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A RISK FRAMEWORK FOR REAL-TIME ADAPTIVE SAFETY IN TEMPORARY TRAFFIC MANAGEMENT

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ABSTRACT

Traditional Temporary Traffic Management (TTM) systems were built for predictability. Yet modern worksites operate within dynamic, uncertain environments shaped by variable driver behaviour, weather, lighting, and human cognition. This paper introduces a novel **risk-capable adaptive framework** for real-time safety and control in TTM, integrating insights from cognitive science, transport engineering, and behavioural safety.

The work draws on findings from the **SAFEye** research program — an eye-tracking methodology developed by Dr Urie Bezuidenhout that measures how people actually see and interpret risk. Combined with NextEra's organisational psychology expertise and Northpower's NZGTTM pilot experience, the approach merges **people, and physics** into a new discipline of *Psychogineering*. The result is a dynamic process that not only measures real-time risk but also adapts to it, aligning perfectly with the NZGTTM's intent to replace compliance with capability.



INTRODUCTION

Temporary traffic management is transforming. For decades, systems such as the Code of Practice for Temporary Traffic Management (CoPTTM) provided static control plans and standardised layouts to manage risk. While effective for consistency, these approaches assume predictability — a rare commodity in live road environments. Modern TTM operates at the intersection of complexity, variability, and human perception.

The NZ Guide to Temporary Traffic Management (NZGTTM)(NZTA, 2023) reframes safety around risk capability: understanding and adapting to risk in real time rather than merely following prescriptive rules. Achieving this requires bridging the gap between engineering precision and human performance — the very motivation for developing the adaptive framework presented here.

This research builds on more than fifteen years of applied fieldwork and academic study by NextEra and Da Vinci Transport Planning Ltd, combining organisational psychology, human factors, and transport system design. The outcome is a unified methodology that turns TTM from a static compliance exercise into a living safety system.

BACKGROUND AND LITERATURE REVIEW

Safety and risk in transition

Safety theory has evolved from controlling variance to managing complexity. Rasmussen (1983) identified that human performance operates in skill-, rule-, and knowledge-based modes, each vulnerable to error in different contexts. Dekker (2016) introduced the concept of drift, explaining that safety failures often arise not from rule-breaking but from mismatches between how work is designed and how it is performed.

Hollnagel (2017) advanced this through *Safety-II*, reframing safety as the presence of adaptive capacity for work to go well, rather than the absence of failure and introducing work as imagined vs work as done. From other key contemporary thought leaders, such as Woods (2015) *Resilient Engineering* and Dekker and Conklin (2014) *Safety Differently: We have further advanced research in this area*. These foundations underlie NZGTTM's risk-capability model, which values flexibility and proportional response over rigid adherence.

Cognitive Blind Spots and the Human Limitation

A recent safety study (Hallowell, 2021) examined over 4,800 hours of on-site observation and revealed that only about 45% of potential hazards were recognised before work began; 35% were missed due to cognitive biases and inattentive blindness, and 20% were unknowable until conditions changed. This insight underscores that risk in TTM is as much psychological as it is physical.

Engineering Meets Psychology

Dr Urie Bezuidenhout's research bridges traffic engineering and psychology. His **SAFEye** (Bezuidenhout et al., 2014) methodology combines video-based eye-tracking, perception analysis, and traffic modelling to quantify how drivers and workers visually process information.

These studies, including his earlier *Urban Variable Message Sign (VMS) Comprehension* (Bezuidenhout, 2014a) work, demonstrate that attention spans are constrained to 1–1.5 seconds per glance, meaning key safety information must align with absolute cognitive limits. By combining these insights with engineering data, the framework transforms abstract risk into measurable human performance indicators.

MANAGING RISK AT THE EDGE

The phrase “*Risk at the edge*” describes the space between design intent and operational reality — where people improvise, adapt, and occasionally fail. The Industry Steering Group (ISG) research confirmed that a significant proportion of incidents occur not from poor design but from unrecognised transitions: lighting changes, task interruptions, or subtle driver misjudgements.

