Digitalisation of supply chains: an information processing perspective

Denis Niedenzu (dtn23@cam.ac.uk)
Centre for International Manufacturing, Institute for Manufacturing, Department of Engineering, University of Cambridge, Cambridge CB3 0FS, United Kingdom

Mukesh Kumar
Centre for International Manufacturing, Institute for Manufacturing, Department of Engineering, University of Cambridge, Cambridge CB3 0FS, United Kingdom

Naoum Tsolakis
Centre for International Manufacturing, Institute for Manufacturing, Department of Engineering, University of Cambridge, Cambridge CB3 0FS, United Kingdom

Manoj Dora
Brunel Business School, Brunel University London, Uxbridge UB8 3PH, United Kingdom

Abstract

The purpose of this research is to explore the relationship of types of supply chain decisions, types of information and types of digital technologies in order to reduce uncertainty in supply chain operations in manufacturing companies. This study has several key findings including that the majority of information is not systematically captured by organisations. On the theoretical side this research extends information processing theory into digital supply chain research, develops a taxonomy for information processing needs and demonstrates the adequacy of digital technologies as enabler of information processing capacity. The practical contributions include the allocation of particular information to supply chain decisions as well as information capturing mechanisms, which will enable companies to quicker access required information for decision-making.

Keywords: Digitalisation, Supply chain, Information processing

Introduction

In order to stay competitive from cost, quality and speed perspectives, manufacturing companies are attempting to expand their supply chains in terms of size and geographical dispersion. However, this expansion increases complexity and uncertainty in supply chains, resulting in lack of information, limited supply chain visibility and fragmented, cross-country supply chains. Supply chain complexity is reflected in the decision-making complexity, which is attributed to the volume and structure of information required to make informed decisions (Manuj and Sahin, 2011). One of the major challenges in today's international manufacturing landscape is the limited capability of firms to capture information and leverage it to support well-informed supply chain decisions and

effectively respond to dynamically changing market requirements (Xu, 2011). This leads to increasing costs for companies, increasing impacts on the environment and in the worst case to product related safety risks. A case in point are recent food scandals such as the egg contamination scandal in 2017 involving the contamination of dutch eggs with the hazardous substance fipronil resulting in major food recalls throughout. Another example of product related safety risks due to complexity and uncertainty in the supply chains is the fatal crash of a Tesla driver in 2016 due to the car's autopilot system not being fit for purpose under the tested conditions.

There is an argument that digitalisation of supply chains can mitigate the above mentioned uncertainty and cope with complexity by assisting in capturing the information required for supply chain decision-making in real-time through smart technologies, such as track and trace technologies and big data analytics. However, there is limited understanding on types of technologies, types of information and their relationship with supply chain decision-making. Therefore, this research aims to present an academic point of view on the extent of digitalisation paired with an industrial exploration of the concept of digital supply chains to answer the research question- How can digital technologies capture required information for supply chain decision-making?. This question has three key sub questions: (1) What are the strategic, tactical and operational decisions in supply chain decision-making?; (2) What information is required for the identified supply chain decisions?; and (3) What does digitalisation in supply chains mean and how can digital technologies be used as an information capturing mechanism to support supply chain decision- making?

Supply chain decision-making, digital technologies for supply chains and information processing theory

This section introduces the theoretical background of the research comprising of a theoretical angle on supply chain decision-making, digitalisation and information processing theory.

Supply chain decision-making

Supply Chain Management (SCM) is defined as "Supply chain management (SCM) is the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer" (Kahraman and Öztayşi, 2014). While a vast body of literature has been created around definitions of SCM, scholars seem to structure their definitions around three core pillars of SCM: 1) Philosophy of SCM, 2) SCM as set of activities to implement management philosophy and 3) SCM as a set of management processes (Mentzer *et al.*, 2001).

