The value of information in supply chain decisions: A review of the literature and research agenda

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Abstract

The purpose of this paper is to provide a structured overview of the value of information in different supply chain decisions and to identify a research agenda based on the current state of research on the topic. The paper uses the systematic literature review methodology to review journal articles published in the 12-year period from 2006 to 2017. Each selected study is analysed using a rigorous review framework of four primary dimensions, including "supply chain decisions", "information", "modelling approach", and "context". The review of articles shows that the current literature is rich in assessing the value of information in inventory decisions, yet insufficient in other supply chain areas such as facility, transportation, sourcing, and pricing. In addition, the value of information is subject to contextual supply chain parameters and varies in accordance with the characteristics of the information (such as accuracy, timeliness, and completeness). Furthermore, the focus of the existing literature is on "information availability" in supply chain decisions, and the impact of important information characteristics on the value of information has not been studied extensively. The research on information timeliness and its influence on supply chain performance is especially limited. Based on the discussion and results of our review, a research agenda is offered and sample research questions are discussed.

Keywords: Value of information, Supply chain management, Value of big data, Information accuracy, Information completeness, Information timeliness

1. Introduction

Over the past two decades, information sharing and information and communication technology (ICT) have been widely discussed as the main enablers to improve supply chain performance and to prevent critical supply chain problems such as the bullwhip effect (Lee, Padmanabhan, & Whang, 1997; Hofmann, 2017). However, access to more information in a supply chain can be challenging in practice. Information sharing requires a high level of trust between collaborating parties in the chain (Ebrahim - Khanjari, Hopp, & Iravani, 2012; Tsanos & Zografos, 2016). In addition, access to information is not cost free and may require significant investments in ICT infrastructures to gather and share data (Lee, So, & Tang, 2000; Zhong, Newman, Huang, & Lan, 2016). Several recent studies show that despite substantial investments in ICT systems, many organizations have failed to gain the expected improvements in their supply chain performance (Fawcett, Wallin, Allred, Fawcett, & Magnan, 2011). This might primarily imply that investment in gathering and sharing information per se does not guarantee enhanced supply chain performance (Wu, Yeniyurt, Kim, & Cavusgil, 2006). It is particularly important to clearly understand which information must be shared in a supply chain and how that information may contribute to an improved design and operation of a supply chain. Evaluating the "value of information" (VOI) before investing in an ICT infrastructure or participating in information sharing with other parties in the chain would be helpful to overcome these drawbacks.

VOI is defined from two different points of view in the literature. VOI can be defined as an estimate of the willingness to pay of a potential user of the information in order to have access to it (Lumsden & Mirzabeiki, 2008; Jonsson & Myrelid, 2016). Another definition, which is the more dominant view in the literature, defines the VOI based on the (expected or realized) benefits of using the information in decision making in a supply chain (Lumsden & Mirzabeiki, 2008). These benefits are described as improvement in one or several key performance indicators (KPIs) achieved through the use of the information compared with the base scenario in which the information is unavailable or unused (Ketzenberg, Van Der Laan, & Teunter, 2006; Davis, King, Hodgson, & Wei, 2011; Ganesh, Raghunathan, & Rajendran, 2014b). In this paper, we adopt the latter definition. This implies that we aim to make a connection between the information and the supply chain decisions. The availability of (further) information has no value unless it contributes (or is expected to contribute) to a better decision(s) in a supply chain.

VOI is a growing topic in supply chain management research (Shiau, Dwivedi, & Tsai, 2015). However, a recent review of the literature on this topic is lacking. In addition, the existing literature does not provide a framework that supports a comprehensive assessment of VOI in supply chain decisions. We are aware of three previous literature reviews on VOI. The earliest was performed by Huang, Lau, & Mak (2003). They presented a review of studies on the impacts of sharing production information on supply chain dynamics up to 2003. As a reference framework, they categorized papers using seven dimensions: (i) supply chain structure, (ii) decision-making level, (iii) information types, (iv) information sharing modes, (v) performance indices, (vi) modelling of the supply chain or analytical methods, and (vii) impact analysis of supply chain parameters. Following the work of Huang et al. (2003), Li, Yan, Wang, & Xia (2005) carried out an in-depth review of 12 selected papers on the last two dimensions. They specifically focused on the value of information sharing and the factors that affect that value in a supply chain. As one important conclusion, they discussed that the value and the factors are dependent on the context and how the information is utilized in decision-making problems. Another review that focuses on the topic of VOI is presented by Ketzenberg, Rosenzweig, Marucheck, & Metters (2007). They investigated 27 papers up to 2005 and introduced a framework to explain how supply chain parameters influence the value of information sharing in "inventory replenishment decision". The five constructs in their framework are (i) the level of uncertainty in the supply chain, (ii) the sensitivity of the supply chain to uncertainty, (iii) the responsiveness of the supply chain, (iv) the available information in the supply chain and (v) the uses of information in supply chain decision making.

Our aim in this paper is to complement and expand the previous works by reviewing and synthesizing the findings of relevant literature published in the 12-year period from 2006 to 2017. Moreover, while inventory decision is the focus in the aforementioned reviews, this paper broadens the scope by considering decisions in other supply chain areas, i.e. facility (location and design), transportation, sourcing and pricing. In addition, we emphasize the impact of information characteristics on VOI, a dimension that is not included in the above-mentioned frameworks. One party in a supply chain may continuously receive information from different sources (e.g. information from sensing/tracking/tracing devices, information from business transactions, and information shared by other parties in the chain). This information usually has heterogeneous characteristics that may highly influence the VOI in a supply chain (Sellitto, Burgess, & Hawking, 2007; Hazen, Boone, Ezell, & Jones-Farmer, 2014). For instance, although the availability of final consumer demand is important for inventory planning by a distributor, the "timeliness", i.e. the timing that the information becomes available for use, is also important to make decisions for optimal supply chain planning (Tsanos & Zografos, 2016). More discussion on the key information characteristics is presented in Sections 2 and 3.

The paper is structured as follows. Section 2 introduces the review methodology. Important findings from the literature are discussed in Section 3. In Section 4, we present an agenda for future research based on the findings from the literature and propose a framework as a guidance tool to evaluate the VOI in supply chain decisions. Section 5 concludes our study.

2. Review methodology

The review process is based on the five-step guide for a structured literature review proposed by Denyer & Tranfield (2009). The steps are explained as follows.

i. Question formulation: establish a clear focus of the review
ii. Locating studies: define the method to locate as much as possible the studies relevant to the review questions
iii. Study selection and evaluation: assess if a study does actually address the review questions using a set of criteria
iv. Analysis and synthesis: decompose each study into parts and explain how the parts relate to each other, then make the connections between those parts and develop the knowledge that readers are unable to acquire from reading the individual studies in isolation
v. Reporting and using the results: report the results of the review

The introduction explained the motivation for and the context of this review. The research questions are formulated as "how the value of information has been modelled in supply chain decisions in the existing literature" and "what factors may influence the value of information in a supply chain decision". In this section, we first clarify how relevant studies are located and then selected (i.e. steps ii and iii). Then, we present the review framework, which includes the dimensions used in analysing the selected literature (i.e. step iv). The results from the review are discussed in Section 3 (i.e. step v).

2.1. Article selection and evaluation

As discussed in the introduction, the scope of this literature review is limited to journal articles published in the 12-year period from 2006 to 2017. Conference proceedings were excluded in our search. The literature search was performed on two databases – Scopus and Web of Science – within limited subject areas, i.e. business, management, decision science, economics. The focus was on articles whose objective was to assess the VOI in supply chain decisions.

To locate relevant studies from the databases, we used the following combination of terms associated with VOI and supply chain management research:

[("value of information" <u>and</u> (logistics <u>or</u> supply chain)) <u>in</u> (abstract, title, keywords)].

