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Theoretical approaches to cash flow modeling for assessing financial sustainability

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Abstract

The article presents a systematic review of theoretical approaches to cash flow modeling for assessing the financial sustainability of organizations. The study is based on an interdisciplinary analysis encompassing economic-mathematical modeling, machine learning algorithms, structural equation modeling methods, and stochastic programming. Special attention is given to the classification of models by data type, level of predictive and explanatory power, and their applicability under conditions of high uncertainty and digital transformation. The advantages and limitations of classical liquidity management models are examined, along with the potential of neural network and ensemble methods in analyzing complex nonlinear relationships, and the resilience of stochastic strategies under stress scenarios. Key non-financial constructs—such as information systems, leadership, and social capital—are identified as having a significant impact on the structure and dynamics of cash flows and contributing to institutional resilience. The integration of predictive and structural factors into hybrid architectures for resilience assessment is analyzed, providing a balance between model accuracy and interpretability. The article offers an original review of models aimed at strategic financial planning in the context of digitalization and organizational transformation. This study will be of interest to researchers in corporate finance, strategic management, applied economics, and practitioners developing resilience models and adaptive cash flow management systems in volatile environments.

Keywords: Cash Flows; Financial Sustainability; Modeling; Structural Equations; Machine Learning; Stochastic Programming; Neural Networks; Information Systems; Leadership; Adaptive Management

1. Introduction

Modern financial practice, both in the global context and within national economies, is undergoing a phase of reappraisal of approaches to cash-flow management amid rising uncertainty and instability in the external environment. The increasing complexity of macroeconomic scenarios, accelerated digitalization and heightened regulatory requirements have tasked organizations with the need for adaptive responses to financial challenges. In this setting, cash-flow management emerges not merely as a liquidity tool but as a key mechanism for securing long-term financial resilience. The growing focus on cash-flow modelling reflects a demand for more precise, flexible and predictive methodologies capable of accounting for complex cost structures, distinctive business models and external stress factors [11].

Theoretical and applied literature has devoted particular attention to forecasting and evaluating cash-flow dynamics as an indicator of organizational resilience. Classical liquidity-management frameworks have given way to more advanced analytical constructs—structural-equation models, machine-learning methods and stochastic programming techniques [4]. For example, deep-neural-network–based models allow for the capture of nonlinear relationships between operational performance and external conditions, while stochastic optimization methods support the formulation of management strategies under conditions of high volatility and limited information. Such solutions are already being deployed in corporate governance, risk management, and strategic planning, especially within capital-intensive and high-risk sectors.

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A comprehensive theoretical appraisal of these approaches requires evaluating their predictive power, adaptability, computational complexity, and applicability across various resilience scenarios. Notably, contemporary studies extend beyond purely financial metrics to consider non-financial dimensions of resilience—such as governance quality, information-system maturity, and organizational agility—thereby demanding a multidisciplinary perspective on cash-flow modelling. In this respect, research efforts that integrate financial evaluation models with factors like social capital, leadership, and technological infrastructure are particularly valuable.

The aim of this study is to conduct a systematic review of theoretical approaches to cash-flow modelling and to assess their applicability for evaluating organizational financial resilience.

2. Materials and Methods

The methodological foundation of this study is based on an analysis of academic publications that address contemporary theoretical approaches to cash-flow modelling for the evaluation of organizational financial resilience. The interdisciplinary nature of the problem dictated the inclusion of works employing both traditional economic–mathematical models and algorithmic and statistical methods.

Within the structural paradigm, the model developed by Arora and Gaur [2] holds particular significance: it dissects operating cash flow into its internal components and examines its interrelation with production and investment parameters. A similar approach is implemented by Han, Lei, and Liu [6], who frame cash flow as an element in the equilibrium model of a firm's life cycle. Dahmer [3] augments this stream of research by incorporating external shocks—including pandemics—into the model, thereby demonstrating how resilience depends on the macroeconomic context.