The concept of supply chain complexity is also attributed to lack of information, which is one of the major challenges in today's organisations (Xu, 2011). Decisions can be of strategic, operational and tactical nature. Strategic decisions set a framework in which the company acts, tactical decisions are taken to satisfy strategic decisions and operational decisions are everyday decisions that serve the tactical decisions (Schmidt and Wilhelm, 2000). Decision making is the thought process of selecting a logical choice from the available options (Kahraman and Öztayşi, 2014). While it is tempting to imply that the more information available for decision-making the better for making a well-judged decision, one has to appreciate that not all information is useful for improving understanding and judgment of the nature of the occurrence for which the decision has to be taken (Saaty, 2008). In order to make the decision, the need and purpose of the decision, its criteria and sub criteria, stakeholders and groups affected need to be understood and taken into consideration (Saaty, 2008). While literature covers

information flows in supply chains generically to a certain extent, it fails to provide clarification about the information needs for a particular decision taken in supply chains. In other words, the relationship between information and supply chain decisions has not been identified to the researcher's knowledge.

Digitalisation and digital technologies in the context of supply chains

Digitalisation is defined as the conversion of analogue information, such as text, into digital information (Princeton University, no date). Supply chain digitalisation refers to the adoption of inter-organizational systems by business organisations to collaborate and transact with their external partners (e.g., key suppliers and customers) along their value/supply chains (Barua *et al.*, 2004; Rai, Patnayakuni and Seth, 2006; Rai, Brown and Tang, 2009; Xue, 2014), in other words: conducting day-to-day business activities with supply chain partners via digital information exchange (Barua *et al.*, 2004). The concept of supply chain digitalisation seems to be of the following nature: (1) Supply chain digitalisation is often considered being risky, primarily because the external parties and environment that organisations need to interact with are beyond their controls (Xue, 2014); and (2) It is a concept that requires commitment of all partners along the entire supply chain, from raw material supplier to end-customer (Barua *et al.*, 2004).

While being risky, supply chain digitalisation is widely regarded as a promising concept. According to literature, firms with higher levels of digitalisation enjoy better business performance (Barua *et al.*, 2004; Fawcett *et al.*, 2011). Along these lines, literature argues that digital technologies, such as big data analytics could support supply chain decision-making by capturing and processing information (Roßmann *et al.*, 2018). However, linkage between digital technologies as information capturing and processing mechanism for particular supply chain decisions has not been established to the researcher's knowledge.

Application of organisational information processing theory

Organisational information processing theory was parented by (Galbraith, 1973; Tushman and Nadler, 1978) and refers to the gathering, interpreting and synthesis of information for organisational decision-making (Tushman and Nadler, 1978). Information refers to *data which are relevant, accurate, timely and concise* (Tushman and Nadler, 1978), hence not all data constitute information (MacKay, 1969; Helvey, 1971). Organisational informational processing theory postulates that the better the match between information processing needs and information processing capacities, the better the organisation's performance (Galbraith, 1973; Tushman and Nadler, 1978).

Organisations are open social systems that must deal with environmental uncertainty (Thompson, 1967). Uncertainty is defined as "*the difference between information possessed and information required to complete a task"* (Downey and Slocum, 1975; Tushman and Nadler, 1978). "*The greater the task uncertainty the higher the amount of information that has to be processed in order to achieve a certain level of performance"* (Galbraith, 1973). Uncertainty decreases when availability of information increases (Miller and Frick, 1949; Shannon and Weaver, 1949; Garner, 1962). Therefore, in order to reduce uncertainty, organisations need to process information. The match between information processing needs and information processing capacities of the organisation will determine its performance (Galbraith, 1973). Literature formulates that "*the amount of information required is a function of the output diversity* (how many products), d*ivision of labour* (among subunits, e.g. departments) *and level of performance required"* (Galbraith, 1973). (Egelhoff, 1991) developed a framework to measure the information-processing capacities in multinational companies with regards to their design. However,

literature does not state explicitly what kind of information needs an organisation has, arguably because of the dependence on type and structure of the organisation. One exception is the work of (Premkumar, Ramamurthy and Saunders, 2005), who generated a taxonomy of information processing needs with regards to various characteristics of the product and procurement environment. From an academic perspective it is very appealing to attempt to provide a general taxonomy of information processing needs according to strategic, tactical and operational information needs, which is currently absent in literature. Furthermore, it would be intriguing to understand, what information processing mechanisms could capture and process required information.

