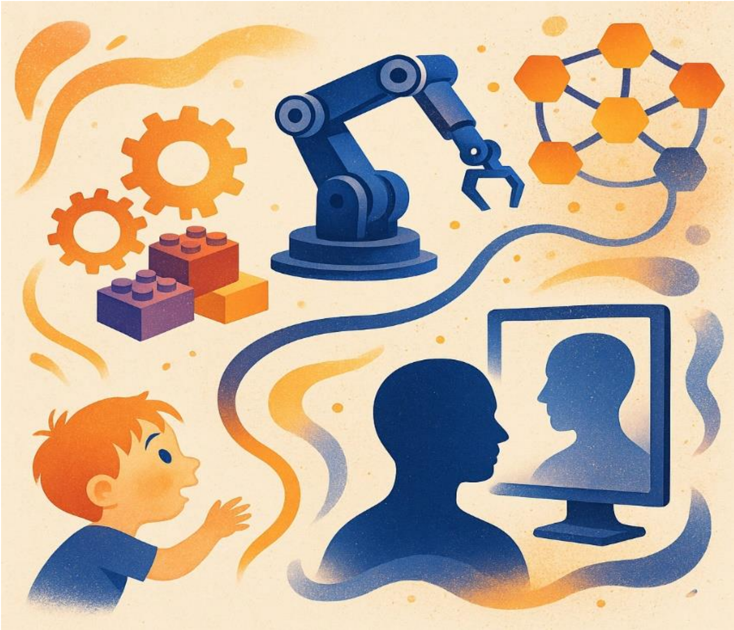

# Teaching FRAM: The Evolution of Understanding Complex Systems

## 1. INTRODUCTION — FROM CURIOSITY TO COMPLEXITY

When we first encounter the world, we do so like a child taking its first steps — seeing, touching, sensing, and asking the simplest of questions: *What is it? How does it work? Why does it do that?*
These are the same questions that drive all human understanding, from early wonder at how toys move to the most sophisticated explorations of how societies and technologies function.

At first, the *WHAT* is tangible. A child learns that blocks fit together, that pushing a ball makes it roll, that pressing a lever releases a spring. The *HOW* emerges through play — through experimenting with things that can be touched and seen. We learn by building models: bricks, Lego, Meccano — small, hands-on systems that reveal cause and effect. These are our first experiments in reasoning about function.

As machines appeared, that same curiosity evolved into engineering. Early engineers were pragmatic thinkers, focused on keeping machines running. They needed to know *how* mechanisms worked, not necessarily *WHY*. The goal was to make systems reliable — to maintain function when parts failed, and to restore it when they broke. Analytical tools such as Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) emerged from this mechanical mindset. They decomposed systems into components and traced how failures propagated to effects.

But humans were never components. When people entered the system — as operators, decision-makers, and designers — the simple model of cause and effect began to fracture. Unlike a valve, or a gear, a person's performance can vary with context, fatigue, or ambiguity. This variability could not be diagrammed in logic trees. Written procedures tried to codify human work, but they captured only the *what* and *how*, never the *why*. Once human and social factors entered the picture, systems became *complex*, not merely *complicated*.

To represent this new complexity, we needed to move beyond the physical — to model systems at the level of *what they do* rather than *what they are*. We needed to focus on *functions*, not parts; on *interactions*, not sequences. That change in perspective marks the beginning of a new kind of analysis: one that would eventually lead to the **Functional Resonance Analysis Method (FRAM)**.

## 2. FROM MECHANISMS TO FUNCTIONS — THE SHIFT IN SEEING

For centuries, the mechanical metaphor shaped our understanding of systems. If a machine failed, one part could be blamed. Fix the part, and the machine would run again. This logic drove the industrial age and worked brilliantly for engines and production lines.

But as systems grew more interconnected, decomposition began to hide rather than reveal understanding. A power grid, an airline network, or a hospital ward could not be understood by analysing components in isolation any more than a symphony can be explained by listing its instruments. The meaning lies in the relationships — in timing, coordination, and adaptation.

Traditional analytical methods like FTA and FMEA were created for physical failures — local, deterministic, traceable. Even Task Analysis and Human Reliability Analysis, though they included people, still treated them as measurable steps in a sequence. What they could not describe was the *fluidity* of human performance: the way people continually adjust their work to fit the moment. In reality, variability is not noise; it is the very thing that keeps systems alive.

The shift from mechanisms to functions begins when we ask not *what failed*, but *what varied*. A function describes what must happen for the system to achieve its purpose — independent of who or what performs it. By modelling *functions*, we step back from the physical to the operational, from detail to purpose.

This change brings clarity. At the functional level, we can see how activities influence one another and how small shifts can cascade across the system. We stop chasing single causes and start exploring patterns of interaction. The **Functional Resonance Analysis Method** formalises this insight: a model not of components, but of relationships — a framework for seeing how systems behave as wholes.

## 3. FROM RELIABILITY TO RESILIENCE — THE HUMAN TURN

The twentieth century's safety revolution was built on *reliability*: if every part works, the whole will too. For machines, this principle holds. For human work, it does not. People do not normally repeat identical actions; they adapt, anticipate, and improvise.

For decades, safety engineering treated humans as unreliable components — sources of error to be constrained by checklists or automation. But for humans failure has further consequences. Psychological and social influences need to be acknowledged. Hence "safety" became a real consideration as well as reliability. Yet these same humans were also the reason for system reliability. Their variability was not a defect but a feature — a source of flexibility and recovery.

