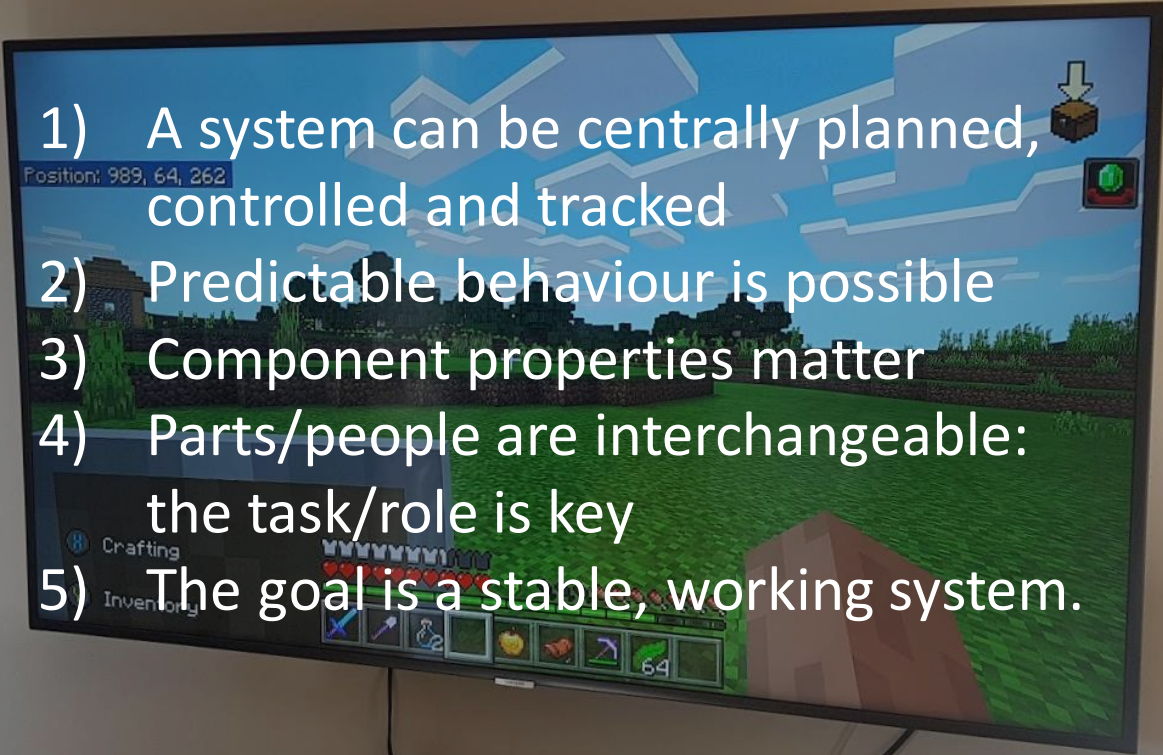
Agent perception shapes behaviour, which shapes the system

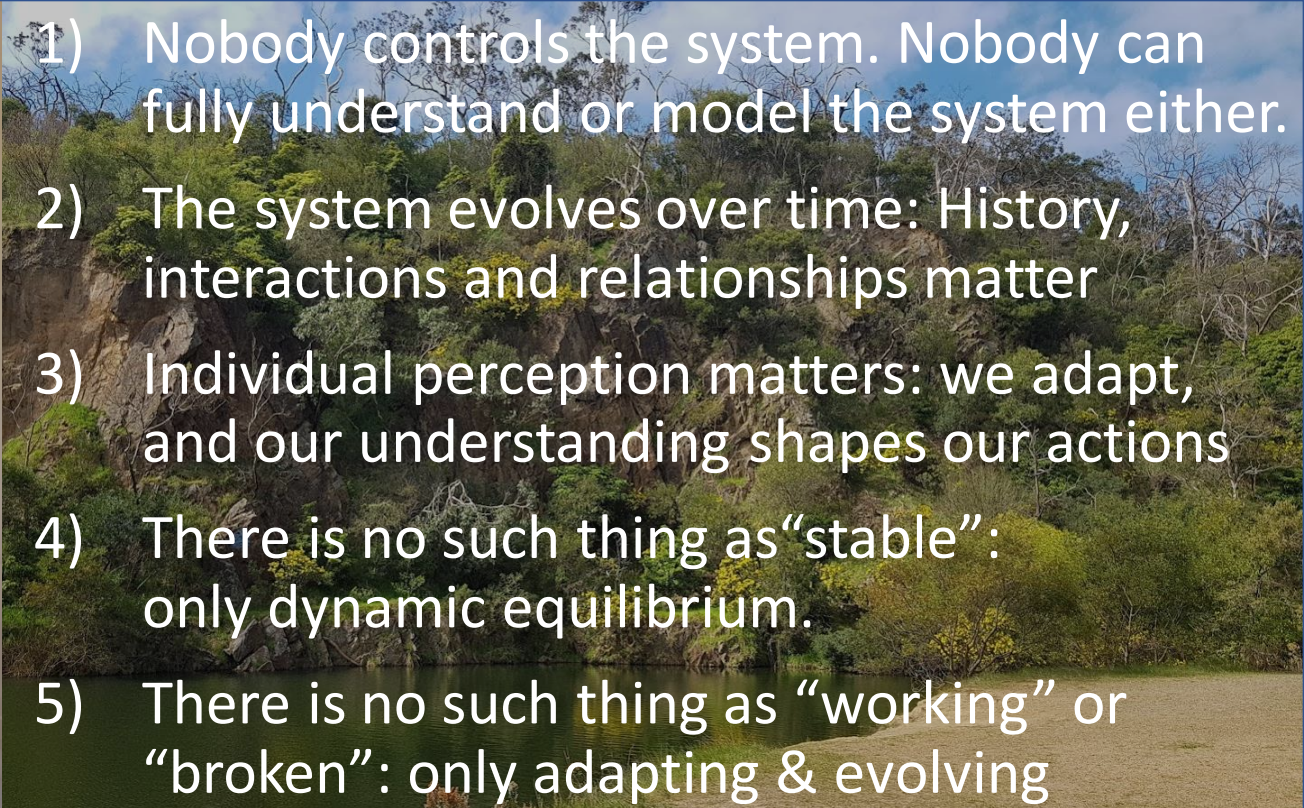
Diversity improves the system's ability to adapt

“Stable” doesn't exist: temporary (dynamic) equilibriums only

There is no such thing as “working” or “broken”: behaviour emerges from interactions

# Is a railway signalling system a complicated system or a complex system?

- 
- 1) A system can be centrally planned, controlled and tracked
  - 2) Predictable behaviour is possible
  - 3) Component properties matter
  - 4) Parts/people are interchangeable: the task/role is key
  - 5) The goal is a stable, working system.

