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TDK Research Article

**A Comprehensive Model for the Assessment of Digitalization
Transformation in Supply Chain Management**

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ABSTRACT:

The evolution of digitalization transformation has become integral to supply chain management (SCM) in the era of Industry 4.0, which organizations seek to build up for their competitive advantages. While numerous literature reviews address the transformation context, few reviews indicate the comprehensive digitalization transformation process till its application. This research aims to validate the self-proposed model by the author based on the premise Systematic literature review of 284 articles from Scopus and Web of Science databases. This model outlines a streamlined process of a digitalization transformation, beginning from data management to the integration of technology enablers, then ultimately contributing to decision making or consultation for SCM. The study provides three primary metrics to assess the model including readiness, adoption, and digital maturity with the aim of navigating companies' digital project in three different stages. A mixed-methods approach will be conducted on qualitative interviews and quantitative survey with SCM experts. Thematic analysis will be employed to extract and synthesize insights from the qualitative data, while correlation analysis and cluster visualization techniques will be applied to evaluate the survey responses. These semi-structured interview questions and survey questionnaire have been developed as part of the ongoing data collection process. The research design of the study provides an approach for model validation along with a process for companies to evolve their digitalization transformation, based on both expert perspective and the existing literature.

Keyword: Digital Maturity, Readiness, Adoption, Model design, Digitalization Transformation

1. INTRODUCTION

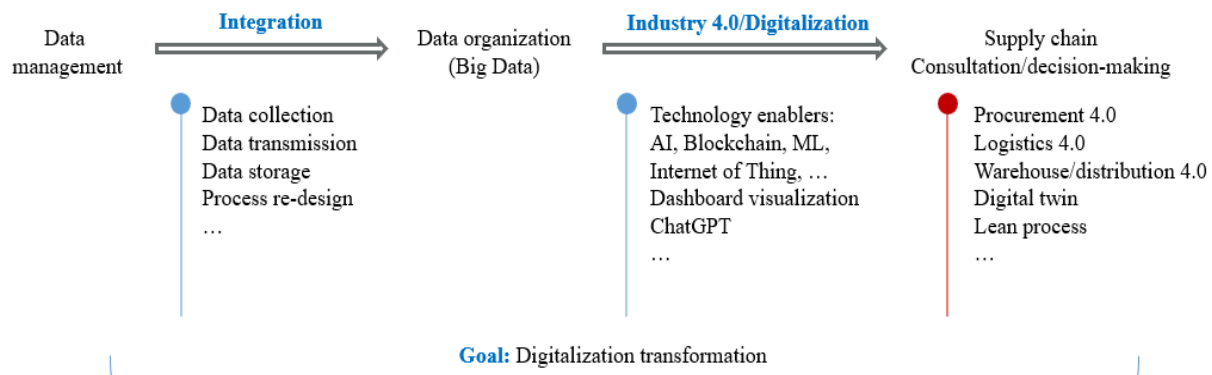
Organizations currently move their competitive position to the digital realm where the supply chain capabilities and visibility are positively impacted by its development (Huang et al., 2023). Top management allocates their resources and investment toward dynamic digitalization initiatives, with the aim of strengthening the entire value chains to implement Industry 4.0 advancement for their businesses. Such direction systematically shaped a digitalization world. (Pérez-Moure et al., 2024) Evident by the fact that the digital evolution of lean thinking enlarged an end-to-end visibility of the organization's value chain, which lead to a widespread and intensive network of potential Supply Chain Collaboration. A favorable environment empowered by digitalization can be seen through several diversified supply chain (SC) activities such as digital order process, delivery tracking, supplier real-time management, lean material, and informational flows. (Pekarcikova et al., 2020)

However, this transformative journey proves a complex and high demanding management as well as execution to catch up with the global evolution pace. Meanwhile, the evolution of Digitalization transformation and Industry 4.0 in Supply chain management (SCM) will continue going beyond what can be expected and even changing in chaotic circumstances. The premise research paper titled "The evolution of Digitalization Transformation and Industry 4.0 in Supply Chain Management: A Systematic Literature Review" by author had affirmed the profound impact of

embracing this evolution throughout the systematic literature review with the database of 284 articles from Scopus and Web of Science sources. A dynamic digital SC landscape grows sustainably being captured by not only scholars and researchers but also implemented in real cases by corporations.

Regarding the study of 284 articles for secondary data, the author built up a digitalization transformation model which offered a structured approach toward the digital process or project within company's SC operation. The model was generalized based on empirical cases and literature practices review applying to supply chain management and operations.

Figure 1: Digitalization transformation conceptual model proposed by author.



Source: Author's own creation

The author developed a model covering the process of digital projects specifically to enhance the supply chain consultation and decision-making function. Through the Systematic Literature Review (SLR), cutting-edge technologies have been progressively permeating industries worldwide. Concurrently, researcher and practitioner delved into the research area of the emergence and embedded of Artificial Intelligence (AI), Machine Learning (ML), Cloud service, Internet of Thing (IoT), Block chain, and other technology enablers (Malik et al., 2023), which all started from data management. Furthermore, to optimize the utilization of these technology enablers, users must prioritize data privacy and security, mitigate legal risks, upgrade IT infrastructure for robust big data management, which can be a part of investing and adopting the data protection digitization. (Hsu et al., 2022) After data management and data organization, several innovative concepts are being evolved within the “factory of the future” framework. The majority of them insist on integrating new technologies to address the industrial problem promptly by employing decision aided tools, robots, algorithm from AI/ML, automation, etc. (Dossou, 2019) Most of the cases of enterprises' digitalization adoption included these elements. First is managing the whole value chain data and organizing them in the Big Data Lake, followed by integrating them into selected technology advancements, and ultimately streamlining for decision-making process within the SCM. From the previous SLR, the author outlined the transformative process indicated in Figure 1, transitioning from data management to data organization, then integrating Industry 4.0 technology to achieve SC 4.0.

