

Exploring the supply chain and organizational interfaces between performance measurement systems and modern digitization

Introduction and background

There is a substantially increasing amount of research on new information technologies and digitization in the context of Industry 4.0 and supply chain management. The integrated technology field in supply chain management, especially multi-stakeholder and interorganizational technology, has seen a large surge in the past decade.

In previous decades, this interorganizational information and process technology was quite limited. For example, facsimile machines and electronic data interchange used to be the most common – peer-to-peer technologies. Internally, inventory management, materials requirements planning and demand management software integrated to form enterprise requirements planning (ERP) systems. The evolution to more integrated and broader systems emerged even further with the Internet and cloud computing receiving greater attention over the years. Eventually, incorporating middle-ware to advance this integration and interorganizational advanced planning and work flow management systems saw growth separately and integratively.

Recently, the advancements have incorporated the broader variety of emergent information and Industry 4.0 technologies that take advantage and integrate blockchain technology, artificial intelligence (AI), predictive analytics, mobile technology and the Internet of Things, cyber-physical systems and even quantum computing. The technological evolution and revolution continue. Realistically, we will not understand the revolutionary technological events faced until the future can thoughtfully look back over the generations.

Speaking of revolutionary technological development, Ray Kurzweil (2001) famously stated in his law of accelerating returns that exponential technological change has and will continue to occur and that . . . “the technological progress in the twenty-first century will be equivalent to the level of the previous 200 centuries.” That is, in the 21st century, we will be making 20,000 years of progress. Given that similar technological acceleration has occurred for a good part of the past 100 years, we need to be capable of managing in this dynamic technological and innovation environment in the future. Performance measurement will have to adjust.

These emergent technologies’ importance has substantial evidence through downloaded articles in blockchain technology, Industry 4.0, smart manufacturing and other digitization technologies in almost every journal supply chain, digitization and operations journals. We are also facing new emergent technology such as 5G and 6G, and quantum computing (Sarkis *et al.*, 2021), which will also contribute to performance analysis, big data and supply chain management. Some of the most currently downloaded papers, based on personal experience and websites of various journals with this information (e.g. *the International Journal of Production Research*), show these topics form – by far – the most downloaded articles and studies. In addition, performance measurement, organizational and supply chain are growing in importance as big data is central to the digitization revolution.

Performance measurement, another major theme of this special issue, has an even longer history. Managing the performance – for example of agricultural outcomes – was critical even



to the early history and probably prehistory of civilization. If community and group performance was not carefully monitored in terms of crops and inventory, whole populations can disappear due to famine. Recordkeeping and performance have been closely tied to human development over the millennia (Basu and Waymire, 2006). That is, performance measurement is not a new idea, even for supply chains. Health care performance – matters of life and death – such as health care performance can be traced to at least the 1700s (McIntyre *et al.*, 2001). It can easily be traced to a time period even before the existence of economics – a precursor to business and management fields – as a discipline. We are still learning about performance measurement for organizations and supply chains as technologies, business, geographical dispersion and other characteristics continue to add complexities.

Organizational and supply chain performance measurement saw growth as a discipline through the evolution of operations and technology development. In accounting and finance, performance measurement focused on financial performance – short term and long term. The argument that only using those categories as a performance measurement limitation goes back to the early years of this journal – *Industrial Management and Data Systems* (see Vollman, 1991). During these developmental periods, activity-based costing, total quality management, benchmarking and continuous improvement all had performance measurement and performance management systems as their underlying structures and systems (De Toni *et al.*, 1997).

In these early-modern (with respect to the operations and supply chain management domain), there was a call to explicitly integrate and consider operational and industrial performance measures and have them be aligned with strategic measures. The development of all-encompassing performance management systems with the linkage to data management systems became an important call in various studies (e.g. Bose, 2006).

The interface between performance measurement systems (PMS) and data management or information systems (IS) plays a relevant role in either success or failure in implementing and using PMSs (Nudurupati *et al.*, 2011, 2016; Bititci *et al.*, 2012; Bourne, 2005; Bourne *et al.*, 2004). Information technology (IT) has evolved considerably in the last 20 years expanding IS potential to automate PMS (Nudurupati *et al.*, 2011, 2016; Bititci *et al.*, 2012).

IS and IT evolution has included integration, which is part of the digitization efforts. In recent years, the big data and all IT evolution have widened the possibilities of developing and implementing information systems from a high volume of structured and non-structured data produced in high speed internal and externally to the organizations and their supply chains (Nudurupati *et al.*, 2016; Bititci *et al.*, 2012). Such changes require new capabilities to deliver more consistent analysis through the application of analytics and data visualization.

Supply chain performance measurement has traditionally been associated with internal management of procurement and purchasing (e.g. Wong and Wong, 2007) or with customer relationship management; in addition to internal operational issues such as inventory and production management. Evaluating suppliers was typically within the purview of the internal performance measurement system, even in cases of the Internet of Things (IoT) applications, were focusing the dyadic relationship (e.g. Dweekat *et al.*, 2017). When looking outwardly, it was again from the perspective of an individual organization, with 50% of measures looking inwardly and 50% looking outwardly (Papakiriakopoulos and Pramataris, 2010).

One of the understudied and limited areas of study for supply chain performance measurement systems is that of multi-tier supply chain performance (Maestrini *et al.*, 2017). Multiple stages and networks for performance management are extremely difficult. Given the emergent and integrated multi-stakeholder technologies and the emergent concerns of sustainability deep into the supply chain, there is not only the motivation but also the capability to address these concerns.

