A Framework for Supply Chain Performance Measurement

Amanda González Cabrera
Institute of Logistics, University of Miskolc, Hungary
amanda.gonzalez.cabrera@student.uni-miskolc.hu

Béla Illés
Institute of Logistics, University of Miskolc, Hungary

Ágota Bányai
Institute of Logistics, University of Miskolc, Hungary

Abstract
Supply chain performance measurement (SCPM) is evolving due to the diffusion of Industry 4.0 technologies. Traditional approaches, such as Beamon's (1999) Resources-Output-Flexibility (R-O-F) model, possess strong strategic logic but do not offer direct procedural guidance and lack digital sensitivity. Process-oriented frameworks, such as Supply Chain Operations Reference (SCOR), propose operational guidance but lack a unifying performance logic based on trade-offs. Digital maturity models apply at an aggregated level and show no direct linkage to performance indicators.

Empirical evidence suggests that while companies face a rising abundance of digital solutions and access to data-driven opportunities, there is still a lack of structured frameworks that jointly consider strategic, operational and digital aspects of performance measurement. The inability of existing frameworks to fully explain performance changes reflects limited explanatory power on how digital technologies rewire performance generation or alter the understanding of traditional performance indicators.

Thus, the identified research gap lies in the fact that existing approaches still fall short of fully integrating strategic performance dimensions, operational process structures, and the heterogeneous impact of digital technologies within a coherent framework. This article proposes an integrated conceptual framework that combines the strategic dimensions of R-O-F and the SCOR process building blocks. Digital sensitivity is introduced as an overarching interpretive attribute of performance indicators that accounts for the non-uniform role digital technologies play in performance generation and measurement.
This framework allows managers, controllers and data specialists to structure and comprehend performance measurement systems based on strategic goals and digital enablement, while linking performance interpretation to both operational processes and the technological context.

1. Introduction
In logistics operations, performance was traditionally measured by financial figures only, such as total costs, return on investment (ROI), or inventory maintenance costs. These singular measurements provide limited backward-looking views and fail to account for qualitative aspects like service level and responsiveness to customers (Beamon, 1999; Gunasekaran & Kobu, 2007). This perspective shifted as businesses expanded globally and supply chains evolved.
The changes led to a rise in holistic performance measurement systems that track financial and operational KPIs, connect measurements to strategy, and enable digitally connected environments (Kaplan & Norton, 1996; Bititci et al., 2012).

An effective Performance Measurement System (PMS) acts as a strategic control tool that facilitates decision-making and enables agility. In other words, an effective PMS provides relevant information for decision-making about your logistics operations, what they should be doing based on strategy, and how to react based on the data. An integrated system makes it easier to understand what is measured, why it matters, and how it can be used in decision-making (Shepherd & Günter, 2006).

Research on Logistics 4.0 has identified similar focal points. The digitalization of supply chains increases the availability of data through technologies like IoT, improved information systems, and automation, thereby enabling greater transparency and supporting responsive, data-driven decision-making (Glistau et al., 2022).

http://dx.doi.org/10.25673/123527

While this research does not focus specifically on performance measurement systems, these are the foundational elements that could enable PMS to do much more. However, with increasing digitalization supply chains are becoming more complex and require the alignment of strategic, operational, and technological aspects within a single system (Meier & Pfeffer, 2022).

1.1. The evolution of performance measurement in supply chains: from financial to multidimensional

The emergence of Industry 4.0 technologies like IoT, cyber-physical systems, or digital twins has disrupted how processes are designed and run (Wang et al., 2016; Ivanov et al., 2019). Data can now be acquired instantly and decisions can be made predictively. In turn, how we think about performance is changing dramatically: from indicators that report what has happened, they are becoming living representations of how responsive and predictive a system can be (Taticchi et al., 2015).

Digitalization not only changes performance levels, but also what performance means. When we talk about "real-time visibility", for instance, we refer to an entirely new plane of control that redefines what we expect of coordination efforts (Büyüközkan & Göçer, 2018). "Predictive capability" describes another qualitative shift from responsive to anticipatory systems (Queiroz et al., 2021).

However, the impact of digitalization is not homogeneous. Some indicators do not rely on digital technologies at all, some are improved by it, and others only exist because of digitalization. Assessing this variation is essential to understanding performance in the context of Industry 4.0 (Frederico et al., 2020).

1.2. Research problem and objective of the article

The growing body of SCPM literature suffers from fragmentation in at least three regards. Logic-centered frameworks resting on strategic performance dimensions provide interpretive parsimony (why measure?) but lack procedural guidelines or digital sensitivity. Popular frameworks centering around processes, in particular SCOR, feature well-established architectures (how to measure?), but lack propositional performance logic rooted in strategic dimensions (Huan et al., 2004; Persson, 2011). Most prominently, approaches to assessing digital maturity often rely on aggregate scores, removed from hard performance indicators (Büyüközkan & Göçer, 2018).