This paper aims to design a conceptual model to validate the author’s self-proposed process and navigate company digitalization transformation journey.

Two research questions (RQ) are developed from the article objective:

RQ1: How does the self-proposed model represent the current practices in digitalization transformation?

RQ2: What key metrics can be used to assess the transformation of a digital SCM project?

The paper will conduct a comprehensive model review to assess the digitalization transformation process throughout 5 sections. The research methodology is presented in Section 2, with a detailed explanation of how the author plans to achieve the research aim. Relevant literature is reviewed in Section 3, clarifying the research model. Narrative summary study is conducted in Section 4, which answers some parts of RQs and how they support the data collection later. Section 5 and 6 will conclude the paper and give out the future direction for fellow researchers.

2. LITERATURE REVIEW

2.1. Model related works

In this section, the author provides a comparison among models developed by prior scholars and researcher, giving an easy understanding of how the digital world immerse in SC management and operation activities.

Table 1: Existing digitalization transformation models.

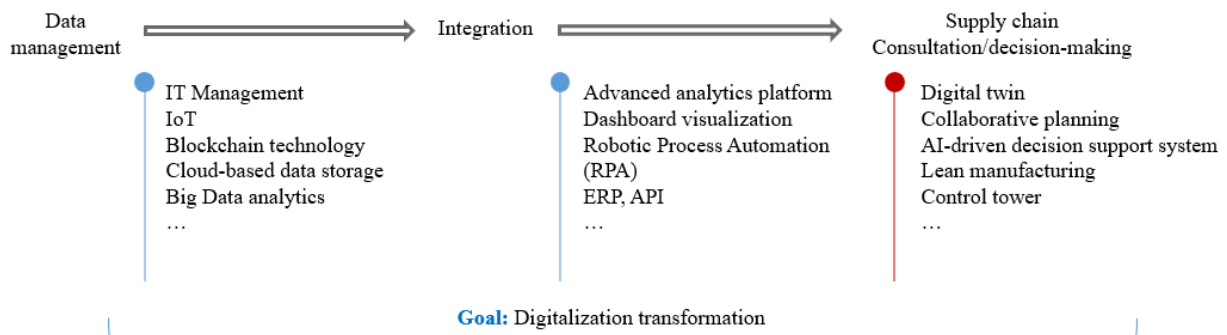
Model Name	Source	Assessment
Digitalization logic: from the emergence to manifestation	(Herold et al., 2021)	- Emergence (Collective theorizing) – Adoption (Active learning) – Manifestation (Catalytic amplification) - Model is presented along with time periods by primary events, clarifies how and why digitalization has been adopted, emerged, and manifested in logistics and supply chain realms. - Future development: The model lacked a deeper understanding of “first mover” companies, the connection between firm-level and field-level changes, and comparison among different industries.
Generic phases of the proposed reference model for data provision processes	(Wang et al., 2020)	- Clarify need – Data acquisition – Data application. - Sub-model provided detailed data sets, scaling data with different dimensions that can be stored in various storage locations such as warehousing data - Future development: The model’s stages purely provide data flow within business activities; it needs to be further aligned with technological solutions.
Conceptual schematization of an emerging practice	(Culot et al., 2024)	- Digital technology – Business process – Impact on performance - 87 digital technologies were considered, classified in 11 macro-categories, analyzed the influence that digital cases/practices deliver in SCM.

		- Future development: Promising area for SC managers to address the future strategy
CAB ² IN model for SSCM in the digital era	(Liu et al., 2023)	- Knowledge – Data – Decision A complex model presents two closed-loop frameworks: physical and digital supply chain, integrates Cloud Service, AI, BDA, BT, and IoT to achieve a sustainable SCM (Society, Economy, and Environment). - Future development: group researchers plan to develop specific algorithms for quickly transferring data into knowledge and decision.
Conceptual Model of Data-driven decision making in the manufacturing Industry	(Chavez et al., 2022)	- Business activities – Enablers – End goal - The models offered a closed loop of three interconnected elements, correlated with each other by transferring data, value and operations among them. - Future development: the study has not delved into research area regarding detail metrics for the exploration of data-driven decision-making (DDDM) model.
Conceptual framework for the identification of influential contexts of the adoption decision	(Simoes et al., 2019)	- Knowledge – Decision – Adoption/Rejection - Model surrounded by technology/ innovation context, external/environment context and internal/organizational context. Internal context is exposed by structural determinants, receptiveness, and readiness => need to provide the ability to identify the type of influence (positive or negative) of each factor in the adoption decision.
Reconfigurability using Industry 4.0 principles	(Mantravadi et al., 2023)	- Manufacturing execution systems (MES)/manufacturing operations management (MOM) – information technology (IT)/operational technology (OT) integration – Industry 4.0 supply chain (reconfigurability – manufacturing flexibility) - The model was analyzed on a smart factory capabilities flow, later elaborated in a hierarchy step how to enable Industry 4.0 with IoT connected MES/MOM. - Future development: the model conceptual has not been evaluated in the company's system.
Digitalization of management network driven by efficient decision-making	(Zhang & Xiao, 2023)	- Motivation – (Digital resource acquisition – Structured digital resource – Digital resource integration – Digital capability formation) – Value creation - The model classified the digital process as one block related to digital project which was explained by the mechanism of digital transformation of enterprises that it is different under different transformation motivation. - Future development: The paper initially focused on the motivation analysis within one single industry, subsequent research area will be investigating how enterprises from various industries collectively affect the whole SC.