Building on these emergent topics, performance management has been facing new demands to comply with sustainability requirements as well as competitive pressures; broadening PMS requirements, designs and implementation. It is necessary to communicate performance information to different stakeholders in diverse formats and timeliness requirements. Therefore, it is essential to investigate the interface between performance measurement systems and digitization to provide better support to the several decisions makers as well as stakeholders.

There are various ways to combine integrated, information technology, digitization and PMS. First, digitization is an important SCM practice for providing operational performance. Second, digitization can be a tool that usage is important for communicating, controlling, measuring and managing performance systems within the supply chain. Third, digitization is also an important focus of new performance management dimension, such as environmental footprints and social responsibility, sustainable development. There is a big challenge for organizations and supply chains how to introduce and develop ITS, and how to integrate performance measurement systems and ITS.

The literature has not adequately addressed the topic. In the last eight years, two different journals on the operations management area have published special issues on performance measurement systems – the *International Journal of Management Review* (IJMR) and the *International Journal of Operations and Production Management* (IJOPM). IJMR and IJOPM calls were similarly titled–“Theoretical Foundations of Performance Measurement and Management Systems”. Therefore, none of the special issues on these topics explored the interfaces between the PMS and information systems – and especially not multi-stakeholder digitization technology linkages – even though IT has emerged as dual role, enabler and barrier to implement and review PMS.

This special issue introduction and background can be summarized – showing its partial complexity – in [Figure 1](#). [Figure 1](#) represents the various core topics and elements, as well as the surrounding contexts that drive the practice and research in the supply chain management domain. We have defined this as the research and practice ecosystem. Practice concerns would relate to competition, sustainability, globalization and a variety of other organizational and supply chain forces that set the context of much of the research and research questions. Research concerns may include theory and methodology that imply the existence of previous knowledge needed to complete the research. Themes and concerns are inside the outer ecosystem cycle. These themes – by no means exhaustive – appear at the nexus of the three core topics of digitization, supply chain management and performance measurement. These inform the potential research topics and concerns.

Potential research topics and concerns

We now consider the potential questions, topics and issues that partially form the scope of concerns covered in this special issue. A number of potential topics appeared within the original call for papers. Our goal in the call for papers – beyond identifying the motivation – was to provide the scope and encourage research study to consider these elements. We briefly delve into these topics – some of which we touched upon in the introductory discussion of the editorial – before introducing the selected papers included in the special issue. The original call for paper topic – as written – is in italicized font. For each topic, we provide a few thoughts on each and why we felt that these topics would be of interest and importance.

The relationships between information systems – such as interorganizational information technologies, Internet of things (IoT), blockchain, big data, industry 4.0, 5G technology – and performance measurement systems. This first category of topics is primarily at the organizational nexus of performance management, performance measurement systems and digitization technologies. The digitization of many supply chain and organizational

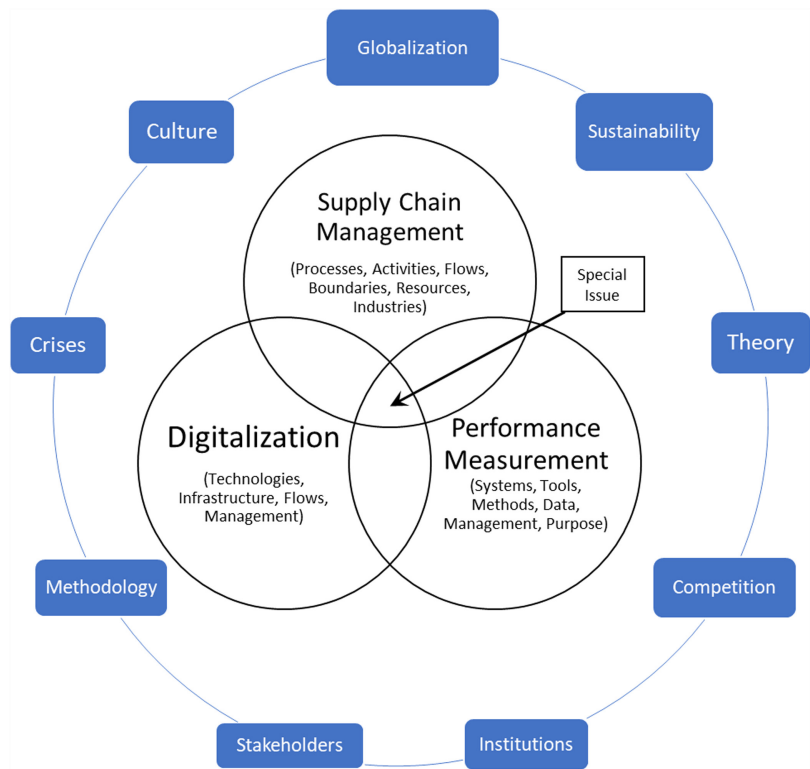


Figure 1.
The research and
practice ecosystem
associated with the
special issue and
context

processes and activities are meant to add and deliver value, but they also should be able to manage information, material and financial flows.

These technologies are complex and can be polysemous. This complexity and ambiguity make digital integration into complex PMS exponentially more difficult. But there are also possibilities from the relationships – whether they are process, influence or integrative relationships – to make the systems and operations more effective and efficient. These are relationships that require investigation. Design, operation and maintenance are only some example operational activities to be managed over the life cycle of these systems.

Relationships and characteristics of these digitization technologies to PMS can be linked to: (1) capabilities, (2) technological interoperability and (3) sustainability, financial and strategic results (Frederico *et al.*, 2021). Capabilities include types of characteristics and abilities that characterize each technology. For example, blockchain offers transparency, traceability, smart contract and security capabilities (Nandi *et al.*, 2021). The capabilities may offer opportunities that go beyond broad collection but exist for monitoring, validating and maintaining reliability of performance measures along the supply chain.

