

Systems in Symmetry: Symmetry in Systems

Critical Value Balance Theory

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Abstract—Systems Engineering is a well understood process in complex systems delivery and Systems Integration is a well-practiced discipline but an insightful understanding of how to test a systems viability and determine its stability is an immature field. This is largely because systems are complex, variable and nuanced to their context which appears to preclude the establishment of a common (simple) insight on which to base understanding.

In this paper, we examine the criticality of system stability, explore why symmetry is the lens through which systems should be viewed and propose a method by which practitioners can establish the stability of their system regardless of context – a method which lends itself to quick assimilation by those encountering systems problems for the first time.

Index Terms—System Integration (SI), System Architecture, Symmetry, System Model

I. INTRODUCTION

All systems are either designed to be stable or devolve to become so. Unstable systems are a transition state from one stable state to the next; stable systems perform an operation or function. Regardless of the size of the system this rule holds true. Which raises the question – how do we define a stable system, what are its characteristics (and why do we talk about symmetry)?

II. DEFINING A SYSTEM

A system is defined as “a combination of elements that function together to produce the capability required to meet a need” by NASA [1], and as “combination of interacting elements organized to achieve one more stated purposes” by INCOSE [2] – given that these are the two pre-eminent learned bodies on this subject, and are in agreement(!), we can accept this as a common definition.

II. DEFINING SYSTEM STABILITY

When looking at the evolution of Crossrail [3], Muruganandan, Davies, Denicol and Whyte proposed that systems integration could be conceptualised as “a dynamic process of balancing stability and change” based on the concept of “reciprocal interdependency” [3] [4] between system elements. Leveson [5] further supports this with the view that “Emergent properties arise from relationships among the parts of the system, that is, by how they interact and fit together”. In that light, the value in a stable system (or

understanding the instability within a system) is the ability to develop a structured approach to integration (the mechanism for creating the whole from its constituent parts) [6] and thereby improve confidence in a successful delivery. This in turn is bound with the concept of Technical Debt through the impacts of decision-making by the system delivery agent to maximise output or deliverability, often in the short term but with long-term consequences. Technical debt needs to be considered and factored into the understanding of stability at the system, sub-system and component level. Technical Debt has many definitions, we propose to use the definitions proposed in [7]:

“Definition 1: TD is a metaphor reflecting technical compromises that can yield short-term benefits but may hurt the long-term health of a system.

Definition 2: TD is the quantitative impact on the long-term health of the system accrued as the result of a technical compromise made to achieve a short-term benefit”.

This neatly sums up the crux of the stability challenge – system elements are under pressure of interdependency and reciprocity and the ability of these elements to achieve the desired outcome is dependent on the stability of that relationship and the absence of technical debt which creates volatility and uncertainty.

A. Assessing Stability

As outlined in [8], the concept of VUCA has been around for almost 40 years, having been introduced in 1985. It has been applied to many complex environments and is now a well-defined concept. The purpose of VUCA is to provide a framework for understanding the context of a system and specifically, the draw out the risks associated with it – and in turn give us a method of capturing technical debt. Drawing on [8] and [9], we can define the VUCA criteria as follows in Table 1. Typically, interfaces, requirements and other system artefacts are defined for the end state system, they are a target against which we build the system we wish to enact. However, these definitions are all from the standpoint of a steady-state system and do not take cognisance of the vulnerability of the system to change. We propose to integrate VUCA into system stability analysis as a tool for identifying and rating system risk and clarifying the reliability of our definitions.

Criteria	Definition
Volatility	How rapid (and unpredictable) the change

	in system element characteristics
Uncertainty	The unpredictability of the context associated with the system element
Complexity	How complex the interactions and interrelationships between system elements
Ambiguity	How clear or confused the situation is and how high is the risk of misunderstanding

Table 1: VUCA Definitions

This approach augments that proposed by the ICE in that bodies report on A Systems Approach to Infrastructure Delivery [10] and expands on the work done in a recent paper on resilient in complex systems [11], the concept of the Resilience Wheel was proposed (see Figure 1). This proposal is in relation to system resilience and the ability to endure and recover from disruption – system stability is a foundational feature of resilience and can be seen to extend the Resilience Wheel back into the system development and delivery phase (where the Wheel focuses on the end-state system).