Source: Author's own creation

The list of models review table 1 introduced different approaches to digitalization transformation by researchers. As can be seen from the highlighted dimensions in every single model, the key themes are data, decision-making, and digital technologies. While these dimensions are consistent, the application and objective of each model moderately vary. Notably, the detail model namely “CAB2IN model for SSCM in the digital era” of (Liu et al., 2023) provided comprehensive framework starting from IIoT interconnectivity to industry 4.0 SC, going through layers including: data sharing & information flow, reconfigurability, process digital twin, distributed control, and digital modularity. Or “Reconfigurability using Industry 4.0 principles” of (Mantravadi et al., 2023) model analyzed full aspects of SCM facilitated by various technology enablers. Among these, the digital resource arrangement process model by (Zhang & Xiao, 2023) is the most closely aligning with the author's model and their perspective of digital transformation mechanism is true for every model. Through a synthesis of existing models, the author refines the self-proposed process to the new one illustrated in below figure 2. Data organization is considered as part of data management and integration is the second main stage of the transformation. Additionally, business at different stages will utilize digital resources according to different needs, formulate corresponding digital capabilities, and unique values (Zhang & Xiao, 2023). Therefore, technology enablers will not only appear in second stage but also depends on the operational and strategic demands of the digital environment shaping the SC activities.

Figure 2: Improved Digitalization transformation conceptual model proposed by author.



Source: Author's own creation

2.2. Model structure

Following the dimension formulation, the author derived concept relevant for the model structure and assessing its theoretical and practical implications. To facilitate different analyses of Industry 4.0, (Schumacher et al., 2016) developed a digital maturity model with 62 items covered by 9 dimensions. The evaluation process involved transparent calculation based on individual items and obtained the transformation level of one dimension. Regarding the author's own model, the conceptual framework acquires a similar structure, assessing the model from general dimension down to specific items. Below existing literature for items in Table 2 briefly indicates the targeted functions within one dimension, though it may overlook the potential cross-dimensional contributions of these enablers.

Table 2: Dimensions and exemplary items of Digitalization transformation Model.

Dimension	Items
Data management	IT Management IoT Blockchain technology Cloud-based data storage Big Data analytics
Digital Integration	Advanced analytics platform Dashboard visualization Robotic Process Automation (RPA) ERP, API
Supply chain consultation/ decision-making	Digital twin Collaborative planning AI-driven decision support system Lean manufacturing Control tower

Source: Author's own creation

Data management: refers to the stage at which enterprises process the organization data for digitalization activities.

IT Management: supports the decision-making process by collecting the information, transmitting and making it available for the organization (Ganbold et al., 2020)

IoT Sensors and Devices: network available for collecting real-time data about diversified SC activities such as inventory levels management, levels of the equipment and environment, detection and reaction to disruption, etc. (Belli et al., 2019)

Blockchain technology: ensures data integrity and transparency by generating robust decentralized data management as well as transactional infrastructure. (Chaouni Benabdellah et al., 2023)

Cloud-Based data storage: offers mechanisms monitoring throughout communication, data storage and computational functions, enabling collaboration efforts across different sites/chains. (Talhi et al., 2020)

Big Data analytics: sets up models based on large quantities of dynamic data coming from various sources, to make predictions and calculations for various parameters such as estimated production capacity, cost of operation or carbon footprint, manufacturing planning, etc. (Liu et al., 2023)

Digital Integration: refers to the stage in which enterprises implement specific technology enabler for specific digitalization objectives.

Advanced analytics platform: provides predictive analytics and machine learning algorithms that could analyze large datasets to forecast demand, optimize inventory, and identify potential disruptions. (Liu et al., 2023)

Dashboard visualization: platforms such as Tableau or Power BI provide real-time, interactive dashboards for monitoring key performance indicators (KPIs) and making data-driven decisions. (Alicke et al., 2022.)

Robotic Process Automation (RPA): automates repetitive tasks such as order processing, invoicing, and data entry, improving efficiency and reducing errors. (Alicke et al., 2022.)

ERP: the Enterprise Resource Planning (ERP) unifies the existing modules and systems on an organization level, making it match the current needs and preparing for upcoming changes in technology and process. (Hwang & Min, 2013)

Supply chain consultation/ decision-making: refers to the stage that make decision or consultation for supply chain operations based on the digitalization transformation.

Digital twin: simulates a virtual manufacture, providing analysis possibilities of different scenarios to support operation planning or decision-making (Patil et al., 2024)

Collaborative planning: enables real-time collaboration among different stakeholders such as suppliers, manufacturers, and distributors for forecasting, production planning, and inventory levels managing. (Ramanathan & Ramanathan, 2020.)

AI-driven decision support system: analyzes historical and real-time data to provide valuable insights for making decisions or predictions based on heuristics and advanced algorithms. (Liu et al., 2023)

Lean manufacturing: involves many business units within manufacturing's information system, with the aim of improving task performance of workforces and cost structures by reducing waste, and convincing decision-makers. (So & Sun, 2010a)

