

Expressions of Control: A Stoichiometric Framework of Industrial Equilibrium



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Objective

To establish that the six patterns behind how control is expressed inform the fitness of the control solution(s) for each expression. Too often control solutions are not properly matched to the expression of the devices or systems concerned. Without a screening mechanism to gauge efficacy, critical decisions are not guided in an informed manner. By applying the principles of stoichiometry to calculate the efficacy of any proposed control solution, we can make better informed – and optimized – control decision-making.

There have been previous instances of modeling control but by going beyond that in attempting to calculate efficacy in this manner, we can readily attempt to describe and measure the Phase State of Control. Stoichiometry does this quite effectively in quantifying relationships between catalysts and reagents in a chemical reaction. We simply follow suit: in our model, we quantify the interaction between Control Solutions as catalysts and Expressions of Control as reagents to measure the control solution fitness and to define the resulting Phase State of Control.

Our model produced six distinct operational profiles. **Table 1** reveals critical statements about the status of control that makes one profile unique from the others. The nature of control can vary depending upon the sector (i.e., use case) and completeness of vertical integration illustrated in **Figure 1**.

Control efficacy is revealed in the stoichiometric alignment of Authority (C), Observation (F), and Constraint (B), which are detailed in **Table 3**. A solution is truly efficacious when its

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mathematical valency perfectly matches the physical requirements of the system concerned, minimizing waste (System Debt) and maximizing yield (Stability).