This search strategy resulted in 169 studies. In order to reach the articles that did not use the phrase "value of information", two additional searches were performed. The second search used keywords that are semantically close to "value" (i.e. profit, cost, benefit, saving, surplus) and "information" (i.e. data, knowledge), as follows:

[((information <u>or</u> data <u>or</u> knowledge) <u>and</u> (value <u>or</u> profit <u>or</u> cost <u>or</u> benefit <u>or</u> saving <u>or</u> surplus)) <u>in</u> (title)] <u>and</u> [(logistics <u>or</u> supply chain) <u>in</u> (abstract, title, keywords)].

We limited the second search to "title" because those keywords commonly appear in the "abstract" or "keywords" of a large amount of potentially irrelevant literature. The third additional search complemented the second search; we changed the search scope from "title" to "title, abstract, keywords", and included "logistics decision" and "supply chain decision" to exclude irrelevant articles. The search criteria was as follows:

[((information) and (value or profit or cost or benefit or saving or surplus)) in (abstract, title, keywords)] and [("logistics decision" or "supply chain decision") in (abstract, title, keywords)].

These two additional searches yielded 229 studies. We combined the results from the three searches, removed duplicate articles, and then read the article titles and abstracts. This process shortened the list to 95 journal articles.

A number of papers list "value of information", "big data" or "data mining" among their keywords. The potential association among these phrases was recognized. Because knowledge and techniques in the fields of big data analytics, particularly data mining, have been applied widely in various supply chain functions (Olson, 2015; Addo-Tenkorang & Helo, 2016; Wang, Gunasekaran, Ngai, & Papadopoulos, 2016; Zhong et al., 2016; Kache & Seuring, 2017), a fourth search was performed similar to the first three searches with the following search criteria:

[("big data" or "data mining") and (logistics or supply chain) and not ("logistics regression") in (abstract, title, keywords)],

which resulted in 158 articles. During the screening, we excluded a large number of articles whose objectives were on technical and algorithmic aspects of big data (e.g. algorithms and frameworks to prepare and extract information from big data) but not on the connection between the value of big data and supply chain decisions. In other words, we focus on the most important "V", i.e. value, among the 5Vs of big data, i.e. volume, variety, velocity, veracity, and value (Opresnik & Taisch, 2015; Addo-Tenkorang & Helo, 2016). Finally, we selected 22 articles that assessed the VOI extracted from big data in a specific supply chain decision(s). With regard to reviews on big data applications in supply chain management (i.e. the 5Vs of big data, where and how big data analytics has been applied in supply chain management), we refer to recent review papers by Addo-Tenkorang & Helo (2016), Zhong et al. (2016), Hofmann (2017), and Nguyen, Zhou, Spiegler, Ieromonachou, & Lin (2017).

In total, 117 journal articles over the period 2006-2017 were selected for the analysis and synthesis steps in this paper. Although Scopus and Web of Science can be trusted to hold the most relevant journal articles on supply chain management topics (Chicksand, Glyn, Helen, Zoe, & Robert, 2012; Fahimnia, Tang, Davarzani, & Sarkis, 2015), there might be relevant articles that not in these databases. Moreover, there could be a marginal chance that some relevant literature was missed with the key words and conditions of the literature search. However, the authors believe that the most relevant articles have been located by those searches and they can provide a comprehensive representation of the existing research on VOI in supply chain decisions. Among those 117 articles, 24 articles (including review papers) discuss the uses of different information in general supply chain contexts, 93 articles study the VOI in a specific supply chain decision-making process. Section 3 focuses on discussing the findings from reviewing these 93 articles. Fig. 1 shows the timely distribution of the selected articles in this review. The number of VOI articles found under the big data and data mining search is limited up to 2013 but is now increasing.

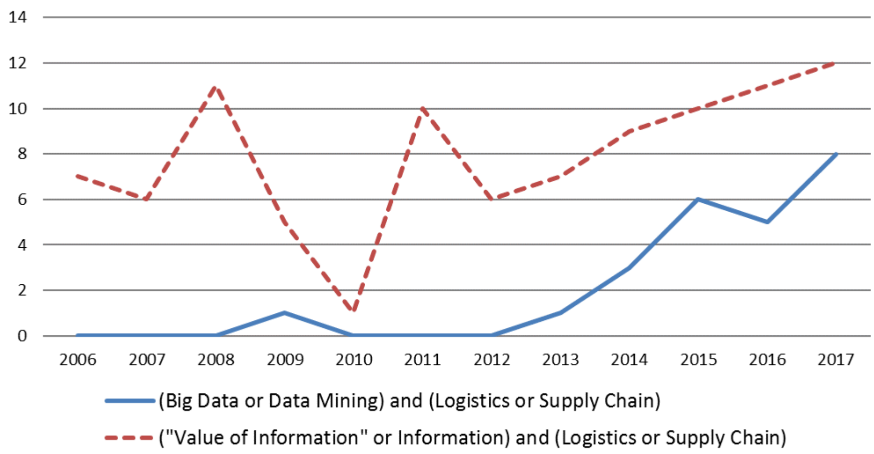

Fig. 1. Time distribution of reviewed articles.

2.2. Review framework

As discussed in the introduction, Huang et al. (2003) used seven elements in the reference framework to review the literature on VOI: (i) decision-making level, (ii) performance indices, (iii) information types, (iv) information sharing modes, (v) modelling of the supply chain/analytical methods, (vi) supply chain structure, and (vii) impact analysis of supply chain parameters. With the aim of revealing the connection between "information" and "supply chain decisions", we integrated those seven elements into a comprehensive framework of four primary dimensions as shown in Fig. 2. The *supply chain decisions* dimension covers the first two elements and is linked to the "why" question, i.e. why one evaluates the value of a piece of information. The *information* dimension covers the elements (iii) and (iv) and the information characteristics; this dimension addresses the nature of the information and it links to the "what" question, i.e. what information with what characteristics is to be evaluated. The *modelling approach* dimension covers element (v) and it answers the "how" question, i.e. how to evaluate the VOI. The *context* dimension covers the last two elements and it defines the supply chain environment in which the VOI is evaluated. These dimensions are explained in detail in the following.

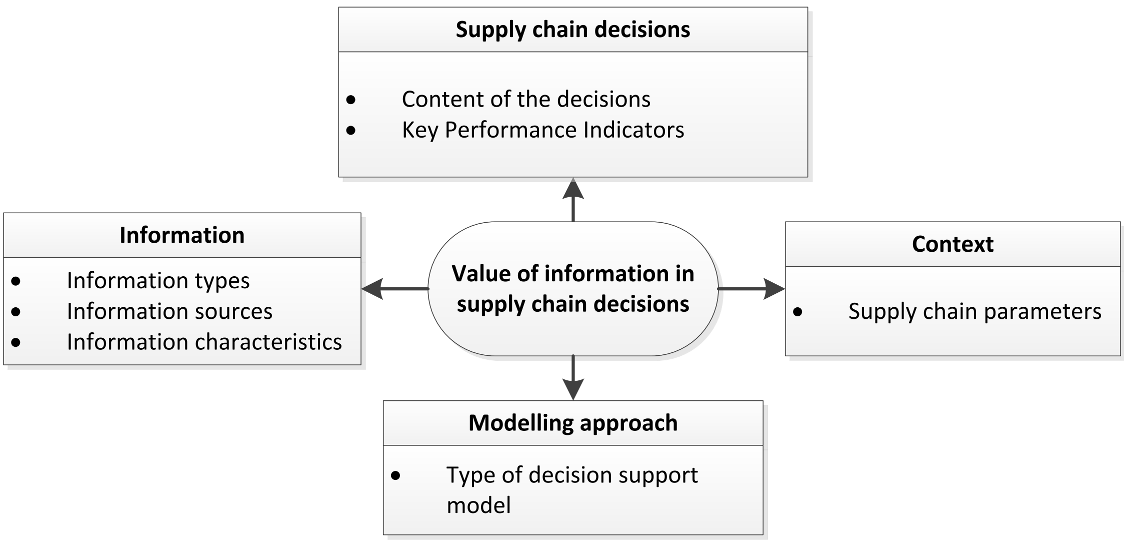

Fig. 2. Review framework.