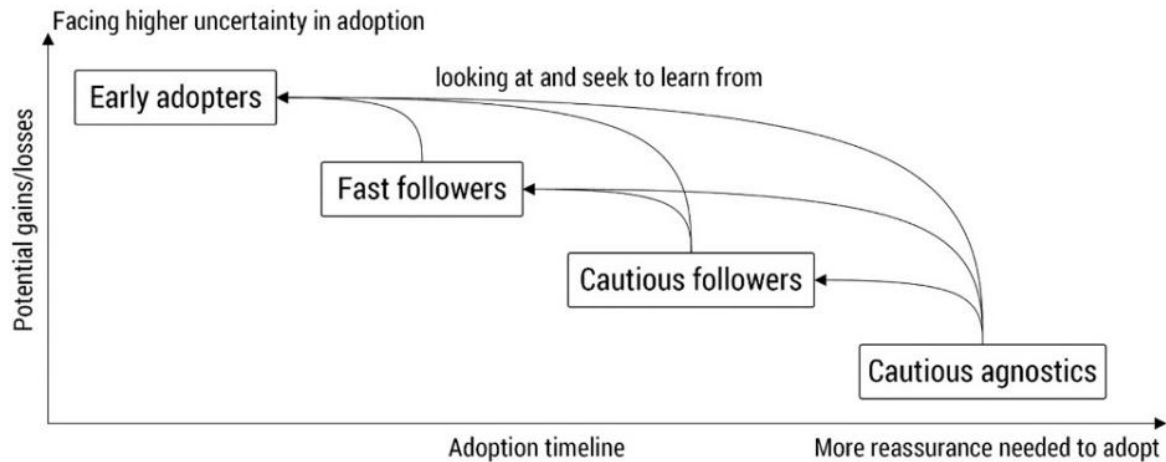
Control tower: provides faster collaboration among teams and parts of the supply chain, better coordination contingency planning across supply chain network. (Qudrat-Ullah & Ali, 2023)

2.3.Model Assessment

Most of the models mentioned its application and function among the dimensions, however, few researchers assessed the digital transformation level after developing them. According to 284 articles in SLR databases, there are 49 papers that discussed the adoption of technology into SCM, while 10 explored the industry readiness when adopting digital tools and only 5 investigated the maturity of the transformation. The author will validate the proposed model in figure 2 by assessing the digitalization transformation of business applying three main dimensions in their processes.

Adoption: refers to a metric that assesses the adopting level of innovative technologies or digital approaches. Below figure 3 is the adoption scale from (Nguyen et al., 2023), which visualizes their differences based on potential gains or losses and adoption timeline. Early adopter is defined as the pioneer in exploring the project which may face highest uncertainty due to lack of historical experiments, while the latest adopter is cautious agnostics who need more reassurance for their adoption decision. In terms of middle levels, Fast followers and Cautious followers' organization are on the way to adopt the technology as well as seek for counselling or reaffirm from the earlier one. (White et al., 2008)

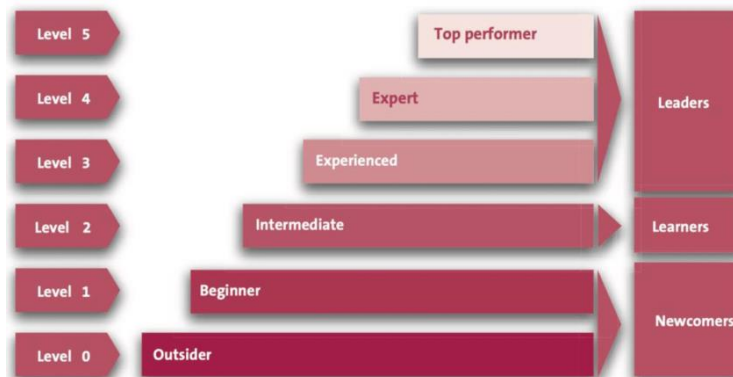
Figure 3: Approaches of technology adopters



Source: (White et al., 2008)

Readiness: refers to a metric that measures the company's readiness to initiate the technology for supply chain and become a leader in that area. The below figure 4 demonstrates a hierarchy of readiness level from knowing nothing – outsider to leading position – top performer. The level of dimension will be evaluated and classified in three groups: Newcomers (Level 0: outsider and level 1: beginner), Learners (Level 2: Intermediate) and Leaders (Level 3: Experienced and above). The readiness level will be examined on model dimensions and items of the dimensions. (Akdil et al., 2018)

Figure 4: IMPULS—Industry 4.0 Readiness



Source: (Akdil et al., 2018)

Digital Maturity: refers to a metric that assesses the maturity of a digital activity including five levels: Initial – Experimental – Practicing – Integrate – Transformed. Level 1 stands for “companies are lack of attributes that supporting concepts of Industry 4.0” and level 5 is “companies can meet all requirements of Industry 4.0”. (Sonntag et al., 2024)

The difference between readiness and maturity models can be explained that: 5 levels of readiness clarify if the organization is ready to start development process or not, while 5 levels of maturity

target to illustrate which level organization transformed to. According to Duffy (2001) finding, navigating company digitalization performance in readiness model can encourage them to make a move for their digital environment, and assessing progress by a maturity model can create a motivation to reach advanced level of maturity. Therefore, using two metrics to evaluate company digitalization transformation is essential for a comprehensive assessment. (Akdil et al., 2018)

3. RESEARCH METHODOLOGY:

In this article, a comprehensive model review is carried out to validate the self-proposed process of digitalization transformation. The following Figure 1 demonstrates the research design and the steps followed by the author to conduct this paper.