Technological interoperability considers how technologies can complement each other allowing for enhancement beyond a single technology for performance management. As an example, linking IoT, AI and blockchain can offer synergistic and complementary capabilities (Kshetri, 2019; Tsang *et al.*, 2021). The outcomes of the relationships are critical as well – in this case the outcomes may also include performance to determine the effectiveness of digitization and PMS. These can include financial, strategic and sustainability outcomes.

Potentialities and use of information systems, organizational and interorganizational, in performance measurement systems for supporting supply chain management: Supply chain processes can be broad and cover many activities and levels of management. There are both hierarchical and process systemic concerns that need to be managed. This linkage of digitization to supply chain performance measurement acknowledges that this linkage requires additional investigation, given the relative emergence of these topics in the broader operations, supply chain and technology management literature. The topic also implies the difficulties in researching these topics.

Methodologies that consider multiple relationships, measures and contexts will be required to effectively study these areas. For example, the sustainable supply chain and resilience perspective has complexities, where integrated performance measures supported by technology are needed (Negri *et al.*, 2021).

Use of information systems and digital technologies to improve new and evolving supply chain performance concerns: flexibility, collaboration, dynamism, transparency, relational capabilities and innovation performance: Performance measurement and management continues to evolve (Bititici *et al.*, 2012). The standard strategic performance measures of cost, quality, time and reliability evident in such models as the supply chain operations reference (SCOR) model (Dweekat *et al.*, 2017) continue to evolve not necessarily in the measure itself but who, where, when and what is measured.

The *who and where* may include measures that affect joint performance rather than individual activity or organizational performance. Joint performance may relate to identifying and building relational capabilities such as whether a relationship between a specific buyer or supplier provides greater returns (based on traditional measures) to both organizations simultaneously than other relationships (Ross *et al.*, 2009). Distributed nature of these multi-stakeholder technologies can acquire data from dispersed global regions as is available in blockchain and distributed ledger technologies (Saber *et al.*, 2019).

The *when* issue is based on temporal boundaries (Sarkis, 2012) for the supply chain. Digitization offers opportunities for quicker and more reliable information exchange. That includes acquisition, adjustment and reporting generation. Thus, although measures may have previously existed, the emergent environment allows collection of not only across and between organizations but can do so in a rapid fashion (Rezaei *et al.*, 2017).

What is measured is also evolving and digitization means the *what* can be very different. For example, emergent concerns of security, disruption and resilience means that potentially new measures are needed. One such example is the conceptual development around the *Zero Trust* supply chain (Collier and Sarkis, 2021). How would performance be evaluated in a situation where cybersecurity, safety and other sensitive concerns are to be monitored and managed? Given the COVID-19 crisis, these issues along with disruption and resilience performance are paramount concerns that need to be carefully monitored and improved – important roles for evolving PMS and digitalization.

Digitization and implications on emergent sustainable supply chain performance dimensions (economic, environmental and social): This topic is related to the previous topics of emerging concerns and measures but has been one of the most important initial aspects of sustainable supply chain management (Hervani *et al.*, 2005). The specific competitive and supply chain topic here is related to sustainability and the supply chain. In the past two decades or so, the importance and research in supply chain sustainability and performance measurement has increased dramatically (Beske-Janssen *et al.*, 2015; Nimsai *et al.*, 2020). With a continued evolution occurring as the United Nations' sustainable development goals (SDGs) get more attention in the practitioner and academic literature (Zimon *et al.*, 2020).

The general sustainability and sustainable development field also has nascent performance measurement advancements that could be adopted within supply chain and

enhanced with digital technologies. In fact, there is a disciplinary field that focuses on advancing ecological indicators with at least one journal dedicated to the field. One nascent accounting and measurement system is *emergy* (with an “m”) management and accounting with innovative application to supply chain management (Tian and Sarkis, 2020) and the circular economy (Alkhuzaim *et al.*, 2021). A difficulty with emergy accounting, as with other tools and techniques such as life cycle accounting, are the accuracy and difficulty in acquiring information to do these analyses. Digital technologies can be extremely useful to help in development of these metrics for supply chains but also for application to supply chains.

In the corporate sustainability governance literature, performance measurement has expanded to include environmental, social and governance (ES&G) performance dimensions (Wang and Sarkis, 2013, 2017). Financial information systems and organizations, such as Bloomberg, have digitalized various ES&G elements including some supply chain performance. Yet, ES&G data are relatively incomplete, inconsistent, with questions of reliability (Abhayawansa and Tyagi, 2021). Whether this reliability can be improved through the various multi-stakeholder technologies, and big data analytics is an open and important research and development question.

An especially pertinent area for sustainable supply chain performance evaluation is related to carbon gases or greenhouse gas performance of supply chains. In this case, the management of data and digitalization of in what has been defined as scope 3 (Li *et al.*, 2019) emissions is necessary for advancement (Diniz *et al.*, 2021).

Applications of digitization in performance analytics and measurement: This topic encourages not just theoretical developments but also use-cases and case studies in various application areas. Performance analytics was meant to encourage the use of descriptive, predictive and prescriptive analytics. That is, considering both past and future observations and recommendations. We envisioned that an important aspect to this category of topics would include the leveraging of big data (Comuzzi and Patel, 2016; Lopes and Martins, 2021).

We are aware of the broad industry applications for a number of these topics ranging from agricultural, insurance, hospitality, financial and utility industries, to durable products such as those in fast moving consumer goods, electronics and automotive industries. A number of these industries have been included in our papers, but applications play an important role in validation of conceptual and theoretical development and support.

