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PAPER

# Re-Engineering Supply Chain Education: A Theoretical Framework for Integrating Financial Asymmetry and Systems Thinking

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## ABSTRACT

Modern industrial and systems engineering curricula excel at teaching students to mitigate physical supply-side disruptions, yet frequently fail to address the intra-supply-chain allocation of financial distress. This theoretical paper proposes a novel, problem-based learning curriculum framework designed to bridge the gap between operational logistics and financial risk-shifting. It critiques the pedagogical reliance on traditional bankruptcy prediction models, demonstrating how they systematically misclassify capital-intensive original equipment manufacturers (OEMs) into distress zones due to the structural liabilities of captive financial divisions. Grounded in systems thinking and Kolb's experiential learning theory, the proposed framework introduces dynamic industry benchmarks into the classroom, specifically utilizing the Strouhal Credibility Index (SCI). By structuring a pedagogical module around the 2020–2022 automotive crisis, and utilizing descriptive statistical comparisons rather than complex econometrics, this framework equips engineering educators with an accessible blueprint to teach the financial bullwhip effect. This ensures future engineering managers understand the structural vulnerabilities embedded within hierarchical supply chains and the limits of OEM-driven supply chain finance.

## KEYWORDS

engineering education, systems thinking, problem-based learning, financial bullwhip effect, supply chain finance

## 1 PEDAGOGICAL BACKGROUND AND THE CURRICULUM GAP

The COVID-19 pandemic and subsequent supply chain disruptions tested the financial resilience of global manufacturing ecosystems, exposing severe vulnerabilities in how liquidity and distress are transmitted across hierarchical value chains. Within modern industrial and systems engineering education, curricula are

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highly adept at addressing the physical manifestations of these crises. The operational consequences of supply-side shocks, such as semiconductor shortages and production bottlenecks, are well-documented and extensively modelled in the classroom. However, this intensive focus on operational optimization has created a critical pedagogical blind spot. The intra-supply-chain allocation of financial distress remains underexplored in engineering management coursework. Future supply chain designers are rarely challenged to evaluate systemic financial questions, such as whether final assemblers with superior market power absorb macroeconomic shocks, or whether they insulate their balance sheets by shifting working capital burdens upstream to their suppliers via the trade credit channel. When engineering programs do attempt to bridge this interdisciplinary gap by introducing corporate distress management, they typically rely on legacy frameworks that are ill-suited for modern industrial contexts. Empirically testing financial dynamics requires a highly precise measure of corporate financial stability. Unfortunately, the default pedagogical tools often include traditional bankruptcy prediction models, most notably Altman's Z-score [2], which exhibit a severe downward bias when applied to capital-intensive transportation sectors. In practice, automotive original equipment manufacturers (OEMs) frequently operate large captive financial service divisions. These divisions artificially inflate consolidated balance sheet liabilities. By continuing to teach these traditional models without contextual adjustment, educators inadvertently train students to utilise metrics that systematically penalize structurally sound original equipment manufacturers.

The consequence of this reliance on outdated models is a mathematically invalid classroom experience. Students are actively taught to misclassify capital-intensive OEMs into distress zones due to the structural liabilities of captive financial divisions. Because cross-sectional comparisons across the value chain are rendered mathematically invalid under these traditional metrics, students cannot accurately measure the distribution of risk. This represents a severe methodological flaw in engineering education that must be resolved. If students cannot accurately diagnose the baseline financial health of a supply chain apex, they are fundamentally unequipped to understand how financial distress ripples through the broader ecosystem.

To adequately prepare the next generation of industrial engineers, modern curricula must transition away from static, flawed metrics and adopt dynamic frameworks. Resolving this methodological flaw requires introducing measures of financial stability that utilize an average linkage approach to benchmark firms against dynamic, empirically derived industry averages. By recognizing the structural vulnerabilities embedded within hierarchical supply chains and acknowledging the limits of OEM-driven supply chain finance, educators can completely reimagine capstone design projects. This paper proposes a theoretical curriculum framework to correct this gap, enabling students to accurately identify the asymmetric transmission of exogenous macroeconomic shocks and ultimately design more holistically resilient manufacturing networks.