In addition, recent contributions following the controlling-oriented tradition show that abundant data alone does not translate to superior decision-making if underlying indicators lack a formal interpretive structure connecting the numbers back to strategy (Werner, 2022; Schäffer, 2024). These shortcomings thus impede our understanding of the impact of digital technologies on performance generation as well as shifts in inherent trade-offs (Tjahjono et al., 2017; Queiroz et al., 2021). Overall, the main research gap lies in the lack of a coherent framework that simultaneously integrates strategic performance dimensions, process structures, and the heterogeneous effects of digital technologies. The purpose of this article is to propose an overarching conceptual framework for how supply chain performance in the Industry 4.0 era can and should be measured. To that end, we outline the integration of the R-O-F strategic logic with the SCOR process architecture while explicitly capturing the variance of digital impact through the lens of digital sensitivity.

We adopt a conceptual approach aimed at laying a coherent theoretical foundation for subsequent quantitative expansions. First, this article contributes to the literature on supply chain performance measurement by conceptually merging the well-established strategic performance dimensions rooted in the R-O-F logic with the SCOR performance measurement process architecture. Where previous metrics have stopped short, we make the connection between performance interpretation and the very operational processes performance is created within. Second, we introduce the notion of digital sensitivity as a cross-cutting attribute for performance indicators that qualitatively alters how individual indicators can be interpreted and contribute to performance. At its core, digital sensitivity captures how advances in digital technologies affect the measurability of supply chain performance. Third, we propose a structured conceptual space (R-O-F × SCOR) complemented by the cross-cutting attribute of digital sensitivity associated with each indicator. This space allows researchers and practitioners to holistically and systematically position potential performance indicators of digitally enabled supply chains.

More generally, by design, this article aims to contribute to the literature seeking to bridge the existing gap between often siloed theoretical performance measurement constructs, digital technologies, and managerial action, as called for recently (Bode et al., 2023). It is crucial to note that this framework does not evaluate or rank specific software solutions; rather, it supports decisions about structuring and interpreting performance measurement.

2. Theoretical foundations and research gap

This section introduces the conceptual framework regarding supply chain performance measurement and digital transformation, outlining the research gap addressed by this study. It starts with a literature review describing the current state of the art across research disciplines: theoretical concepts, technology advancements, and user-driven needs. Subsequently, this work defines the terminology used throughout the study. After consolidating insights gathered from literature research and concept definition, this section concludes with a discussion of mainstream frameworks' limitations and positions the contribution of this study.

2.1. Current state of knowledge in supply chain performance measurement

The SCPM research landscape is commonly structured along three closely interlinked yet partially siloed pillars: (1) theoretical and conceptual perspectives; (2) technology and software solutions; and (3) end-user-centered management applications. While each of these pillars will be briefly outlined in turn below, it is against this background that contributions to this research area should aim to develop approaches towards a more comprehensive, cross-pillar perspective on performance measurement in supply chains.

Building on a theoretical perspective first, discussions around performance measurement in SCM have shifted from cost-based approaches towards holistic performance systems comprised of efficiency, effectiveness, and flexibility measures (Gunasekaran & Kobu, 2007).

Very recently, Meier & Pfeffer (2022) have added to this discussion by arguing that measurement of SCM performance in digitalized settings requires the concurrent consideration of planning, doing, and checking under the umbrella of a single analytical construct.

Recent literature further emphasizes that Industry 4.0 technologies significantly reshape supply chain performance measurement by linking digital capabilities with performance outcomes. A comprehensive review by Govindan et al. (2022) highlights that while numerous performance indicators and digital enablers have been identified, there remains a lack of integrated frameworks that connect digital technologies, process structures, and strategic performance dimensions.

At the same time, Werner (2022) and Bode et al. (2023) show that considering the vertical fit between operative processes and overall business strategy continues to be of key importance for supply management, especially in settings characterized by high dynamism and data abundance. Both contributions point to the essential role of KPI systems for ensuring transparency in these contexts.

From a software and technology-centered perspective, "traditional" Enterprise Resource Planning (ERP) systems, but also Advanced Planning and Scheduling (APS) systems and digital twins, have created an unprecedented level of availability, detail, and timeliness of potentially useful performance information.
Each of these technologies allows for more or less real-time data capture as well as data-driven "what-if" analyses to support decision-making. Neither, however, provides guidance on how to conceptualize or think about the resulting performance indicators. In essence, the existence of tailored software solutions does not equal useful performance measurement.

Lastly, from an end-user point-of-view, it is important to note that performance measurement systems have to address various stakeholders with varying, and at times conflicting, objectives and information needs.

Supply chain managers typically value aggregated and timely performance information that allows them to manage. Controllers, on the other hand, need performance indicators that are accurate, consistent, and comparable year-over-year. Data analysts and IT specialists finally, are likely to value software-ready and scalable data architectures. All of these perspectives need to be considered when thinking about performance measurement.