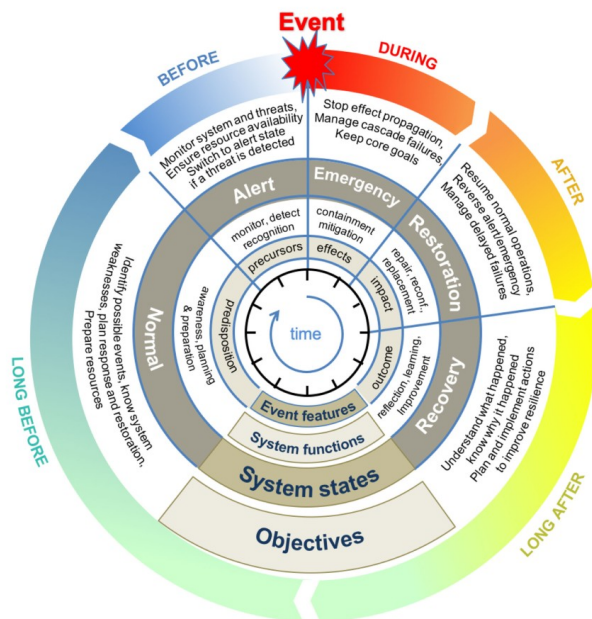


Figure 1: Resilience Wheel [11]

B. Definition of System Stability

Through exploring the criteria of stable systems and the ability to respond and endure challenge and change, we are able to propose a definition of system stability which is immediately recognisable and intuitively understandable. System Stability can therefore be defined as the characteristic of the end-state system which enables it to deliver its intended outcome for the duration of its intended service life.

C. System Stability and Systems Integration

The authors of this paper have explore this in greater depths in

an earlier publication [12] but in summary follow the work of Whyte and Davies [13] suggest SI as the process of making constituent parts of systems work together, which aligns with the systems engineering definition provided by the SEBoK [14]. The process of making parts work depends on the predictability of those parts being present when needed and doing that they are expected to do, in other words, the *stability* of the system is paramount.

III. HEURISTICS

“A heuristic describes a simple procedure that resembles a decision rule. By using them, one can quickly find an approximate solution to these types of problems.” [15].

Why do we talk about heuristics? Because one of the most pressing challenges experienced by engineers is a lack of time. An experience well understood by the authors in their professional experience on major projects including HS2, Crossrail and others. That time pressure means we need a tool which enables the practitioner to respond to the context they find themselves in quickly and effectively. A heuristic approach provides that tool. When considered alongside other tools in the practitioners’ toolbox, this provides them the flexibility to develop low-level strategies and at the macro level apply them to a successful outcome – a process called a *hyper-heuristic methodology* [16]. Hyper-heuristics is outside the bounds of this paper but is an interesting topic to explore and offers an answer to the inaccuracy or “good enough” problem associated with heuristics on their own. A subject the authors are keen to pursue in a later paper.

In developing a heuristic tool for system stability, we considered the following requirements:

ID	Requirement	Rationale
T-001	The tool shall be context agnostic	A generic tool will have the most applicability
T-002	The tool shall accommodate both positive and negative relationships	To enable the user to apply the tool to any type of relationship
T-003	The tool shall be intuitive to understand and apply	The tool must be usable under pressure and with minimal cognitive demand
T-004	The tool shall be applicable with minimal preparation time	To enable the user to apply the tool whilst under pressure
T-005	The tool output shall be testable by the user	To enable the user to verify and validate the outputs

Table 2: Requirements of the Tool

If any of these requirements are not satisfied, the tool will not be adopted by the user – either because it is too constrained (T-001, T-002), takes too much time and/or effort to use (T-003, T-004) or is unverifiable (T-005). The last is important

because the user needs to be assured the tool is not giving them misdirection, ease of verification allows the user to prove the tool on one set of relationships and then have confidence in others.