Stakeholder involvement in integrating digitization and performance measurement systems: We have been using the term multi-stakeholder technologies as the major vehicle for digitization. Blockchain, IoT and cloud computing are example applications, where there is linkage to multiple groups of people and organizations, representing buyers, suppliers, developers, platform providers, communities, social agencies, individual investors and media, for example. Each of these groups and organizations represent different requirements and expectations (Sarkis *et al.*, 2021).

Thus, the use and application of any supply chain performance management digitization can have more than one group of stakeholders involved. Investigating the multiplicity of roles is needed. For example, adoption of these technologies for supply chain performance requires the trust, data supply and support of multiple stakeholders (Ageron *et al.*, 2020; Wei and Sun, 2021).

Empirical and decision support-based business models in integrating information systems and performance measurement systems to manage the complexities and potential paradoxes of these relationships: Empirical means models based on actual practice that can be utilized to explain various phenomena. In this case, we were thinking of prescriptive outcomes to help organizations further develop and integrate supply chain systems. Given the complexity of relationships that we observed in the other topics, the models are not likely to be simple and be able to support this complex decision making perspective. The literature for decades has been clear that managers do not wish to have complex models and that they be “simple,

robust, easy to control, adaptive, as complete as possible, and easy to communicate with” (Little, 1970). Guest editorial

Tools that are developed and deployed need to be accessible to managers while being robust and based on scientific principles. These characteristics are difficult to balance. Some of the “soft-computing” literature has sought out this balance, and these tools need to help inform and structure managerial decision making (Bai *et al.*, 2018). Models applied in case study situations are a specific way for these models to be empirically tested and validated.

These general topics were provided as guidance for contributors to provide a general idea of the scope of work we wished to include in the special issue. We kept the methodological boundaries and requirements quite general and encouraged qualitative and quantitative work. That included analytical predictive modeling to qualitative techniques for evaluation of case study data. We also considered both empirical and conceptual efforts. We felt that the evolving nature of the field required this flexibility.

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A bibliometric overview

We have provided a qualitative thematic and development background for the topics of this special issue. To provide a slightly more structured evaluation, we complete a high-level evaluation of the literature using the core and related terms from Figure 1 – supply chain, digitalization/digitization and performance measurement. We do not intend this to be an exhaustive bibliometric evaluation of the literature but only provide some general observations of the nexus. Only a select few graphics and results are highlighted here based on our exploratory analysis.

We use the Web of Science scientific index for building our database. We used Industry 4.0, smart manufacturing, digitization, digitalization (and variations), blockchain, Internet of Things, big data and information technology for the first major set using the “or”. Supply chain and logistics for the second term (using the “or”) for the second search term set. Performance meas*, performance indicator or KPI was used for the third set. The major sets were then tied together with an “and” search operator.

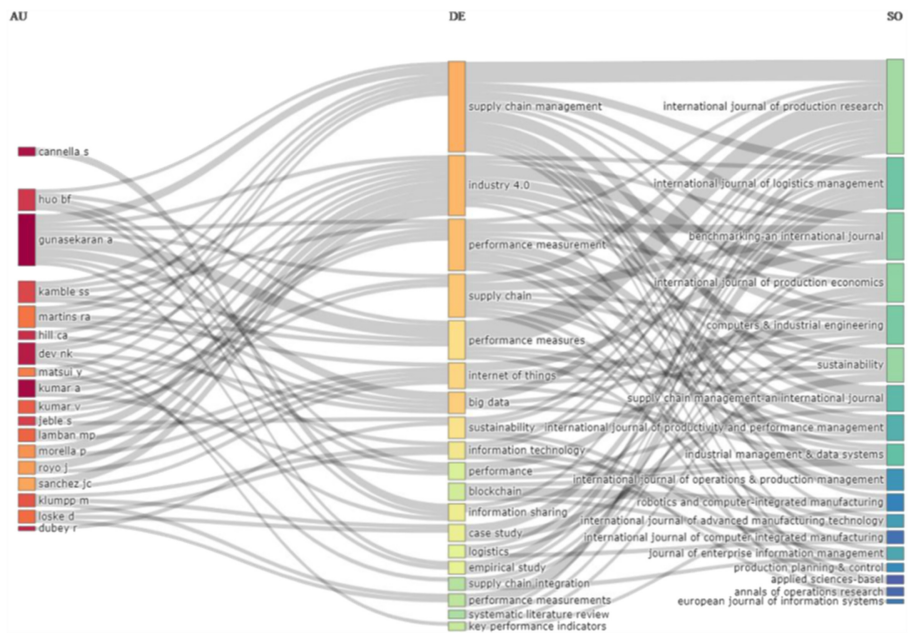
After some cleaning to only include peer-reviewed journal articles, we arrived at 195 papers that fit within our search string. We believe this to be close to the magnitude of articles at this nexus – again we just wanted to get a general feel of the field and it is not meant to be scientifically exhaustive.

The first result (not shown graphically) is that the earliest publication appeared in 1997 – which is well before the major review articles on supply chain performance measurement appeared. Since that time, as in most field and disciplines, the growth has been great with the preponderance of articles appearing in the last five years. This supports our contention that the field is emerging and growing.

We put in a Sankey-like chart to summarize the major authors, keywords and outlets (see Figure 2). As mentioned in our introduction, some journals such as IJPR had special issues around similar topics. Not surprisingly, the major keywords and topics included supply chain management (the most common term) and performance measurement (the third most common term). Supply chain and performance measurement also had slight variations in the next set of the top five. Clearly, these terms together would represent first and second major topics in our nexus. The term that seems to have gained substantive mention is “Industry 4.0”. Industry 4.0 is arguably the most recent term of the three to appear. Surprisingly, the older term of “information technology” did not appear as often.