2.2. Conceptual definitions

To ensure conceptual clarity, the key terms used in this study are defined as follows:

SCPM is defined as a structured system of metrics and analytical processes used to evaluate the efficiency, effectiveness, and adaptability of supply chain operations (Gunasekaran & Kobu, 2007).
A performance indicator is a quantifiable measure that reflects the performance of a specific process, resource, or outcome within the supply chain and supports decision-making and control.

Efficiency refers to the optimal utilization of resources, while effectiveness describes the extent to which customer requirements and service objectives are fulfilled.

Flexibility is defined as the ability of a supply chain to respond to changes in demand, supply, or operational conditions without significant performance degradation.

Digitalization refers to the integration of digital technologies, data infrastructures, and analytical

tools into operational and decision-making processes (Meier & Pfeffer, 2022).

Building on these concepts, digital sensitivity is defined in this study as an interpretive attribute of performance indicators that describes the extent to which their conceptual meaning, measurability, and operational relevance depend on digital technologies, thereby linking technological capabilities to performance interpretation. In this study, performance generation refers to the underlying operational processes that produce measurable outcomes.

2.3. Research gap identification

Beamon's (1999) approach emerged as a response to silo-based monetary metrics by arguing that cost cannot be used as the only performance indicator for evaluating supply chain effectiveness. Instead of individual metrics, Beamon (1999) defined a system of three interrelated categories. Resource-Related (R) metrics not only take financial expenditures into account but instead focus on how efficiently a company uses its operational resources to produce its products. Output-Oriented (O) metrics aim to measure external effectiveness by analyzing how well the supply chain lives up to the customer's quality and service level requirements. Lastly, Flexibility (F) metrics operationalize how well the supply chain can adjust to certain changes like volume, mix, or scheduling without jeopardizing the entire chain.

Since then, SCOR (APICS, 2017) has become another well-known framework for supply chain architecture. This study builds on the classical SCOR framework (APICS, 2017), as it provides a stable and widely accepted process structure. While newer developments such as the Digital SCOR (SCOR DS) model extend the classical framework towards digitally enabled supply networks by incorporating capabilities such as real-time visibility, advanced analytics, and integrated data flows (ASCM, 2020), their primary focus remains on process standardization and capability maturity rather than on providing a coherent interpretive logic for performance measurement. In particular, SCOR DS does not explicitly address how digitalization alters the meaning and comparability of performance indicators across strategic dimensions, which further highlights the need for an integrated framework connecting strategy, processes, and digitalization.

Based on the SCOR framework, companies can structure their logistics processes according to best practices and use these processes to analyze their operations (Huan et al., 2004). While dimension-based approaches offer substantial strategic reasoning for their frameworks, they provide little guidance on how to break down the supply chain according to processes. Moreover, they lack explicit consideration of digitalization and its impact on performance. Process-based frameworks lack a coherent performance logic and fail to establish key trade-offs.

New research shows that digitalization accentuates this lack of logic even more. While digitalization allows for more data to be collected and more KPIs to be analyzed, companies lack the frameworks to attach heterogeneous meaning to these indicators on a strategic level (Werner, 2022).

This research gap builds upon prior literature on performance measurement frameworks and attempts to combine the logical setup of performance dimensions with a detailed breakdown of supply chain processes and the idiosyncratic effects of digitalization on performance (e.g. generation vs. interpretation). Furthermore, addressing this gap requires an integrated perspective that links strategic intent, process structure, and the varying role of digital technologies in shaping performance outcomes. Therefore, this study proposes a conceptual framework that systematically connects these elements into a unified structure for performance measurement in digitally enabled supply chains.

3. Digital sensitivity as a cross-cutting interpretive attribute

The most common misunderstanding we see when discussing digitalization and performance is creating a fourth bucket of performance called "digitalization." However, digitalization is not a performance dimension in itself - it should be understood as a means to an end. Baking it into a performance dimension risks incentivizing companies to make technology investments with no regard to their effect on efficiency or effectiveness. Also, aggregation is difficult as digitalization consists of constructs that are often very heterogeneous.

Several recent studies have shown the same regarding digitized supply chains - digital technologies are enabling mechanisms that shift how performance-related data is generated, available, and interpreted but are not actual performance dimensions of their own (Meier & Pfeffer, 2022).

Instead of expanding the number of competition dimensions, digitalization can be conceptualized as a superordinate mediating layer that changes how the raw information feeding into classic KPIs is generated, perceived, and interpreted. This allows us to keep the tried and tested R-O-F buckets while extending them towards digitalized processes (Büyüközkan & Göçer, 2018).

We define digital sensitivity as an interpretive attribute of performance indicators that

qualitatively describes the degree to which their conceptual meaning, measurability, and operational relevance depend on digital technologies and digital data infrastructures. This definition aligns with some of the newest research on performance measurement and controlling that argues performance indicators do not just have a value but also a context in which they are generated and should be interpreted (Schäffer, 2024).

It is an attribute, not a dimension. It describes how an indicator is measured within the already established buckets of R, O, or F. Its purpose is to help explain why an indicator has the value it has and where digitalization-related investments will yield the largest returns.