IV. SYMMETRY

Start with the assumption that a stable system is a balanced one. Balanced, by definition, has the characteristic of symmetry, such as symmetry of force (Newton's Laws) or conservation of mass. Symmetry derives from the Greek word *symmetros*, drawn from *syn* meaning 'same' and *metros* meaning 'measure' and used to describe something 'with equal measure' [17]. The defining characteristic of symmetry is balance.

We can therefore infer that system stability is intrinsically linked to balance. To ensure system stability, it is necessary for balance to be measured, understood and enacted.

A. System Dynamics

"Systems thinking is a framework for seeing the interconnections in a system and a discipline for seeing and understanding the relevant aspects of the whole system - the 'structures' that underlie complex situations" [18] – one of its clearest embodiments is System Dynamics modelling.

The System Dynamics Society states: "System Dynamics complements systems thinking by quantifying interactions and develops a time-dependent view of how the system behaves. The approach focuses on building computer models that represent and simulate complex problems in which behavior changes. These models bring to light less visible relationships, dynamic complexity, delays, and unintended consequences of interactions." [19].

Understanding the system of interest is critical for any practitioner and the tool we will explore here is predicated on having a system model on which to apply it.

B. Critical Value Balance Theory

All elements in a system interact with a number of other elements within that system (for simplicity we shall treat the target system and its context as one as refer only to the 'system'). Whilst the exact nature of these interactions vary from one interface to the next, they are all characterised by reciprocity and, if they are to remain stable, balance. The co-acting forces on either side of the interface must match to prevent instability at the interface. The forces co-acting on the interface we term Critical Values.

This characteristic can be observed in daily life, relationships and projects, all of which are or are part of complex systems.

C. Demonstration of the Critical Values Model

The critical values present at an interface can be visualised through a simply flow diagram as illustrated in Figure 1 (above). As demonstrated, each party in the relationship (we

refer to these parties as poles as these are dipolar structures) is directly related to their counterparty with a pair of opposing forces which must be balanced.

From observation and logical deduction there are three pairs which appear at all interfaces. These are:

Pole_1	Pole_2
Risk	Reward
Supply	Demand
Freedom	Control

Table 3: Critical Dipolar Pairs

These exist because every interface involves the supply or demand of resources (be it physical, logical or spatial) with a degree of freedom or control to ensure it happens smoothly within a tolerable profile of risk for a pre-defined reward.

Each relationship pair should be assessed independently as they each reflect a different aspect of the pair. For a relationship in a real system, all three will be active but not all will have the same degree of stability.

D. Logical Proofs of the Model

Proof 1: Supply vs Demand

Supply is the value associated with the provision of an output at the interface; Demand is the value associated with the provision of capacity at the interface (i.e. the ability to absorb Supply).

If $Demand < Supply$ a surplus builds at the interface which does not get used. This is inefficient.

If $Demand > Supply$ a deficit builds at the interface where demand is not met and the system does not fulfil its purpose.

Supply and Demand must be matched to each other to ensure efficiency and retain balance. A system which develops a deficit or a surplus amasses penalties

Note: A system which intentionally builds a deficit or surplus can be said to do neither, since these characteristics are the intent of the system the accrual or vacation or resource is a design feature.

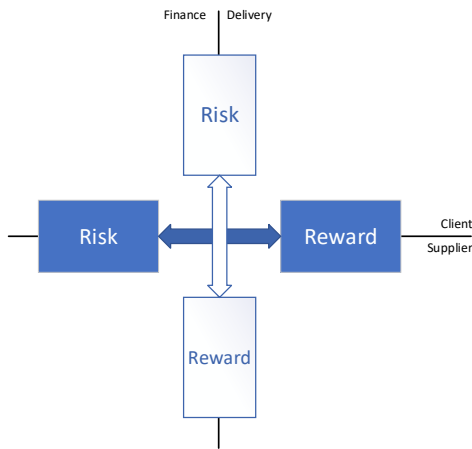


Figure 2: Risk vs Reward Lines of Symmetry 1

Equally, there is a version of this model with Risk and Reward the other way around as illustrated in Figure 2. In this version, the Client reaps the benefits of the project and the Supplier holds the risks associated with failure to deliver; the Finance department gain the rewards of success whilst the Delivery department attempt to mitigate the risks of potential failure.