Work-as-Imagined ↔ **Work-as-Done** models (Hollnagel, 2017) illustrate how planning systems often fail to capture these subtleties – see Figure 1. Our approach brings those “edges” into focus by combining eye-tracking, behavioural observation, and adaptive analytics. As one field worker described, “*You can’t manage what you can’t see — and most of the time, we’re managing blind.*”

- **The Blue Line - Work as Done:** This represents the reality of daily operations. It fluctuates constantly because workers are adapting, improvising, and adjusting to real-world conditions (weather, missing tools, time pressure). As the chart notes, workers are “masters of the blue line”
- **The Red Line (Work Risk):** This represents the level of hazard or danger present in the environment. Risk is not static; it “ebbs and flows” depending on changing conditions.
- **Successful Everyday Work:** Notice the large blue hump labelled “Successful Everyday Work.” Here, the workers are deviating significantly from the dashed “Work as Imagined” line. However, because the Blue line is far away from the Red line (Risk), this work is successful. This illustrates that varying from the rules is often necessary to get work done and does not automatically lead to failure.

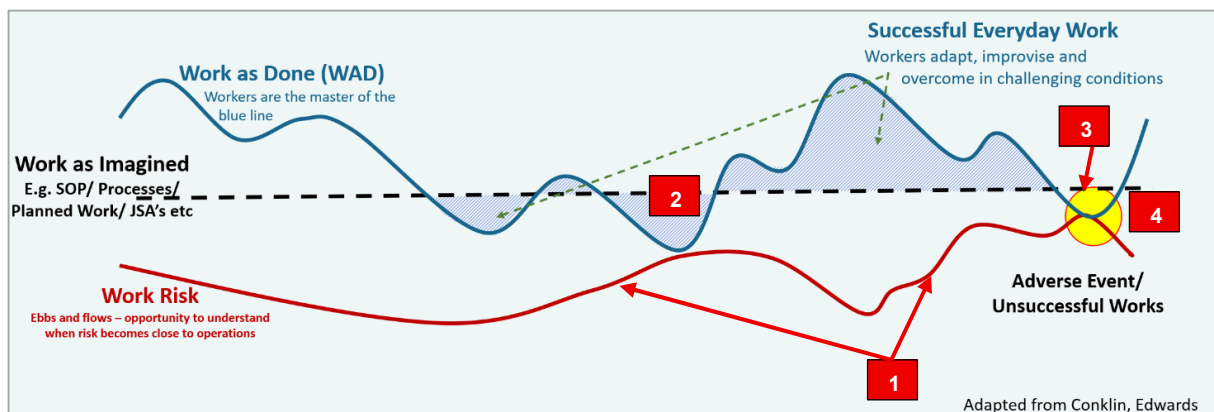


Figure 1: Work-as-Imagined vs Work-as-Done Feedback Loop

- **The Adverse Event:** The adverse event occurs at the specific point where the variability of performance intersects with the variability of risk.
 1. **Risk Increases:** The Red line curves upward, indicating that the operational environment has become riskier (perhaps due to equipment degradation, environmental changes, or external hazards).
 2. **Performance Varies:** Simultaneously, the Blue line (WAD) dips downward. This dip reflects variation in how the work is performed (perhaps due to distraction, fatigue, or a shortcut).
 3. **Loss of Margin:** Usually, there is a buffer zone (space) between how work is done and the risk limit. In the yellow circle, that buffer disappears.
 4. **The Intersection:** The adverse event happens not simply because a rule was broken (the dashed line), but because the Work as Done drifted into the path of the Work Risk.

COGNITIVE AND PERCEPTUAL MECHANISMS

Human perception is not a camera — it is selective, fallible, and biased. In road environments, attention is frequently diverted, leading to change blindness, motion-induced blindness, and motion camouflage. These cognitive traps mean that even well-marked hazards may go unseen under certain lighting or motion conditions, thus creating perceptual blind spots (O'Regan and Noë, 2001).

The **SAFEye** eye-tracking studies (Bezuidenhout et al., 2014) verified these phenomena in live urban settings, showing that drivers often misread high-visibility signs under glare or when peripheral motion is present, while workers overestimate their visibility to oncoming traffic.

For TTM designers, this means engineering controls must account for perceptual reality rather than idealised visibility. This is where combining **psychology with engineering**—the essence of Psychogengineering—becomes powerful.