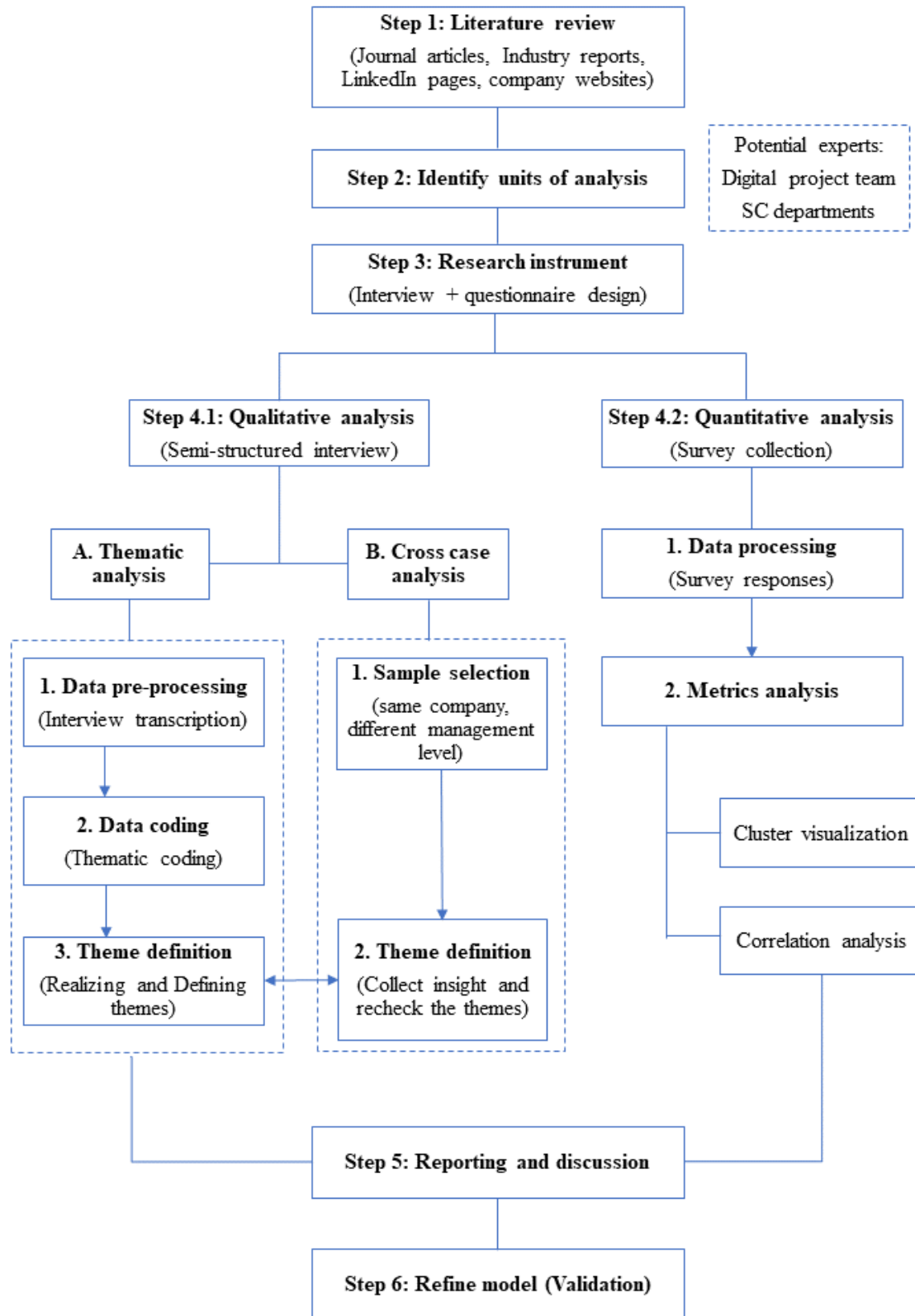
The research aims to answer the following research questions:

RQ1. How does the self-proposed model represent the current practices in digitalization transformation?

RQ2. What key metrics can be used to assess the transformation of a digital SCM project?

In order to answer the research questions, a mixed method is conducted on both qualitative and quantitative analysis, with the aim of gaining a broad-based assessment. This study consists of six main steps as Figure 5. The review of materials in the first step provides information regarding units of analysis and supporting system for thorough sample selection in the next step. This paper primarily focuses on the potential experts which either relating to digital projects or working in SC management and operation sectors. In terms of this filtering, the author can get insightful information, while the respondents have an overall understanding as well as familiarity of the topic's terms and definitions associated with it. After formulating the research instruments, the qualitative and quantitative analyses are conducted concentrating on checking the model theoretical and practical values.

Figure 5: Research methodology process



Source: Author's own creation

3.1. Qualitative analysis

Two thematic processes are executed on the qualitative data derived from the semi-structured interviews with potential experts. The questions are built to get the perception of the enterprises' digital environments within the SCM activities, how they progress through the digitalization journey. Additionally, the author aims to profoundly evaluate common challenges during integrating the technology enablers among different digitalization stages. The list of questions is outlined below in three clear sections in order to not only provide interviewees with an overview understanding of the author's topic, but also embrace the project development stages.

Interview: (Vilalta-Perdomo et al., 2023)

Introduction: provide information about the term and definition, example, follow up

1. Can you briefly introduce your company, your role?
2. What activities do you carry out in the supply chain? the digitalization project?
3. What resources/materials/information do you do in these activities?

Implementation: (Mantravadi et al., 2023)

4. What is your current state for digitalization?
5. What data visualization and analytics tools do you use, and how do the device interface?
6. How do you plan to mitigate your most pressing supply chain issue using manufacturing IT tools?
7. How do you coordinate with your supply chain networks?
8. How would you use the data from your digitalization tool to respond to the market need?

Future development:

9. What is missing from your supply chain management?
10. What kind of digital applications are you interested in?
11. What kind of improvement are you interested in?
12. What level of digital maturity do you intend to achieve?