Digital sensitivity can thus be understood as an analytical lens that links technology to the interpretation of performance.

The chart below provides three distinct levels of digital sensitivity:

Level 0: Digitally independent indicators. These capture aspects observable independently of digital technologies. They were significant in pre-digital environments.

Level 1: Digitally supported indicators. These represent aspects whose accuracy or timeliness are enhanced by digital technologies. Digitalization alters the speed and granularity of feedback.

Level 2: Digitally driven indicators. These are fundamentally dependent on digital technologies and cannot be meaningfully defined without advanced connectivity or automation. They emerge as a result of digital enablement.

This typology mirrors the growing disaggregation of performance indicators seen in digitized supply chains and is aligned with recent studies that point out the diverse effects of digitalization on performance measurement practices.

Table 1 presents a conceptual synthesis of these levels. The examples shown above are non-exhaustive and should not be considered as a recommended set of KPIs. Rather, they are provided to help conceptually illustrate the distinction between the three levels of digital sensitivity.

By making a clear distinction between digitally independent, supported, and driven indicators, this approach enables finer-grained interpretations of performance changes when implementing digital transformations. For example, this allows organizations to avoid falsely attributing improved performance to operational improvements when in reality it is just a result of better measurement. Digital sensitivity does not introduce an additional analytical dimension but functions as a cross-cutting interpretive layer applied to each element of the framework.

Table 1: Conceptual levels of digital sensitivity for performance indicators in supply chains

Sensitivity	Description	Distinctive features	Illustrative examples
Level 0: Digitally independent	Conceptual meaning largely unchanged by digital technologies	- Measurable with traditional infrastructure - Low dependence on real-time connectivity - Stable interpretation across technological contexts	- Total logistics cost ratio - Fixed production capacity - Contractual delivery time from suppliers
Level 1: Digitally supported	Interpretation enhanced by digital technologies	- Improved accuracy and timeliness through digitalization - Same conceptual definition, better measurement - Faster feedback for decision-making	- Order fulfillment time - Forecast accuracy - Inventory turnover
Level 2: Digitally driven	Inherently dependent on digital capabilities	- Only definable/observable with advanced digital infrastructure - Reflects emerging capabilities of digitized systems - Did not exist as a practical metric in pre-digital environments	- Real-time end-to-end visibility - Data latency between links - Predictive maintenance coverage

4. Integrated R-O-F × SCOR framework with digital sensitivity as an interpretive attribute

Building on the theoretical foundations discussed above, this section introduces the proposed integrated framework for supply chain performance measurement in digitally enabled environments. The framework combines strategic performance dimensions, operational process structures, and digital sensitivity into a unified conceptual architecture.

4.1. Layered architecture of performance measurement

The overall view of our proposed framework presents itself as a three-layer structure, which conceptually ties together strategic performance dimensions with operational process structure and finally digital sensitivity. Figure 1 visualizes this relationship where performance can be read through WHAT is measured (strategic dimension), WHERE it is generated (process structure) and HOW digitalization affects it (digital sensitivity).

WHAT stands for the proposed R-O-F dimensions that serve as an interpretive logic for performance measures. WHERE follows the SCOR process structure (Plan-Source-Make-Deliver-Return) and describes where along the supply chain the generation of performance takes place. HOW is the cross-cutting interpretation criterion embedded in performance indicators and describes the character of digital technologies' influence on their measurement.

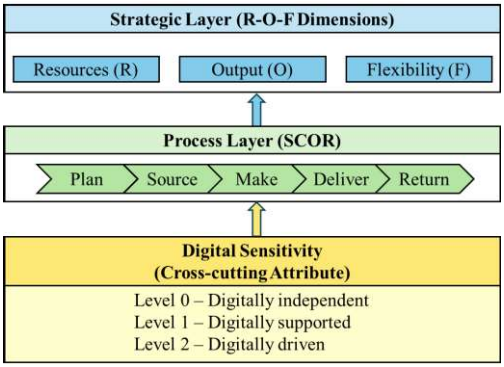

Figure 1: Conceptual layered architecture for performance measurement in digitized supply chain

Conceptual considerations suggest that establishing coherent performance measurement systems requires the integration of available data (HOW), operational processes (WHERE), and strategic interpretive logic (WHAT) within a unified framework. This is particularly important in digitally enabled environments, where the interdependencies between these elements become more pronounced. The three levels of digital sensitivity differentiate how digitalization affects the SCM performance construct.
This architecture emphasizes that performance emerges from the interaction between operational measures, procedural structures, and strategic dimensions, highlighting the systemic nature of supply chain performance (Lambert et al., 1998).

4.2. The R-O-F × SCOR matrix framework

The intersections define potential domains for performance measurement (Table 2). This matrix structure follows logic consistent with previous approaches (Chan & Qi, 2003; Persson, 2011), combining Beamon's (1999) strategic logic with SCOR process architecture.