The algorithmic paradigm is exemplified by the studies of Adebayo, Mensah and Ayuko [1], Karatas, Klinkert and Hirsa [7], and Laghari, Ahmed, and López García [8]. These works explore the application of machine-learning techniques, including neural-network architectures and ensemble methods, for forecasting cash flows and assessing their impact on resilience metrics. Models presented in these studies are designed to handle high-dimensional, non-stationary data, capturing nonlinear relationships among variables and adapting to evolving external conditions.

A distinct block of research falls under the stochastic paradigm, in which cash flows are treated as random variables with inherent uncertainty. Salas-Molina [10] attempts to adapt classical cash-management models to real-world data through the use of random trajectories in simulation experiments. Engineer, Lindskog, and Thorgerson [5] extend traditional cash-flow concepts by introducing multiple prior probabilities and regulatory uncertainty into their framework. In both cases, cash flow is modelled stochastically, sensitive to both internal fluctuations and external shocks. Notably, Ochoa Crespo, Feria Domínguez, and Cordero Guzmán [9] integrate cash flows into a structural-equation model that links financial resilience with non-financial factors—such as governance quality, information-system maturity, social capital, and adaptive capacity—thereby shifting the focus from isolated financial metrics to a holistic assessment of resilience.

Additional contributions include the retrospective default-probability analysis by Danieli, Bet, and Fabrizi [4], which leverages cash-flow dynamics as an indicator of solvency risk, and the adaptive SEIJR model proposed by Ye et al. [11], which reconceptualizes cash flows and financial interdependencies through an epidemiological lens, reflecting a growing interest in multidisciplinary approaches to supply-chain resilience.

Overall, the methodological approach relies on a systematic classification, comparative analysis, and synthesis of modern theoretical constructs that model cash flows as a key variable in the assessment of financial resilience. The choice of content analysis as a method was driven by the need to organize heterogeneous sources and formalize comparative criteria for the applicability of diverse models.

3. Results

Cash-flow modeling in the academic literature encompasses a wide range of conceptual and methodological approaches, varying in both analytical depth and suitability for assessing financial resilience. Our comparative analysis identified four principal directions:

- Classical models
- Structural models
- Machine-learning algorithms

- Stochastic programming

Each direction is characterized by its own modeling framework, dependency structure and domain of applicability. The results of our systematization are shown in Table 1.

Table 1 Comparative Characteristics of Approaches to Cash Flow Modeling (Compiled by the author based on sources: [2], [5], [6], [9])

Approach	Modeling Framework	Applicability to Resilience
Classical Models	Baumol, Miller–Orr	Limited under high σ
Structural Models	SEM, regression chains	High explanatory power
Machine Learning	DNN, Random Forests	High predictive accuracy
Stochastic Programming	MILP, ensemble-based SP	Reliability under uncertainty

As shown in Table 1, these approaches differ in their methodological foundations and their effectiveness for resilience assessment. Traditional cash-management models—such as Baumol's and Miller–Orr's frameworks—have long been used to evaluate liquidity and determine optimal transaction sizes. However, Salas-Molina [10] and Engsner et al. [5] demonstrate that these models exhibit limited applicability under conditions of high volatility, since they do not capture nonlinear dependencies or the multifactor nature of risk. Their theoretical simplicity ensures interpretability but reduces predictive accuracy in uncertain environments.

By contrast, the structural-modeling paradigm employs structural-equation models and regression chains to account simultaneously for interrelated variables and latent factors. The studies of Arora and Gaur [2], Han et al. [6] and Ochoa Crespo et al. [9] show that structural models offer strong explanatory power, enabling analysis of how organisational, operational, and external factors drive cash-flow dynamics and contribute to overall resilience. These models are particularly valuable when unpacking complex cause-and-effect relationships within corporate governance systems.

Algorithmic methods based on machine learning—particularly deep neural networks (DNN) and decision-tree ensembles such as Random Forests—achieve high forecasting accuracy even when data are unstable and dimensionality is high. Adebayo et al. [1], Karatas et al. [7], and Laghari et al. [8] demonstrate that neural and ensemble models can uncover implicit patterns and adapt to shifts in the external environment. Their chief advantage lies in detecting complex nonlinear relationships that traditional statistical techniques cannot capture. At the same time, the high computational burden and limited interpretability of these models present challenges for managerial decision-making.