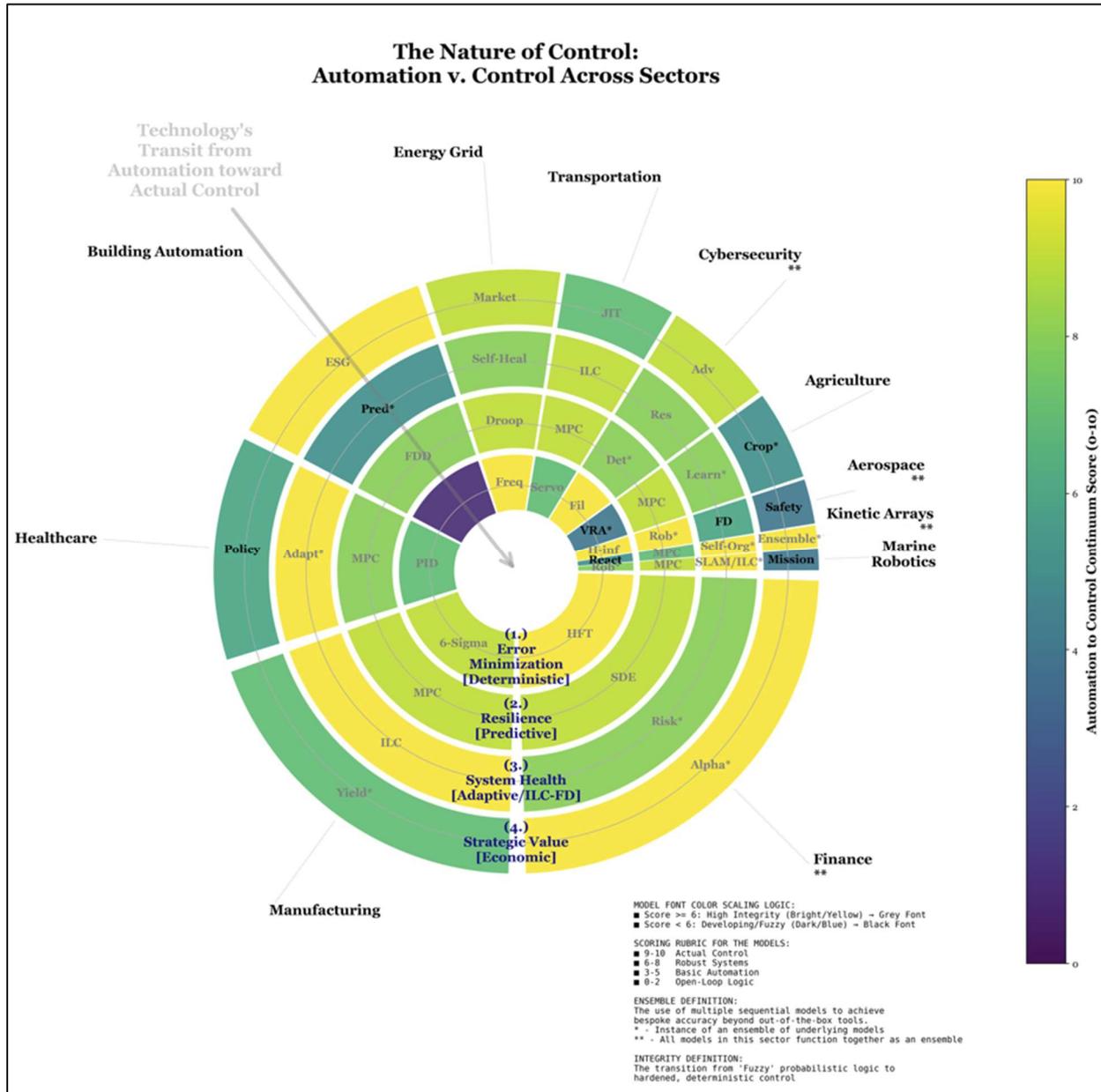


Figure 1: The Nature of Control

Our model categorized eleven economic sectors into one of six descriptive profiles based on their GDP contributions. These profiles each have distinct signatures that are characteristic of the

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challenges facing those engaged in control activities. Understanding these profiles stoichiometrically is the first milestone in the sequence on the way to establishing control.

Profile	Sector(s)	Control Status
The Digital Kite	<ul style="list-style-type: none">Building Automation	Broken: top-heavy control structure with no physical grounding (Ring 4)
The Monolith	<ul style="list-style-type: none">AerospaceKinetic Arrays	Rigid: massive & inflexible density (Rings 3 & 4) that lacks a "Cortex" (Ring 2)
The Adversarial Suite	<ul style="list-style-type: none">FinanceCybersecurity	Reflexive: decentralized control map where rings are in conflict
The Adaptive Suite	<ul style="list-style-type: none">HealthcareAgriculture	Symbiotic: high-efficiency state where the Cortex (Ring 2) and Sensors (Ring 1) work in a tight loop
The Distributed Infrastructure	<ul style="list-style-type: none">Energy GridTransportation	Essential: high-density, high-width sectors where control implicit in the vertical
The Precision Kinetic	<ul style="list-style-type: none">ManufacturingMarine Robotics	Operational: every ring is perfectly weighted to trigger Immutable Objects the moment a tolerance is threatened; proprioceptive

Table 1: Profiles of Control (Reagents)

Stoichiometry as a Paradigm for Control Efficacy Measurement

Control is commonly treated either as a software problem or a hardware problem but in this examination we undertake a stoichiometric approach where the balance of reagent and catalyst is sought. Stoichiometry is the branch of chemistry that quantifies relationships between reactants and products in a chemical reaction. Based on the Law of Conservation of Mass, balanced chemical equations are used to determine how much of a reactant is needed or how much product will be formed. Control behaves according to a distinct stoichiometry: it requires a solution with a specific number of informational bridges (analogous to chemical bond sites) that correspond to the valence commands of the system concerned. A stoichiometric mismatch between these sites results in unpaired signals, manifesting in control debt, a type of technical debt.

It is critical however to understand the profile of the system before undertaking a prospective control solution. For instance, a control solution that is designed to filter signal noise (amplitude modulation) would not be very helpful for a system that seeks to solve its hysteresis issue (frequency modulation). A stoichiometric approach would identify and quantify a control solution fitness for a given control profile. The Expressions of Control for each profile are illustrated in **Figure 2**.

Control Efficacy – or Model Fitness – is found in the balancing of reagent and catalyst. Control is not an app. Rather it is the result of a solution that is bonded to a suitable control profile that behaves like a chemical reaction which must reach equilibrium to be efficacious, which stoichiometrically produces a suite of three calculated measures demonstrated in **Table 3**.

