The Problem of Paradigm

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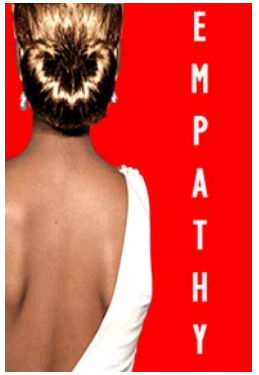
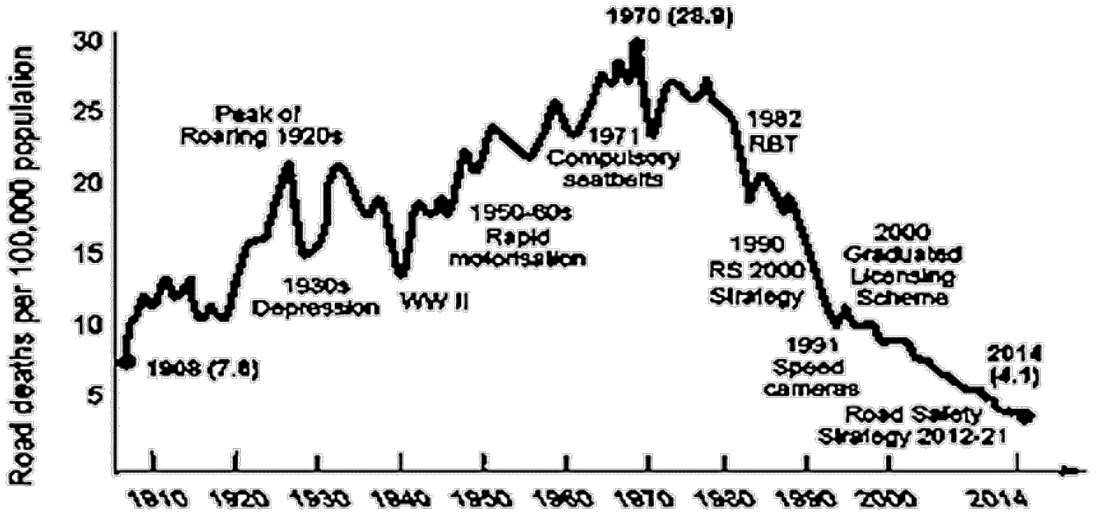


PhD: “The Adverse Effects of Paradigm and Pragmatism on Road Safety”

- In 1910, there were about 4,000 motor vehicles in NSW (pop’n: 4.37 million; 1MV per 1100)
- In 2017, there were more than 6,000,000 motor vehicles (pop’n: 7.81 million; 1MV per 1.3)
- Road deaths per 100,000 people in 2017 was less than half that of 1910



What is paradigm?

"[W]e, individually and collectively, make sense of reality through constructs **which are fallible as time passes**. …"

Le Coze (2018), on Kuhn's The Structure of Scientific Revolutions (1962)

(Paradigm: a closed set of scientific theories that are coherent and are well accepted by the larger scientific community.)

"If I have seen further it is by standing on the shoulders of Giants."

While you're up there…
Make sure the giants are standing on firm footing,
aren't leaning strangely,
and look behind you to see whether a nearby hill might give an even better view.

(Paradigm shift: scientific truth, at any given moment, cannot be established solely by objective criteria. Science must account for subjective perspectives as well, since all objective conclusions are ultimately founded upon subjective conditioning.)

Example: high school maths problem

"If A > b and C > d, prove that AC > bd"

i.e. AC – bd > 0

=> More than 10 seconds of thought required!