Conceptual framework

The literature review identifies two gaps to be investigated: (1) the relationship between supply chain decisions and information, (2) the relationship between information and digital technologies. The relationship between information and supply chain decisions would be of major interest considering the argument in literature that well-judged decisions depend on the selection of the right information per decision rather than an abundant presence of information. In 2011, literature argued that companies lack the ability to capture and process information required for supply chain decision-making (Wu and Pagell, 2011; Xu, 2011). Until today, this argument has not been proven otherwise to the researcher's knowledge. The following conceptual framework portrays the current state of supply chain decision-making identified from literature. It explains that information needs of organisations are not clear and information is partially available. The future state, which is subject to the research will establish the linkage between digital technologies as information capturing mechanisms, information and supply chain decisions. Allocating particular information to supply chain decisions and matching information with the appropriate capturing mechanism is an exciting linkage that has not been investigated before in this level of detail. The conceptual framework illustrates the research questions and conceptualises the scope of the investigated industrial challenges.

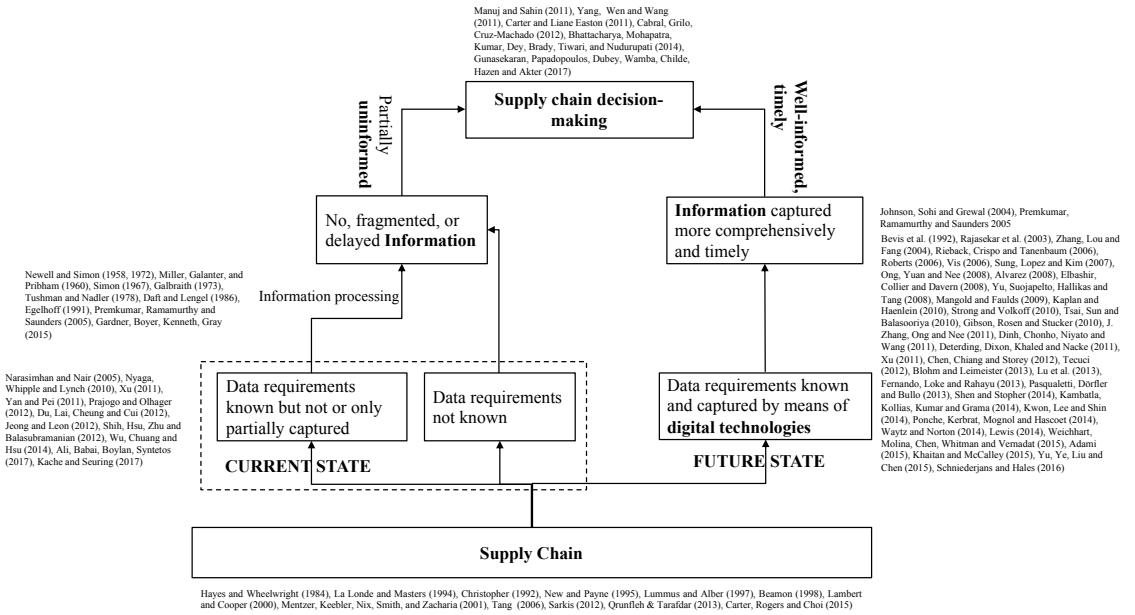

Figure 1: Conceptual framework

Methodology

To answer the research question, the linkage between (1) supply chain decision-making, (2) information and (3) digital technologies to capture required information needs to be established and was approached with the research framework illustrated in Figure 1.