## 2 LITERATURE REVIEW

The integration of complex financial dynamics into industrial and systems engineering curricula represents a critical, yet underexplored, frontier in modern technical education. While the COVID-19 pandemic and subsequent supply chain disruptions exposed severe vulnerabilities in global manufacturing ecosystems, engineering education has historically struggled to unify physical supply chain optimization with its underlying financial realities. This literature review synthesizes the current pedagogical paradigms in engineering management, critiques the persistent reliance on legacy corporate distress models, and establishes the theoretical necessity for a curriculum framework grounded in systems thinking and experiential learning.

## 2.1 The operational bias in engineering management curricula

Historically, supply chain management coursework within industrial engineering programs has prioritized physical network optimization. Rooted in operations research, these curricula train students to mitigate physical bottlenecks, optimize inventory routing, and reduce cycle times. While this foundational knowledge is essential, it creates a pedagogical silo where the financial mechanics of corporate distress are frequently relegated exclusively to business and finance programs.

Through the lens of systems thinking [6], [14], this operational bias is highly problematic. Systems thinking requires students to view supply chains not merely as linear pipelines of material flow, but as complex, interconnected socio-technical and financial networks [5]. When engineering students are not taught how financial asymmetry dictates operational decisions, their understanding of the system remains incomplete. For example, while students are frequently taught the operational bullwhip effect—how small fluctuations in consumer demand cause massive physical inventory swings upstream [9]—they are rarely exposed to its financial counterpart. Consequently, graduates enter the workforce unable to recognize that the intra-supply-chain allocation of financial distress is strategically managed by final assemblers. Therefore, a modern curriculum must evolve to teach students that physical inventory optimization cannot be decoupled from working capital management, risk-shifting, and liquidity preservation.

## 2.2 Pedagogical flaws in teaching corporate distress measurement

When engineering management curricula do attempt to bridge this interdisciplinary gap by introducing financial stability metrics, they typically default to foundational frameworks. However, teaching these legacy models presents a severe pedagogical risk. Traditional bankruptcy prediction models, most notably Altman's Z-score [2], exhibit a severe downward bias when applied to capital-intensive transportation sectors. In practice, automotive OEMs frequently operate large financial service divisions, which artificially inflate consolidated balance sheet liabilities. Continuing to teach Altman's Z-score without significant industry adjustment means educators are passing down a captive finance penalty to their students. From a constructivist learning perspective S [12], teaching students to apply a universally flawed model actively hinders their ability to assess real-world engineering problems, rendering cross-sectional comparisons across the value chain mathematically invalid.

Critics may argue that modern corporate distress prediction has evolved far beyond foundational ratio analysis, frequently employing machine learning algorithms [3], [10] or Merton-based structural models [4], [11]. However, while these advanced probabilistic models offer superior predictive accuracy for quantitative analysts, they present a severe black box problem in the engineering classroom [13]. Constructivist pedagogy requires students to understand the underlying mechanical relationship of a system [12]. If an engineering student feeds OEM data into a neural network, the algorithm may correctly classify the firm, but the student remains blind to the intra-supply-chain mechanics driving that classification. Therefore, replacing legacy models with dynamic ratio adjustments, such as the Strouhal Credibility Index (SCI), represents a state-of-the-art pedagogical intervention. By utilizing an average linkage approach, it maintains the mathematical transparency required for students to manually trace how captive finance liabilities distort baseline stability, bridging the gap between high-level predictive accuracy and classroom comprehensibility.

### 2.3 Experiential learning and dynamic industry benchmarks

To resolve these methodological flaws in the classroom, educators must adopt dynamic teaching tools that resonate with how engineering students learn best. The proposed curriculum framework leverages Kolb's experiential learning theory [8], which posits that knowledge is created through the transformation of experience. Kolb's continuous cycle consists of four stages: (1) concrete experience, (2) reflective observation, (3) abstract conceptualization, and (4) active experimentation. Traditional lecture-based financial instruction often traps engineering students in passive conceptualization, failing to connect the mathematics to real-world systemic failures.

Incorporating dynamic industry benchmarks aligns perfectly with Kolb's framework and problem-based learning methodologies. By transitioning away from static legacy models and introducing tools that utilize an average linkage approach, educators can provide students with raw, standardized financial reporting data (based on IFRS or US GAAP framework) and task them with mathematically equalizing fundamental dimensions of financial stability. This active engagement allows students to explicitly test the asymmetric transmission of exogenous macroeconomic shocks. By performing comparative statistical analyses to identify the financial bullwhip effect, students transition from passive recipients of legacy theories into active analysts of modern supply chain crises.