Proof 2: Freedom vs Control

Freedom is the value associated with the delivery of the system; Control is the value associated with the constraint of delivery.

If $Freedom < Control$ then delivery is hindered and creativity stifled. As a result progress is impeded.

If $Freedom > Control$ then the system is out of control and risks increase.

Freedom and Control need to be proportionate and in balance to each other to allow the maximum freedom of design, delivery and innovation whilst maintaining the minimum necessary level of control through which to assure the outcome.

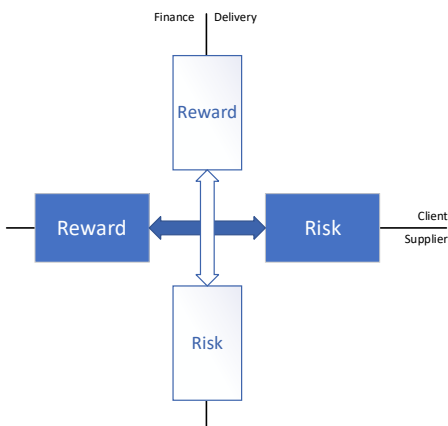


Figure 3: Risk vs Reward Lines of Symmetry 2

This relationship can be demonstrated for all interfaces and relationships between system components. Co-acting forces define these interfaces and determine the degree of stability of

the system at the component level. It is the establishment of this symmetry, which creates the robustness and stability in the system.

E. Tool

Building on this, we can posit a tool which tests the balance of the interfaces and thereby allows the practitioner to test the stability of the system.

Our tool can be defined as a table, as follows:

Give	GiveBalance	Give
Pole_1	Dipolar Stability	Pole_2
Stability	Σ Stability	Stability

Figure 4: Dipolar Stability Grid

Where Pole_1 and Pole_2 are the two ends of the interface pair.

Where Give is defined as: the force acting at the interface (establishing a pair of co-acting forces) which is needed to balance the interface. All applicable forces must be assessed to determine veracity and value to inform the determination of balance. In this model, and in advance of research data providing greater sensitivity, we are hypothesising logical values of 0 and 1. An interface either has a property or it does not. The value of each pair is defined as GiveBalance - defined as: the equality and reciprocity of across an interface. Here 1 is a Balanced interface and 0 is an Unbalanced interface.

The Stability of each pair is qualified by how volatile, uncertain or ambiguous a force definition impacts its stability. We omit Complexity as the purpose of this tool is to assess complex systems and a further assessment of complexity is not valid.

In terms of quantifying the value of Stability we assess against the VUA of VUCA. Where 0 is a low volatility, low uncertainty, low ambiguity interface and 1 is high. The criteria are summed to provide an aggregate score for Σ Stability. The use of a binary score for both Give and Stability are based on the fact that the characteristics are absolutes – something is either balanced or it is not, it is volatile or it is not – and understanding the degree of balance or volatility is irrelevant from an assessment perspective and will be accommodated within any mitigations applied.

Dipolar Stability is the weighted value of the dipolar pair and is calculated by dividing GiveBalance by Σ Stability. We could at this point use a binary score for Σ Stability which would achieve the same outcome in terms of identifying instability however, we have chosen to use a weighted Σ Stability as we believe this will be more useful for the practitioner in application. You will see that the method works with both binary and weighted Σ Stability values.

Calculating Give Values:

	Unbalanced	Balanced
GiveBalance	0	1

Table 4: GiveBalance Values

Calculating Stability Values:

	Volatility	Uncertainty	Ambiguity
Stability	0, 1	0, 1	0, 1

Table 5: Stability Values

Thus:

$$\sum \text{Stability} = \text{Volatility} + \text{Uncertainty} + \text{Ambiguity}$$

$\sum \text{Stability}$ will therefore carry a value of 0, 1, 2 or 3.