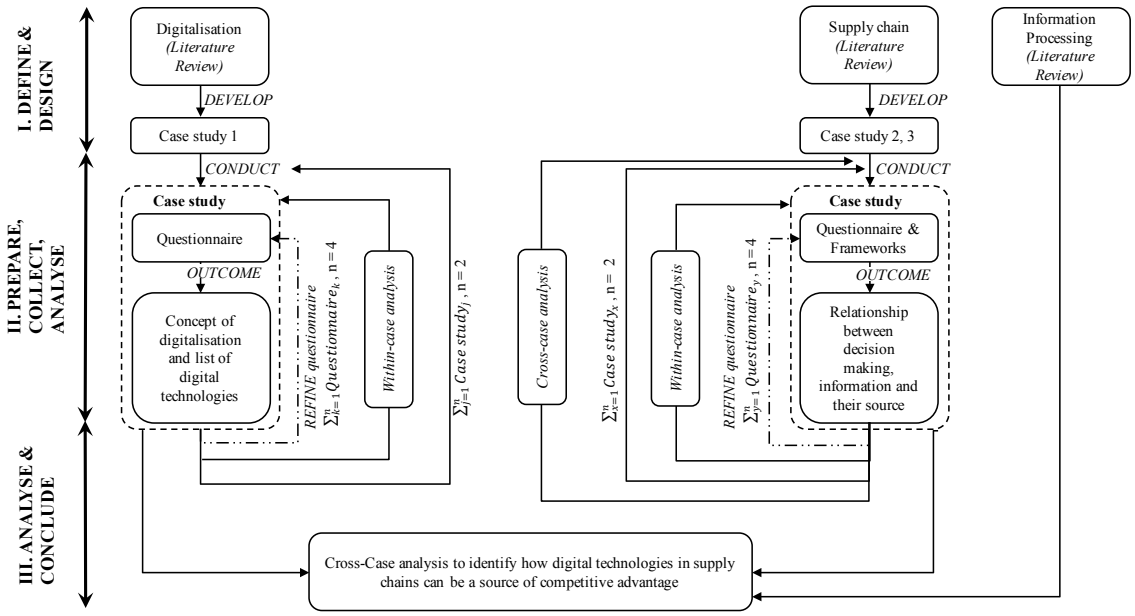

Figure 2 – Methodological Framework

The research was split into three phases: I. Define & Design, II. Prepare, Collect, Analyse, III. Analyse & Conclude. The first phase of the research included a literature review on supply chains, digitalisation and information processing. Furthermore, a qualitative case study approach was developed, involving 15 manufacturing companies and 7 research institutions. Case study selection criteria were developed to identify best-in-class companies.

Following the case studies' selection criteria, data was collected and analysed in Phase II. To perform this research, semi-structured interviews were conducted along with a binary Design Structure Matrix (DSM). Semi-structured interviews were chosen to allow for flexibility in the covered topics due to the exploratory nature of the research (Yin, 2009). The DSM is generally used to find out relations in a complex system (Eppinger and Browning, 2012). This is well suited to identify the relationship between information, supply chain decisions and digital technologies. Additional tools employed involved heat maps and data displays to demonstrate results as proposed by (Miles, Huberman and Saldaña, 2014). Phase III involved the cross-case analysis from all case studies. To ensure a high quality of research, construct validity, internal validity, external validity and reliability tests were employed throughout the research according to (Yin, 2009).