2.2.1. Supply chain decisions dimension

Supply chain decisions utilize information to improve the KPIs of the supply chain. The decision dimension defines the objective of evaluating the VOI, the content of the decision (i.e. what is decided?), and what KPIs are targeted in the decision. In this review, the taxonomy of supply chain decisions is grounded on five determinant drivers of supply chain performance introduced by Chopra & Meindl (2013), i.e. facilities, inventory, transportation, sourcing, and pricing.

- The facilities category includes the changes in the physical infrastructures (e.g. production and storage sites) of the chain. Example are changes in the role, location, capacity, and layout of the facilities.
- Inventory refers to raw materials, work in process and finished goods within the supply chain. Ketzenberg et al. (2007) classified the inventory decisions from the uses of information into three categories: (i) replenishment decisions concern inventory review policies, order quantity, and order timing; (ii) capacity allocation decisions refer to production planning at upstream members and the allocation of capacities to downstream members in situations of insufficient inventory to meet the total demand or when inventory imbalances arise; (iii) supply chain coordination decisions describe joint replenishment policies to improve the chain-wide efficiency, e.g. vendor managed inventory.
- Transportation decisions concern the movement of inventory from point to point in the supply chain. This category also includes decisions on internal transportation and distribution processes at warehouses.
- Sourcing decisions determine who will perform a particular supply chain activity in the short term or the long term. Example decisions are in-house/outsource production and supplier selection.
- Pricing decisions are about the strategies (e.g. differential pricing or discounting) used to define the price of products and services provided by the company.

2.2.2. Information dimension

The information dimension identifies the type of the information that is used in the decision making, the source of the information, and the characteristics of the information. Concerning information types, Huang et al. (2003) presented six categories of information: (i) product, (ii) process, (iii) inventory, (iv) resource, (v) order, and (vi) planning. We extend this categorization based on our review as discussed further in Section 3.

With regard to the source of information, we made a distinction between three sources of information in this paper. (i) Company-internal refers to information available within the company, such as commercial information, customers' historical information, RFID (radiofrequency identification)-enabled warehousing information. (ii) Chain-internal relates to information sharing among actors in the chain. (iii) Chain-external includes information that originates from sources outside the chain, such as public or paid-subscription governmental data, real-time traffic data or real-time port data.

There are many information characteristics mentioned in the literature, such as relevance, timeliness, accuracy, completeness, consistency, format, security, etc. Information characteristics are also addressed under two other terms: information quality dimensions (Miller, 1996; Gustavsson & Wänström, 2009), information value attributes (Sellitto et al., 2007; Herrala, Leviäkangas, & Haapasalo, 2009; Leviäkangas, 2011). We consider these terms interchangeable in the perspective of how they affect the VOI. The focus of this review paper is on three intrinsic characteristics: accuracy, timeliness, and completeness (Cappiello, Francalanci, & Pernici, 2003; Hazen et al., 2014) (Table 1). We argue that these characteristics are innate and objective to information, whereas other characteristics can be controlled by the information systems and the information-sharing agreement (Nelson, Todd, & Wixom, 2005).

Table 1. Definition of intrinsic characteristics of information

Characteristics	Definition
Accuracy	Accuracy defines how the available information reflects the underlying reality
Timeliness	Timeliness indicates how up to date the information is and how well it meets the demand for information in a particular time and space
Completeness	Completeness refers to different levels of detail of the information

2.2.3. Context dimension

The context dimension describes the supply chain factors that affect the VOI. Within the area of inventory decisions, Li et al. (2005) list the trends of impact (i.e. increase or decrease) of six factors on the VOI: demand variance, capacity, order batch size, service level, inventory costs and lead time. Ketzenberg et al. (2007) organize these factors and introduces new factors (i.e. supply chain structure and the number of facilities in the supply chain, inventory review policies, product perishability) into their framework as mentioned in the introduction. For instance, demand variance is an indicator of the uncertainty level in the supply chain; capacity is relevant to the responsiveness of the supply chain.

2.2.4. Modelling approach dimension

As mentioned in the introduction, analysing VOI in a supply chain decision is equivalent to studying how the information is used to improve the decision making in the chain. Delen & Demirkan (2013) and Wang et al. (2016) categorize the decision models into three categories. (i) Descriptive models build the past and the current state of information in the supply chain. (ii) Predictive models utilize the output of descriptive models to project the future state of information in the supply chain. (iii) Prescriptive models use the outputs from descriptive and predictive models to determine the most appropriate decisions to improve the supply chain performance. Particularly in the field of VOI, predictive modelling techniques include data mining and forecasting, and prescriptive modelling techniques include optimization, simulation, and multi-criteria decision making.

3. Findings

The results from studying the selected articles are presented based on the aforementioned review framework. We discuss the findings on the information dimension, the context dimension, and the modelling approach dimension in Sections 3.1, 3.2, and 3.3. Section 3.4 gives an overview of the supply chain decisions. Each sub-section of Section 3.4 is dedicated to reviewing the decisions in a specific supply chain area, the information types used in those decisions, and the information characteristics that affect the VOI.

3.1. Information dimension

3.1.1. Information types

Because this paper covers a broader scope of supply chain decisions, the six-category information model presented by Huang et al. (2003) was extended to include nine information categories: demand, inventory, planning, product, manufacturing process, transportation process, return product, supply, public information (Fig. 3). Demand (i.e. consumer demand) and inventory (i.e. inventory level, point of sale [POS]) categories are the most analysed information types because they are very relevant to inventory decisions, which are studied in a large number of articles. Research on other information categories is limited. The planning information category includes planned orders, order policy, and demand forecast. The product category includes information on product location, product condition, and product cost. The manufacturing process category includes production-related information, i.e. capacity, yield, shopfloor operations, resource constraints. The transportation process category includes shipment content, delivery lead time, and advance load information. The return-product category is the information on quantity, timing, and condition of return product. The value of return-product information has received growing attention with the recent development of reverse supply chains (Karaer & Lee, 2007; Flapper, Gayon, & Vercraene, 2012; Panagiotidou, Nenes, Zikopoulos, & Tagaras, 2017). The supply category includes information on supplier characteristics and supply quantity. Public information includes information outside the supply chain such as weather forecast information, information from social media, real-time traffic condition.