- 
- 1) Nobody controls the system. Nobody can fully understand or model the system either.
  - 2) The system evolves over time: History, interactions and relationships matter
  - 3) Individual perception matters: we adapt, and our understanding shapes our actions
  - 4) There is no such thing as “stable”: only dynamic equilibrium.
  - 5) There is no such thing as “working” or “broken”: only adapting & evolving

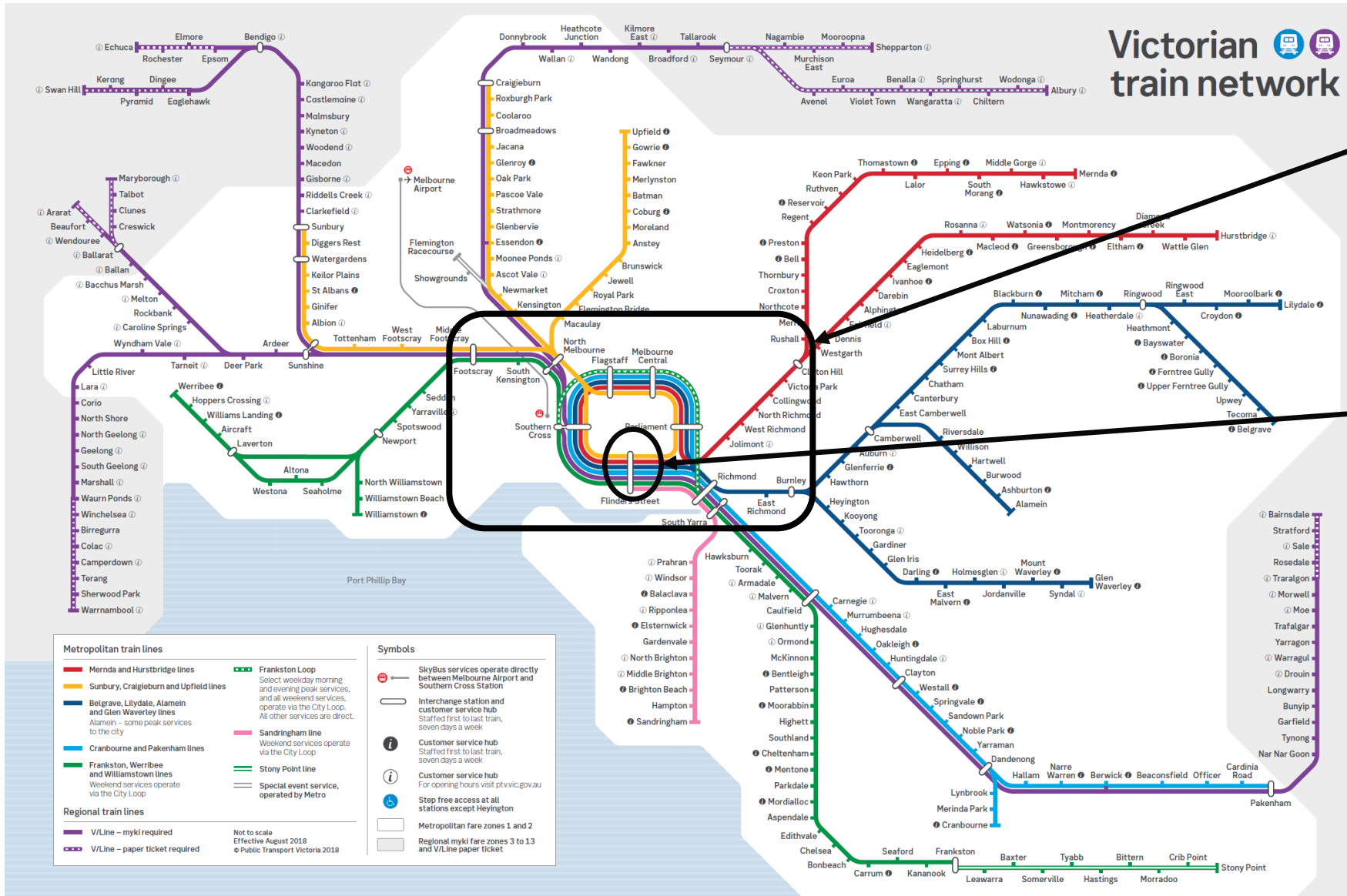
And if the system doesn't quite work how we (engineers) were trained to think it does ...

... what next?

# Rail safety from the resilience literature

- Signalling takes “an extreme version of a command and control strategy... passenger safety appears to be achieved by defining very clearly in advance what are the necessary prerequisites of safe operation and forbidding operation outside them” (Hale & Heijer 2006)
- Rail is an “ultra safe system [where] a serious accident or adverse event may trigger a crisis of public confidence for all operators” (Almaberti 2006; Dekker 2011 & 2017 also described rail as an ultra safe system)
  - High supervision, tight control & legislation
  - Progressive reduction of freedom to adapt
  - Tends behaviours towards overcompliance
- “Signalling has evolved by accident”: i.e. accidents are the primary driver of technological advances and rule changes (Woodbridge, 2017)

# Melbourne city loop – an evolved system



**Rail network bottleneck:**

- Concentrated train movements
- Vulnerable to cascading disruptions

**Human system compensates:**

- Senior train control desk
- Fluid reallocation of train IDs
- Absorb minor delays
- Manage & recover from trigger events
- Permanent police & emergency services liaison

# Learning from disruptions: July 13, 2017: “Trainageddon”

“Metro's automatic train control centre failed at 4pm, leaving the operator scrambling and at a loss to identify what caused the system failure.”

“With the system down, train controllers were staring at blank screens and literally did not know where in the network Melbourne's trains were, so all trains were brought to a halt for safety's sake.”

**Adam Carey, July 14 2017**

**“Why Melbourne's train network melted down yet again”**

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*Passengers were stuck on trains for nearly two hours*

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*Trams, buses, taxis and  
Ubers were overcrowded:  
Uber surcharge was 3.6x*

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*The backlog of passengers  
took several more hours  
to clear*

# Learning from disruptions: Feedback from the media



NATIONAL VICTORIA

## Metro's \$80m back-up system may have failed at moment Melbourne needed it

By [Adam Carey](#)

Updated July 14, 2017 –  
5.55pm, first published at  
4.23pm



The \$80 million back-up system for Melbourne's rail network may have triggered the glitch that brought down the city's train system on Thursday, stranding or delaying an estimated 175,000 passengers.