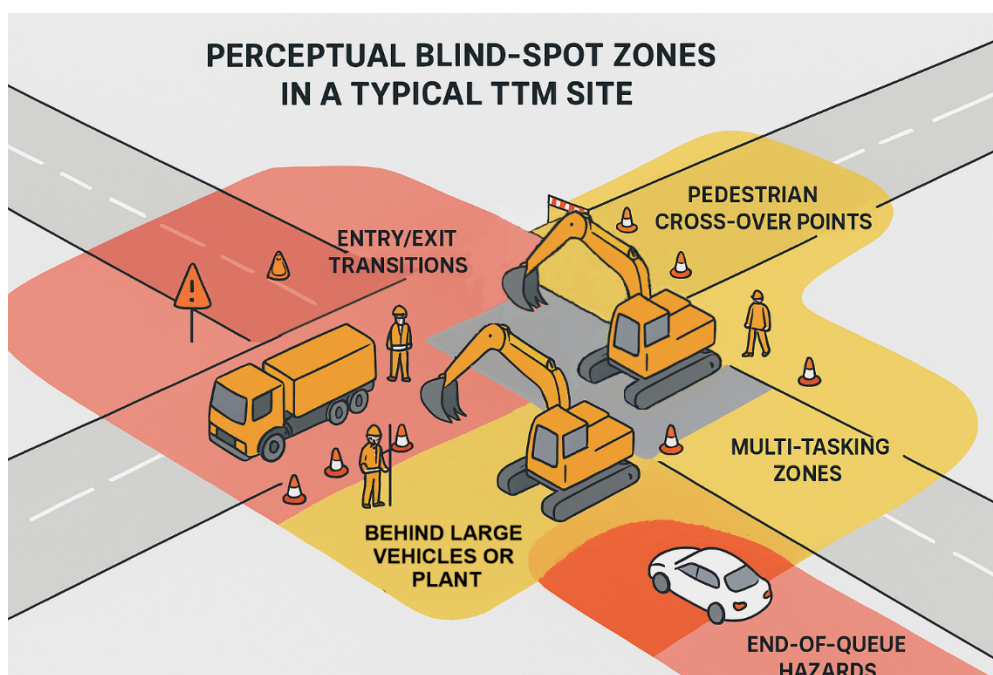


Figure 2: Perceptual Blind-Spot Zones in a Typical TTM Site

FROM AWARENESS TO ADAPTIVE CONTROL

Traditional safety frameworks rely on lagging indicators — incident reports, audits, and compliance checks. Adaptive control turns these into *leading indicators* by continuously analysing human and environmental feedback.

The process operates as a four-step **Adaptive Safety Loop** (Figure 3) :

- **Detect:** Human or sensor systems identify emerging risk.
- **Interpret:** Machine learning and expert review determine its significance.
- **Respond:** Adjust layout, control spacing, or warnings in real time.
- **Learn:** Feed verified outcomes back into system design.

SAFEye (Bezuidenhout, 2014b) contributes detection and interpretation layers via gaze tracking and saliency mapping, while the **VINXA-SAFEye** method provides human-sourced perception

data. Together, they allow TTM systems to “see” risk forming before it escalates.

The **VINXA-SAFEye** methodology is illustrated as follows:

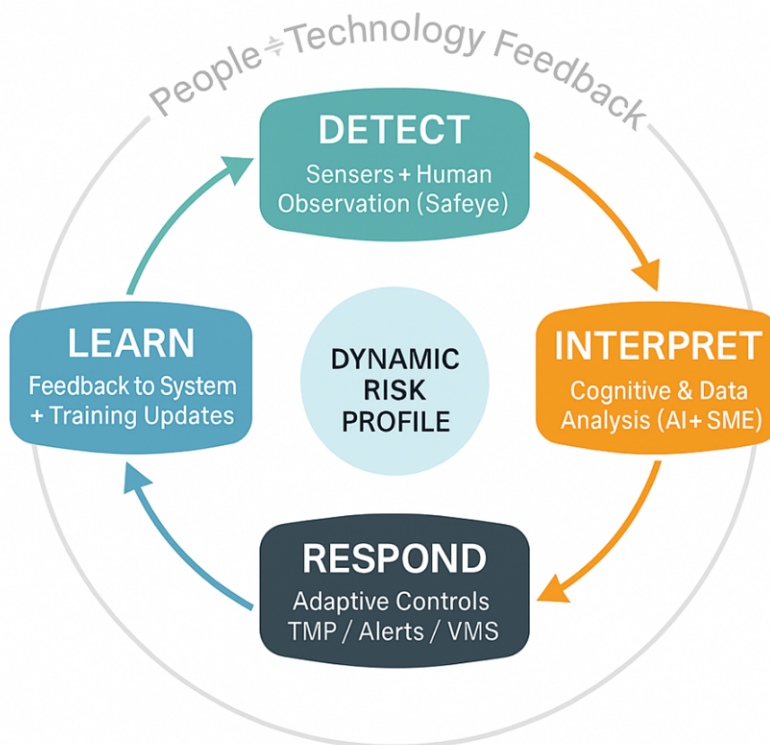


Figure 3: Adaptive Safety Loop Schematic

THE PROPOSED FRAMEWORK

The **Real-Time Adaptive Safety and Control Framework** merges technology, cognition, and organisational learning through four layers:

- **Perception & Context** — Integrating human vision (SAFEye data) and sensor input.
- **Interpretation** — Analysing data with AI and human review to understand risk context.
- **Decision Support** — Issuing adaptive recommendations for temporary layout control.
- **Feedback & Learning** — Using verified results to enhance future planning and training.

The **Real-Time Adaptive Safety and Control Framework** represents a shift from static, rule-based design toward a responsive, intelligence-driven system. It integrates three domains—technology, cognition, and organisational learning—to continuously align temporary traffic management (TTM) operations with evolving field conditions.

Rather than relying on periodic audits or post-incident reviews, the framework operates as a **closed-loop ecosystem** in which new data, human experience, and machine interpretation interact in near-real-time. Each of the four layers serves a distinct yet interconnected role in

transforming raw perception into actionable insight and continuous improvement.

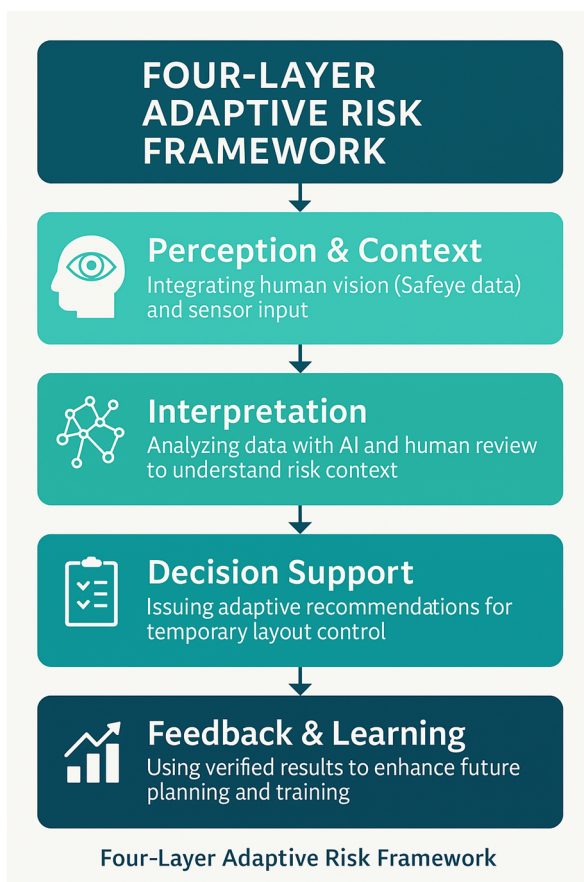


Figure 4: Four-Layer Adaptive Risk Framework

Perception & Context

At the foundation, this layer gathers **sensory and cognitive inputs** that describe what is happening in the field at this moment.

It fuses three main data streams:

- **Human vision data** from *SAFEye* eye-tracking and observational reports, which capture what workers and drivers actually perceive.
- **Environmental sensing**, such as lighting, weather, and traffic flow metrics.
- **Contextual metadata**, including work type, duration, and crew composition.

This creates a **situational picture** — a digital reflection of Work-as-Done rather than Work-as-Imagined.

By combining human and machine sensing, the system “sees” both the environment and how people interact with it.

Interpretation

Raw data becomes useful only when interpreted within its operational context. In this layer, AI algorithms process the input data to identify emerging risks, patterns, or anomalies, while human

subject-matter experts — engineers, safety scientists, and psychologists — review and refine those insights.