### 2.4 Alignment with global engineering accreditation standards

Finally, the necessity of this pedagogical shift is reinforced by the stringent requirements of global engineering accreditation bodies. Frameworks established by ABET in the USA and the EUR-ACE framework in Europe explicitly mandate that engineering graduates must possess the ability to design complex systems within realistic constraints, prioritizing economic, environmental, and ethical considerations [1], [7].

To satisfy these rigorous outcomes, engineering management students must look beyond baseline profitability and evaluate the ethical and long-term economic implications of risk-shifting within hierarchical supply chains. The curriculum must illustrate that corporate resilience in final manufacturers is heavily subsidized by the liquidity of upstream partners. By studying empirical data from systemic supply-side contractions, students must be challenged to recognize that optimizing a supply chain through OEM-centric working capital management can structurally degrade the financial health of the supplier base, ultimately threatening long-term supply chain viability. Integrating these advanced financial realities into the curriculum is not merely an interdisciplinary enhancement; it is a fundamental requirement for producing competent, ethically aware engineering leaders capable of safeguarding the entire manufacturing ecosystem.

## 3 THE PROPOSED INSTRUCTIONAL FRAMEWORK: THE FINANCIAL BULLWHIP MODULE

To bridge the gap between theoretical knowledge and practical application, this paper outlines a highly structured, three-phase problem-based learning module that educators can implement within senior-level industrial engineering or supply chain management capstone courses. The primary objective of this instructional framework is to translate advanced financial realities into an accessible pedagogical blueprint. The module begins with dataset formulation and the critical deconstruction of legacy financial models. Educators are advised to provide students with a proprietary panel dataset comprising consolidated financial data from 40 global market leaders in the mobility and transportation manufacturing sectors. To facilitate a robust comparative analysis, educators should ensure the sample is stratified into three distinct sub-industries: (I) Top 20 automotive OEMs, (ii) Top 10 automotive suppliers, and (iii) Top 10 aircraft manufacturers and suppliers. Furthermore, the instructional data must span a six-year period from 2017 to 2022, extracted from annual reports prepared under standardized reporting frameworks (IFRS or US GAAP). Pedagogically, this timeframe is critical because it strategically encapsulates a full macroeconomic cycle, including the pre-pandemic baseline, the acute COVID-19 exogenous shock, and the subsequent supply chain disruption phase. Armed with this data, educators task students with analyzing the firms using traditional bankruptcy prediction models, demonstrating how captive divisions artificially inflate consolidated balance sheet liabilities.

Once students recognize that traditional tools systematically penalize structurally sound OEMs and misclassify them into the distress zone, the module transitions into its second phase: the application of dynamic industry benchmarks. To overcome this methodological limitation, educators introduce the SCI, which relies on an average linkage approach to benchmark firms against dynamic, empirically derived industry averages. To ensure complete replicability and transparency within the classroom environment, students are required to rely exclusively on publicly available, audited consolidated financial data prepared under standardized reporting frameworks, strictly avoiding subjective or proprietary managerial estimates. The core activity tasks students with calculating six fundamental dimensions of financial stability:

profitability $$R_1 = \frac{EBIT}{Sales}$$

capital structure $$R_2 = \frac{Equity}{Assets}$$

long-term financing $$R_3 = \frac{Equity}{Non-Current\ Assets}$$

asset turnover $$R_4 = \frac{Sales}{Assets}$$

current ratio $$R_5 = \frac{Current\ Assets}{Current\ Liabilities}$$

internal financing $$R_6 = \frac{Retained\ Earnings}{Assets}$$

For each ratio $i$, students calculate the pooled industry average $\overline{R_i}$ across the entire sample to establish a macroeconomic baseline. Educators then guide the cohort to formulate the index as the arithmetic mean of a firm's relative outperformance or underperformance across these six dimensions:

$$SCI_{j,t} = \frac{1}{6}\sum_{i=1}^{6}\frac{R_{i,j,t}}{\overline{R_i}}$$

By performing this mathematical equalization, students stratify the sample firms into three distinct financial health zones based on their scores:

| | |
|---|---|
| high credibility (outperformers) | SCI > 1.20 |
| the stable grey zone | 0.80 < SCI < 1.20 |
| low credibility (distress) | SCI < 0.80 |