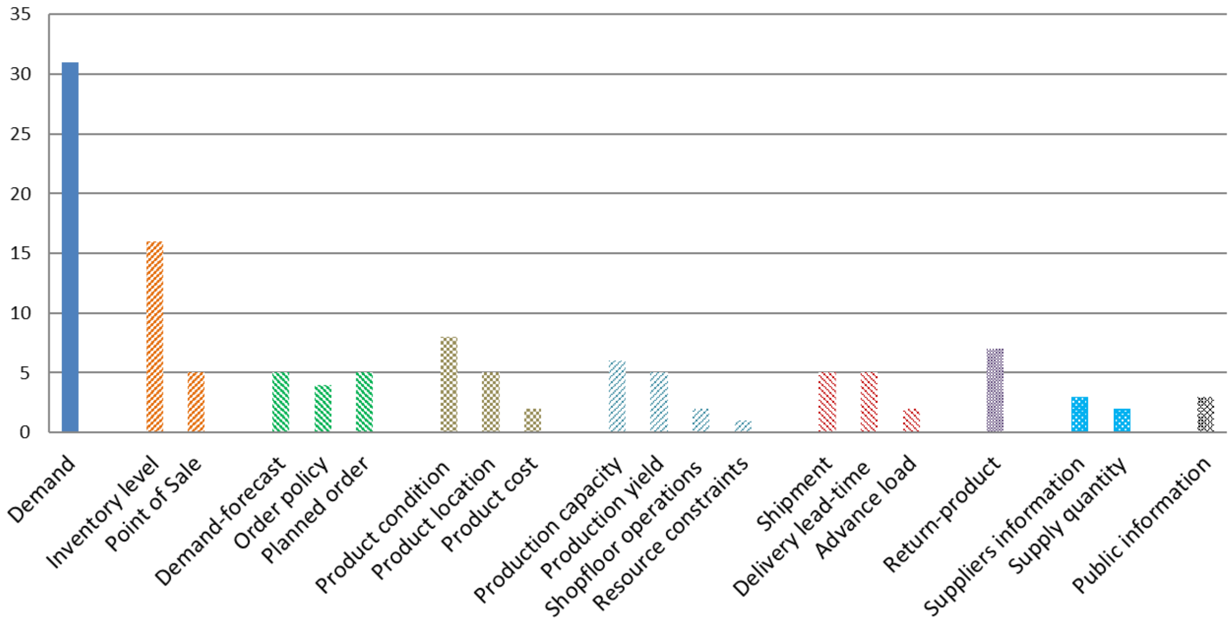

Fig. 3. Number of articles per information type.

3.1.2. Information sources

In terms of information sources, chain-internal information sharing has been the focal point of the literature (covering about 69% of the reviewed articles). Information can be shared from downstream to upstream in the chain, such as demand information (Viswanathan, Widiarta, & Piplani, 2007), or reversely, such as manufacturer's production capacity information shared to retailers (Bakal, Erkip, & Güllü, 2011), or between actors of two different chains at the same stage such as sharing load information among shippers (Zolfagharinia & Haughton, 2014). In chain-internal information sharing, sharing raw data (e.g. demand forecast, inventory level) is very common (Rached, Bahroun, & Campagne, 2015). The data receivers need to process the data to extract the desired information; for an example of information processing, see Jonsson & Mattsson (2013). Most company-internal information (28% of the reviewed articles) is generated from sensing, tracking, and tracing technologies. Examples are RFID data in warehouses and shopfloor (Zhong et al., 2015), shipment data (Flamini, Nigro, & Pacciarelli, 2011), product location (Bryan & Srinivasan, 2014), and condition data (Ketzenberg, Bloemhof, & Gaukler, 2015; Li & Wang, 2017; Salinas Segura & Thiesse, 2017). We found three articles (3% of the reviewed articles) discussing the VOI from chain-external information sources: the value of weather information in warehouse workforce planning by Steinker, Hoberg, & Thonemann (2017), the VOI extracted from social media in operations management by Cui, Gallino, Moreno, & Zhang (2017), and the value of real-time traffic information in vehicle routing by Flamini, Nigro, & Pacciarelli (2017).

3.1.3. Information characteristics

The characteristics of information are not explicitly discussed in most of the reviewed articles. Most existing papers investigate the VOI based only on "information availability" (Fig. 4). In other words, these studies consider two scenarios of decision making, with and without a specific piece of information. Despite a long list of information characteristics as mentioned, this review found that indeed the three intrinsic characteristics, i.e. completeness, accuracy, timeliness, are expressly deliberated upon the most. These characteristics have been modelled differently in the literature (Table 2). Timeliness is modelled by parameters that indicate the timing of obtaining the information in advance of decision making. Inaccuracy is incorporated by adding information errors, which usually follow statistical distributions, to the actual base values. Information inaccuracy can occur as a result of both human factors, e.g. overstating demand forecast (Yan & Pei, 2012), and system factors, e.g. tracking system measurement errors (Flamini et al., 2011). Completeness is studied through multiple scenarios: no information, partial information, and complete information. Overall, information completeness and accuracy are often explored but research on information timeliness is still very limited, as also suggested more than a decade ago by Huang et al. (2003).

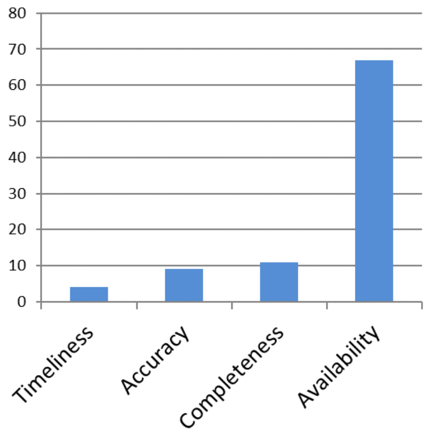

Fig. 4. Number of articles per information characteristic.

3.2. Context dimension

The value of an information type can be affected by many supply chain factors. For example, the value of demand information is influenced by production capacity, product substitution, product lifetime, order batch size, lead time, etc. In Table 3, we summarize the factors and their influences on the VOI discussed in the 24 reviewed articles that go beyond a numerical sensitivity test and deliberately investigate the effect of supply chain factors on the VOI by performing scenario analyses.

The results are consistent in most articles. Still, there are some contradictory findings in the literature. The effect of demand uncertainty is an example. A common finding in the literature is that the VOI increases as demand uncertainty increases, as concluded on the value of product condition information in Ferguson & Ketzenberg (2006), i.e. model A. Yet Ketzenberg et al. (2015) found a contradictory result which implies that the value of product condition information decreases as demand uncertainty increases, i.e. model B. In order to understand the contradictory findings, it is essential to analyse how the factor is related to the changes in KPIs achieved from using the information in decision making. In model A, the supplier shares the information to the retailer in this period before the retailer places the order. It eliminates the product outdating uncertainty when the retailer realizes the demand in the next period. Thus, the retailer total cost (as KPI) depends primarily on the lost-sale cost due to the demand uncertainty. In model B, the retailer places the order in this period and learns about the product condition via RFID tags in the next period after the products arrive. Therefore, the information only helps in optimizing issuing policy (first expired first out) to mitigate the product outdating. In this case, the retailer total cost is not only dependent on the demand uncertainty but also on the product outdating uncertainty.

3.3. Modelling approach dimension

Table 4 summarizes the types of decision support models used for assessment of VOI in the reviewed articles. Approximately 11% of the articles use predictive models, including forecasting methods (de Brito & van der Laan, 2009; Scott, 2015; Steinker et al., 2017), data mining (Lin, Chuang, Liou, & Wu, 2009; Yi, 2014; Lee, 2017), and big data analytics (Zhong et al., 2015; Kaur & Singh, 2017). Fifty percent of the articles use prescriptive analytical models, which are complex mathematical models, game theory, and probability theory. For example, with game theory, actors' quantitative decisions (e.g. order quantity, pricing) are adjusted corresponding to the information received from other actors. Optimization models (including heuristics, dynamic, integer, stochastic, and mixed-integer programming) are also used in 26% of reviewed articles. A limited literature (13%) applied simulation (mostly discrete-event simulation) in their studies.

In a study on the use of POS and order data in demand forecasting, Williams & Waller (2011) conclude that the modelling approach (i.e. bottom-up and top-down forecasting) should be selected according to the availability of the information. In addition, the choice of a modelling approach may have an impact on the assessment of the VOI. In a study by de Brito & van der Laan (2009), the value of demand information is examined with four different forecasting models, which have different requirements on information completeness. The most informed model (i.e. the model that requires the most detailed information) does not necessarily lead to the highest VOI.