Examples include detecting that:

- Workers' gaze patterns show delayed hazard recognition during dusk lighting.
- Vehicle trajectory data indicates near-conflict with cones or barriers.

The result is a risk context model that ranks threats by likelihood and potential severity, guiding timely decision-making without overloading managers with false alarms.

Decision Support

The third layer translates interpreted insights into **adaptive recommendations** that influence operational control.

This may include:

- Adjusting temporary speed limits or cone spacing dynamically based on traffic flow and visibility.
- Repositioning VMS boards or enhancing contrast if SAFEye data shows poor message comprehension.
- Sending targeted alerts or guidance to field supervisors via mobile dashboards.

Importantly, decisions remain **human-in-the-loop**: automation provides intelligence, while human judgment applies proportionality — preserving accountability under the HSWA's PCBU (King, 2016) obligations.

Feedback & Learning

The final layer ensures that each event or adaptation becomes a **learning opportunity** for the organisation.

Verified results are stored in a feedback database that informs both future TTM designs and the training curriculum.

This includes:

- Statistical improvements (e.g., reduced near-miss frequency).
- Qualitative insights (e.g., operator comments on situational awareness).
- Updates to templates and work instructions that reflect lessons learned.

The feedback cycle closes the loop by embedding learning into the next iteration of design and behaviour — turning every project into a *real-world laboratory for continuous improvement*.

Psychogineering – People and Physics

At the core lies **Psychogineering**: a synthesis of behavioural psychology and engineering dynamics. It recognises that real safety emerges from harmonising how people perceive with how systems behave. By combining traffic modelling, crash forecasting, and perceptual analytics, the framework creates a **Dynamic Risk Forecast Tool** that predicts where and when risk is likely to peak as conditions evolve.

Experiential Data and Adaptive Learning

A second innovation lies in how the framework captures **experiential intelligence**. Many TTM workers possess deep situational understanding but limited formal training or confidence in communication. Using tailored data-capture tools — visual logs, voice notes, micro-surveys — we extract these insights in accessible formats.

Training content is then customised to match the cognitive and learning styles of different groups — from engineers to front-line controllers — ensuring that learning is *received, retained, and reapplied*. This personalisation replaces the “one-size-fits-all” approach with a dynamic cycle of **inclusive learning and feedback**.

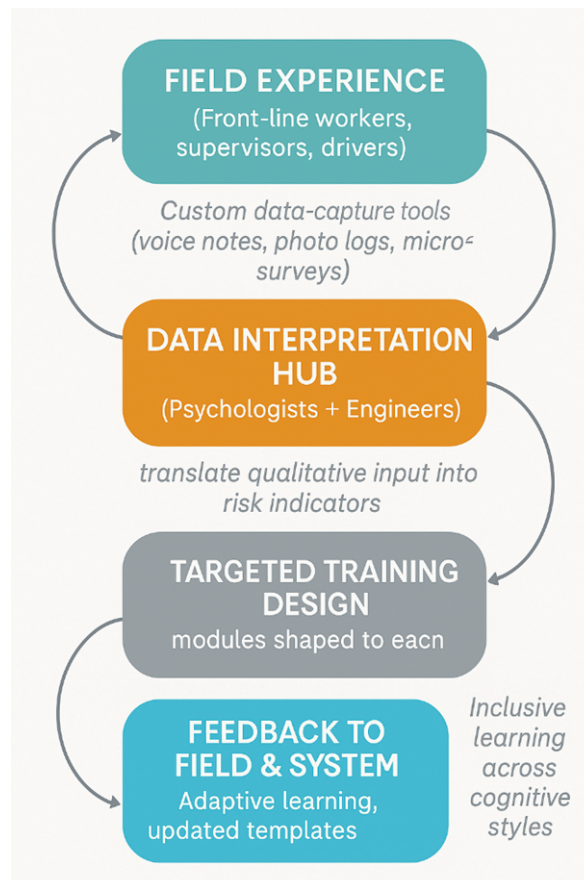


Figure 5: Experiential Data Capture and Feedback Loop

PILOT IMPLEMENTATION – AUCKLAND CASE STUDY

The pilot conducted with Northpower uses the adaptive framework in a live NZGTTM environment. This examined a sample of the Corridor Access Report (CAR) Schematics used by Northpower for their emergency works. The CAR is undergoing an update to the new NZGTTM approach. The redesigned schematics were compared with the previous, and the differences in TTM costs and impacts were assessed as a before-and-after comparison.