Table 2: R-O-F × SCOR measurement space for supply chain performance indicators

	SCOR Process				
	Plan	**Source**	**Make**	**Deli-ver**	**Re-turn**
Resour-ces	R-P	R-S	R-M	R-D	R-R
Output	O-P	O-S	O-M	O-D	O-R
Flexibi-lity	F-P	F-S	F-M	F-D	F-R

Unlike other approaches, the proposed matrix incorporates digital sensitivity as an interpretive attribute rather than an additional performance dimension.

This allows explicitly distinguishing whether indicators are digital technology dependent. Furthermore, while providing a systematic structure for developing relevant indicators, the framework itself does not suggest concrete indicators but rather a conceptual measurement space. Accommodating these perspectives counteracts arbitrary KPI inflation criticized above and allows for intended flexibility (Shepherd & Günter, 2006; Taticchi et al., 2015).

Additionally, different stakeholder groups are supported by the framework since it allows positioning indicators systematically based on their strategic relevance, process attribution, as well as digital enablement, thereby promoting communication between management, controlling, and IT.

The comprehensive overview allows for gap analysis, trade-off assessments, and context-based prioritization. Digital sensitivity (0, 1, 2) holds true for each respective KPI within a domain.

4.3. Conceptual architecture of the measurement space

In this context, performance indicators are positioned along the integrated framework axes based on their SCOR process and R-O-F performance dimension, while digital sensitivity is treated as an interpretive attribute applied to each indicator. This allows for a more contextualized interpretation of performance indicators. For instance, forecast accuracy can be positioned in Resources (influences inventories) and the Plan process. Its level of sensitivity can be described as: using simple statistics (0); configured in an advanced ERP system (1); driven by digital twin technology (2). It is important to notice how granularity increases when digital components are factored into the performance indicator descriptions. With this positioning, it will be possible to discern if an improvement is driven by operational improvement, a measurement artifact, or a rebasing of the definition. This will be

particularly useful when assessing the impact of digitalization efforts.

Figure 2 shows an example of how performance indicators can be positioned along the integrated framework. The interpretation consists first of identifying the SCOR process where the indicator originates, then locating the indicator in the strategic dimension (R-O-F) where it belongs. Third, we assess the degree of digital sensitivity to understand how much and how digital technologies affect the measurement and interpretation of the indicator. This sequential interpretation enables managers to distinguish between operational improvements, enhanced measurement capabilities, and the emergence of digitally driven performance metrics.

This conceptual representation emphasizes three fundamental principles:

- Process orientation as the backbone.
- Strategic logic as an interpretive framework.
- Digital sensitivity as an analytical lens.

Together, these principles ensure that performance measurement remains aligned with both operational realities and strategic objectives, while also accounting for the transformative role of digital technologies.

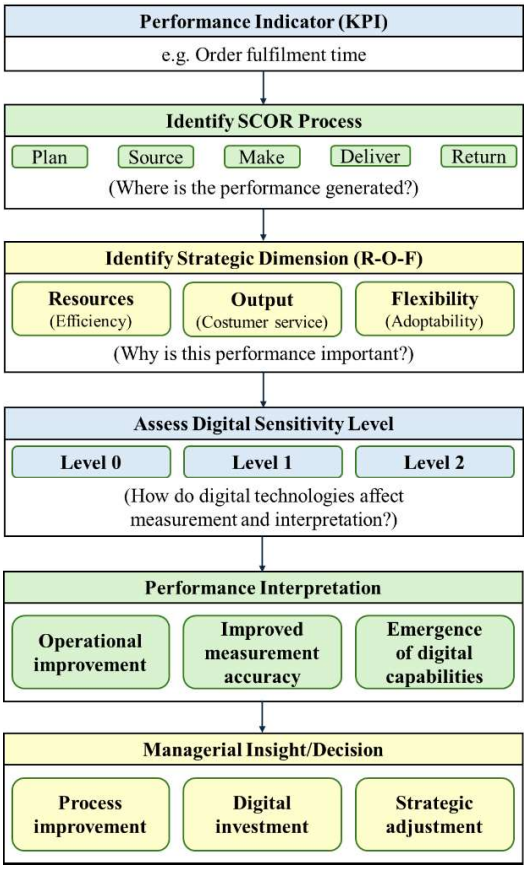

Figure 2: Conceptual architecture of the measurement space for digitized supply chains

4.3.1. Illustrative application example

This section presents four examples of how performance indicators can be positioned within the described conceptual framework. For reasons of illustration, we assume a manufacturing company with several tiers in its supply chain of industrial goods that aims at enhancing the logistics performance of its outbound supply, but wants to avoid tying up capital unnecessarily and retaining flexibility in operations.

Order fulfillment time is a rather classical performance indicator in the management of distribution. The indicator signifies the service experienced by the customer and is therefore located in the Output (O) dimension. Moreover, it is mainly related to the Deliver (D) process of the SCOR framework since it describes the effectiveness of outbound logistics flows. It can be reasonably argued that order fulfillment time remains conceptually the same when firms operate with low digital maturity, but that digital technologies help to track and measure it more accurately and in a more timely manner. Hence, order fulfillment time can be considered as digitally supported (Level 1).