Adopt a different paradigm:

$$\frac{AC}{bd} > 1$$

$$\frac{A}{b} . \frac{C}{d} > 1$$

=> Trivially true with less than 10 seconds of thought

Emergence of the current engineering paradigm: engineering as a profession

Professionalisation of the workforce: in the US, between 1940 and 2019, the proportion of people aged 24 to 29 graduating with a bachelor degree rose from 38.1% to 93.5%

Fundamental characteristics defining a profession:

- high-level systematic knowledge gained through education
- a central professional organisation
- autonomy for its members in the execution of the occupation (the exercise of judgment)

Professionalisation and education

Barber (1963): in emerging professions, the bid for professional status is supported by university schools; universities will try to ‘strengthen’ weak schools. Engineering: practical vs academic = ‘weak’

Engineering is based in the scientific tradition. As training transitioned to Universities, the paradigm for engineering that emerged reflected (Rojter, 2004):

> “… [an] academic culture, operating within engineering schools and faculties in Australia, that is based on scientific norms derived from science…”

Finniston report (1980, UK govt), Glover and Kelly (1987), Mulder (2000), Lloyd et al. (2001), Rojter (2004), Menzel, Aaltio and Ulijn (2007), King (2011), Frezza, Nordquest and Moodey (2013), Trevelyan (2013), Trevelyan (2014), Cunningham and Kelly (2016) (etc) raising and emphasizing:

- **value of social knowledge in engineering practice**
- **the need to teach the humanities to students**

=> Science-based paradigm pursued to the expense of engineering practice needs

1987 Association of Consulting Engineers, Australia, submission: *"…most engineers were not people orientated, and that many lack communication skills."*

1988 Review of the Discipline of Engineering: *"…judged as unsatisfactory the [lack of] emphasis given to oral and written communications skills, industrial relations and the management of people, the management of costs and resources, engineering as part of a broader business context, and the involvement with non-engineering disciplines in project work."*

1996 major review of engineering education recommends: *"…no less than a cultural change in engineering education which must be more outward looking with the capability to produce graduates to lead the engineering profession in its involvement with the great social, economic, environmental and cultural challenges of our time."*

Sharma et al. (2018): 13% of the engineering workforce are women; women in their 20s to 30s leave the profession at ten times the rate of men. Only 6,000 of the 18,000 required engineers every year are filled by graduates from Australian universities.

Joint report (2019), Royal Swedish Academy of Engineering Sciences (IVA), Swedish Association of Engineering Industries & the Swedish Association of Graduate Engineers: the percentage of women accepted into engineering programs is still only 25-30%.

Engineering vs traffic engineering

- Engineering disciplines: domain knowledge built around fundamental units
- Traffic engineering: the fundamental unit is the road user (i.e. a person)

McLean (1988): "Unlike branches of engineering which are based on making use of materials with definite physical properties, there are few absolute physical laws in traffic engineering."

- Australia: insufficient market for a dedicated traffic engineering degree
- Exposure to traffic engineering is via a few units in a 4-year civil engineering degree

Hauer (1999, unpublished): *"...they... cannot recognize the basic fact that people adapt to circumstances whereas inanimate matter does not. ... speed, reaction time and similar parameters are treated as constants in all the formulae and computation that are at the root of geometric [road] design standards."*

Ewing and Dumbaugh (2009): *"...the fundamental shortcoming of conventional traffic safety theory is that it fails to account for the moderating role of human behavior on crash incidence."*

Noland (2013): *"Engineering tends to focus on deterministic goals and deterministic modeling, primarily for forecasting the effects of various changes.... when dealing with human behavior more stochastic approaches need to be taken."*

=> Distinctly different paradigms

Professional judgment

Collins and Leathley (1995): **errors to which all humans are prone** *[emphasis added]*, based on social psychology and cognitive psychology. E.g. Tuler (1988), “mental models” giving rise to cognitive biases

Rae and Alexander (2017): experts may have superior understanding of causal mechanisms, but further domain expertise does not translate into increased accuracy

=> prior knowledge **without an understanding of bias or feedback on inaccuracies** *[emphasis added]* merely gives a false sense of competence

Delattro (1992, policing), van Zandt (1992, law) & Elstein (1992, medical), Hawse and Wood (2017, literature review): professional practices and human cognitive theory relevant to developing professional judgment