Recognising this marked the **human turn** in safety science. The focus shifted from *why people fail* to *how people succeed*. Out of that shift grew the field of **resilience engineering**, which asked a new question: *How do systems continue to function under change and uncertainty?* Resilience is not the absence of failure; it is the presence of adaptive capacity.

To understand resilience, we must represent not just what fails, but how functions interact to sustain performance. FRAM provides that language. It models how variability in one function influences others, how performance adjustments ripple across the network, and how ordinary adaptations sometimes align to create extraordinary outcomes. Where traditional reliability models dissect failure, FRAM reveals emergence. It reframes safety as something a system *does*, not something it *has*.

## 4. SEEING SYSTEMS IN MOTION — HOW FRAM MODELS WORK

A system is not a structure; it is a flow of activities that continuously shape one another. FRAM allows us to *see* that flow.

Each function in a FRAM model is represented as a **hexagon**, defined by six aspects:

- **Input (I):** what it needs to start
- **Output (O):** what it produces
- **Precondition (P):** what must be true before it can occur
- **Resource (R):** what it uses to operate
- **Control (C):** what guides or constrains it
- **Time (T):** when or for how long it acts

Functions connect through these aspects. An output from one becomes an input, precondition, or control for another. The model thus forms a network — not a chain — where interactions, not sequences, determine behaviour.

FRAM embraces *variability*: too early, too late, too little, too much, imprecise, or none. Variations in one function can propagate through others, sometimes harmlessly, sometimes catastrophically. When several variations align, their combined effect can be amplified — a process known as **functional resonance**.

Consider two examples. In a **Formula One pit stop**, twelve crew members perform interdependent functions: stabilise the car, remove tyres, attach new ones, release safely. A delay of even half a second in one role can ripple through the whole operation, turning coordination into chaos. In a **hospital trauma team**, diagnostic and treatment functions occur in parallel. A late lab result, an ambiguous instruction, or a missing resource can alter timing elsewhere, changing the outcome for the patient.

FRAM allows these dynamics to be visualised and explored. The **FRAM Model Visualiser (FMV)** can animate these relationships, showing how variability moves through the network — how the system adapts, absorbs, or amplifies it.

This capacity to reveal motion makes FRAM more than a diagramming method. It becomes a way of *seeing work happen* — safely, unsafely, or somewhere in between.

## 5. FROM ANALYSIS TO UNDERSTANDING — LEARNING THROUGH FRAM

To analyse is to separate; to understand is to connect.
Most analytical methods disassemble systems. FRAM reconnects them — showing how safety, performance, and failure emerge from the same web of interactions.

Learning FRAM is not about memorising a procedure; it is about adopting a new way of seeing. It trains us to think in terms of relationships and adjustments, not rules and errors. The FRAM model becomes a *mirror* of reality — a way to compare *Work-as-Imagined* (plans and procedures) with *Work-as-Done* (actual performance).

That comparison is where learning happens. It exposes the quiet adaptations that keep systems running and the unnoticed gaps where drift begins. It teaches that reliability is not achieved by removing variability but by managing it intelligently.

In classrooms, FRAM transforms learning into exploration. Students can adjust timing, remove resources, or introduce delays, then observe how system behaviour changes. The model becomes a laboratory for resilience — a way to experience the dynamics of complexity safely.

In organisations, FRAM promotes reflection rather than blame. It invites teams to ask: *What was happening across the system?* instead of *Who made the mistake?*
It reframes control as coordination and turns analysis into learning.

## 6. FRAM AS A LIVING MIRROR — DESIGNING SYSTEMS THAT LEARN

When a system can observe its own functioning, it begins to learn.
FRAM enables this reflection. When coupled with real-time data, it evolves into a **digital twin** — a living model that represents how the system behaves under actual conditions.

Each function becomes a sensor of performance. Data about timing, workload, and resource availability can feed into the model, allowing it to visualise where variability is building or resilience is thinning.
The model becomes both descriptive and diagnostic — capable of identifying where the system is flexible, brittle, or drifting toward resonance.

This is not automation but *introspection*: the system watching itself. FRAM-based digital twins can support decision-makers by showing how small changes propagate, enabling early intervention before failure occurs. They make resilience visible in real time.

Teaching FRAM, therefore, is also teaching the foundations of intelligent systems — systems that learn through feedback, that reflect on their performance, that understand the conditions of their own safety. FRAM becomes the nervous system of such learning systems — the part that feels and interprets, not just executes.

## EPILOGUE — THE EVOLUTION OF UNDERSTANDING

All understanding begins with curiosity. We look at the world and ask: *What is it? How does it work? Why does it do that?* Every model humanity has built — from the machine to the digital twin — is an evolving answer to those questions.

FRAM represents a new level in that evolution. It moves us from objects to functions, from causes to couplings, from control to coordination. It teaches that knowledge resides in relationships, that variability is not error but information, and that safety is something systems continually *do*.

To teach FRAM is to teach systemic literacy — a way of perceiving interdependence and emergence. It prepares learners and organisations to view systems not as mechanisms to be fixed, but as living processes to be understood and guided.

Thus, the journey that began with a child's curiosity — *What is it? How does it work? Why does it do that?* — returns transformed.
Only now, with FRAM, our systems can begin to ask the same questions of themselves.