Inventory turnover is another well-established performance indicator describing how intensively inventory is used in production and distribution. We can assign this indicator to the Resources (R) dimension and associate it most closely with Source (S) and Make (M). Similar to the previous example, digitalization mainly helps to track inventory turnover more accurately and in real-time thanks to ERP systems and digital tracking systems throughout the supply chain. Therefore, inventory turnover can also be assigned to digital sensitivity Level 1.

Capacity utilization of production equipment is another classical efficiency indicator that clearly belongs in Resource (R) and Make (M). Monitoring capacity utilization might be supported by digital technologies, but the definition of the indicator itself does not require them. Thus, we can assign it to digital sensitivity Level 0.

On the other hand, shipment visibility in real-time is an example of a digitally enabled (Level 2) performance indicator. Shipment visibility in real-time means that the status and location of shipments can be tracked continuously along the supply chain due to integrated digital systems. This KPI thus belongs in Output (O) and is related to Deliver (D). Of course, shipment visibility in real-time would not be definable without digital technologies. Table 3 summarizes the above descriptions and shows where these exemplary KPIs are positioned in the R-O-F × SCOR measurement space.

Table 3: Illustrative positioning of performance indicators within the proposed SCPM space

Performance Indicator	Strategic Dimension	SCOR Process	Digital Sensitivity
Order fulfillment time	Output (O)	Deliver (D)	Level 1
Inventory turnover	Resources (R)	Source / Make	Level 1
Production capacity utilization	Resources (R)	Make (M)	Level 0
Real-time shipment visibility	Output (O)	Deliver (D)	Level 2

Table 3 provides an overview of illustrative performance indicators and systematically represents their relationship to the R-O-F dimensions, the SCOR processes, and their level of digital sensitivity. The structured depiction will enable easier comparison to other indicators and support findings on their strategic position, process affiliation and dependency on digital technologies. This example illustrates how specific performance indicators can be mapped to the R-O-F × SCOR measurement space. Here, digital sensitivity has been allocated as an orthogonal characteristic. When used in conjunction with the strategy dimensions, SCOR process elements, and digital sensitivity levels, additional insights can be gained into supply chain performance. For example, it becomes possible to determine whether performance has improved due to operational enhancements, better measurement, or the addition of digitally enabled metrics.

4.4. Event-Conditioned Performance Interpretation

In fact, Khourshed and Beshr (2024) have shown that the lifecycle of SCPMSs should be assessed dynamically when facing unexpected events. These findings support our recommendation to continuously monitor and evaluate the performance measurement system, taking into account the current conditions of the operations. More specifically, within our framework, performance measures should be contextualized based on the current state in which they occur. For instance, under disruptions, efficiency metrics might no longer have any explanatory power, while responsiveness or resilience metrics may apply. Notably, this aligns with recent findings highlighting the need to focus on agility and resilience in digitalized supply chains (Bode et al., 2023).

5. Discussion

Saunila et al. (2024) empirically show that performance measurement systems do not create performance but merely allow for its influence, provided that governance is sufficient and managers take action. Therefore, this model should always be viewed as an interpretive framework and not as an engine for performance optimization. Interpretation enables supply chain governance and target alignment. Recent research on Supply Chain 5.0 performance measurement systems further emphasizes the need for integrating digital, strategic, and operational perspectives, highlighting existing gaps in current SCPM frameworks (Jouicha et al., 2025).

The developed framework contributes to theory by integrating strategic dimensions, linking process structures, and differentiating the impact of digitalization. Incorporating R-O-F into SCOR as well as digital sensitivity creates an appropriate common interpretive basis.

More precisely, the framework contribution addresses the identified research gap by directly connecting the three aforementioned disconnected building blocks: performance logic with a focus on strategy, process-related structures, and heterogeneous digitalization effects.

First, the developed framework can help to disentangle how performance is created by showing how digitalization shifts the interpretation (trade-offs) but does not replace any of the established dimensions. Additionally, this work contributes by explicitly incorporating the linkage between multidimensional performance constructs and process orientation and thus enabling fine-grained theoretical analyses (Chan & Qi, 2003).

In addition, digital sensitivity is a new analytical lens that allows explaining why certain performance indicators might react differently in systems with different levels of digitalization, thus extending previous SCPM work.

Last but not least, digital sensitivity addresses the literature gap related to the recognition of heterogeneous impact.

Practitioners can use this framework as guidance for organizing measurement systems in digitalized settings. Too often, practitioners select KPIs on an ad hoc basis. Building the framework around the three dimensions of strategy, process orientation, and digital sensitivity supports users in selecting suitable performance indicators based on what matters most.

For example, managers may use the framework for their structured decision support. Thus, managers ensure that decisions are based on KPIs that are aligned with corporate strategy. Controllers may use the framework to ensure consistency when evaluating corporate performance or discussing trade-offs between performance drivers. In contrast, data analysts and IT specialists can use the structure to bundle performance-relevant data in IT systems (Werner, 2022).