The thematic analysis in this study is divided into two projects, one follows Braun and Clarke's guidelines (using thematic analysis in psychology) and one based on cross case analysis. The author uses the cross-case synthesis method of case study research as it enables the researcher to draw robust cross-case conclusions on the phenomenon (Mantravadi et al., 2023). The proposed case in the article is selected two pairs of managers and executive staffs in one digital project to examine the digitalization process from two points of view, one manages the supply chain digital strategy, one executes the digital action steps. The analysis concluded from the cross-case method will be a tool to recheck the defined theme in first thematic results, which can reconfirm the author's manual processing and coding interview transcript to paper theme. Below table 1 provides a template to collect different viewpoints from one large corporation of two legal entities, which can give a subjective comparison in their digital environment.

Table 3: Cross-case analysis

Robert Bosch Group	Robert Bosch Kft	Robert Bosch Vietnam
Digital project management level	Project Manager in Hungary	Project Manager in Vietnam
Execution level	Project member in Hungary	Project member in Vietnam

Source: Author's own creation

3.2. Quantitative analysis

3.2.1. Data collecting and processing

To evaluate three dimensions based on their exemplary items, a quantitative analysis is carried out within three metrics: adoption level, readiness, and digital maturity. The survey is conducted by quantitative ranking method forming among individual items. Each dimension is examined by one similar question about the importance level of all items within the dimension. Each item is examined by three questions related to three metrics. All questions in the survey require one answer to as Likert-scale reaching from 1 – lowest level to 5 – highest level. For example, for the item “*Robotic Process Automation (RPA)*” in the dimension “*Digital integration*”, the questionnaire is formulated as below table:

Table 4. Exemplary question to measure a maturity item.

Adoption	Early adopt	Fast follower	Cautious follower	Cautious agnostic
which labels best described organization’s adoption to the below digitalization? Robotic Process Automation (RPA) (Baycik & Gowda, 2024)				

Readiness	L1: Beginner	L2: Intermediate	L3: Experienced	L4: Expert	L5: Top performer
Are there already applications that automate routine tasks, e.g., robotic process automation? (Sonntag et al., 2024)	There is no automation of processes	There is first partial automation of processes as well as the first takeover of routine tasks. First tests with automation tool	There are initial processes that have been fully automated with automation tools. The automation of sub-processes is established in the manufacturing company.	Routine processes are immediately automated in various business units with the help of automation tools	All processes are automated by automation tools throughout the manufacturing company. No employee takes over routine tasks anymore.

Digital maturity	L1: Initial	L2: Experimental	L3: Practicing	L4: Integrated	L5: Transformed
To what extent are the production equipment and systems automated	Machine level: Partial	Machine level: Exact (Loading/Unloading + Operation)	Production line/cell level: Partial	Production line/cell level: Exact (Loading/Unloading + Operation)	Factory level: Partial

(Sonntag et al., 2024)				+Transportation)	
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Source: Author's own creation

After receiving responses to the questionnaire (e.g., questionnaire integrated into a Google form), the answers are processed in software supported manners. Below section is approaches for analyzing the result expected from survey's respondents.

Adoption result analysis: The respondent will be asked to self-assess which of the adoption level best indicated their organization for the mentioned technology (White et al., 2008). And to conduct the adoption level of one dimension, the author will pick the level with highest coverage within the items of that dimension. Below table describe an example of analyzing sample result:

Table 5. Exemplary result analysis to measure adoption dimension.

Dimension	Items	Adoption level per item
Data management	IT Management	Fast follower
	IoT	Early adopter
	Blockchain technology	Fast follower
	Cloud-based data storage	Fast follower
	Big Data analytics	Cautious follower
		⇒ <i>Fast follower</i>

Source: Author's own creation

Readiness result analysis: The respondent will be asked to evaluate each item readiness level, and then the dimension readiness level will be the lowest level of all fields in one dimension since it measures how well a company meets a minimum requirement for a dimension. The readiness score will be dimension level multiplying for important points. According to what (Grufman et al., 2020) did in their readiness model, important points were calculated by the number of quotes from one dimension divided for the total number of quotes, then multiply for 100. The author will slightly adjust (Grufman et al., 2020) method by letting respondent decide the important points for 3 dimensions in the scale of 100. For example, dimension Data management can occupy 25 out of 100 points, dimension Digital Integration can occupy 30 out of 100 points and dimension Supply chain decision-making/consultation takes the rest 45 out of 100 points. If the lowest readiness level of 5 items in dimension Data management is 3 then the readiness score is 3 times 25 equal 0.75.

Figure 6: Readiness score formular

$$\left(\begin{array}{c} \text{Level} \\ (?) \end{array} \right) \otimes \left(\begin{array}{c} \text{Importance} \\ \text{points} \end{array} \right) = \left(\begin{array}{c} \text{Readiness} \\ \text{score} \end{array} \right)$$

Source: (Grufman et al., 2020)

Digital Maturity result analysis: The response of maturity question will be converted and put in these factors: maturity level, weighting factor, and number of maturity item.

$$M_D = \frac{\sum_{i=1}^n M_{Dli} * g_{Dli}}{\sum_{i=1}^n g_{Dli}}$$

M: Maturity

D: Dimension

I: Item

g: Weighting factor

n: Number of Maturity item

The weighting factor (g_{Dli}) equals the average importance rating from all surveyed respondents, designed based on Likert scale from 1 – unimportant to 5 – very important for each item. Below is the example for dimension Data management's maturity:

$M_{1/1}$ (IT Management) = 3; $g_{1/1} = 2.7$

$M_{1/2}$ (IoT) = 4; $g_{1/2} = 3.2$

$M_{1/3}$ (Blockchain technology) = 1; $g_{1/3} = 4.5$

$M_{1/4}$ (Cloud-based data storage) = 2; $g_{1/4} = 1.7$

$M_{1/5}$ (Big Data analytics) = 5; $g_{1/5} = 4.1$

$M_1 = \frac{3*2.7+4*3.2+1*4.5+2*1.7+5*4.1}{2.7+3.2+4.5+1.7+4.1} = 3.04$

The maturity of Data management in this example is 3.04 out of 5, which is assessed as Level 3: Practicing in digital transformation process.