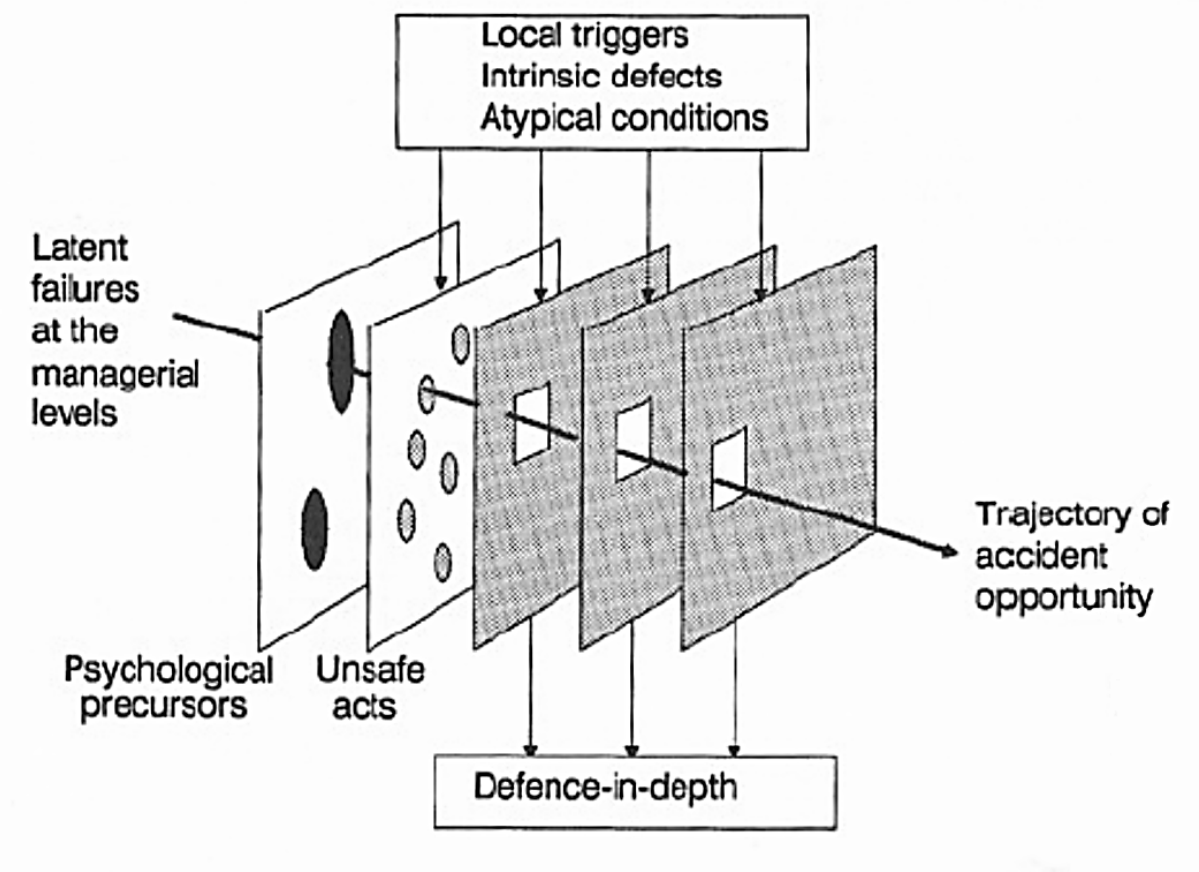
Davis (1992):

“…empirical research into clinical judgment is more advanced than such research into engineering judgment.”

Feynman (2001, p183):

“As far as I can tell, ‘engineering judgment’ means they're just going to make up numbers!”

=> Expected, but not taught



Rasmussen (1997, via Le Croze (2018)):
“fallacy of defence-in-depth” argument

Why hasn’t this changed (much)?

- Universities as an academic system
  - Rojter (2004): engineering lecturers appointed on the basis of research doctoral degrees
    => scientific knowledge over broader skillset
  - Barriers and penalties to inter-disciplinary and multi-disciplinary research
    => little category spanning among research-lecturers
  - easier to quantify and award grades against scientific performance
- Scientific route to engineering versus humanities route to social sciences
  => social science academics don’t communicate well with/aren’t relevant to engineering students
- Students are trained to value scientific knowledge over humanities
  => don’t push the broadening of University curricula (and can instead oppose it)
- Government research bodies => reinforce scientific approach through funding guidelines
- Professional bodies => accreditation, mutual recognition, etc.