Managers should be aware that without aligning metric systems with strategy (R-O-F), organizations may drown in data but starve for insights. Similar thoughts are shared by very recent research showing that companies will have to balance data availability and information guidance of their performance measurement systems in order to make valuable decisions (Schäffer, 2024).

While digitalization might provide companies with ample data, without an interpretation through the R-O-F logic, these data do not become useful for creating valuable and strategic knowledge. However, using the different sensitivities allows users to better understand whether an improvement was driven by best practice in operations or solely enabled by digital technology. Knowing this allows managers to better evaluate proposed digitalization projects and ensure that resources are not allocated to technologies that do not address core performance trade-offs. In addition, using the framework allows users to structure conversations between functions. By linking strategy and KPIs to processes and data, users can establish a shared understanding across functions. Lastly, the matrix allows for discussing these trade-offs. By making corporate trade-offs visible, it allows management to make informed decisions on where to allocate resources and where to focus investment efforts. This framework should not be viewed as a one-size-fits-all approach; rather, it should be adapted to each industry (Christopher, 2016).

Therefore, it works for businesses in various industries and at different levels of digitalization. It can be used to support digitalization projects as well as sustain day-to-day business performance.

6. Conclusions and future research

Overall, this article has aimed to propose an integrated conceptual framework for SC performance measurement adapted to Industry 4.0. SCPM has been reinterpreted through a framework combining R-O-F dimensions and SCOR architecture under the perspective of digital sensitivity. In doing so, this article addresses gaps in current practices related to fragmentation and digital context issues. More particularly, this research addresses the literature gap highlighted in Section 2 by offering a unified conceptual framework capable of encompassing strategic performance dimensions, process-oriented performance structure, and the heterogeneous impact of digital technologies. Bridging these key elements not only strengthens SCPM's conceptual foundations by associating its strategic logic with process-oriented concepts but also provides a comprehensive space for performance measurement interpretation.

The main contributions can be summarized as follows: (1) reinterpretation of performance measurement in Industry 4.0; (2) proposal of an integrated R-O-F × SCOR framework; (3) introduction of digital sensitivity as a cross-cutting attribute of performance indicators within the SCPM framework.

Additionally, this study provides academics and practitioners with a means of structuring the alignment between performance measurement system design, organizational decision needs, and technological capabilities.

As with any study, there are limitations to be considered. First, this article proposes a theoretical framework supported by interpretative examples instead of empirical evidence. Second, this study does not provide a quantitative aggregation model; the dimension structure only facilitates a qualitative interpretation of SC performance. Lastly, the implementation of this framework needs to be contextualized depending on each industry.

In addition, it is important to note that the usefulness of this conceptual framework depends on its integration into decision-making processes and governance structures. After all, no matter how sophisticated a performance measurement system may be, it will not lead to performance by itself (Saunila et al., 2024).
Future research directions include:

- Empirical validation across multiple sectors to test the framework's applicability.
- Extension to emerging dimensions like sustainability and resilience within the R-O-F logic.
- Development of decision support tools based on the conceptual matrix.
- Quantitative operationalization, including the development of composite indices and scenario-based analysis to evaluate dynamic trade-offs.

Moreover, additional research could be conducted to understand how different levels of digital maturity can impact this framework, particularly for the operationalization of the concept of digital sensitivity.

This article provides future research with a structured conceptual background for performance measurement. The SCPM framework proposed here can serve both practical and academic purposes. On the one hand, it allows examining how supply chain performance can be defined and interpreted in the context of increasing digitalization. On the other hand, it can help managers, controllers, and data specialists make sense of the performance information they need to design their performance measurement systems and align them with organizational decision needs and technological resources. It is hoped that this framework will

inspire future empirical studies to test, improve, and adapt it to their practical contexts.

References

APICS. (2017). *Supply chain operations reference (SCOR) model* (Version 12.0). American Production and Inventory Control Society, Supply Chain Council. https://datafinder.ru/images/expert-bi/scor/scor-v12-0-framework-introduction.pdf

ASCM. (2020). Digital Standard for Supply Chain (SCOR DS). Association for Supply Chain Management (ASCM). https://www.ascm.org/corporate-solutions/standards-tools/scor-ds

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management, 19*(3), 275-292. https://doi.org/10.1108/01443579910249714

Bititci, U., Garengo, P., Dörfler, V., & Nudurupati, S. (2012). Performance measurement: Challenges for tomorrow. *International Journal of Management Reviews, 14*(3), 305-327. https://doi.org/10.1111/j.1468-2370.2011.00318.x

Bode, C., Bogaschewsky, R., Eßig, M., & Lasch, R. (Eds.). (2023). *Supply management research: Aktuelle Forschungsergebnisse 2023.* Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-42635-4

Büyüközkan, G., & Göçer, F. (2018). Digital supply chain: Literature review and a proposed framework for future research. *Computers in Industry, 97*, 157-177. https://doi.org/10.1016/j.compind.2018.02.010

Chan, F. T. S., & Qi, H. J. (2003). An innovative performance measurement method for supply chain management. *Supply Chain Management: An International Journal, 8*(3), 209-223. https://doi.org/10.1108/13598540310484618

Christopher, M. (2016). *Logistics and supply chain management* (5th ed.). Pearson Education.