Stochastic programming (SP)—including mixed-integer linear programming (MILP) and ensemble-based stochastic frameworks—focuses on devising robust cash-flow management strategies under uncertainty. Salas-Molina [10] illustrates how a stochastic model can be calibrated to empirical data via scenario generation and optimisation of liquidity-management policies. This approach accommodates a broad spectrum of external scenarios and enables stress-testing, making it particularly valuable for resilience assessment in crisis contexts.

Evaluating organisational resilience through the lens of cash-flow models requires incorporating both quantitative financial metrics and qualitative constructs that indirectly affect financial stability. Recent empirical work highlights the growing significance of variables such as internal governance processes, digital maturity, social capital, and adaptive response mechanisms. Unlike classical financial ratios, these constructs are not always directly measurable, necessitating rigorous validation of their reliability and validity before they can be integrated into analytical frameworks.

Among the sources reviewed, the study by Ochoa Crespo et al. [9] offers the most rigorous methodological treatment of construct verification. It applies a structural-equation-modeling approach in which constructs were evaluated multidimensionally using consistency coefficients and average variance extracted. This method formally tests the concordance between latent variables and observed indicators, thereby minimising systematic measurement error. The results are summarised in Table 2.

Table 2 Reliability and construct validity (Source: [9])

	Cronbach's alpha	**Composite reliability (rhea)**	**Composite reliability (hoc)**	**Average variance extracted (AVE)**
Business practices	0.864	0.870	0.909	0.714
Employees	0.879	0.896	0.906	0.618
Financial performance	0.838	0.847	0.904	0.760
Information systems	0.794	0.830	0.905	0.827
Management and leadership	0.798	0.810	0.908	0.831
Organizational and financial resilience	0.866	0.875	0.909	0.715
Reactive resilience	0.799	0.808	0.908	0.832
Social capital	0.921	0.923	0.941	0.761

All Cronbach's α values exceed the 0.70 threshold, indicating high internal consistency of the scales. In particular, "Social capital" achieves α = 0.921, underscoring the stability of its indicators. Composite reliabilities (ρ_a and ρc) all surpass 0.80, confirming measurement consistency and minimal internal error. The AVE values, ranging from 0.618 to 0.832, demonstrate sufficient variance representation and support the convergent validity of the constructs.

Importantly, these constructs are incorporated into the resilience-assessment model as key variables—rather than auxiliary metrics—reflecting an organization's ability to adapt to external change, to establish effective managerial and information processes, and to maintain internal coordination. For example, the high reliability of "Information systems" (AVE = 0.827) highlights its significance in the context of digital transformation and end-to-end process resilience. The metrics for "Management and leadership" and "Reactive resilience" emphasize the critical role of adaptive management mechanisms alongside financial indicators.

Thus, the findings presented in Table 2 validate the inclusion of these constructs in comprehensive resilience models. Their strong statistical reliability lays the groundwork for subsequent quantitative analyses of the relationships among managerial, informational, and social factors and cash-flow dynamics.

4. Discussion

The review of theoretical approaches to cash-flow modelling reveals two fundamentally distinct methodological streams: classical liquidity-management models and contemporary frameworks grounded in machine learning (ML) and stochastic programming (SP). Each offers unique research insights, yet their suitability for assessing financial resilience differs markedly.

Classical models—exemplified by Baumol's and Miller–Orr's formulations—have occupied a central place in economic theory since the mid-20th century [2]. Their chief virtue lies in analytical transparency and ease of interpretation. In these schemes, cash flow is treated as a stochastic process that drifts from a predetermined target, at which point corrective measures are triggered. This design enables formal management of cash balances under predictable volatility, as demonstrated by Salas-Molina [10] and Engineer et al. [5].

Nevertheless, these models' limitations become evident in today's environment of heightened uncertainty, nonlinearity, and interdependent risk factors. Amid digital transformation and increasingly complex operational chains, an organization's resilience hinges on its ability to manage liquidity proactively and to forecast cash-flow behavior under atypical conditions. In this context, ML- and SP-based models gain prominence, as shown by Adebayo et al. [1], Karatas et al. [7] and Laghari et al. [8].