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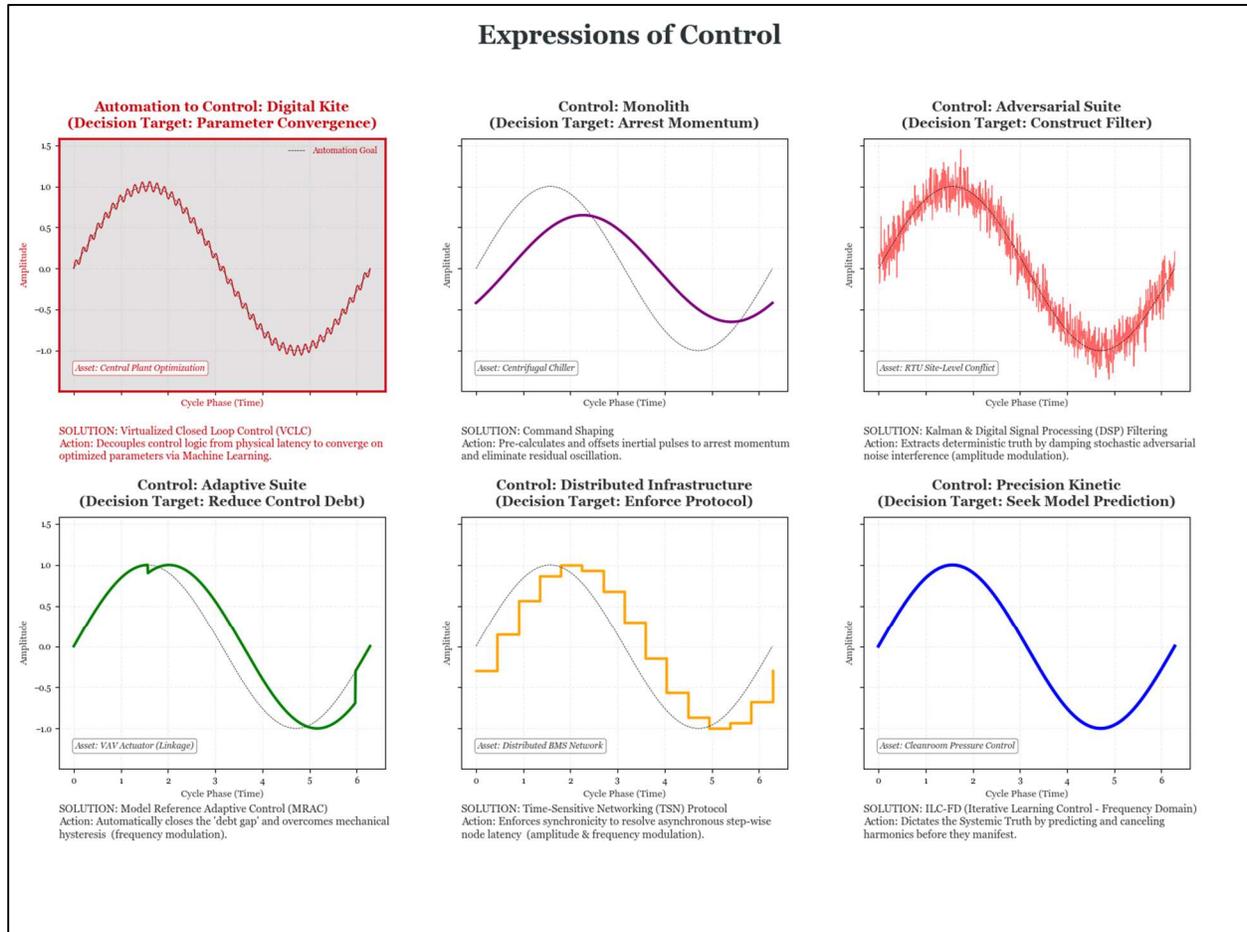


Figure 2: Expressions of Control by Profile

Modeling control performance is not an original thought. Modeling Control Efficacy via stoichiometry, however, is an abstraction borrowed from another science. Three major antecedents to this shell-style notation modeling effort come to mind, each with interesting commonalities and differences with the stoichiometric approach as summarized in **Table 2**.