Discussion

Supply chain decision-making and linkage with information

The relationship between supply chain decisions, required information and their source and digital technologies are developed from literature and validated through case studies. The results table needs to be read "from columns to rows": 1) Supply chain decision d, requires information a, b, c; 2) Technology t is capable of delivering information a, b, c; 3) In source s, information a,b, c can be found. The majority of supply chain decisions identified, be it on a strategic, tactical or operational level, require information from both

information categories: internal and external. However, much information required for supply chain decision-making lie outside the boundaries of the company according to interview participants. This can be explained by acknowledging that manufacturing companies by implication are generally collaborating with supply chain partners to produce and deliver a product. Hence, much information required for supply chain decision-making will focus on supply chain partners about which information needs to be captured. Besides information about **supply chain partners**, further information about the environment needs to be collected according to the interview participants. Especially **consumer preferences & demand**, **infrastructural conditions** as well as **legislation** appear to be crucial for supply chain decision-making on strategic, tactical and operational level in this respect.

In terms of noticeable patterns within the area of company internal information, it appears that **required raw material** and **interfirm logistics & despatch details** are very important. Certainly, knowing the raw material requirements and logistics details are crucial in determining the delivery time for the customer and hence ensure high customer satisfaction in this respect. The next paragraph discusses digitalisation of supply chains and links information for supply chain decision-making with digital technologies as capturing mechanism.

Digitalisation of supply chains and digital technologies

The views on digitalisation of supply chains presented in academia appear to be of a generic nature as opposed to the views in industry, which attribute precise characteristics to the concept. According to industry, digitalisation of supply chains is structured around interconnectedness between systems, vertical and horizontal information exchange, collection and instant access to real world information in real time and combination of different technologies. This characterisation implicitly incorporates the academic perspective: the idea of inter-organisational collaboration and exchange of information is in line with the interviewees' opinions in that *"the information exchange happens vertically, within a company, and horizontally, across supply chain partners, such as suppliers, manufacturers, end-customers, etc."* and *"Organisational and processual linkages of procedures in the entire supply chain are a key component of a digital supply chains"*. Hence, the definition in literature presents a fraction of the characteristics interview participants declared. The following definition of digital supply chains is suggested based on academic and industrial perspectives:

Digital supply chains are interconnected cyber-physical systems capable of storing, processing, providing and vertically and horizontally exchanging information along the entire supply chain in real-time by the means of enabling digital technologies.

Having focused on discussing types of information to be captured, digital technologies need to be discussed. It is evident from Figure 3 that companies are currently capturing company internal information with MES and ERP systems. However, the required external information is not systematically captured in any of the interviewed companies. From the interviews, it appears that capturing external information to do with suppliers, hence data transparency along the supply chain, involves focusing on building trust and establishing data security between supply chain partners while capturing other external information seems to be a matter of technological feasibility, which is fundamentally different. Building trust and ensuring data security involves participation of partners in the supply network and is a prerequisite for capturing network information. Hence, the challenge is to *"convince supply network partners of the benefits of digitalisation"*. Table 1 establishes the taxonomy of information processing needs.

Figure 3 – Relationship between supply chain decision, information and digital technologies