## Print and television headlines on 14 July 2017

**Metro Trains fined \$1.2m over computer malfunction that shut down network**

Updated 1 Sep 2017, 7:23am



# Learning from disruptions: Level Crossing Removal Project



## Focus on passenger flow first:

- Minimise humans: plan for lowest patronage period
- Coordinate replacement trams, buses
- Keep city “spokes” operational
- Passenger safety, comfort & quality of experience
- Staff on the ground

## Information sharing

- Twice daily information sharing to improve each peak
- Flexible allocation of customer service staff
- Cross agency & public systems

## Other parts of the (engineering?) solution

- News & social media: public information campaign
- Passengers can make decisions to ease congestion
- Local businesses & community: [#thanksforyourpatience](#)



Home Moments Search Twitter

**LEVEL CROSSING REMOVAL PROJECT**

Tweets	Following	Followers	Likes
6,093	275	5,987	1,547

**Level Crossings**  
@levelcrossings

Removing 75 #levelcrossings & overseeing other rail projects in Melb. We're here Mon-Fri 9-5. Social media policy & feedback/complaints: [bit.ly/2qG6W7U](https://bit.ly/2qG6W7U)

Melbourne, Victoria  
[levelcrossings.vic.gov.au](https://levelcrossings.vic.gov.au)  
Joined May 2015  
1,666 Photos and videos

**Tweets Tweets & replies Media**

Pinned Tweet

**Level Crossings** @levelcrossings · 11 Feb 2018  
Visit [bit.ly/PlannedDisrupt...](https://bit.ly/PlannedDisrupt...) or call 1800 105 105 for information about disruptions due to #levelcrossing works

# Learning from disruptions: Level Crossing Removal Project shutdowns

January 2018: 8 days	“Put the buses out there”: Good press & community response Improvements each day:	Day 1 delay >3 hrs By day 7, delay ~1 hr
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April 2019 35 days	300,000 passenger trips per day Data & digital technology: tablet counters, bus GPS integration Realtime passenger information & choice of CBD destination Communications saturation campaign achieved 45% mode shift	Day 1 delay ~3 hrs Day 35 delay: 0 to 15 mins

# A perfect storm – and a resilient response

## Major incident during a partial loop shutdown



1. Major works shutdown day 20
2. Mode shift to adjacent line
3. Pedestrian fatality at 4PM

"At no point did we grind the whole thing to a halt but it was a long and difficult evening.



When you take out another railway line for a tragic event like that then we have a limited number of options to play with.

We pulled an additional 20-30 buses into the mix, we rebalanced our resources between the Caulfield and Sandringham routes and we talked to people to keep them moving."

PTV CEO Jeroan Weimar, quoted in ABC news article 16 April 2019

"PTV rejects calls for compensation for commuters after Sandringham train line chaos"

# Rail safety is both complicated and complex

## Conventional engineering approach

- Minimise or engineer out things that can go wrong from a position of high-level authority
- Mitigate residual risk with systems and processes
- Then require & ensure obedience to those systems and processes
- Prerequisites:
  - Standards & governance
  - Central control
  - Synoptic legibility – the controller must understand the system in real-time

## Resilience engineering approach

- Practice (at crisis management) makes perfect
- Maintain the ability to identify emergencies and recover smoothly
- Safety decay is not linear:
  - Small events are not leading indicators of a large event
  - A catastrophe is actually a cascade of small events
- Adaptation & evolution are to the system's advantage
- Any agent can alter the system

# Rail safety is both complicated and complex

## Conventional engineering approach

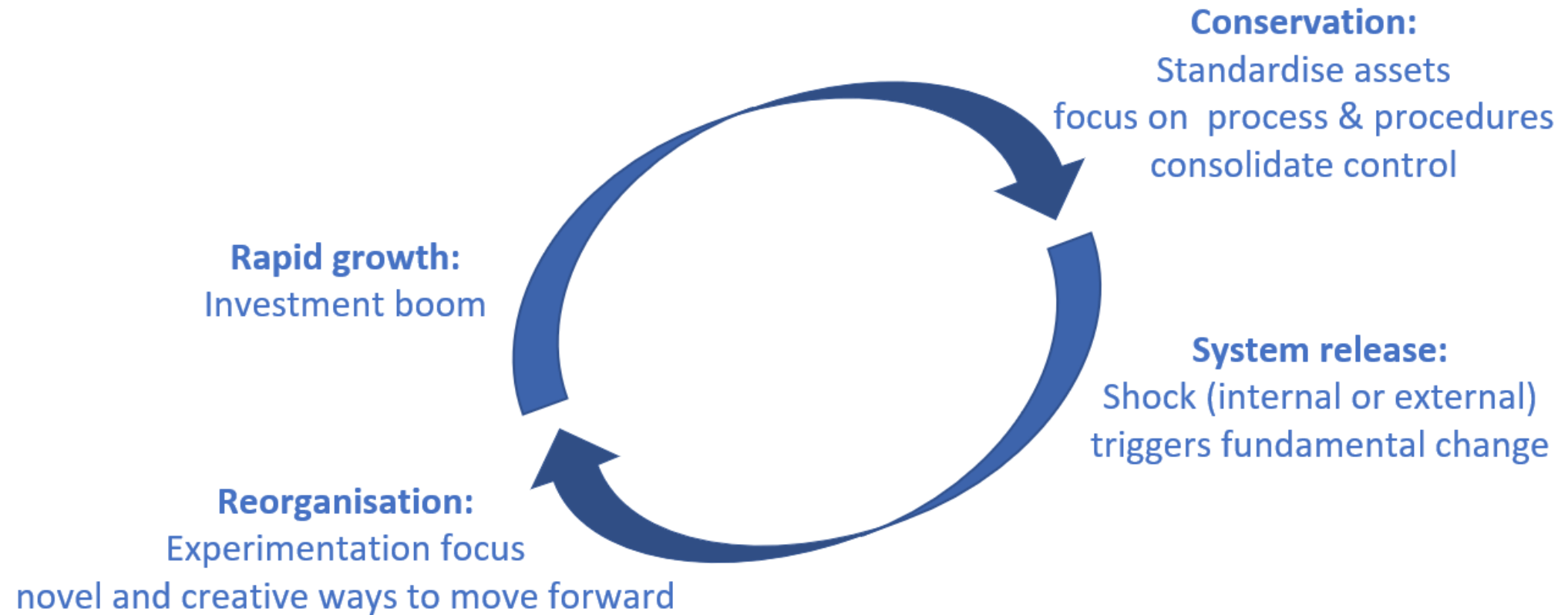
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## *New to the engineer's toolkit!*