Antecedent 1 (W. Ross Ashby): Ashby's Law of Requisite Variety

"Only variety can destroy variety" per Ashby. Applying Ashby to our stoichiometric model, the variety of the control solution ($B \times F$) must be equal to or greater than the variety of the system concerned. If a system has 10 possible "states" of failure, and the controller only has 3 vehicles (B) of action, there is a lack of requisite variety to stabilize it. This is known in Stoichiometry as Negative Saturation. Of these antecedents, Ashby comes closest to describing our stoichiometric model, but Ashby describes the logical constraint or what must happen rather than provide a mathematic proof.

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Antecedent 2 (Stafford Beer): Viable System Model

Beer looked at transduction: how information is turned into action. He also sought to understand how much command a system needed from above versus how much it could handle locally (stoichiometric C). Like Ashby's law of Requisite Variety, there is no mathematic proof as the VSM is a structural map.

Antecedent 3 (Rudolph Kálmán): State – Space Representation

In 1960, Kálmán introduced State-Space representation which breaks systems into two mathematical categories: (1.) Observability: Can we determine the internal state of the system by looking at the outputs? (stoichiometric F); and (2.) Controllability: Can we move the system to any state we want using a set of inputs? (stoichiometric B). Kálmán's work in State – Space did result in a mathematic model, but one that calculated position and stability, not efficacy or phase transition.

Feature or Concept	Stoichiometric Model	Rudolf Kálmán	W. Ross Ashby	Stafford Beer
Core Metric	Phase State via Valence (C, F, B)	State (\hat{x})	Variety (V)	Viability
Primary Goal	Structural integrity (A_s)	Minimize estimation error (Filter)	Match system variety (Req. Variety)	Maintain internal stability (VSM)
Debt Control	Remove structural dependency on an external source ($C=0$)	Error Covariance: The uncertainty of state	Lack of Variety: Inability to respond to a disturbance	Autonomic Failure: Loss of system identity
Definition of Success	System is Sovereign ($C=0$) and Visible ($V_m > 0$)	An observable and controllable system	The regulator has enough states to block noise	The system survives and adapts (Self-governance)
Structural Logic	Chemical synthesis / bonding of reagents to profiles	Matrix Algebra (LTI systems)	Cybernetic feedback loops (Black Box)	Recursive organizational layers

Table 2: Stoichiometric Model Comparison to Kálmán, Ashby & Beer

Calculating the Stoichiometric Control Solutions Efficacy

Our Stoichiometric model calculates efficacy in a suite of three measures: (1.) Balance or Saturation Index; (2) an Autonomy Threshold to directly expose Control Debt; and (3.) Audit Depth's (sensors concerned) ratio to Control Debt, known as Visibility Ratio.

Saturation Index	Autonomy Threshold	Visibility Ratio
$\sum B_{Solution} - \sum C_{Expression} = 0$	$\sum C_{Soltiuon} \rightarrow 0$	$\sum F_{Solution} \geq 2$

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Table 3: Stoichiometric Efficacy of Control

The higher Command Debt (C) is the greater the acceleration of energy required – known as Control Debt - will be to service a synthetic stability. Instability drives Control Debt.

Supporting the sectors' color gradients in **Figure 1** are five measures of interest. Two are for Control to gauge how much has already been achieved and two for Control Debt to gauge how much remains to be achieved. Control Efficiency and Control Debt are complements that sum to 100%.

These measures are poles on a continuum whose initial application would most likely be for a Risk Assessment analysis, but they have stoichiometric meaning as well. **Table 4** summarizes the impacts of Command Debt (C).

State	$\sum C_{\text{Solution}}$ Value	Debt Status	Physical Reality
Autonomous	0	Zero Debt	The system concerned has reached a state of self-governance.
Reactive	1	Primary Debt	The system is "Ionized." It needs a schedule or a start signal from a master to function.
Subordinate	>1	Compounded Debt	The system is a slave role. It requires multiple external inputs (e.g., Weather + Utility Price + BMS) to calculate its next move.