In the final phase of the module, students apply their newly constructed index to simulate the financial bullwhip effect. Having established a robust, sector-neutral measure of financial stability, educators guide the classroom to utilize it to test the asymmetric transmission of exogenous shocks across the automotive value chain. The instructional design leverages the COVID-19 pandemic as a quasi-natural experiment. Students are challenged to quantitatively test a specific operational hypothesis: that during systemic supply-side crises, final car manufacturers insulated their own financial credibility by pushing margin compression and inventory burdens upstream to their Tier 1 suppliers. By calculating the mean credibility scores and standard deviations of final OEMs against Tier 1 suppliers across the pre- and post-shock periods, students trace the divergence in financial stability. The culminating pedagogical moment occurs when students visually and statistically observe the asymmetric impact of the shock. They discover firsthand that while OEM credibility scores stabilize or recover, Tier 1 suppliers absorb a disproportionate liquidity shock, suffering a severe and statistically observable credibility penalty relative to the historical sample mean.

While contemporary supply chains face evolving disruptions—such as geopolitical fragmentation or algorithmic demand shocks—the 2020–2022 automotive crisis provides a pedagogically pristine quasi-natural experiment. This specific timeframe strategically encapsulates a completely closed macroeconomic cycle—a stable pre-shock baseline, a severe exogenous contraction, and a subsequent recovery phase—allowing students to isolate and observe the pure mechanics of the financial bullwhip effect without the confounding variables of ongoing, unresolved modern crises.

## 4 PROPOSED ASSESSMENT AND EVALUATION STRATEGY

To provide educators with a clear blueprint for deployment, Table 1 outlines the complete curriculum map for the financial bullwhip module, aligning Kolb's experiential learning cycle with specific engineering learning objectives, instructional activities, and assessment mechanisms.

**Table 1.** Curriculum map for the financial bullwhip module

| Module Phase | Kolb's Cycle Alignment | Learning Objective | Instructional Activitiy | Assessment Mechanism |
|---|---|---|---|---|
| Phase I: Deconstructing the Penalty | Concrete Experience and Reflective Observation | Identify and critique the structural liabilities of captive financial divisions within legacy metrics | Students calculate Altman's Z-score on a panel dataset comprising 40 market leaders and identify OEM misclassifications | Formative: peer-reviewed data workshops debating the limitations of traditional bankruptcy prediction models |
| Phase II: Applying Dynamic Benchmarks | Abstract Conceptualisation | Calculate and apply dynamic measures of financial stability utilising an average linkage approach | Students calculate six fundamental dimensions of financial stability and establish a pooled macroeconomic baseline using the Strouhal Credibility Index | Formative: A cohort cross-examination of the mathematical equalisation and stratification of the sample firms into distinct financial health zones |
| Phase III: Simulating the Shock | Active Experimentation | Quantify the asymmetric transmission of exogenous macroeconomic shocks using descriptive statistics | Students compare mean index scores pre- and post-shock to prove OEMs insulated their financial credibility by pushing burdens upstream | Summative: executive policy memo detailing the economic magnitude of the divergence and proposing supply chain finance interventions |

*Source:* Author's own elaboration based on [8].

Within the context of problem-based learning, educators must deploy both formative and summative evaluation mechanisms that move beyond rote memorization of formulas. Formative assessment should occur continuously during the data analysis workshops, specifically targeting the students' ability to critique traditional models and accurately compute dynamic benchmarks. Educators can evaluate collaborative student teams on their capacity to calculate the pooled industry average across the entire sample to establish a macroeconomic baseline. Peer-review sessions serve as an excellent formative tool, allowing cohorts to debate their justifications for stratifying firms into distinct financial health zones. This collaborative evaluation ensures that students have thoroughly comprehended the underlying mechanics of the SCI before advancing to comparative modelling.