## Resilience engineering approach

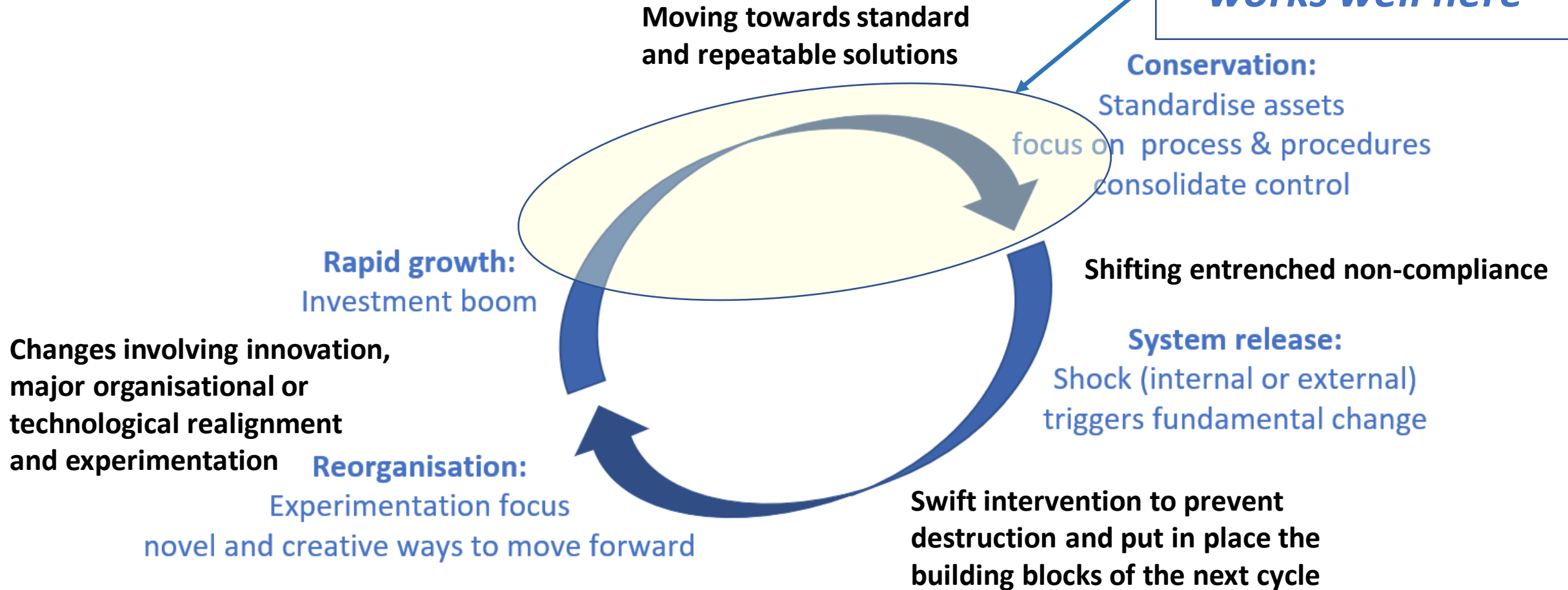
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# Complex Systems Adaptive Cycle