Table 4: Command Debt of Status of a Prospective Solution

Scoring Control Solutions for Informed Decision Making

The C, F and B measures are not independent variables but rather a triangulation of control intent. Interpreting them as a suite reveals the fitness of the logic. Efficacy is found when the geometric signature of the control solution's suite matches the physical signature of the monolith it is intended to govern.

Table 5 compares several potential control solutions to the Monolith Control Profile (heavy mass, high inertial load). Each of the three measures factors into the overall evaluation. The Saturation Index (B) drives the categorization of the Autonomy Status (C), which is then used as the primary sorting criterion, followed by the Visibility Multiplier (F) as the secondary sorting criterion.

Whenever $F = 0$ for a potential control solution, we cannot distinguish between control and automation. $F = 0$ is the point at which that particular control solution is disqualified from being categorized as control. Control by definition must be observable.

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Description of Measures		Objective Constraints	Degrees of Freedom	State Space
Rank	Model Name	Saturation Index (B)	Autonomy Status (C)	Visibility Multiplier (F)
1	Iterative Learning Control – Frequency Domain	+0	No control debt	5.00x
2	Standard PID Loop	-2	No control debt	0.33x
3	Manual HOA Switch	-2	No control debt	0.00x
4	Model Predictive Control	+0	Control debt	2.67x
5	Reinforcement (Q) Learning	+0	Control debt	2.67x
6	Auto-Regressive Integrated Moving Avg (ARIMA)	-3	Control debt	1.00x

Table 5: Control Solutions Comparison for Monolithic Systems Profile

Figure 3 illustrates a comparison between two qualified control solutions ($F > 0$), again for the Monolith control profile. We can visualize the synthesis of control profile and control solution and quickly reference the stoichiometric measures to gauge the efficacy of the syntheses' bonds.