Table 2. Modelling timeliness, accuracy, and completeness in the existing literature.

Characteristic	Article	Types of information	Modelling	
Timeliness	(Liu, Srinivasan, & Vepkhvadze, 2009)	Product location (tracking)	q-period lagged information (q = 0, 1, 2, …; q = 0: real-time information)	
	(Tjokroamidjojo, Kutanoglu, & Taylor, 2006)	Advance load information	Number of days in advance that the information is shared	
	(Zolfagharinia & Haughton, 2014)			
	(Banerjee & Golhar, 2017)	Product specifications	Two moments of sharing the information by the retailer: before or after the supplier starts the base unit production	
Accuracy	(Ketzenberg, 2009)	Demand, yield, capacity	A probability p (0, 0.05, 0.25, 0.5) that inaccuracy occurs in randomizing the information (p = 0: accurate information)	
	(Flamini et al., 2011)	Product location	Randomizing measurement errors (follow a uniform distribution)	
	(Kaman, Savasaneril, & Serin, 2013)	Shopfloor operations	Randomizing errors between actual and observed states (follow a uniform distribution)	
	(Cannella, Framinan, Bruccoleri, Barbosa-Póvoa, & Relvas, 2015)	Inventory level	Adding error as a percentage of the record	
	(Cui, Allon, Bassamboo, & Van Mieghem, 2015)	POS, replenishment policy	Adding decision deviations (follow a normal distribution) to the order quantity, which is based on the replenishment policy	
	(Kwak & Gavirneni, 2015)	Demand	Adding information errors (follow a normal distribution) to the actual values	
	(Ketzenberg et al., 2015)	Product condition		
	(Rached et al., 2015)	Demand, delivery lead time		
	(Lu, Feng, Lai, & Wang, 2017)	Demand		
Completeness			***Partial information***	***Complete information***
	(Ketzenberg et al., 2006)	Demand, return quantity, recovery rate	A limited number of information signals to limit the range of the variables	Infinite number of information signals
	(Bakal & Akcali, 2006)	Yield rate	Different support for uniform distribution, e.g. (0, 1), (0.4, 0.6)	Uniform distribution with very small interval
	(Chen, Yang, & Yen, 2007)	Inventory, demand, capacity	Sharing 1 or 2 types of information	Sharing 3 types of information
	(Larbi, Alpan, Baptiste, & Penz, 2011)	Content of inbound trucks in a sequence	A small number of inbound trucks	A very large number
	(Liu & Kumar, 2011)	Inventory level	Weekly and mix of weekly/daily	Daily sharing
	(Bryan, Srinivasan, & Viswanathan, 2016)	Shipment location	Tracking devices installed at a number of transportation stages	Tracking devices installed at all the transportation stages
	(Karaer & Lee, 2007)	Inventory level	The information only includes mean and variance of the distributions	Detailed values
	(Mukhopadhyay, Yao, & Yue, 2008)	Product cost		
	(de Brito & van der Laan, 2009)	Demand, product return		
	(Cheong & Song, 2013)	Yield		
	(Wagner, 2015)	Demand		

Table 3. Effect of supply chain factors.

Article	Studied information type	Influencing factor	VOI increase		VOI decrease	
			as factor increases	as factor decreases	as factor increases	as factor decreases
(Byrne & Heavey, 2006)	Demand	Production capacity			x	
(Ferguson & Ketzenberg, 2006)	Product condition	Demand uncertainty	x			
(Chiang & Feng, 2007)	Inventory level	Holding cost	x			
(Karaer & Lee, 2007)	Return-product location and quantity	Lead time of reverse channel	x			
(Choudhury, Agarwal, Singh, & Bandyopadhyay, 2008)	Inventory level	Demand uncertainty	x			
		Network size (number of retailers)			x	
		Production capacity	x			
(Ferguson & Ketzenberg, 2008)	Demand and inventory level	Product lifetime		x		
(Ganesh, Raghunathan, & Rajendran, 2008)	Demand	Product substitution			x	
(Bakal et al., 2011)	Production capacity (supplier)	Production capacity	x			
(Davis et al., 2011)	Inventory level	Capacity			x	
		Penalty cost				x
		Demand uncertainty			x	
(Hussain & Drake, 2011)	Demand	Order batch size		x		
(Flapper et al., 2012)	Advance return	Return time	x			
(Bendre & Nielsen, 2013)	Lead time	Lost-sale cost	x			
(Kaman et al., 2013)	Shopfloor operations	Holding cost	x			
(Ketzenberg, Geismar, Metters, & van der Laan, 2013)	Unattended POS (vending machine)	Demand uncertainty	x			
(Ganesh et al., 2014b)	Demand	Product substitution			x	
(Ruiz-Benítez, Ketzenberg, & van der Laan, 2014)	Return-product quantity	Shipping cost			x	
		Decay rate of product	x			
(Zolfagharinia & Haughton, 2014)	Advance load	Service radius and trip length	x			
(Ketzenberg et al., 2015)	Product condition	Demand uncertainty			x	
(Rached et al., 2015)	Demand and delivery lead time	Holding cost	x			
(Yan & Pei, 2015)	Demand	Product differentiation			x	
(Shang, Zhou, & Van Houtum, 2010)	Demand	Logistics system	VOI is significant when the logistics systems is flexible to enable flexible ordering			
(Xue, Shen, Tan, Zhang, & Fan, 2011)	Supply quantity	Review policy	VOI depends on the inventory review policy			
(Cho & Lee, 2013)	Demand	Lead time	VOI is significant when lead time is shorter than the seasonal period			
(Babai, Boylan, Syntetos, & Ali, 2016)	Demand	Autoregressive demand parameter	VOI is significant when the parameter is less than 0.7			

Table 4. Employed decision support models in the reviewed articles

Type of decision support model	Articles
Analytical	(Bakal & Akcali, 2006), (Hsiao & Shieh, 2006), (Ketzenberg et al., 2006), (Lin & Tsao, 2006), (Chiang & Feng, 2007), (Karaer & Lee, 2007), (Ganesh et al., 2008), (Ha & Tong, 2008), (Wu & Edwin Cheng, 2008), (Yao & Dresner, 2008), (Chen & Lee, 2009), (Liu et al., 2009), (Shang et al., 2010), (Bakal et al., 2011), (Jakšič, Fransoo, Tan, De Kok, & Rusjan, 2011), (Xue et al., 2011), (Axsäter & Viswanathan, 2012), (Chen, Liang, & Li, 2012), (Yang, Aydin, Babich, & Beil, 2012), (Cho & Lee, 2013), (Ganesh, Raghunathan, & Rajendran, 2014a), (Ganesh et al., 2014b), (Giloni, Hurvich, & Seshadri, 2014), (Lee & Cho, 2014), (Ruiz-Benítez et al., 2014), (Salzarulo & Jacobs, 2014), (Cannella et al., 2015), (Cui et al., 2015), (Kwak & Gavirneni, 2015), (Rached et al., 2015), (Wagner, 2015), (Babai et al., 2016), (Bian, Shang, & Zhang, 2016), (Bryan et al., 2016), (Sabitha, Rajendran, Kalpakam, & Ziegler, 2016), (Banerjee & Golhar, 2017), (Huang & Wang, 2017), (Li & Wang, 2017), (Lu et al., 2017), (Panagiotidou et al., 2017)
Game theory	(Mukhopadhyay et al., 2008), (Wu, Zhai, Zhang, & Xu, 2011), (Yan & Pei, 2012, 2015), (Ma, Shang, & Wang, 2017), (Zhang, Zhu, & Gou, 2017)
Dynamic programming	(Ferguson & Ketzenberg, 2008), (Ketzenberg, 2009), (Davis et al., 2011), (Flapper et al., 2012), (Bendre & Nielsen, 2013), (Kaman et al., 2013), (Ketzenberg et al., 2013), (Ketzenberg et al., 2015), (Yang et al., 2016), (Flamini et al., 2017), (Gaukler, Ketzenberg, & Salin, 2017)
Integer programming	(Tjokroamidjojo et al., 2006), (Chen et al., 2007), (Krikke, le Blanc, van Krieken, & Fleuren, 2008), (Thomas, Krishnamoorthy, Venkateswaran, & Singh, 2015)
Stochastic programming	(Cheong & Song, 2013), (Bryan & Srinivasan, 2014), (Rijpkema, Hendrix, Rossi, & van der Vorst, 2016)
Mixed-integer programming	(Zolfagharinia & Haughton, 2014), (Kaur & Singh, 2017)
Heuristics	(Ferguson & Ketzenberg, 2006), (Viswanathan et al., 2007), (Flamini et al., 2011), (Larbi et al., 2011), (Dettenbach & Thonemann, 2015)
Data mining	(Lin et al., 2009), (Yi, 2014), (Lee, 2017), (Tsai & Huang, 2017), (Cui et al., 2017)
Big data analytics	(Zhong et al., 2015)
Forecasting	(de Brito & van der Laan, 2009), (Williams & Waller, 2011), (Scott, 2015), (Steinker et al., 2017)
Monte Carlo simulation	(Sohn & Lim, 2008), (Salinas Segura & Thiesse, 2017)
System dynamics	(Hussain & Drake, 2011), (Li, Pedrielli, Lee, & Chew, 2016)
Discrete-event simulation	(Byrne & Heavey, 2006), (Choudhury et al., 2008), (Kim, Tang, Kumara, Yee, & Tew, 2008), (Schmidt, 2009), (Liu & Kumar, 2011), (Rijpkema, Rossi, & van der Vorst, 2012), (Jonsson & Mattsson, 2013), (Rached, Bahroun, & Campagne, 2016)