Taxonomy of information processing needs	Information capturing mechanism
Strategic	
Customer profile (target group, potential sale)	Big data analytics
Retailer profile (location, capacity, price)	Big data analytics
Wholesaler profile (location, capacity price)	Big data analytics
Supplier profile (location, capacity, price)	Big data analytics
Logistics provider (transportation rates)	-
Political situation in sales market	Big data analytics
Legislation and taxation	Big data analytics
Infrastructural conditions	Big data analytics
Competitive landscape	Big data analytics
Consumer preferences & demand	Big data analytics, MES & ERP
Profitability	-
Required approval studies	-
Maintenance cost	MES & ERP
Production labour	MES & ERP
Technological advancement	-
Request for quotation & order	MES & ERP
Required raw material	Big data analytics, MES & ERP
Supply	MES & ERP
Inter-firm logistics & despatch details	MES & ERP
Intra-firm logistics	MES & ERP, Track & Trace
Monthly schedules	MES & ERP
Report inventory	MES & ERP, Tack & Trace
Reports on supplier performance	MES & ERP
Quality complaints	MES & ERP, Track & Trace
Tactical	
Customer profile (target group, potential sale)	Big data analytics
Retailer profile (location, capacity, price)	Big data analytics
Wholesaler profile (location, capacity price)	Big data analytics
Supplier profile (location, capacity, price)	Big data analytics
Logistics provider (transportation rates)	-
Political situation in sales market	Big data analytics
Legislation and taxation	Big data analytics
Infrastructural conditions	Big data analytics
Competitive landscape	Big data analytics
Consumer preferences & demand	Big data analytics, MES & ERP
Maintenance cost	MES & ERP
Production labour	MES & ERP
Request for quotation & order	MES & ERP
Required raw material	MES & ERP
Supply	MES & ERP
Intra-firm logistics	MES & ERP, Track & Trace
Monthly schedules	MES & ERP
Report inventory	MES & ERP, Track & Trace
Reports on supplier performance	MES & ERP
Quality complaints	MES & ERP, Track & Trace
Operational	
Customer profile (target group, potential sale)	Big data analytics
Retailer profile (location, capacity, price)	Big data analytics
Wholesaler profile (location, capacity price)	Big data analytics
Supplier profile (location, capacity, price)	Big data analytics

Legislation and taxation	Big data analytics
Consumer preferences & demand	Big data analytics, MES & ERP
Request for quotation & order	MES & ERP
Required raw material	MES & ERP
Intra-firm logistics	MES & ERP, Track & Trace
Monthly schedules	MES & ERP
Report inventory	MES & ERP, Track & Trace
Quality complaints	MES & ERP, Track & Trace

Table 1 – Taxonomy of information processing needs

Conclusion

Digital technologies integrated into a system capable of delivering company internal and external information help companies reduce uncertainty in a highly complex and dynamic environment.

In order to come to this conclusion, three case studies were conducted investigating (a) the concept of digitalisation, (b) identifying required information for supply chain decisions and (c) linking digital technologies to required information. The key findings of the research are as follows:

Firstly, by establishing the linkage between supply chain decisions information needs it was found that the majority of information required for supply chain decision-making lies outside the boundaries of the manufacturing company's supply chain. The second implication this research suggests is that a considerable amount of information required for supply chain decision-making is not captured internally, which adds to uncertainty in decision-making. This finding is in line with (Wu and Pagell, 2011; Xu, 2011) argument, that companies lack information. Three key technologies are identified to capture information and reduce uncertainty in companies. Finally, this research extends information processing theory by (1) establishing a general taxonomy for information processing needs in manufacturing companies, which has never been done before and (2) by demonstrating how digital can act as information capturing and processing mechanism, extending the information processing capacity of a company. A conceptual framework is developed depicting the digital technologies, information and decisions in supply chains. This framework needs to be tested further in various contexts, such as sustainability and resilience.

References

Barua, A., Konana, P., Whinston, A. B. and Yin, F. (2004) 'An Empirical Investigation of Net-Enabled Business Value', *MIS Quarterly*, 28(4), pp. 585–620.

Downey, K. and Slocum, J. (1975) 'Uncertainty: Measures, Research, and Sources of Variation', *Academy of Management Journal*, 18, p. 562.

Egelhoff, W. (1991) 'Information-Processing Theory and the Multinational Enterprise', *Journal of International Business Studies*, 22(3), pp. 341–368.

Eppinger, S. and Browning, T. (2012) *Design structure matrix methods and applications*. MIT Press.

Fawcett, S. E., Wallin, C., Allred, C., Fawcett, A. M. and Magnan, G. M. (2011) 'Information technology as an enabler of Supply Chain Collaboration:A dynamic-capabilities perspectives', *Journal of Supply Chain Management*, 47(1), p. 22. doi: 10.1111/j.1745-493X.2010.03213.x.

Galbraith, J. R. (1973) *Designing Complex Organizations*. Boston: Addison-Wesley.