Each of the major authors contributed to almost all terms. The one term that the major authors did not contribute is to blockchain supply chain performance measurement. This is an interesting result and may be due to the relative novelty of blockchain in this area, showing an opportunity for junior and less established scholars to pursue.

Figure 2.
The relationships and flows of authors, topics and publication outlets for the 195 identified publications at the nexus of digitalization, supply chains and performance measurement



Note(s): AU = Author; DE = Keywords; SO = Publication Outlet

The top journal is IJPR, which publishes a very large number of publications every year. So, this is not surprising. IMDS is listed in the top ten, but this is before the recording of the papers of this special issue. It is expected that IMDS is a natural home to this nexus of research and that the special issue will contribute to moving IMDS up the ranking of quantity and topics.

We completed a co-occurrence of keywords analysis to help us categorize various themes. This information results in thematic networks and are grouped using an algorithm of simple centers (Cobo *et al.*, 2011). The similitude is calculated from the co-occurrence of the keywords identified in the set of publications. These co-occurrence groups are the general themes. Themes are grouped into four categories, according to the algorithm. Figure 3 summarizes the themes and keywords. They include:

- (1) Motor themes (upper-right quadrant) are well-developed and important for the nexus research field;
- (2) Niche themes (upper-left quadrant) well-developed internal ties but unimportant external ties they have a marginal role for the development of research field;
- (3) Emerging or declining themes (lower-left quadrant), these themes are weakly developed and marginal and
- (4) Basic themes (lower-right quadrant) are important for a research field but not well-developed.

Let us take a close look at the motor themes. In these themes, we see three solidly developed and linked themes. The first one is more methodologically focused as regression, and logistic regression models played a large role in recent studies. These types of studies seem to also focus on performance improvement as an output measure. It is likely that these papers are

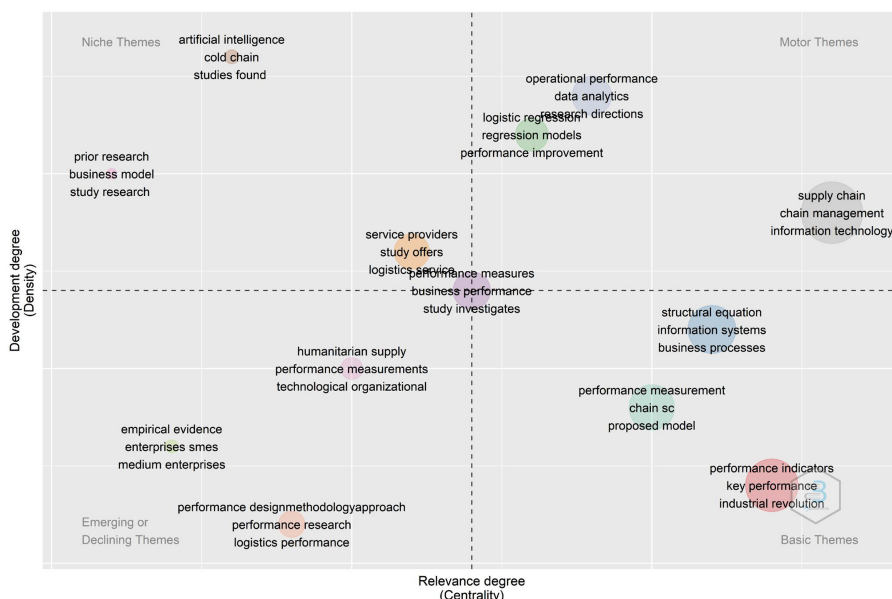


Figure 3. A thematic categorization of various keywords and topics for the 195 identified publications at the nexus of digitalization, supply chains and performance measurement

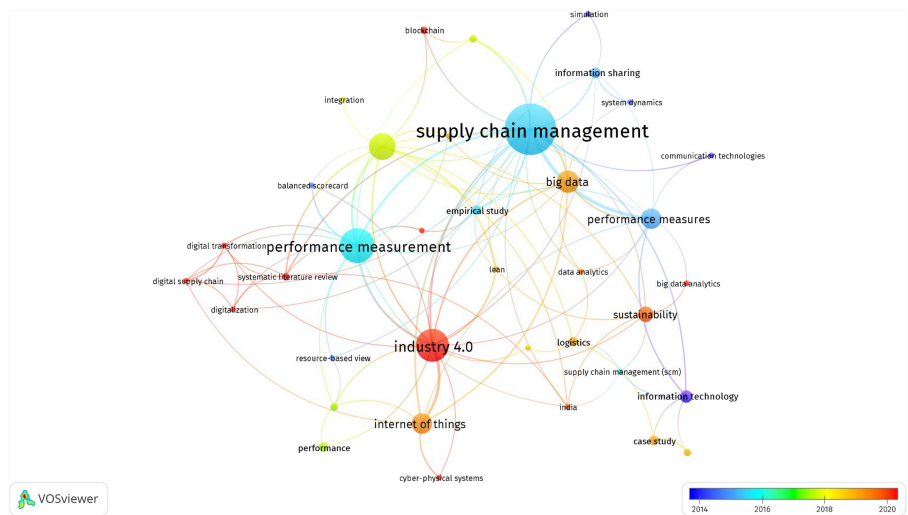
relationships between digitization and supply chain performance. Another grouping is about data analytics to evaluate operational performance as a research direction. These are core topics that are well-linked internally and externally. The last major motor theme is less surprising as the roles of information technology and supply chain management have existed and continue to be core topics.