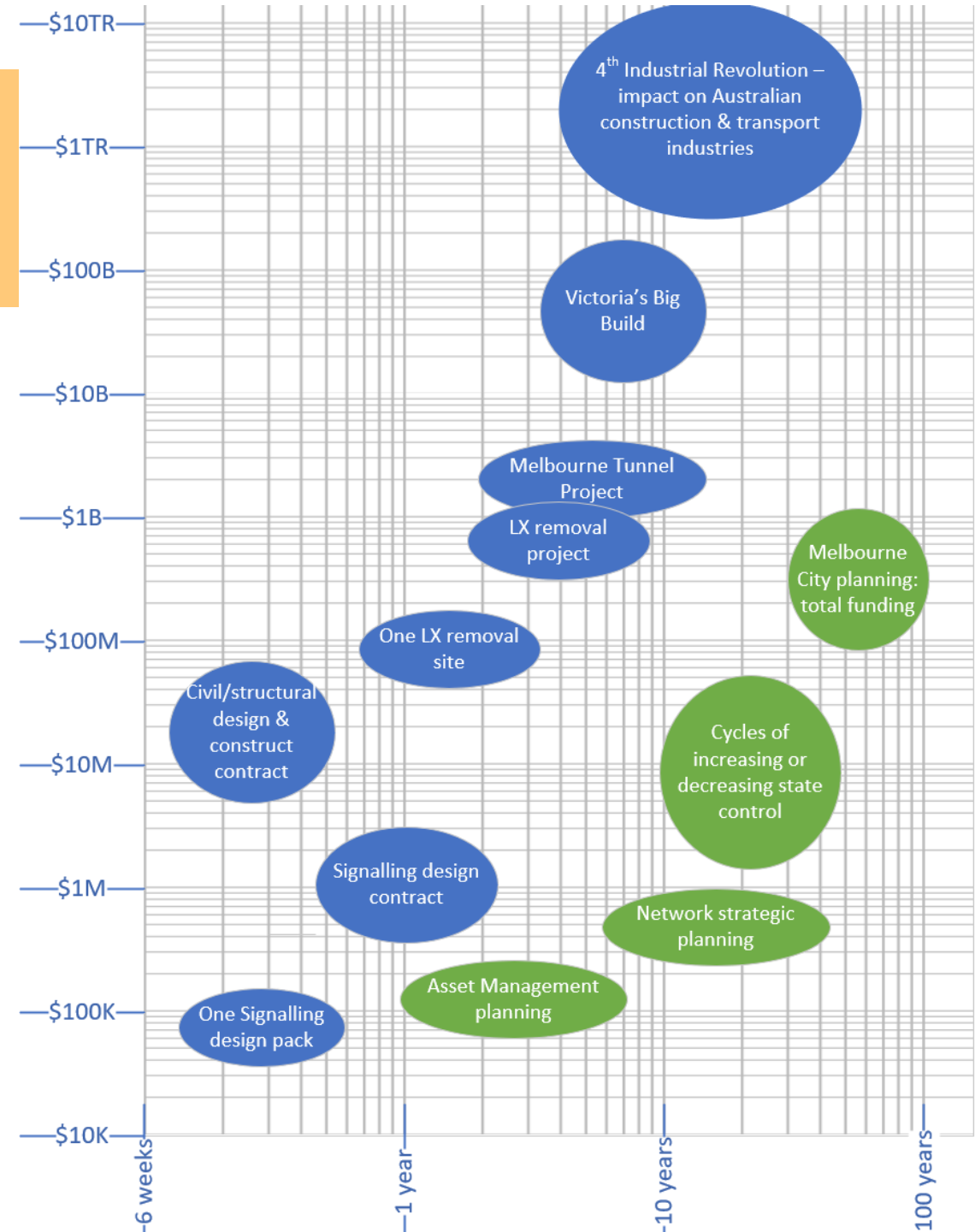


# Complex Systems Adaptive Cycle

*Complicated  
problem solving  
works well here*



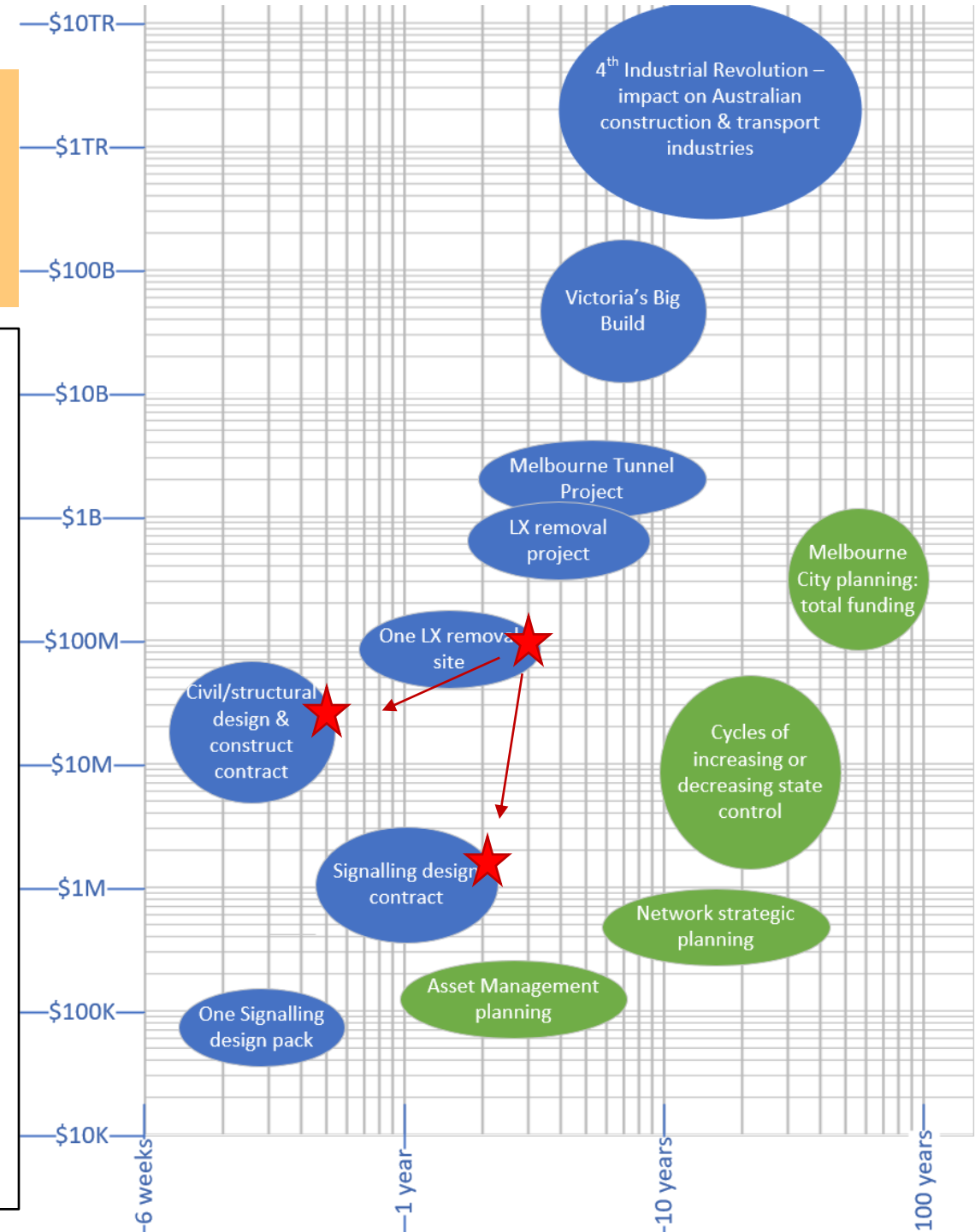
# Interactions across scales



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## 3D Signal Sighting

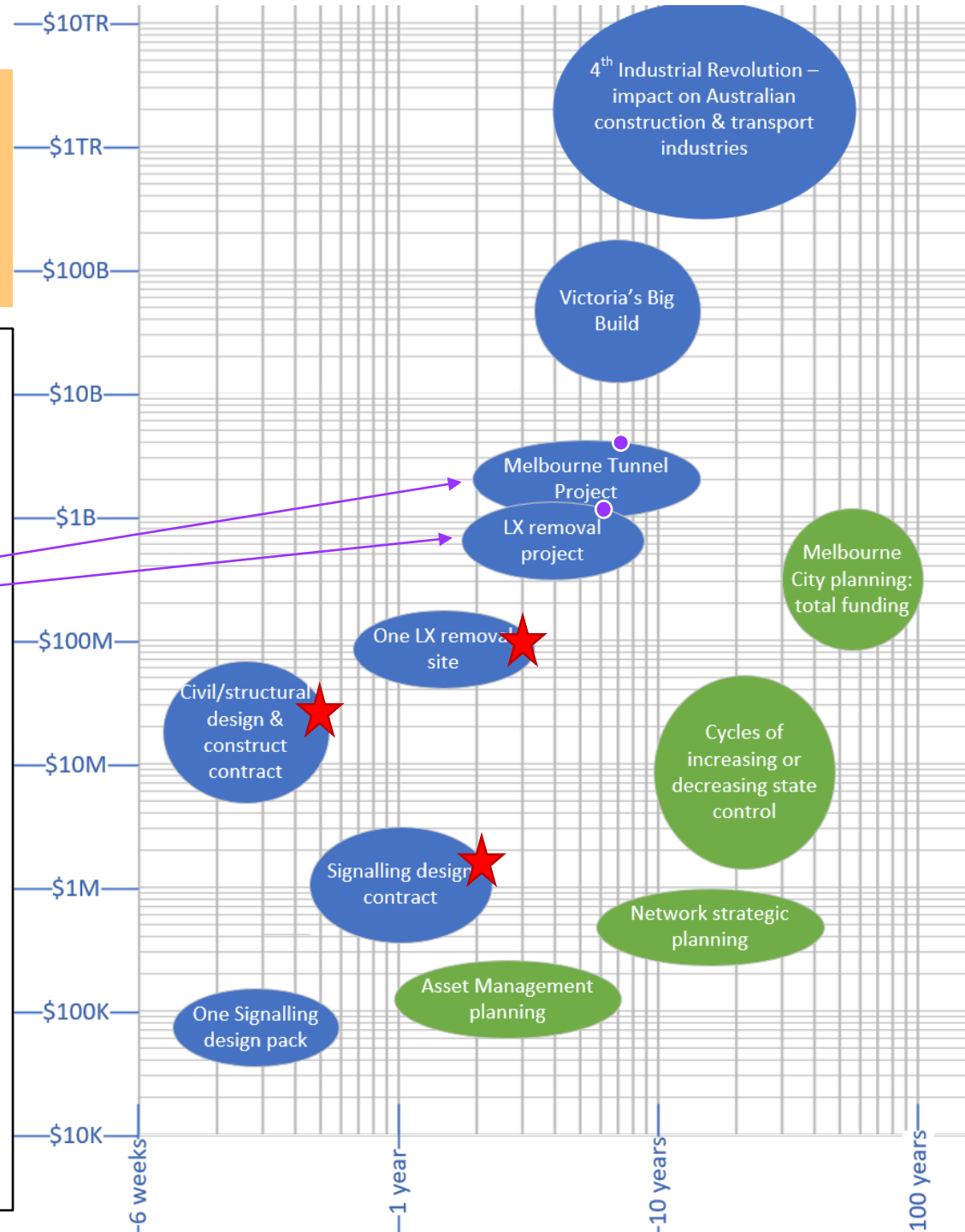