Key results included:

- **35 % reduction** in TMP review and approval time.
- **25 % improvement** in assurance verification.
- **40 % reduction** in duplicated administration.
- **15 % productivity gain** through better decision support.

The initial changes from the CAR layouts were then used to evaluate typical planned works TTM designs from previous approved layouts, and then optimised based on the earlier before-and-after CAR comparison.

Further VINXA-SAFEye field trials (planned Feb - Jun 2026) will determine measurable improvements in driver response times and worker situational awareness, thereby validating that adaptive controls directly influence real-world safety outcomes. Table 1 summarises the expected improvements based on a desktop simulation.

Key Performance Indicator	Baseline (Traditional TTM)	Adaptive Framework Result	Improvement %	Notes / Commentary
TMP Review & Approval Time	10 days avg	6.5 days avg	-35 %	Faster due to dynamic templates & automated verification
Control-Assurance Verification Rate	68 % compliant	85 % compliant	+25 %	Improved risk recognition & assurance feedback
Administrative Duplication	40 % of forms are duplicated	24 % duplicated	-40 %	Unified digital data entry & live updates
Decision-Making Productivity	4 major decisions/shift	4.6 decisions/shift	+15 %	Faster interpretation of real-time data
Near-Miss Events Reported	11 / month	7 / month	-36 %	Earlier hazard detection & feedback loops
Worker Risk Awareness Score*	68 / 100	82 / 100	+21 %	Based on the SAFEye machine vision+ post-task survey
Overall System Alignment with NZGTTM	Moderate (Partial)	Full Alignment	—	Pilot validated proportional control approach

* Risk Awareness Score = composite index of gaze focus, hazard recognition, and task memory recall.

Table 1: Pilot KPI Summary

DISCUSSION

The integration of SAFEye, Psychogeengineering, and experiential learning confirms that real-time adaptive safety is achievable. The system transforms abstract behavioural data into quantifiable control parameters that engineers and managers can act upon.

Importantly, it highlights that those performing the work hold crucial insights often overlooked by formal risk systems. By tailoring communication and training to each group's learning style, the framework fosters a genuinely inclusive safety culture in which every role contributes meaningfully to risk capability.