Methodologically, in the basic theme quadrant, we see structural equation modeling is seeing a bit more development and relevance. This informs us that more robust and rigorous approaches are being used. The industrial revolution – with Industry 4.0 as the major relationship here – is also very relevant but less developed. It is likely that this topic will gain greatly and we shall see is well-connected amongst the current publications.

Figure 4 is the last bibliometric figure to give us a general overview of the digitization, supply chain and performance measurement research nexus. Figure 4 provides us at least three pieces of information – level of occurrence, relationships between keywords and the relative currency. We see that the most often mentioned keywords are the same ones we observed earlier with supply chain management and performance measurement/measures being the larger mentions. Industry 4.0 is one of the larger ones as well. These three also are well-linked in the relationships. Big data and IoT have also seen significant mention in the sample articles. Blockchain and various elements and descriptions of digitization are relatively lightly mentioned. But, this is where the “currency” of the topic comes into play.

The colors of the keyword nodes represent the relative currency. As can be seen by the color spectrum legend, redder nodes tend to be more recent, while blue and purple nodes are a bit older. Although the legend goes from 2014, earlier articles are also captured by the purple. The more recent topics include the aforementioned Industry 4.0, digital keywords and blockchain. These are clearly emergent topics having only received attention within the past four years. Older topics include information technology and simulation of the nexus topics. Supply chain management and performance measures have existed for a longer period of time within our special issue context. Ones that may be still emerging but are more recent are in yellow and orange and include big data, sustainability and IoT.

Figure 4. Relative importance, relationships, and currency of keywords and topics for the 195 identified publications at the nexus of digitalization, supply chains and performance measurement



We found that many submissions fell within the scope of what we proposed as topics and also emerging and more recent terms based on our general and truncated bibliometric analysis; there were also unique perspectives in the studies submitted. We now provide those publications that were able to make it through the peer review process in a timely fashion and appear in this special issue. Many solid contributions were submitted, but they may have required a little more effort to get support from the reviewers; we also wish to recognize these other works and hopefully many of them will appear in future articles in this field. Now, we provide an overview of the articles and our perspective on them and their relationships to each other and broader studies.

Papers in the special issue

The first paper of this special issue is titled “Enablers to supply chain performance on the basis of digitization technologies” (Gupta *et al.*, 2021). The title provides the major goals of this paper which include identifying the key enablers for digitization transformation and improving supply chain management performance. They rank these enablers using a quantitative ranking approach.

The enablers identified include big data analytics, IoT, blockchain technology and Industry 4.0. Within these major enabler categories, a number of sub-categories and factors are introduced. A total of 25 specific factors cover the four major categories. A concern with these categories is overlap, but the authors do a good job defining and referencing them. A series of experts are used to help evaluate the enabler importance, and they use the best-worst method (BWM) to accomplish this task.

The top two factors for managing the supply chain’s performance were data science capabilities and tracking and localization of products. These are capabilities and requirements characteristics that they felt would be most important across the supply chain. Some of the categories in this paper focused on specific technology or the capabilities that they offer. Although fitting into specific categories – they could be supported by a number of other categories – the experts probably saw these as important foundational aspects.

Although significant results were presented, the authors do present direction for future research such as broader studies and using correlative approaches to investigate

relationships. These latter approaches would include structural equation modeling. Another approach used by another study in our special issue is a tool that makes direct and explicit linkages and interaction such as DEMATEL or the analytical network process (ANP) – both of which have limitations as well.

The other side of the coin of enablers for improving supply chain performance – which include external and internal organizational dimensions – is the consideration of barriers with lack of enablers representing a barrier. In the next paper of this special issue “Barriers to big data analytics for enhancing manufacturing firm’s performance – a multiple case study,” (Raut *et al.*, 2021) the most important digitization dimension found by the first paper (Gupta *et al.*, 2021) is further evaluated.

Delving into the barriers of big data analytics using a joint analytical approach of Grey-DEMATEL and ANP is used. Evaluation for these types of managerial multidimensional studies have recently adopted a mixture of optimization and soft computing techniques. These techniques to solve complex problems were part of a special issue in IMDS from 2018 (see Tseng *et al.*, 2018) focusing on responsible consumption and production – which covered supply chain sustainability concerns, some of which are covered in this special issue.

This second paper (Raut *et al.*, 2021) studied fifteen big data analytics barriers. They were very closely tied to a focus on the India country context and across three interrelated durable product industries, automotive, machine tools and electronics industries. Using the literature, the authors found barriers that could have been grouped along organizational, technological and potential operational issues. Some were quite specific and operational, such as “lack of data storage facility”. Interestingly, this basic operational concern was found to be the largest barrier. Which brings into consideration on whether the authors could have separated the barriers into critical short-term and long-term dimensions. But not all industries had the same ordering of barriers, although similarities did exist.

Not only could there be variation across industries, but experts – of which 15 were used for this study – could have variations. This aspect of the study was not fully evaluated, but the consideration of this limitation is important. For example, the previous study relied on a smaller set of experts to arrive at their observations. One of the difficulties is selecting the appropriate experts, in this case all had over a decade to a quarter-century worth of experience.

An interestingly methodological step was to validate the initial DEMATEL results with an ANP approach, which validated the original DEMATEL results. It would have been interesting to vary the ANP weighting parameters to determine the sensitivity of the results, but that would have required significantly more space and time. As it is in this paper, the ANP description had to be shortened to be able to present these results in a single manuscript.