Table 5. The uses of different information types in supply chain decisions

Inventory decision		Articles	Major types of information used in the decision
Replenishment	Inventory review policy	(Xue et al., 2011), (Babai et al., 2016)	Demand, supply quantity
Replenishment	Reorder point	(Schmidt, 2009), (Shang et al., 2010), (Liu & Kumar, 2011), (Salzarulo & Jacobs, 2014), (Cui et al., 2017), (Salinas Segura & Thiesse, 2017)	Demand, inventory level
Replenishment	Safety stock	(Schmidt, 2009)	Demand
Replenishment	Order frequency/timing	(Lin & Tsao, 2006), (Viswanathan et al., 2007), (Yao & Dresner, 2008), (Axsäter & Viswanathan, 2012), (Ketzenberg et al., 2013), (Bryan & Srinivasan, 2014), (Ketzenberg et al., 2015), (Gaukler et al., 2017)	Demand, inventory level, POS, planned order from downstream, location of product, production lot freezing and plan
Replenishment	Order quantity	(Ferguson & Ketzenberg, 2006), (Hsiao & Shieh, 2006), (Ketzenberg et al., 2006), (Chen et al., 2007), (Chiang & Feng, 2007), (Ferguson & Ketzenberg, 2008), (Bakal et al., 2011), (Hussain & Drake, 2011), (Jakšič et al., 2011), (Williams & Waller, 2011), (Bendre & Nielsen, 2013), (Cheong & Song, 2013), (Jonsson & Mattsson, 2013), (Cannella et al., 2015), (Cui et al., 2015), (Rached et al., 2015), (Dettenbach & Thonemann, 2015), (Ketzenberg et al., 2015), (Bryan et al., 2016), (Li et al., 2016), (Rached et al., 2016), (Yang et al., 2016), (Banerjee & Golhar, 2017), (Panagiotidou et al., 2017)	Demand, inventory level, POS, demand forecast, planned order, supply lead time, supply quantity, shipment position, yield distribution, production capacity, product location, product condition
Replenishment	Order-up-to level	(Choudhury et al., 2008), (Ganesh et al., 2008), (Wu & Edwin Cheng, 2008), (Chen & Lee, 2009), (de Brito & van der Laan, 2009), (Liu et al., 2009), (Davis et al., 2011), (Cho & Lee, 2013), (Ganesh et al., 2014a), (Ganesh et al., 2014b), (Giloni et al., 2014), (Kwak & Gavirneni, 2015), (Sabitha et al., 2016), (Lu et al., 2017)	Demand, inventory level, planned order, return product probability, product location, shipment position
Capacity allocation		(Byrne & Heavey, 2006), (Ketzenberg et al., 2006), (Karaer & Lee, 2007), (Sohn & Lim, 2008), (Ketzenberg, 2009), (Flapper et al., 2012), (Rijpkema et al., 2012), (Kaman et al., 2013), (Salzarulo & Jacobs, 2014), (Thomas et al., 2015), (Rijpkema et al., 2016)	Demand, inventory level, POS, advance return, return product visibility, recovery yield, production capacity, resource constraints in production, shopfloor operations, product condition
SC coordination		(Chen et al., 2007), (Viswanathan et al., 2007), (Choudhury et al., 2008), (Ferguson & Ketzenberg, 2008), (Yao & Dresner, 2008), (Thomas et al., 2015)	Demand, inventory level, planned order, production capacity, resource constraints in production

Transportation decision		
Service network design	(Shang et al., 2010)	Demand
Design and scheduling of services	(Tjokroamidjojo et al., 2006), (Flamini et al., 2011), (Larbi et al., 2011), (Ruiz-Benítez et al., 2014), (Lee, 2017), (Steinker et al., 2017), (Tsai & Huang, 2017)	Inventory level, return-product quantity, shipment (products types and quantities, sequences), product location, advance load
Vehicle routing	(Krikke et al., 2008), (Flamini et al., 2011), (Yi, 2014), (Zolfagharinia & Haughton, 2014), (Zhong et al., 2015), (Flamini et al., 2017)	Product location, advance load, inventory level, shopfloor operations
Empty vehicle repositioning	(Kim et al., 2008)	Product location (RFID)
Sourcing decision		
Selecting key suppliers	(Lin et al., 2009), (Wu et al., 2011), (Yang et al., 2012), (Kaur & Singh, 2017)	Suppliers' reliability, supplier's production cost, product quality
Modifying sourcing contract terms	(Ha & Tong, 2008), (Lee & Cho, 2014), (Wagner, 2015)	Demand, inventory level
Pricing decision		
Determining wholesale price	(Mukhopadhyay et al., 2008), (Bian et al., 2016), (Huang & Wang, 2017), (Ma et al., 2017), (Zhang et al., 2017)	Product cost
Postponing pricing decision	(Bakal & Akcali, 2006)	Yield rate
Determining real-time/dynamic price	(Scott, 2015), (Li & Wang, 2017)	Real-time demand (load)
Determining prices in competing retailers	(Chen et al., 2012), (Yan & Pei, 2012, 2015)	Demand, demand forecast

3.4. Supply chain decisions dimension

Information is traditionally known as a substitute for inventory (and capacity) in the literature (Tan, Lyman, & Wisner, 2002; Borgman & Rachan, 2007). Therefore, it is not surprising that a large number of articles study the VOI in inventory decisions (Fig. 5). Transportation is the second major area. There is a limited literature on sourcing and pricing decisions. Our search of the literature found no works on VOI in facilities decisions. The reason may be that facilities decisions require an enormous volume of historic data on uncertain supply chain parameters such as demand and supply, which are often not available to researchers. Most of the literature on supply chain network design and facilities decisions focuses on decision-making environments in which no information or limited information (i.e. probability distribution) on supply chain parameters is available (Govindan, Fattahi, & Keyvanshokooh, 2017). Table 5 summarizes the supply chain decisions from the uses of information in each supply chain area. In the following sub-sections, the existing literature for each decision area is discussed separately in detail.