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# Interactions across scales

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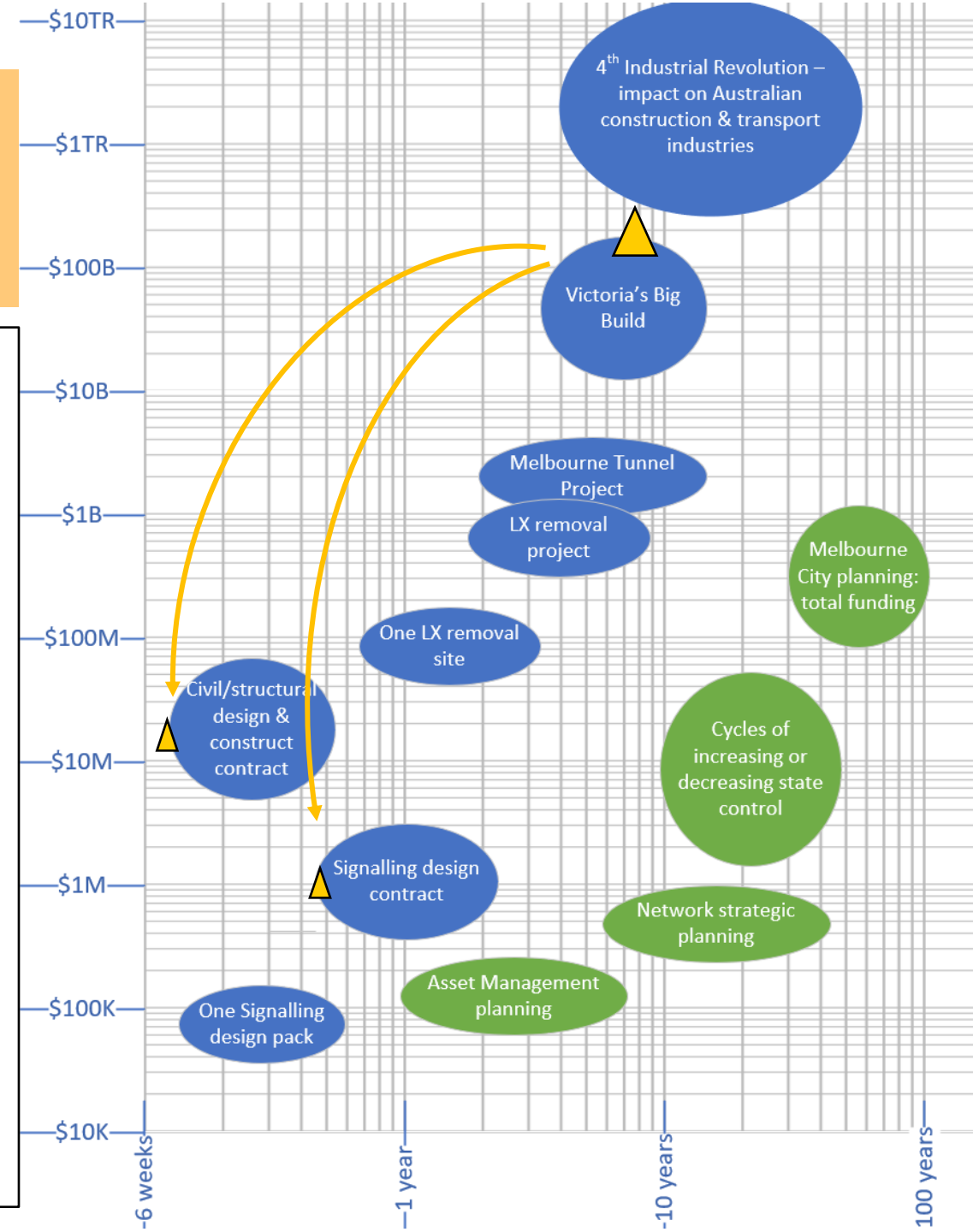
- Issue typically comes up late in a cycle:  
Not a good time for innovation
- Early conservation phase:  
limited support