The lack of facilities was the largest overall concern, but some variations appeared across industries. It is not clear what the true impacts for each of these were. DEMATEL is advantageous in offering some explanations of relationships of cause and effect of factors and can be done easily in a visual context. In the end, the most prominent barriers across each of the industries were about uncertainty in long-term returns and benefits, issues that are very traditional, which both relate to long-term strategy.

The investment in big data analytics for manufacturing performance improvements can be quite substantial, especially if large in-house facilities are to be developed; also, it has been argued that poorly run big data analytics can cost organizations hundreds of billions of dollars (Corbett, 2018). Digitization shows that you need substantive infrastructure and technology investment; it is not just about have data tools and data science approaches, but acquiring, managing, storing, in addition to exploiting data. Thus, it is not just about how these systems can help monitor and manage supply chain performance, but performance measures of these interorganizational systems require significant examination.

We move from big data analytics as a digitization approach to one of the current “hottest” topics in supply chain digitization – blockchain technology (Kouhizadeh *et al.*, 2021; Sarkis *et al.*, 2021). There has been significant controversy about this multi-stakeholder digital technology, and similar to big data, as we discussed in the previous paper requires its own performance evaluation and how it contributes to the supply chain.

The next paper of the special issue, titled “Blockchain performance in supply chain management: application in blockchain integration companies” (Hong and Hales, 2021), investigates this issue of blockchain contribution and performance in a supply chain. They introduce a holistic performance assessment model including four criteria and 24 total sub-criteria. The four major criteria include: the natural environment – as opposed to a general competitive environment, economic and business, customer, and information factors.

The methodology in this paper also relied on DEMATEL, but not solely on that approach – which is similar to the previous paper which consolidated and contrasted with ANP. Hong and Hales (2021) also use a survey methodology and use principal components analysis (PCA) – an exploratory factor analysis – to support the DEMATEL evaluation.

The PCA confirmed that the factors used were valid and not just based on the literature categories. This step is usually missing from a significant portion of the DEMATEL factors evaluation studies. The results focus on the various *potential* performance contributions and relationships amongst performance from blockchain adoption. It will be interesting to see how well these experts believe that the various performance outcomes will occur.

The major contribution can arguably be the framework and not necessarily the results – as these may depend on industry, timing and various pressures faced by an organization and its supply chain.

The theoretical reasoning that grounds this work focuses on one of the more popular theories in supply chain management – relational theory (Dyer and Singh, 1998; Fu *et al.*, 2017). Systems theory was also argued as an underlying theoretical perspective. Supply chain performance may be considered systemically and can have complexities and feedback. The argument is that systems allow for consideration across multiple organizations and can include a system-of-systems and sub-systems (Ackoff, 1971).

The blockchain performance supply chain measures identified by Hong and Hales (2021) in this special issue include environmental measures, the natural environment and performance measures. The next article in this special issue digs deeper into these ecological concerns and relationships to supply chain performance measurement in a digital era.

The next article targeting ecological concerns is titled “Green sourcing in the era of industry 4.0: towards green and digitalized competitive advantages” (Mohammed *et al.*, 2021). This case is focusing primarily on the upstream supply chain. Similar to other approaches in the other studies in this special issue, the multidimensional nature of evaluating suppliers for a sourcing decision has to be made.

The authors focus on three dimensions of criteria – a characteristic of the other papers with similar consideration where higher-level criteria are also decomposed into sub-criteria. Typically, when we consider greening and sustainability dimensions the focus is on the triple-bottom-line of economic, social and environmental dimensions (Elkington, 1998). Reviews of digitization activities as Industry 4.0 amongst supply chains and greening have been completed, but performance measurement was not well-developed or mentioned in the various reviewed studies (e.g. see Birkel and Muller, 2020).

In this paper, Mohammed *et al.*, 2021 introduce the three dimensions in their evaluation as operational, environmental and digitization factors when evaluating suppliers. Given the uncertainty and multidimensionality of these situations, the use of soft-computing methodological approaches (Tseng *et al.*, 2018) are used. In this case, a fuzzy multi-objective optimization on the basis of ratio analysis (f-MOORA) approach is utilized. Thus,

the contribution is two-fold: the first is the consideration of digitization as a supply selection category and the second is methodological introducing f-MOORA to a decision.

No underlying organizational or supply chain theory is utilized in this study, unlike some of the other studies that have included discussion of organizational theory (resource-based view, systems theory) or supply chain theory (relational theory). They do utilize some elements of fuzzy set theory and sustainability theory, but do not explicitly identify these as theories in the traditional sense.

The practical proof-of-concept for this study is completed for a food processing company in Iran. In this case, two managers were included in the decision environment. A total of 10 factors across the three decision dimensions are used in the illustrative example.

Overall, the consideration for supplier sourcing selection has been multidimensional. The supplier selection literature has utilized technology, along with business and other factors (e.g. see [Sarkis and Talluri, 2002](#)) and extensively included in greening and sustainability supplier selection (e.g. [Govindan et al., 2015](#)). In this case, digitization has expanded to interorganizational technology through Industry 4.0 and other technologies and the work continues to expand along this domain.

The next paper in this special issue is titled “The Organizational Collaboration Framework of Smart Logistics Ecological Chain: A Multi-case Study in China” ([Liu et al., 2021](#)). Like the previous article, it is ecologically focused but not in the same way, as a performance measurement. It uses the ecosystem, or ecological, analogy for upstream and downstream ecologies of organizations and activities that may be influenced by digitization.

This article ([Liu et al., 2021](#)) does considers the China context, which happens to also be the region evaluated in the final paper in this special issue ([Sun et al., 2021](#)) which we review next. The major theoretical contribution of this work is building on previous supply chain collaboration theory that essentially purports that greater collaboration in the supply chain can build competitiveness for a supply chain ([Soosay and Hyland, 2015](#)).