The questionnaire survey for quantitative method is briefly outlined in two parts as below. First is screening question to collect demographic data about respondents and their company digital projects. Second is the list of readiness and maturity checking questions, grounded in different literatures which also examined these two metrics in technology and SC topics.

Screening question (Baycik & Gowda, 2024)

Q1. What is your current professional title? If "Other", please type your title in the space given below.

Executive leadership (VPs, CXO's, directors)

Manager

Consultant

Analyst

Other

Q2. How many years of experience do you have in operations and/or supply chain management?

Less than 5 years

5 to 10 years

11 to 20 years

More than 20 years

Q3. Which of the below best represents your function?

Procurement/Purchasing

Supply/Demand Planning

Operations

Sales/Marketing

Strategy

Other

Q4. How familiar are you with the benefits and impact of digital transformation for organizations?
1 (not at all) through 5 (highly familiar)

Q5. In your opinion, on a scale from 1 to 5, how important are the benefits of digital transformation below for organizations? 1: least important, 5 most important.

List of 14 items.

Table 6. Questionnaire survey for checking readiness level and maturity level

Items	Readiness questionnaire	Maturity questionnaire
IT Management	Is there a consensual relationship between the business units and IT? (Sonntag et al., 2024)	How are security and privacy controls implemented throughout the manufacturing company? (Sonntag et al., 2024)
IoT	“Internet technology is too difficult to understand for supply chain activities” (Tarofder et al., 2017)	“With IoT adoption, we have been able to identify the visibility of supply chain to more transparency and visibility of information and material flows” (Lee et al., 2022)
Blockchain technology	“My firm’s decision to implement BC SCM would depend on industry standards in place” (Wong et al., 2020)	To what extent business activities in your company require the use of blockchain technologies for tracking purchase orders, change orders, receipts, shipment notifications, or other trade-related documents, ... (Ruangkanjanases et al., 2022)
Cloud-based data storage	Is there a metadata management system that creates and stores metadata describing important functional entities as data is processed? (Sonntag et al., 2024)	Which functions can your company's products fulfill the following options? (Sonntag et al., 2024)
Big Data analytics	Does a data model exist? (Sonntag et al., 2024)	Are Big data requirements being considered in the manufacturing company? (Sonntag et al., 2024)
Advanced analytics platform	Does the manufacturing company use Natural Language Processing (NLP) to extract and process natural language information and text? (Akdil et al., 2018)	Is machine learning technology being developed and deployed in the manufacturing company? (Sonntag et al., 2024)
Dashboard visualization	To what extent does your supply chain an end-to-end visibility? (Akdil et al., 2018)	How are insights gained from existing data? (Sonntag et al., 2024)

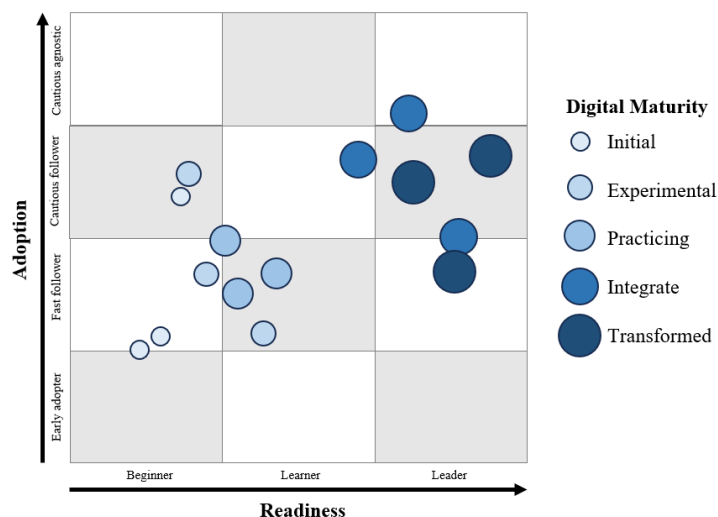
Robotic Process Automation (RPA)	Are there already applications that automate routine tasks, e.g., robotic process automation? (Sonntag et al., 2024)	To what extent are the production equipment and systems automated? (Sonntag et al., 2024)
ERP	To what extent can products be tracked throughout their lifecycle? (Akdil et al., 2018)	To what extent are your company ERP integrating to? (Hwang & Min, 2013)
Digital twin	“I believe that My organization has a clear strategic vision for integrating DTT” (Patil et al., 2024)	What is the level of real-time traceability of the operation in the digital environment? (Digital-twin concept) (Sonntag et al., 2024)
Collaborative planning	What is the penetration degree of enabling technologies in your enterprise? (Akdil et al., 2018)	To what extent is the current supply chain integrated? (Akdil et al., 2018)
AI-driven decision support system	Are there defined use cases and objectives related to artificial intelligence? (Sonntag et al., 2024)	Is there a defined AI transformation strategy from top management? (Sonntag et al., 2024)
Lean manufacturing	“Manager shows no commitment at all or has a negative attitude toward Lean” (Kaltenbrunner et al., 2017)	What is the degree of use in last 3 years on restructuring your manufacturing processes and layout to obtain process focus and streamlining towards lean manufacturing? (So & Sun, 2010)
Control tower	Which specific operational areas or domains are monitored within the tower?	What level of analytics is currently used in the CT? (Akdil et al., 2018)

Source: Author’s own creation

3.2.2. Result presenting

In the following, results obtained from questionnaire and software will be visualized in a three-parameter model equivalent to three examined metrics. Figure 6 provides an example of how the result of the survey will be presented. From this visualization, the author expects to gain some insight from the metrics and the dimensions’ patterns, the cluster can be formulated with enough respondents.