Garner, W. R. (1962). (1962) *Uncertainty and structure as psychological concepts*. Oxford: Wiley.

Helvey, T. C. (1971) *The age of information: an interdisciplinary survey of cybernetics*. Educational Technology Publiations.

Kahraman, C. and Öztayşi, B. (2014) *Supply Chain Management Under Fuzziness*. Sringer. doi: 10.1007/978-3-642-53939-8.

MacKay, D. M. (1969) *Information, Mechanism and Meaning*. Cambridge Mass.

Manuj, I. and Sahin, F. (2011) 'A model of supply chain and supply chain decision-making complexity',

International Journal of Physical Distribution & Logistics Management, 41(5), pp. 511–549.
Mentzer, J. T., William, D., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D. and Zacharia, Z. G. (2001) 'Defining Supply Chain Management', *Journal of Business Logistics*, 22(2), pp. 1–25. doi: 10.1002/j.2158-1592.2001.tb00001.x.
Miles, M. B., Huberman, A. M. and Saldaña, J. (2014) *Qualitative Data Analysis: A Methods Sourcebook*. 3rd edn. Sage Publications, Inc.
Miller, G. A. and Frick, F. C. (1949) 'Statistical behavioristics and sequences of responses', *Psychological Review*, 56(6), p. 311.
Premkumar, G., Ramamurthy, K. and Saunders, C. S. (2005) 'Information Processing View of Organizations : An Exploratory Examination of Fit in the Context of Interorganizational Relationships', *Journal of Management Information Systems*, 1222. doi: 10.1080/07421222.2003.11045841.
Princeton University (no date) 'Digitalisation', *Thesaurus*.
Rai, A., Brown, P. and Tang, X. (2009) 'Organizational Assimilation of Electronic Procurement Innovations', *Journal of Management Information Systems*, 26(1), pp. 257–296. doi: 10.2753/MIS0742-1222260110.
Rai, A., Patnayakuni, R. and Seth, N. (2006) 'Firm Performance Impacts of Digitally Enabled Supply Chain Integration Capabilities', *MIS Quarterly*, 30(2), pp. 225–246.
Roßmann, B., Canzaniello, A., von der Gracht, H. and Hartmann, E. (2018) 'The future and social impact of Big Data Analytics in Supply Chain Management: Results from a Delphi study', *Technological Forecasting and Social Change*. Elsevier, 130, pp. 135–149. doi: 10.1016/j.techfore.2017.10.005.
Saaty, T. L. (2008) 'Decision making with the analytic hierarchy process', *International Journal of Services Sciences*, 1(1), p. 83. doi: 10.1504/IJSSCI.2008.017590.
Shannon, C. and Weaver, W. (1949) *The Mathmatical Theory of Information*. University. Urbana.
Thompson, J. D. (1967) *Organizations in action: Social science bases of administrative theory*. Transaction publishers.
Tushman, M. L. and Nadler, D. A. (1978) 'Information Processing as an Integrating Concept in Organizational Design', *Academy of Management Review*, 3(3), pp. 613–624.
Wu, Z. and Pagell, M. (2011) 'Balancing priorities: Decision-making in sustainable supply chain management', *Journal of Operations Management*. Elsevier B.V., 29(6), pp. 577–590. doi: 10.1016/j.jom.2010.10.001.
Xu, L. Da (2011) 'Information architecture for supply chain quality management', *International Journal of Production Research*, 49(1), pp. 183–198. doi: 10.1080/00207543.2010.508944.
Xue, L. (2014) 'Governance-knowledge fit and strategic risk taking in supply chain digitization', *Decision Support Systems*. Elsevier B.V., 62, pp. 54–65. doi: 10.1016/j.dss.2014.03.003.
Yin, R. K. (2009) *Case Study Research: Design and Methods*. 4th edn. Edited by L. Bickman and D. J. Rog. California: SAGE Publications, Inc.