# Interactions across scales

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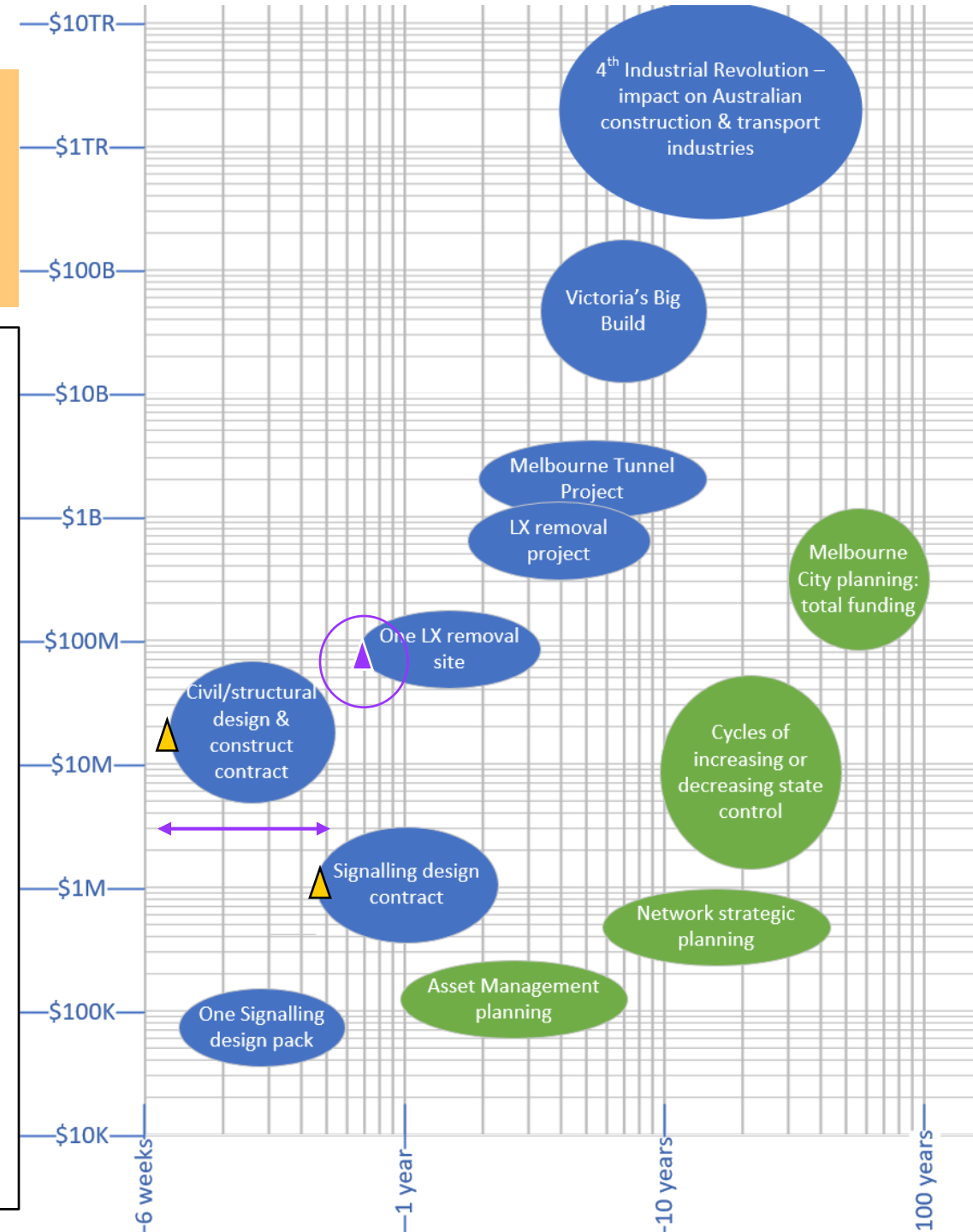
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- Right mindset to run A/B experiment to de-risk an upcoming contract



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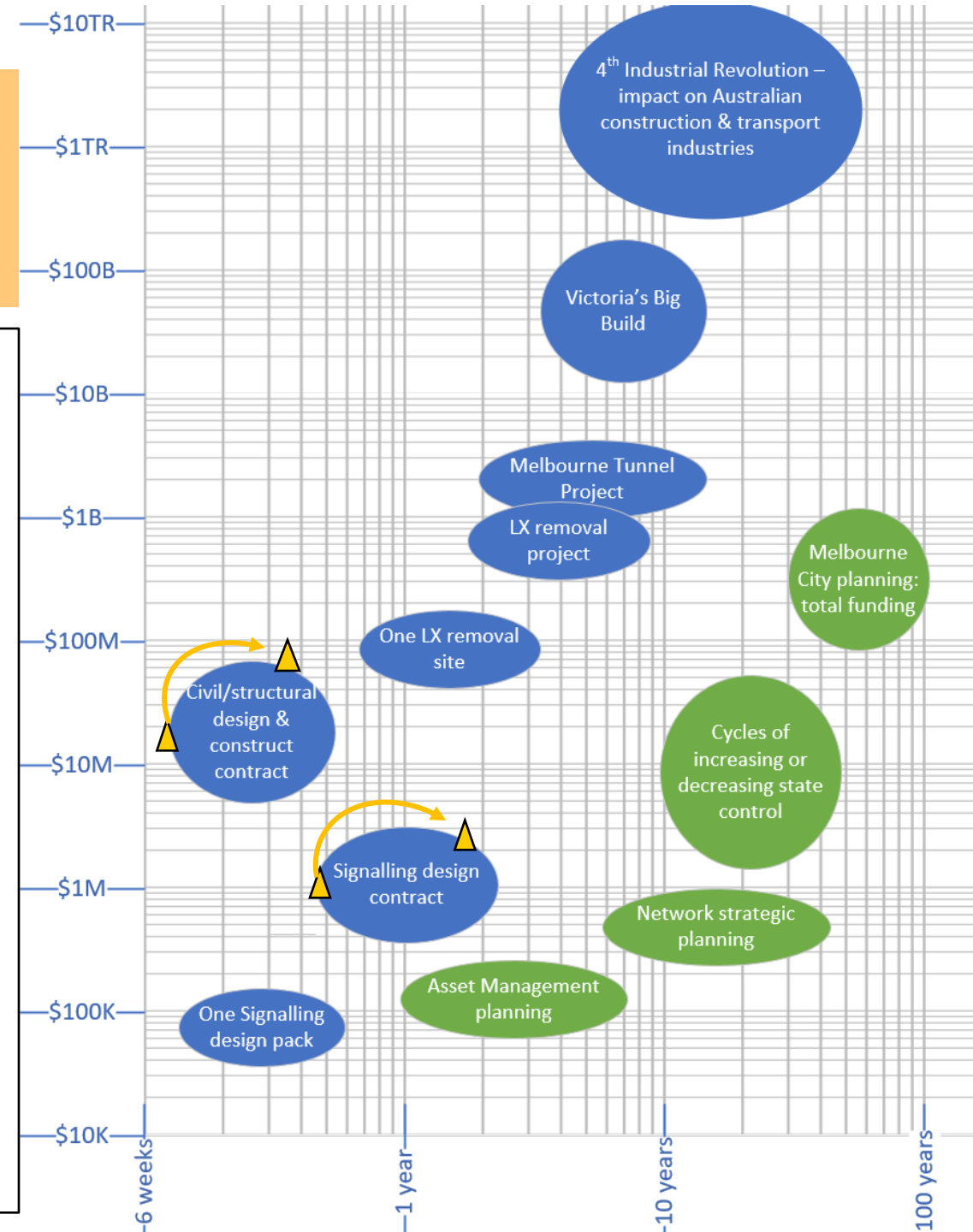
- Issue typically comes up late in a cycle: Not a good time for innovation
- Right mindset to run A/B experiment to de-risk an upcoming contract
- Challenges coordinating across timescales
- Coordinate lightly from the next scale up