Figure 7: Cluster visualization



Source: Author's own creation

Regarding the model analysis, Pearson Correlation Coefficient (r) method will be carried out to explore the connection among 3 metrics, 3 dimensions and their coefficient relationship altogether. SPSS software will be mainly used to interpret databases and visualize the correlation.

4. DISCUSSION

4.1. Realization for author's improved model

Based on the addendum literature review, the author generated an improved version of digitalization transformation model. The former version included three stages – data management, data organization and supply chain consultation/decision-making, while the latter version adjusted the second stage to *digital integration* and incorporated *data organization* as part of *data management*.

Additionally, the list of items per dimension also changed to align with the findings of other researchers' models. The initial author's model elaborated dimensions based on the function of each stage. For example, *data management* was supposed to deal with the organization data such as collecting, storing, transmitting, etc., while *supply chain consultation/decision-making* was designed as Industry 4.0 Supply chain without emphasizing the decision-making benefits by technology advancements. As can be seen from first author's model, the author defined it as how one digital process can be applied in SCM, starting from *data management*, deploying the technology enablers by available big data set, and finally building up a digital SC. The original model is technology-centric transformation approach.

However, with the comparative analysis of diversified digital integration and transformation models in table 1, technology enabler could be integrated at any stage to fulfill distinct functions for that specific dimension. Subsequently, enterprises can decide the strategy to adopt multiple digital enablers for their operation and management, all leading to one common goal of making decisions for their SC. By completing the process and achieving the SC's goals, businesses can

transform from the conventional SC to a comprehensive Industry 4.0 or digitalized SCM. Thus, the improved model is a digitalization transformation process-based approach.

4.2. Recommendation from measuring metrics

The digital models reviewed in table 1 focused on the examination of digital processes, value delivery at different stages, or enterprises' capabilities during digitalization. As mentioned in the Introduction section, successful implementation of the Industry 4.0 strategies require organizational complexity in execution while catching with the evolution speed. (Akdil et al., 2018) Such demands the company rely on three stages within any given model, either process-based or technology-centric one. However, to address the challenges related to execution, management, and effectiveness and efficiency of what they invested in, a structured approach to digitalization transformation needs measuring metrics as a guidance for running on the right track of any model. Therefore, the author designs a concept to reach the same goal of model validation, applying three metrics to measure the digital context within SCM including adoption level, readiness score, digital maturity level. Since maturity model frameworks are significantly important to evaluate organizations (Akdil et al., 2018). Likewise, the author's metrics can be utilized to assess if the organization can be ready for technology integration, be matured to achieve the transformation and be agile to adopt with the evolution speed. By examining these three metrics, the author probably gains insights from SC departments or rather digital project team regarding how they immerse digital environment for their operation and management. Relying on the expected recommendation, the correlation among the metrics, dimensions, and items can be validated at the end.

4.3. Future research direction

Firstly, with the validation methodology for the author's proposed model, the actual primary data is top priority to examine both the methodology and the proposed digitalization transformation model. Subsequently, the research will collect data for two concurrent analysis approaches at the same study – qualitative and quantitative.

Secondly, the list of items within each dimension is influenced by previous literature review and the author's perspectives. While this list can be further developed to align closely with the specific context of individual companies, this paper mainly focused on common items and their core functions serving the targeted dimensions. With an understanding of the mechanism, the scholar or researcher in the future can enlarge the list of items for testing their own models based on author's research methodology.

5. CONCLUSION

In conclusion, the aim of this study is to design a conceptual model to validate the author's self-proposed process and navigate company digitalization transformation journey. The previous Systematic literature review of 284 articles from Scopus and Web of Science served as a robust foundation for the subsequent literature review.

Theoretical contribution: This study contributes to the scientific area a mixed-analysis method for model validation, which offers several important theoretical contributions. Firstly, it presents a methodology to examine the model, and secondly it outlines an analysis approach for metrics measuring synthetic.

Recalling the RQs given in the introduction section, the author can come up with some closing result for each of them:

RQ1: How does the self-proposed model represent the current practices in digitalization transformation? This question can be satisfied by the current models in the market, investigated by scholars and researchers. The author then concluded the author's own model, drawing insights from established literatures. The finding is that most of the digitalization transformation will position themselves either with a digitalization process or a technology enabler, and a selection would depend on company's transformational context.

RQ2: What key metrics can be used to assess the transformation of a digital SCM project? The context mentioned in RQ1's answer could be measured by three metrics: adoption, readiness, and maturity. These metrics altogether synthesize and represent a logical path for digitalization processes in several business fields which include varying levels of transformation.

Managerial contribution: For managers, project leaders and executives, this study contributes checking tools for the SC department's digital maturity, summarize all crucial steps for adopting, integrating and transforming the digitalization process. The primary objective for managers is achieving the goal of consulting or decision-making for their SCM based on the digital integration and organization data. Through this approach, SCM can evolve to a higher digital level.

In summary, this comprehensive review emphasizes the methodology to validate a digitalization transformation model. By initiating technology integration from scratch, organizations can position themselves as leaders of the digital era and drive their sustainable growth in dynamic circumstances of supply chains. And fellow scholars can leverage this paper for conducting in-depth analyses of this transformative era.

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