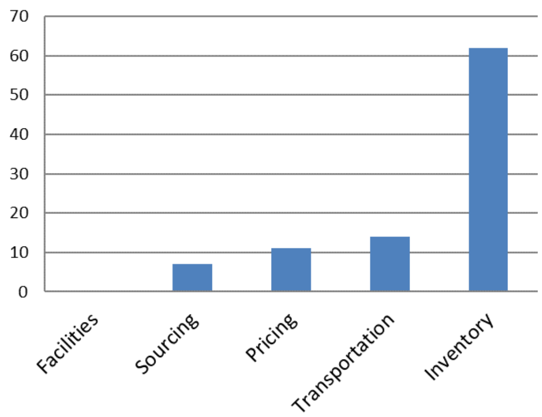

Fig. 5. Number of articles per supply chain area.

3.4.1. Inventory decisions

Inventory decisions are categorized into replenishment, capacity allocation, and supply chain coordination. In terms of information type, the major focus is on the value of demand, inventory, planning, and manufacturing process information categories (Table 5). There has also been increasing interest in evaluating the value of product information, transportation process information and return-product information. For instance, product condition information captured by sensing devices improves order-quantity decisions in perishable supply chains by reducing product spoilage uncertainty (Ketzenberg et al., 2015; Salinas Segura & Thiesse, 2017). Product location information from tracking devices is also valuable because it diminishes the uncertainty about replenishment arrival time, especially when products have to be transported through multiple facilities before reaching the retailers (Bryan & Srinivasan, 2014). Delivery lead-time information also reduces the uncertainty of replenishment arrival time and subsequently contributes to better decisions on order quantity (Rached et al., 2015, 2016). Return-product quantity information is also useful in making decisions on production plans for new products (Karaer & Lee, 2007).

Regarding information accuracy, inaccurate inventory records are prevalent, especially at retailers (Kang & Gershwin, 2005). The existence of errors considerably reduces the VOI, yet it is important to pinpoint the range of errors in which the VOI remains appreciable. Kwak & Gavirneni (2015) show that as the variance of errors exceeds the variance of demand, inaccurate inventory-level information shared by retailers has no more value to the supplier. In other studies, Cannella et al. (2015) and Lu et al. (2017) show that inaccurate inventory records may eradicate the bullwhip effect avoidance features resulting from collaborative sharing of inventory level information. Ketzenberg et al. (2015) indicate that product travel time and temperature information is useful in inventory issuing policy when the errors are less than 14% of the actual values. Note that these figures are subject to supply chain context and case-specific parametric settings.

Concerning information completeness, the existing literature shows that in some cases partial information can perform almost as well as complete information. In a study of demand, return-product quantity and recovery rate information by Ketzenberg et al. (2006), the value of more than five information signals (partial information) converges quickly to within 1% difference from the value of infinite information signals (complete information). As concluded by Cheong & Song (2013), partial supplier yield rate information (i.e. when only mean and variance are known) can be sufficient in determining the newsvendor's regular ordering quantity; however, partial information cannot replace complete information in a strategic decision to select reliable suppliers because an improvement in the mean and variance of the yield rate cannot guarantee a monotonic profit improvement.

Information timeliness in inventory decisions is studied only by Liu et al. (2009) and Banerjee & Golhar (2017). Banerjee & Golhar (2017) study the timing of sharing the product specification information from the retailer to the manufacturer (i.e. before or after the manufacturer starts the base unit production). Using a trade-off model between the supply chain costs and the benefits resulting from the retailer's behaviour of intentionally delaying information sharing, the authors indicate the importance of timely information sharing among supply chain partners. Liu et al. (2009) show that real-time tracking information of product location allows a cost-effective policy on order quantity and timing, whereas delayed information in the long run will entail an increase in holding and shortage costs.

Regarding KPIs in inventory decisions, the combination of holding and shortage costs is the most considered performance measure. A few articles studying perishable products also consider the outdating cost (Ferguson & Ketzenberg, 2006, 2008; Ketzenberg et al., 2015). Moreover, a common practice is to include transportation costs in the inventory costs model. As a result, the impact of an information type and its value in reducing transportation or inventory cost cannot be seen separately. The impact of information on KPI's may look inconsistent in some cases. For instance, in evaluating the VOI in reducing inventory costs, Rached et al. (2015) conclude that the gains from sharing demand information and warehouse-retailer lead-time information simultaneously are not cumulative; whereas Ketzenberg et al. (2006) suggest that investing in an additional type of information (between two types: demand and return product) results in an additional payoff. The difference between these findings lies in how the information helps to reduce the costs. In Rached et al. (2015), both demand and lead time play the same role in order-quantity decisions to reduce the retailer's holding cost. As a result, either piece of information is sufficient for the decision. In Ketzenberg et al. (2006), demand and return complement each other in the order-quantity decision. Thus, the additional information type will result in additional holding cost reduction for retailers.

3.4.2. Transportation decisions

The value of different information is studied in different transportation and distribution decisions including strategic decisions (e.g. service network design), tactical decisions (e.g. service design and scheduling of services), and operational decisions (e.g. vehicle routing and empty vehicle repositioning). Lumsden & Mirzabeiki (2008) indicate that product location information as a critical information type for all supply chain members. For instance, it is used to optimize vehicle routing (Flamini et al., 2011; Yi, 2014). Kim et al. (2008) also discuss the value of product location information enabled by RFID in decisions on repositioning empty vehicles. Larbi et al. (2011) utilize the shipment information of inbound trucks in optimizing cross-docking outbound scheduling. Besides supporting inventory decisions, inventory-level information also helps to coordinate the transportation (i.e. routing and scheduling of services) (Krikke et al., 2008; Ruiz-Benítez et al., 2014).

The effect of information timeliness in transportation decisions is discussed in two articles. Tjokroamidjojo et al. (2006) and Zolfagharinia & Haughton (2014) answer the question of how much time in advance the load information should be provided by shippers to carriers so that it brings a positive value to the decision making. Tjokroamidjojo et al. (2006) show that 3-day and 5-day advanced load information (ALI) have close values. Zolfagharinia & Haughton (2014) suggest that it is not practical to have more than 3-day ALI in the trucking industry, and show that the value of 3-day ALI is only slightly higher than the value of 2-day ALI. In other words, significant cost improvement can be achieved with 2-day ALI, which considerably eases the information-sharing effort for shippers.

Examining information completeness in the case of scheduling cross-docking operations, Larbi et al. (2011) indicate that knowing the content of the next 14 inbound trucks is as good as knowing the content of all the trucks in the sequence. This number can be even lower if the number of destinations decreases. Nevertheless, the VOI in this case needs to be tested against important supply chain factors such as the cross-docking capacity to act corresponding to the level of information obtained.

Flamini et al. (2011) quantify the VOI on location and condition of transported goods in optimizing vehicle routing of the distribution process. Information inaccuracy due to measurement errors of tracking systems is reported to cause performance deterioration; however, the levels of deterioration are in accordance with the routing algorithms used.

3.4.3. Sourcing decisions

In sourcing decisions, information is used in selecting suppliers or modifying sourcing contract terms. Concerning supplier selection, Lin et al. (2009) propose a data-mining-based framework that gathers the big data of suppliers' characteristics and shipment records to cluster potential suppliers into primary and secondary supplier groups. On more tactical decisions on short-term sourcing, Wu et al. (2011) study the benefits to a buyer when suppliers share their product quality information; based on the information, the order quantities are adjusted. By having the supplier's reliability and product cost information, a buyer can switch between single-sourcing (winner-take-all) and dual-sourcing (diversification) strategies (Yang et al., 2012).