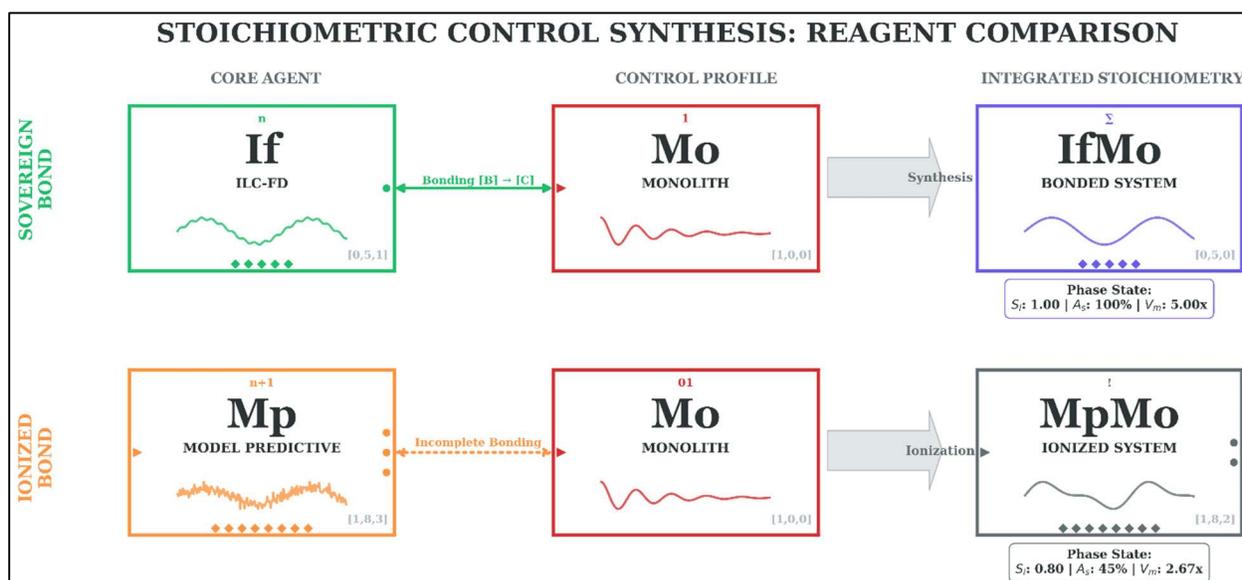


Figure 3: The Stoichiometry of Control

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Phase State of Control

A collateral benefit to calculating Control Efficacy is that these stoichiometric measures also allow for the a priori definition of the boundaries of Phase State. In physics, a phase of matter is a region of material that is physically distinct and uniform in its properties, while a state of matter refers to the common classifications of solid, liquid, gas, or plasma. Expressions of Control should be mapped for their Phase States just as matter is.

Phase State also has its antecedents, but it differs from the concepts developed by the researchers noted in **Table 6** in that Phase State requires that it be calculable whereas the concepts developed by these researchers do not. A Phase State must also meet the three criteria enumerated below. It should be noted that while Visibility ($F \geq 2$) is a prerequisite for a measurable phase, Equilibrium is the prerequisite for a stable phase. A reagent cannot be catalyzed if it is not detected. If $F < 2$, the system has no measurable phase state meaning it is unresolvable. This condition is referred to as "Quantum Overlay."

1. Repeatability: When the Saturation Index or Balance = 0, a system's command resources are balanced with the system's variety, thereby creating a repeatable Phase State.
2. Thresholds: Autonomy is governed by a non-linear transition triggered when specific volumetric or energetic limits are breached. For example, the shift from $C=0$ to $C=1$ represents the threshold of Ionization: the precise moment the system's innate quality transitions from Sovereign stability to a high-energy, subsidized state. This boundary is not a gradient, but a calculable phase limit.
3. Equilibrium: The system must maintain a steady state where the internal variety and external command are in a balanced flux. A Sovereign system ($C=0$) is in a low-energy, stable phase whereas an Ionized system ($C>0$) is in a high-energy phase that requires the reagent to suppress entropy, the metabolic tax paid for Control Debt.

Researcher	Concept	Threshold	Stoichiometric Alignment
René Thom	Catastrophe	The "Fold" where stability is lost.	Ionization: The jump from $C=0$ to $C=1$ (A_s collapse).
Stuart Kauffman	Edge of Chaos	The narrow zone between order and noise.	Critical Synthesis: The point where B-Margin = 0.
Ilya Prigogine	Dissipation	Order maintained by external energy flow.	Subordinate Flow: V_m maintained by external C tether.
Christopher Langton	Lambda (λ)	A parameter that tunes system behavior.	Purity (S_i): The tuning of autonomy via C-reduction.

Table 6: Phase State of Control Ancestry

Figure 4 is a Phase State of the Monolith control profile (heavy mass, high inertial load). As a point of interest, the other profiles' Triple Points are displayed in subdued fashion to demonstrate

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where their boundaries would meet. For our purposes, however, all the other elements in Figure 3 are specific to the Monolith control profile.