Machine-learning methods—particularly ensemble approaches like Random Forests and deep neural networks (DNNs)—deliver strong adaptability and predictive accuracy when handling large, noisy datasets with numerous correlated variables. Laghari et al. [8] underscore that these techniques can uncover nonlinear dependencies and latent patterns inaccessible to traditional statistical methods. The theoretical significance lies in broadening the permissible

set of functional relationships and enabling reliable extrapolation of cash-flow dynamics in novel or crisis scenarios. Of special interest is hybrid modelling, which marries the interpretability of classical or ensemble algorithms with the high predictive power of DNNs. Such hybrid solutions preserve managerial relevance by maintaining partial transparency of the decision logic while ensuring forecasting precision.

Contemporary financial-resilience assessments increasingly call for integrating structural and predictive indicators beyond conventional accounting metrics. In our theoretical analysis, we paid particular attention to embedding cash-flow models within a comprehensive resilience framework. This entails incorporating both direct financial flows and intermediary constructs—such as governance quality, digital maturity, and social capital—that underpin an organization's adaptive capacity.

Of particular interest from an integrative-modelling standpoint is the study by Ochoa Crespo et al. [9], which implements a structural-equation model incorporating information-system maturity, management leadership, and social capital. In this framework, cash flows are treated as an outcome variable that depends on the internal organisational context and, in turn, shapes overall business resilience. Figure 1 presents a directed graph of contemporaneous relationships among financial and macroeconomic variables.

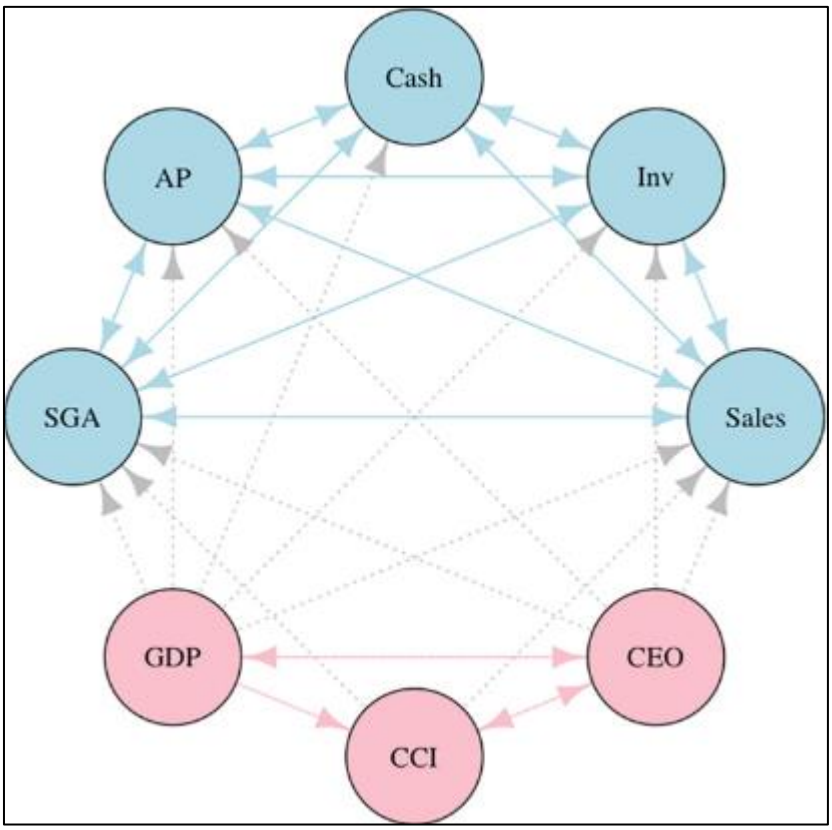

Figure 1 Directed Graph of Contemporaneous Relationships (Source: [2])

This visualization demonstrates how key internal metrics—such as Cash, Inventory, Sales, and SGA expenses—interact within a corporate environment, while also capturing the influence of broader macroeconomic constructs including GDP, Consumer Confidence Index, and CEO-related factors. The directionality of the graph edges reflects real-time interdependencies that align with the structural equation modeling approach, enabling the representation of latent interactions between operational drivers and contextual economic conditions. Incorporating such visual models into resilience analysis allows researchers and practitioners to identify control points, feedback loops, and exogenous stressors that impact cash flow behavior under uncertainty.