# Interactions across scales

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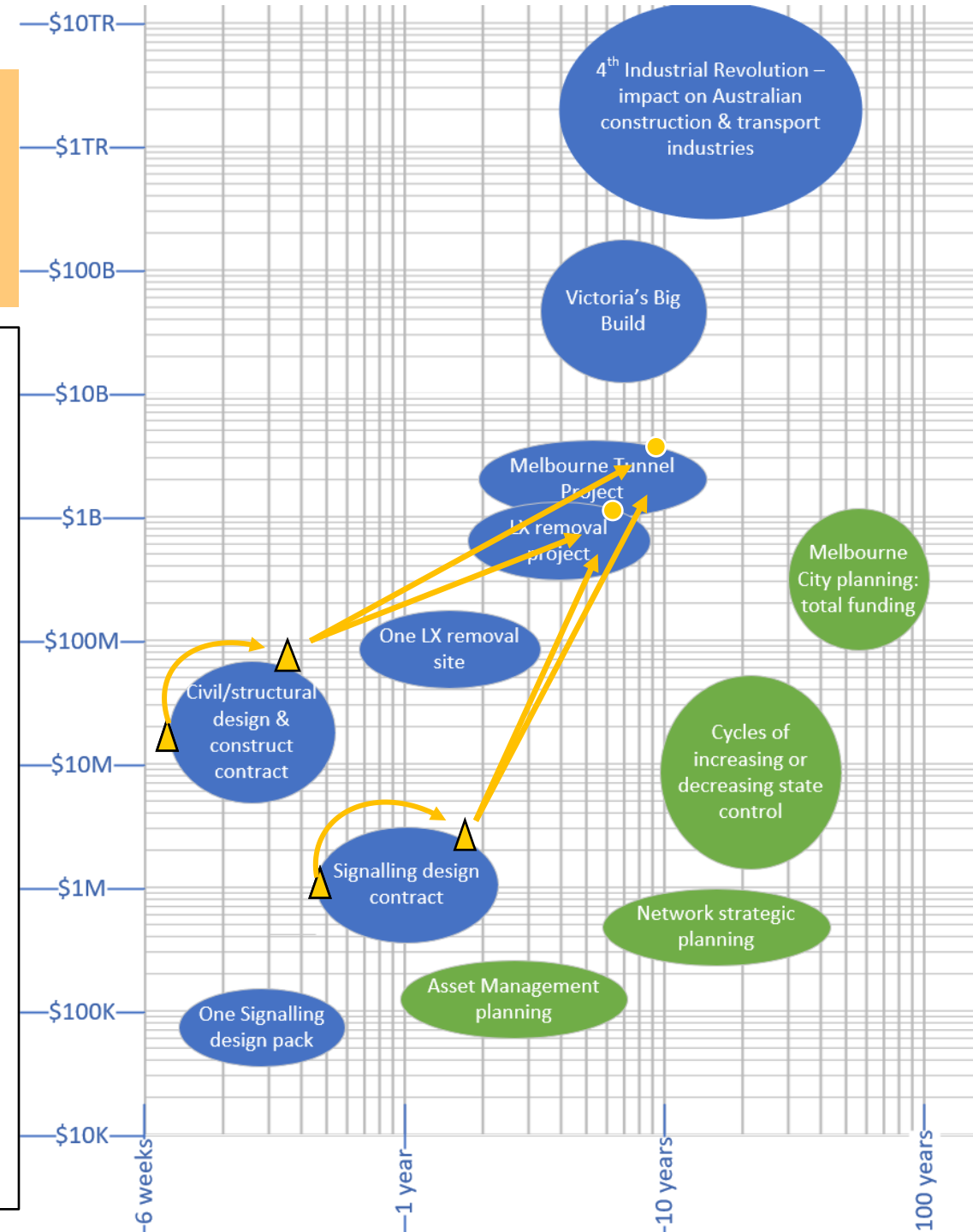
- Issue typically comes up late in a cycle:  
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- Right mindset to run A/B experiment to  
de-risk the next contract
- Formalise & standardise method



# Interactions across scales

## 3D Signal Sighting

- Issue typically comes up late in a cycle:  
Not a good time for innovation
- Right mindset to run A/B experiment to de-risk the next contract
- Formalise & standardise method
- Next step: Lock into a standard and roll out over the Big Build
  - Timescale: 12 months to a few years
  - Interim: communicate over interfaces
    - Sharing information (IRSE paper)
    - Sharing people (normal industry percolation)



# 3D Interactive Signal Sighting

Andreevski, I. and Walker, M.  
3D Signal Sighting Workflow.

*IRSE Australasia National Technical Meeting, 18 July 2019.*



**Engineering already uses complex systems tools:**

- Case study from Melbourne network (context & history)
- Graphics engine with 3D project area model (technical system)
- Sequence of structured workshops (human system)
- Version control, baselines & gates (focus on interfaces)
- Business case with cost & time spent/saved (resource flows)

## System as designed

≠

## System in the real world

(Resilience engineering is very interested in this mismatch)

### Controlled complicatedness

- Central control
- Predictable behaviour
- Requires:
  - Standards & governance
  - Central control
  - Synoptic legibility
- Conventional system safety
- Conventional systems engineering assurance

### Working with complexity

- Technical and human systems interact & adapt, evolving over time
- Use feedback loops to change behaviour
- “Problems” can be part of a solution
- Complex adaptive cycle
  - Rapid growth
  - Conservation
  - System release
  - Reorganisation
- Different system scales and timeframes
- Communication across boundaries



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