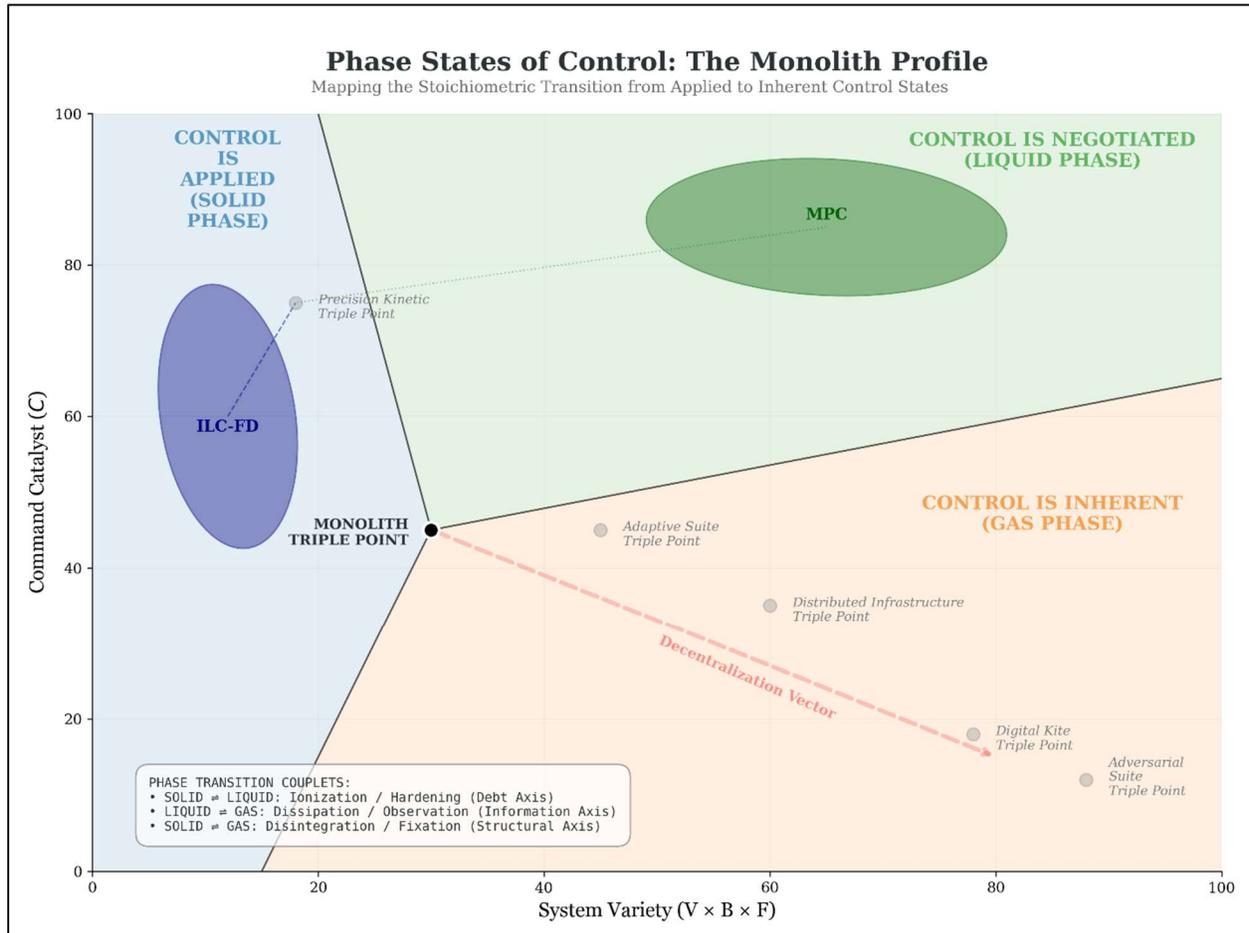


Figure 4: Phase State of a Monolith Profile

The benefit of mapping Phase State of Control in the manner suggested is that we can see the Phase State for any proposed control solution for a given control profile. In the case of the Monolith control profile, we can see where the integrated stoichiometries of this control profile and two possible control solutions – ILC-FD (Iterative Learning Control–Frequency Domain) and Model Predictive Control (MPC) – land in our Monolith Phase State of Control graph.

The Monolith profile when paired with ILC-FD and MPC lands in two distinct Phase States. What should we make of this? This divergence is not merely a matter of efficiency. It reflects how stoichiometric interplay between control profile and control solution dictates how – and if – equilibrium can be maintained.

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Phase State of Control Conclusion

The efficacy of ILC-FD in **Figure 4** is a function of its phase proximity to the Precision Kinetic Triple Point. Phase Proximity serves as a high-fidelity proxy, allowing a legacy Monolith profile to mimic the behavioral characteristics of a Precision Kinetic profile by amortizing data debt to achieve structural stability in the Solid Phase. In other words, with higher fidelity the Expression of Control (**Figure 2**) for a Monolith resembles that of the Precision Kinetic. More exacting control means better and more predictable performance.