Frederico, G. F., Garza-Reyes, J. A., Anosike, A., & Kumar, V. (2020). Supply Chain 4.0: Concepts, maturity and research agenda. *Supply Chain Management: An International Journal, 25*(2), 262-282.
https://doi.org/10.1108/SCM-09-2018-0339

Glistau, E., Coello Machado, N. I., & Trojahn, S. (2022). Logistics 4.0: Goals, trends and solutions. *Advanced Logistic Systems: Theory and Practice*, 16(1), 5-18.
https://doi.org/10.32971/als.2022.001

Govindan, K., Kannan, D., Jørgensen, T. B., & Nielsen, T. S. (2022). Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence. *Transportation Research Part E: Logistics and Transportation Review*, 164, 102725. https://doi.org/10.1016/j.tre.2022.102725

Gunasekaran, A., & Kobu, B. (2007). Performance measures and metrics in logistics and supply chain management: A review of recent literature (1995-2004) for research and applications. *International Journal of Production Research, 45*(12), 2819-2840. https://doi.org/10.1080/00207540600806513

Huan, S. H., Sheoran, S. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management: An International Journal, 9*(1), 23-29. https://doi.org/10.1108/13598540410517557

Ivanov, D., Dolgui, A., Sokolov, B., & Ivanova, M. (2019). Disruptions in supply chains and recovery policies. *IFAC-PapersOnLine, 52*(13), 355-360. https://doi.org/10.1016/j.ifacol.2019.11.146

Jouicha, Y., Cherrafi, A., Hamani, N., & Elfezazi, S. (2025). Performance measurement systems for Supply Chain 5.0: Gaps, challenges, and future research avenues. *IFAC-PapersOnLine, 59*(10), 2933-2938. https://doi.org/10.1016/j.ifacol.2025.09.493

Kaplan, R. S., & Norton, D. P. (1996). *The balanced scorecard: Translating strategy into action*. Harvard Business School Press.

Khourshed, N., & Beshr, M. (2024). Evaluating supply chain performance measurement system lifecycle during unexpected events. *Production & Manufacturing Research, 12*(1), 2345616. https://doi.org/10.1080/21693277.2024.2345616

Lambert, D. M., Cooper, M. C., & Pagh, J. D. (1998). Supply chain management: Implementation issues and research opportunities. *The International Journal of Logistics Management, 9*(2), 1-20. https://doi.org/10.1108/09574099810805807

Meier, K.-J., & Pfeffer, M. (Eds.). (2022). Produktion und Logistik in der digitalen Transformation: Analyse - Planung - Praxiserfahrungen. Springer Fachmedien Wiesbaden.

Persson, F. (2011). SCOR template - A simulation-based dynamic supply chain analysis tool. *International Journal of Production Economics, 131*(1), 288-294. https://doi.org/10.1016/j.ijpe.2010.09.029

Queiroz, M. M., Pereira, S. C. F., Telles, R., & Machado, M. C. (2021). Industry 4.0 and digital supply chain capabilities: A framework for understanding digital transformation. *Benchmarking: An International Journal, 28*(5), 1761-1782.
https://doi.org/10.1108/BIJ-12-2018-0435

Saunila, M., Ukko, J., & Jääskeläinen, A. (2024). The importance of performance measurement and management in sustainable supply chain governance among SMEs. *International Journal of Operations & Production Management, 44*(13), 229-250. https://doi.org/10.1108/IJOPM-06-2023-0492

Schäffer, U. (2024). Wie effizient darf es sein? *Controlling & Management Review, 68*(3), 3-7. https://doi.org/10.1007/s12176-023-1090-4

Shepherd, C., & Günter, H. (2006). Measuring supply chain performance: Current research and future directions. *International Journal of Productivity and Performance Management, 55*(3-4), 242-258. https://doi.org/10.1108/17410400610653219

Taticchi, P., Garengo, P., Nudurupati, S. S., Tonelli, F., & Pasqualino, R. (2015). A review of decision-support tools and performance measurement and sustainable supply chain management. *International Journal of Production Research, 53*(21), 6473-6494. https://doi.org/10.1080/00207543.2014.939239

Tjahjono, B., Esplugues, C., Ares, E., & Pelaez, G. (2017). What does Industry 4.0 mean to supply chain? *Procedia Manufacturing, 13*, 1175-1182. https://doi.org/10.1016/j.promfg.2017.09.191

Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing smart factory of Industry 4.0: An outlook. *International Journal of Distributed Sensor Networks, 12*(1). https://doi.org/10.1155/2016/3159805

Werner, H. (2022). Supply chain controlling: Grundlagen, Performance-Messung und Handlungsempfehlungen. Springer Fachmedien Wiesbaden.