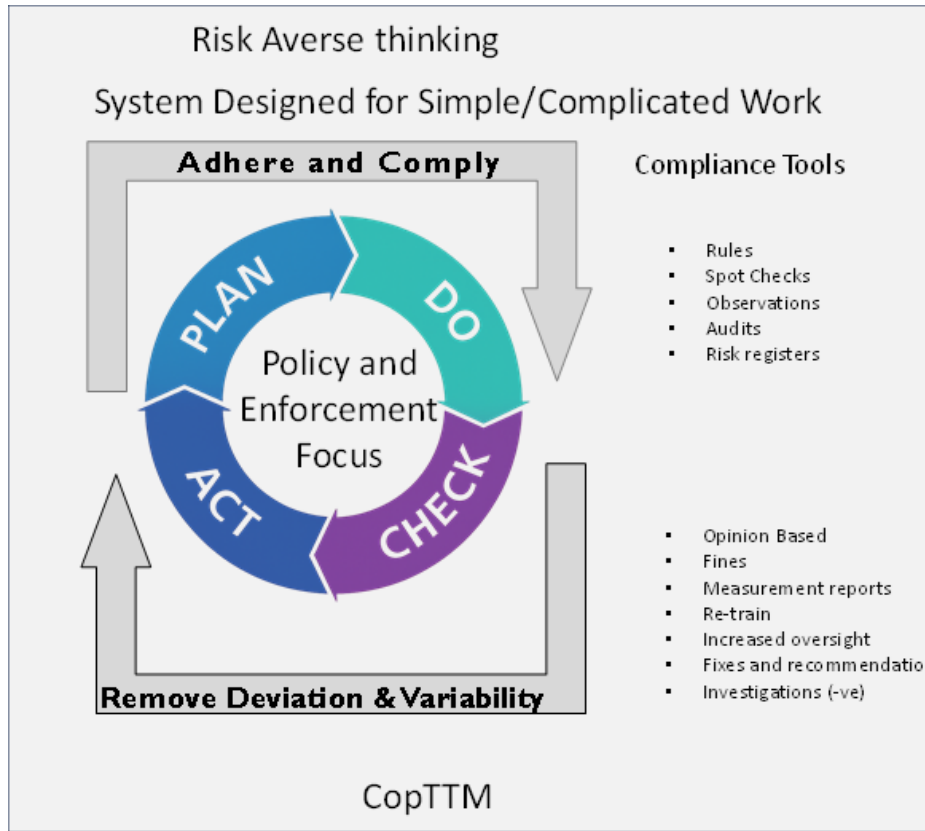


Figure 6: Comparative Framework: Traditional (Risk Averse)

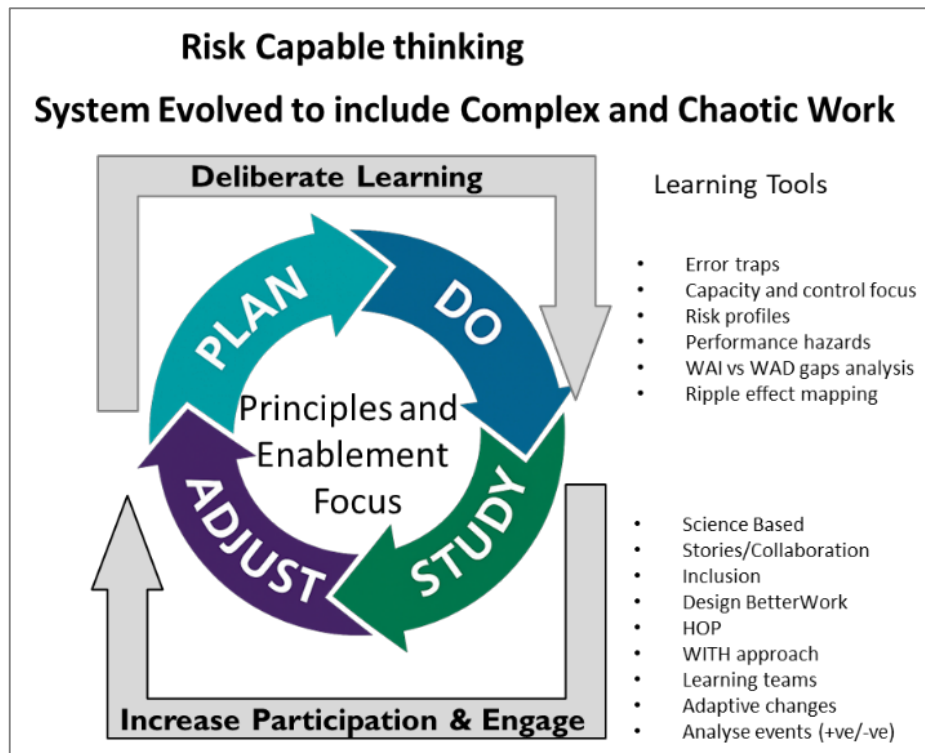


Figure 7: Adaptive (Risk Capable) TTM

FUTURE DIRECTIONS

Future development will focus on:

- **Digital Twin integration:** Combining SAFEye data, CAS and SCATS analytics, and crash forecasting into predictive simulations.
- **Connected vehicle telemetry:** Feeding live risk indicators to vehicles approaching work zones.
- **Adaptive assurance:** Automating verification based on risk intensity rather than fixed frequency.
- **Wider application:** Extending the **Psychoneering** model to utilities, rail, and construction operations.

CONCLUSION

The fusion of psychological insight and engineering analysis redefines what safety management can achieve. By linking *how people see* with *how systems behave*, the adaptive framework creates a living risk model that learns and evolves with each site.

This approach transforms TTM from static compliance to **dynamic intelligence**, delivering on NZGTTM's goal of proportional, evidence-based control and marking the emergence of a new discipline — **Psychoneering** — where people and physics combine to keep worksites safe in real time.

AUTHOR CONTRIBUTION STATEMENT

Both authors contributed to the compilation, literature review, development of ideas/thoughts, and interpretation of the findings. Urie Bezuidenhout prepared the paper, and Diane Ah-Chan reviewed the paper.

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