=> Paradigm is self-reinforcing

Embodied (taught) paradigm versus fundamental paradigm: Engineers as problem-solvers

Case study on the adverse effect of engineering paradigm:
Traffic Conflicts Technique (TCT)

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- a method for undertaking safety studies based on traffic interactions (or ‘conflicts’ or ‘events’) as a surrogate for crash-related (mass) data
- potential to overcome (numerous) mass data limitations in safety studies
- theoretical framework establishes a mindset or paradigm for road safety researchers
- many outstanding issues, hasn’t been operationalised despite 50 years of work

=> identified issues considered as technical problems rather than due to a lack of new perspective (i.e. not considered as an adverse effect of established paradigm)

Case study approach

Reject paradigm (theoretical framework) and re-examine from first principles; examine results in terms of the outstanding issues

i.e. Reject:

- The definition of a conflict
- Models theorised to associate conflicts with crashes
- Established indicators in current use

(But also new technologies that might expand the field on their own)

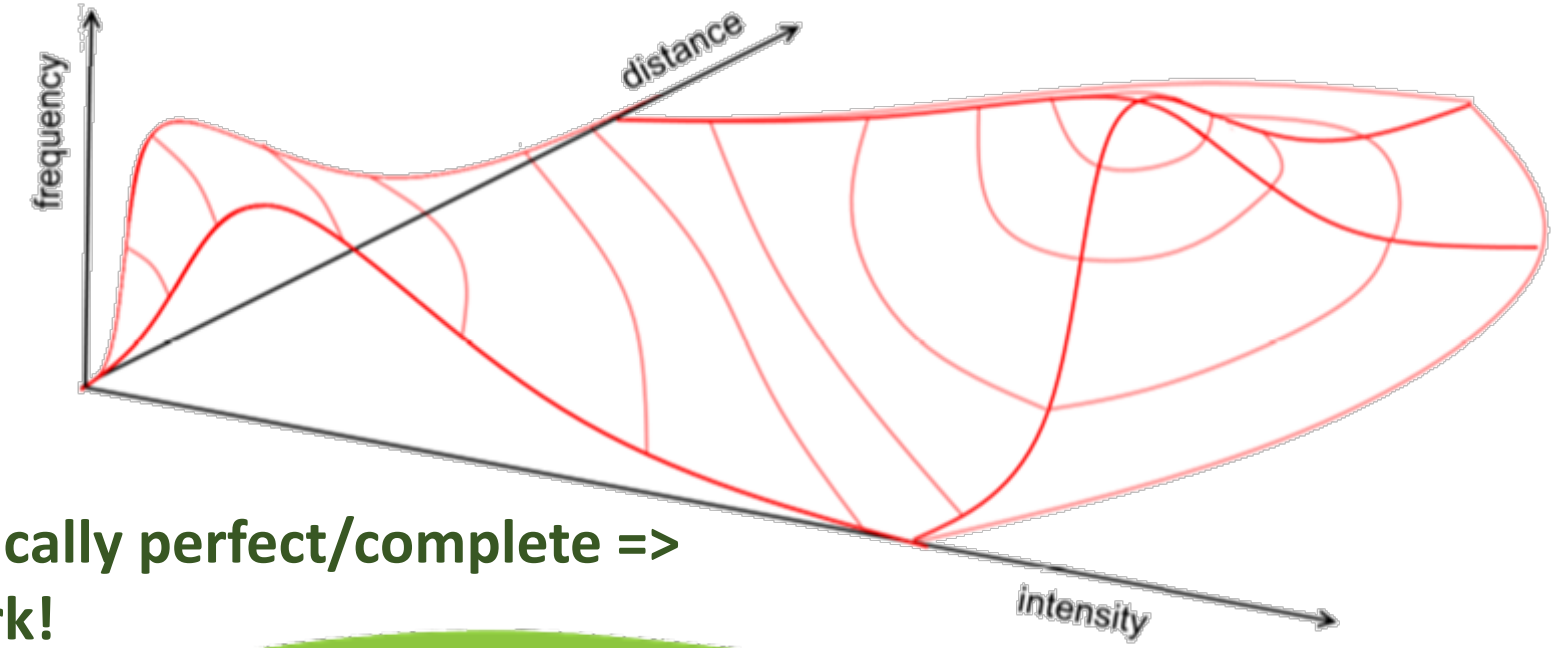
Left with: "Non-crash traffic events can be used as a surrogate indicator for crash events to reveal information about the safety conditions at a site"