Analysis of this approach confirms its relevance for uncovering complex mediated dependencies that traditional regression models cannot detect. The results of our systematization of the key factors determining the cash contribution of flows to resilience are summarized in Table 3.

Table 3 Factors Determining the Contribution of Cash Flows to Business Resilience (Compiled by the author based on sources: [1], [8], [9], [10])

Factor	Type of Data	Model Type	Impact on Resilience
Financial Reporting	Accounting Metrics	DNN, RF	Direct
Information Systems	IT Maturity Assessment	SEM, ML	Indirect (via control)
Management and Leadership	Survey Data	SEM, Structural	Direct and mediated
Predictive Flows	Forecast Data	SP, MILP	High

As Table 3 shows, financial-reporting metrics continue to exert substantial explanatory power within algorithmic models, especially when ensemble methods and neural-network architectures are employed. These models deliver high predictive accuracy and enable rapid identification of short-term resilience risks. However, an organisation's strategic resilience ultimately depends on the volume and structure of its cash flows and the quality of the processes that underpin its stability. In this context, information systems act as an indirect yet critically important factor: their maturity and level of integration into the management architecture mediate an organisation's ability to control, monitor and adapt, as emphasised in the SEM framework of Ochoa Crespo et al. [9]. Similarly, management and leadership constitute a category that exerts both direct influence on decision making and mediated effects via organisational culture, staff motivation, and the robustness of team coordination. Structural models formalise these relationships and quantify the contribution of qualitative managerial variables to cash-flow dynamics and resultant resilience.

Looking ahead, special attention should be given to predictive cash flows generated through scenario forecasting. Stochastic programming—including MILP approaches, as illustrated by Salas-Molina [10]—accommodates a broad range of potential future states and supports the design of resilience strategies under uncertainty. Overall, embedding cash-flow models within resilience assessment demands a holistic approach that combines quantitative financial data with qualitative characteristics of the internal environment. Hybrid architectures—integrating the predictive strength of algorithmic models with the interpretive clarity of structural-equation frameworks—offer the most comprehensive basis for evaluating business resilience.

5. Conclusion

This study has systematically organized contemporary theoretical approaches to cash-flow modelling and assessed their suitability for evaluating organizational financial resilience amid heightened volatility and digital transformation. It was found that traditional liquidity-management models—while offering analytical transparency—possess limited predictive power and adaptability under conditions of high uncertainty. Their relevance remains primarily for short-term cash-balance regulation in stable environments.

In contrast, structural models, machine-learning algorithms, and stochastic programming demonstrate a markedly greater capacity to capture complex interdependencies between financial and non-financial variables and to adapt to evolving external conditions. Structural modelling exhibits strong explanatory power, particularly when integrating factors such as information-system maturity, management quality, and social capital into the analytical framework. Machine learning—especially deep neural networks and Random Forests—delivers high forecasting accuracy, making it a promising tool for resilience-scenario development and predictive analytics.

Stochastic programming, in turn, plays a crucial role in ensuring robust decision-making across multiple plausible external scenarios. These methods enable the formulation of financial-management strategies that remain resilient to shocks and systemic disruptions, including macroeconomic crises and sectoral upheavals.

The analysis of non-financial constructs—validated by high statistical reliability—revealed that variables related to information systems, leadership, organizational adaptability and social capital can and should be incorporated into resilience-assessment models alongside conventional accounting metrics. This integration shifts the focus from an isolated analysis of liquidity to a holistic understanding of resilience as a multidimensional and multilayered phenomenon.

Accordingly, cash-flow models today function not only as forecasting tools but also as integrative platforms for evaluating a business's adaptive capacity. Future advancements should pursue hybrid architectures that combine the

interpretive strengths of structural-equation models, the predictive precision of machine-learning algorithms and the scenario-based robustness of stochastic programming.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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