Dipolar Stability is therefore:

$$\text{Dipolar Stability} = \frac{\text{Give}_{\text{Balance}}}{\sum \text{Stability}}$$

Yielding potential results of 0, 1, $\frac{1}{2}$ or $\frac{1}{3}$. Values 0, $\frac{1}{2}$ and $\frac{1}{3}$ represent an unstable dipole and are equivalent to a binary 0. A yield of 1 is the equivalent of a binary 1 and represents a stable system (strictly speaking ∞ is also possible through a 1/0 but since in real terms nothing is infinitely stable we would treat this as a 1). When applied to each Dipole within a system, this allows the system engineer to assess the stability of each interface and build a composite picture of the whole system.

We define this as the Critical Value Balance Method of Demonstrating System Stability.

F. Logical Proofs of the Tool

Proof 1: System Stability – High

Bread is a fundamental food for many in the UK, bakery requires flour for bread production. There is therefore a need to buy flour to make bread.

This is an example of a Supply vs Demand Pair.

$\text{Give}_{\text{Balance}}$ is assessed as: 1 – the demand and supply are balanced.

Stability is assessed as:

	Volatility	Uncertainty	Ambiguity
Stability	0	0	0
Rationale	The demand is consistent and unlikely to change, supply is consistent and a fundamental agricultural output	Changes will be slow and marginal	Low risk of misunderstanding in the relationship

Therefore: $\sum \text{Stability} = 0 + 0 + 0 = 0$

Dipolar Stability is therefore:

$$\text{Dipolar Stability} = \frac{1}{0} = \infty \equiv 1$$

Proof 2: System Stability - Low

Stock markets move in complex and often unpredictable ways. The demand for buying and selling stocks and shares fluctuates with geopolitical change and economic uncertainty. The demand however, the presence of Risk and Reward, is always present. Investors buy stock and/or shares at the risk of a fall in value but in the anticipation (either through luck or calculation) of a higher return than the price paid, a Reward.

This is an example of a Risk vs Reward Pair.

$\text{Give}_{\text{Balance}}$ is assessed as: 1 – Risk and Reward and in balance since there is always a risk and reward opportunity present in a fair market.

Stability is assessed as:

	Volatility	Uncertainty	Ambiguity
Stability	1	1	1
Rationale	Market conditions can change rapidly and prices vary outside the buyer or sellers control	Price changes can happen rapidly and without warning, leading to a highly unpredictable market	Changes in the market are not always understood and underlying factors are not easily visible

Therefore: $\sum \text{Stability} = 1 + 1 + 1 = 3$

Dipolar Stability is therefore:

$$\text{Dipolar Stability} = \frac{1}{3} = \frac{1}{3} \equiv 0$$

V. NOTES ON APPLICATION

This method is intended to be used in concert with a system model like system dynamics which provides a clear set of interfaces between system elements, however it can be used on discrete or ad hoc interfaces as they are identified. Similarly, the practitioner can start with one system element and apply the model as the starting point of a map of the system seen through its interfaces. It is recommended that the practitioner develop a good system model to support application but it is not essential.

VI. DISCUSSION AND CONCLUSION

The ability to determine systemic stability and identify areas of instability opens up a wide range of options for the system engineer seeking to increase stability or seek to understand the cause of some other problem. In doing this, we have created a tool for system engineers which is simple, easy to use and repeatable. When combined with other heuristics in a hyper-

heuristic toolkit, or in combination with system modelling of the kind proposed in [20], we believe this adds a valuable item to the practitioner's toolkit.

This paper has demonstrated proof of concept of the Critical Value Balance Method of Demonstrating System Stability (aka the Symmetry Method). This proof has been logical but not empirical here and the natural next step is for the Method to be applied and empirically demonstrated. Following this demonstration, the next step is to expand the proof to include systems of unlimited size and complexity to demonstrate its applicability and uncover any limitations in the Method. This will be the subject of the next iteration of this paper.

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