The article uses a qualitative case study approach – unlike the previous studies in this special issue rely on quantitative analytical techniques. Their core evaluation is a comparative analysis for each case company, there are four companies in their sample and the six relationships.

The primary and central construct of their framework for smart logistics – defined by digital capabilities and considered to be part of the Industry 4.0 and smart factory initiatives ([Rauch et al., 2019](#)) – is digital empowerment of the ecological operator. In this case the ecological operator means an agent within the logistics activities.

The authors investigate through a comparative analysis the linkages of five hypotheses linked to the core digital empowerment construct. In this case, smart technology, competition and customization are the major antecedents (where customization is a proposed negative relationship). The digital empowerment construct is hypothesized to directly influence collaboration and information sharing. There is also an indirect influence of digital empowerment to collaboration, mediated by information sharing.

A series of hypotheses are formed and may be testable at a future stage. The literature and the case studies support the theoretical direction and causation. It would be interesting to see if this study’s hypotheses hold. Interestingly, information process theory or organizational information process theory (OIPT) could have been used in this instance, given the similarities in relationships and constructs (e.g. see [Liu et al., 2015](#); [Wei and Sun, 2021](#)).

Although positioned in China, the general theoretical relationships are likely to hold given the generalizations from the literature. As is well-known the limitation of case study qualitative research is the issue of generalization, but on the face and based on the development in this paper, the theoretical model does offer a generalization that go beyond China.

Although performance in terms of collaboration level may be determined for the supply chain – collaboration scales and instruments do exist given the early developments of

collaboration theory. The other constructs are relatively new but also would need to be measured. This study can inform various scales for digitization and by extension performance measures. Scale development and confirmation are critical for research (e.g. [Zhu et al., 2008](#)); but also for benchmarking and performance evaluation. Scale development is a critical issue that is required for many of the emergent digitization technologies, especially if organizations wish to evaluate their performance and supporting performance within the supply chain. These qualitative studies can inform performance and scale measures that incorporate logistics, digitization and coordination.

The last paper in this special issue focuses even more specifically on China. The title of the final paper in this special issue is “Do China’s power supply chain systems perform well? A data-based path-index meta-frontier analysis” ([Sun et al., 2021](#)).

In this paper, [Sun et al. \(2021\)](#) return to analytical methodologies to evaluate performance. The methodology used based on data envelopment analysis (DEA) one of the most popular benchmarking and performance analysis tools on the market which has been used in thousands of studies under hundreds of variations.

One of the more recent variations is utilizing a multi-stage and network DEA models for performance evaluation of supply chains ([Chen and Yan, 2011](#)). In this case, the authors in this study utilize a meta-frontier model based on DEA to evaluate the power system supply chain in China. It is based on the broader family of two-staged network DEA models. The interesting aspect of this model and study is to decompose the DEA result to consider intermediate performance of variable that flow between the stages.

Two-stage DEA models can consider first stage performance, second stage performance or overall performance. The model proposed in this study considers the variables that are hidden between the two stages (in this case power generation sub-systems and power retail sub-systems). The authors present a robust model which – although applied to one case here – has multiple potential applications in other situations.

Of course, the limitation is being able to structure the two-stage models, so they can theoretically and practically make sense. In addition, the selection of inputs and outputs at the multiple stages needs to be considered very carefully and can be heavily dependent on data availability.

In fact, a whole special issue could have been devoted to developing and applying DEA to digitization performance in the supply chain. They mention that the digital aspects of the production technology are implicit. Although not explicit, they can also digitize the data capture, as mentioned in an earlier big data evaluation.

Conclusion

In this editorial, we provided background on the development and importance of this special issue on supply chain, performance measurement and digitization. We then provided some insights into the various topics and themes we thought may be covered in this special issue. We related these topics to the emergent literature, both within and outside IMDS published studies. To further confirm the broader perspective of the themes and topics, we completed a relatively truncated – high level – bibliometric analysis of the topics at this nexus. We identified the relative importance, relationships, emergence and currency of the various keywords. The bibliometric analysis was only meant to give a general snapshot, not an exhaustive review of the literature but even then 195 articles at the nexus were found.

We then introduced and reviewed the various articles in this special issue. The purpose was not only to introduce the topics but to provide some critical analysis of the importance of the topic, methodology used and theoretical perspectives administered. One major finding is that more theory development and integration was needed. Some papers mentioned basic theory, while others left us with guessing at the major theoretical

foundations – at least guessing from an organizational or supply chain theoretic perspective. That is, significant room for theory building and testing is still needed in these papers, but overall as well. Interestingly, even in the bibliometric analysis few theoretical perspectives emerged.

We did see that from a methodological perspective, analytical approaches emerged to aid in decision making. These formal models fell into the soft-computing area. What seemed to be missing from our study, but needed more fully, are broader empirical studies. Each of the papers in the special issue introduced some empirics, but the data sample sizes were relatively smaller. This is very likely due to the relative recency of the topics that are still evolving. Clearly, broader and more rigorous empirical studies are needed to help in theory building and testing.

In our final concluding statement, we wish to show our appreciation to the editors-in-chief to entrust us with this topic and managing this special issue. We thank the reviewers who volunteered their valuable time to help use deliver this special issue. Finally, all the contributors, both those published and those who submitted to help us provide the readership of IMDS some insights into this important topic. We are especially appreciative of all these contributors because this special issue was organized and completed during one of the most devastating crises in history. We wish everyone good health as they read through this special issue.

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