=> Extreme Value (EV) theory is the only theory proven to be able to link observations of more common events to the likelihood of rarely observed extreme events occurring

Traffic Event Theory (TET)

"A traffic event is a road user's encounter with the road system." (TCT: conflict definition involves two vehicles)

- Events are rated by 'severity', which statistically link these to crashes via EV theory (TCT: 'conflict' is undefined)
- Severity has two characteristics: proximity and intensity (TCT: 'severity' is poorly defined (Shelby, 2011))
- Proximity and intensity: indicators are continuous, unambiguous and measurable/calculable
  e.g. distance (proximity) and delta-V (intensity); collected as frequency distributions + uniquely linked for EV results to be interpretable (TCT: composite indicators combine proximity with intensity)



Mathematically perfect/complete => should work!

Combining proximity and intensity as ‘severity’ indicators in TCT

E.g. Time to Collision (TTC) = (distance between collision-course vehicles) / (velocity 2 – velocity 1)

- low TTC = low distance **OR** large difference in velocities **OR** a bit of both
  => ambiguous, a single value can represent multiple states (+ problem: situations with no collision course)
- to link TTC values to crash risk, only valid way is via EV theory
  => what is the result from applying EV theory if TTC values are ambiguous?

Analogy: weather indicator, add temperature and rainfall. In Adelaide, a value of 40 could result from:

- 40°C + 0mm of rainfall (summer); or 5°C + 35mm of rainfall (winter); or something in between

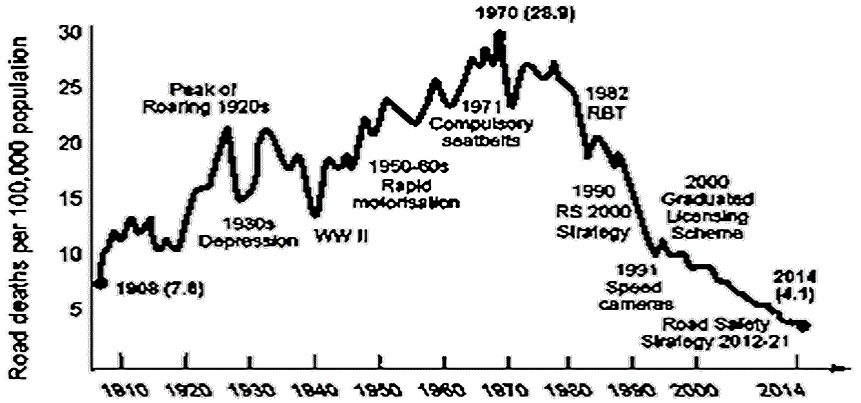
⇒ Apply EV theory, get probability of a value >40 = all days that are… hot and dry/ cold and wet/ in between?!

⇒ *“… a quantitative value, with no explicitly defined interpretation”* (Shelby (2011) re: concepts of ‘severity’)

Q: Why use a composite indicator if wanting to apply EV theory?

⇒ **TCT: a paradigm to which EV theory has been applied**
(poor results, ≈works if v relatively constant as d then dominates e.g. highways)

⇒ **TET: a paradigm based on EV theory (should work, being tested)**



- McLean (1988): early road safety field (c1960 = before professionalisation) concluded that road safety could not be considered solely from an engineering perspective
- Human Factors Committee established in 1962 => productive road safety research agenda

Heifetz and Linsky (2002): theory of adaptive leadership

- technical problems can be addressed by a technician or expert who fine tunes ways of getting things done
- adaptive problems require deeper transformation by more people in the community who have to change their values, behaviour, or attitudes

Golden Age engineers: problem-solvers;
dynamic, politically-aware, socially engaged entrepreneurs