For the summative assessment, educators must design an evaluative instrument that forces students to interpret their mathematical findings through the lens of a senior engineering manager. Traditional multiple-choice examinations are inadequate for this level of analytical synthesis. Instead, educators should assign a comprehensive policy memo or an executive board presentation. In this capstone deliverable, students must articulate the real-world economic magnitude of their comparative estimates. Specifically, they must translate the diverging index scores into actionable supply chain intelligence, explaining how Tier 1 suppliers absorb a disproportionate liquidity shock. To achieve a high level of proficiency, students must explicitly contextualize the variance between the two tiers, demonstrating how the supplier penalty significantly deviates from the historical sample mean. By requiring students to articulate these specific quantitative outcomes, the assessment confirms their mastery over the concept of the financial bullwhip effect and proves their ability to link macroeconomic exogenous shocks to downstream operational vulnerabilities. Finally, the summative assessment must require students to transition from diagnosing a systemic failure to proposing structural engineering solutions. A core tenet of modern engineering accreditation is the ability to design and improve systems to mitigate identified risks. Therefore, the evaluation rubric must heavily weight a student's capacity to formulate strategic countermeasures that protect the most vulnerable nodes of the ecosystem.

Educators should instruct students to explore the mitigating role of foundational supply chain finance instruments—such as reverse factoring—to determine whether proactive liquidity interventions by OEMs can effectively dampen this upstream transmission. Mastering these traditional interventions provides the critical cognitive scaffolding required before students can subsequently evaluate state-of-the-art, technologically driven solutions, such as blockchain-enabled deep-tier supply chain finance or smart contract liquidity provisioning.

## 5 CONCLUSIONS AND FUTURE DIRECTIONS

This theoretical curriculum framework set out to resolve a persistent methodological flaw in corporate distress measurement as it is currently taught within industrial engineering and supply chain management programs. By proposing a problem-based learning module centered on the SCI, this paper demonstrates that training students to evaluate capital-intensive firms against dynamic industry benchmarks successfully eliminates the captive finance penalty that plagues traditional bankruptcy models. For engineering educators, implementing this shift ensures that students accurately perceive the stark asymmetry in how exogenous macroeconomic shocks are absorbed within the automotive value chain. By embedding these comparative statistics into classroom simulations, academic programs can provide students with robust quantitative evidence of a financial bullwhip effect, proving that corporate resilience in final OEMs is heavily subsidized by the liquidity of upstream partners.

Equipping engineering graduates with this interdisciplinary knowledge yields critical implications for future corporate practitioners and policymakers. When students independently calculate the divergence in credibility scores, they tangibly internalize the systemic risk of OEM-centric working capital management. This instructional design forces future supply chain managers to confront the reality that while pushing inventory and payment terms upstream protects short-term OEM liquidity, it structurally degrades the financial health of the supplier base, potentially threatening long-term supply chain viability. Furthermore, training engineers to view supply chains as interconnected financial networks ensures that future policymakers recognize that during macroeconomic crises, liquidity interventions targeted solely at final manufacturers may fail to reach the most vulnerable nodes of the ecosystem. Students learn firsthand that targeted relief must account for the upstream accumulation of financial distress.

While, this framework offers a rigorous blueprint for modernizing engineering syllabi, educators must remain cognizant of its pedagogical limitations. First, the proposed instructional dataset is restricted to 40 global market leaders. While these specific firms represent the vast majority of global market capitalization and production volume in the automotive and aerospace sectors, expanding the sample to include smaller, peripheral firms would introduce unobservable structural heterogeneity and dilute the macroeconomic significance of evaluating the true supply chain apex. Educators must caution students that the findings may not fully generalize to small- and medium-sized enterprises (SMEs) operating on the periphery of these ecosystems. Additionally, the financial bullwhip effect compounds further upstream, but the lack of consolidated public data for private Tier 2 and Tier 3 suppliers limits the direct observation of these deeper nodes within a classroom setting.

These limitations highlight several critical paths for future educational research. Most immediately, engineering education scholars must empirically test this theoretical curriculum framework within active classrooms to measure student learning outcomes, assessing the cognitive load required for engineering cohorts to master dynamic modelling. Methodologically, the teaching modules should be expanded and empirically tested across other highly capital-intensive sectors burdened by unique balance sheet structures, such as telecommunications infrastructure. Future studies utilizing proprietary procurement datasets could illuminate whether the supplier penalty is passed down further to Tier 2 and Tier 3 manufacturers. Finally, educational researchers should explore the mitigating role of supply chain finance instruments—such as reverse factoring—to determine whether proactive liquidity interventions by OEMs can be effectively taught as standardized engineering design solutions. By continuously refining how financial risk-shifting is taught, academic institutions can cultivate a new generation of supply chain leaders fully equipped to navigate, neutralize, and ultimately solve complex systemic vulnerabilities.

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