Modifying terms in contracts under information sharing is studied by Wagner (2015), Lee & Cho (2014), and Ha & Tong (2008). From a retailer's perspective, Lee & Cho (2014) suggest that the value of stock-out quantity information may be significant because the retailer can specify the penalty cost to the supplier in the contract under deterministic and stochastic demand situations. From a supplier's perspective, shared demand information in a two-echelon supply chain allows the supplier to switch contract types, such as from linear price-based contracts to quantity-based contracts (Ha & Tong, 2008). The value of demand information is also examined by Wagner (2015) in a two-echelon supply chain. Two levels of information are modelled in this study: complete information refers to knowing the demand's full distribution function, and incomplete information equals knowing only the mean and variance of the demand distribution. The analytics show that with complete information, the supplier can adjust the wholesale price in such a way that benefits both firms only if the supplier correctly assesses the level of information known by the retailer.

3.4.4. Pricing decisions

A limited literature addresses the VOI in pricing decisions. Bakal & Akcali (2006) study the value of perfect yield rate information in making pricing decisions in the automotive parts remanufacturing industry. Because perfect yield information is difficult to attain, the authors suggest a strategy of postponing pricing decisions to deal with the random yield. In the study by Mukhopadhyay et al. (2008) about wholesale price, a traditional retailer shares with the manufacturer its cost of adding an extra value to the products. Accordingly, the manufacturer decides the wholesale price to the retailer and the direct price for their own online channel. The value of sharing the cost information is positive to the retailer only when the value-added cost is lower than a threshold value; beyond this value, sharing the information is no longer beneficial to the retailer. Ma et al. (2017) report a similar finding that the manufacturer's profit always increases when using the shared cost information by retailers in wholesale price decisions, whereas the benefit of sharing information to retailers is uncertain. Also in the context of manufacturer-retailer information sharing, Bian et al. (2016) and Huang & Wang (2017) conclude that sharing demand-forecast information benefits the manufacturer and hurts the retailer in the short term; however, because the value of information sharing is positive to the entire supply chain, the manufacturer can motivate the retailer to share information using the compensation policy suggested in the paper. Scott (2015) proposes an analytical method that utilizes the value of load information shared by shippers to carriers to estimate real-time truckload market prices; the study indicates that the more in advance the information is shared, the better price the shippers can receive.

4. An agenda for future research

In this paper, we review the VOI literature in the 12-year period from 2006 to 2017. Each selected article has been studied based on four dimensions of the review framework, i.e. supply chain decisions, information, modelling approach, and context. Based on the literature and the findings from the previous section, opportunities for future research in each dimension of the review framework are discussed in this section. Furthermore, based on the literature studied, a step-wise approach to evaluate the VOI in the supply chain domain is presented at the end of this section.

4.1. Key areas and questions for future research

Based on our review and analysis of the literature in this paper, we propose the following directions and scientific questions for future research on VOI in the supply chain domain.

- *Supply chain decisions: expanding the research beyond inventory decisions and looking into interdependencies of different decisions*

  As mentioned in the previous section, the main focus in the current VOI literature is on assessing the VOI in inventory decisions, yet other areas of supply chain management such as facilities, transportation, sourcing, and pricing are not adequately explored in the literature. With the evolution towards virtual supply chains enhanced by the Internet of Things, the increasing use of advanced ICTs, and inter-organizational information exchange, the availability of information in the supply chain has been improved (Kache & Seuring, 2017; Nguyen et al., 2017). Decision makers have access to more and new information types, i.e. the increasing (big) data variety in supply chains (Hofmann, 2017). Thus, there is a need for further research on how to make the utmost use of different existing and new information types in strategic, tactical, and specially operational planning decisions (Verdouw, Beulens, & van der Vorst, 2013; Buijs & Wortmann, 2014). Furthermore, much more information is available in real time across the supply chain. As a result, we need to focus further on using real-time information to improve the supply chain processes at the operational level (especially in handling unexpected events). In addition, the existing literature on VOI has not fully captured the interdependence among chain processes. VOI has been primarily studied in different single decisions. The VOI in decisions that involve interdependent processes and the VOI in managing the interdependence among supply chain processes are therefore promising research areas to study. The following general questions need further attention in each specific supply chain area:

(1) *What is the value of existing and new information types in supply chain operational decision making?*
Example of new information types are real-time chain products (location and condition) and real-time chain resources based on virtual objects in virtual supply chains (Verdouw, Beulens, Reijers, & van der Vorst, 2015). Moreover, the use of chain-external information such as information extracted from social media networks using big data and predictive analytics and real-time public information need more investigation from supply chain researchers and practitioners (Chavez, Yu, Jacobs, & Feng, 2017; Flamini et al., 2017).

(2) *What is the value of supply chain information in coordinating interdependent supply chain processes?*
Concerning two core and interdependent processes in supply chains, i.e. production and distribution, the problem of coordinating and integrating production and distribution planning at tactical and operational levels has been studied extensively (Bilgen & Ozkarahan, 2004; Fahimnia, Farahani, Marian, & Luong, 2013). Recent studies on this problem have compounded operations research models with emerging ICTs following the research agenda suggested by Bilgen & Ozkarahan (2004). However, necessary information (e.g. order information, warehouse operations information, traffic conditions) is assumed to be available (and accurate, complete, and timely) in most of the proposed models (Moons, Ramaekers, Caris, & Arda, 2017). In real life, this information is often unknown, particularly the timing characteristic of order information.

- *Information: attention to information characteristics in the assessment of VOI in the supply chain domain*
The main focus of the literature has been on the availability of information, and the importance and implications of information characteristics in determining the VOI is generally lacking. Particularly timeliness is an information characteristic that is not adequately addressed. Because more accurate/complete/timely information is costly and requires a high level of effort, a better understanding of what degree of accuracy/completeness/timeliness is needed in each decision process can be promising from a practical point of view (Hazen et al., 2014). We suggest the following question for future research:

(3) *What is the value of information in supply chain decision making resulting from different characteristics of the information?*
This question is indeed a general question and can be applied to all categories of supply chain decisions as mentioned in the previous sub-sections. For instance, in information sharing within collaborative transportation, we need to study how the VOI varies in the time dimension, the accuracy dimension, and the completeness dimension. Such an analysis can lead to an effective and efficient information-sharing agreement among supply chain actors or a more viable investment in developing the infrastructure for information gathering and processing.

- *Context: looking into the dynamic and multi-actor characteristic of VOI*

Although the VOI literature has explored the effects of different supply chain factors in some specific cases, social aspects of VOI are generally overlooked (Montoya-Torres & Ortiz-Vargas, 2014). Information characteristics are subject to supply chain actors' behaviours and interests. Having dissimilar goals and capabilities for information gathering, sharing, and processing, their information-sharing approaches are diverse about which information to share, when and how much to share, and how accurate it will be, etc. As a result, the VOI in a multi-actor context can be very dynamic. Therefore, considering the multi-actor nature of VOI, the following question is worth investigating:

(4) *What are the dynamic values of information in a supply chain multi-actor context?*
Continuing with the example about collaborative transportation, answering the above question can help a chain actor to form a feasible and beneficial collaboration with a group of suitable actors. Similarly, as suggested by Fahimnia et al. (2013), VOI in information-sharing models to solve the integrated production-distribution problem needs to be considered in a multi-actor context with different patterns of supply chain actors' ownership and power positions. Based on actor-network theory and resource-dependence theory, Hazen, Skipper, Ezell, & Boone (2016) also discuss future research topics, including how one actor's capability and adoption of big data analytics affect the sustainability performance of another actor in the supply chain. This research direction can be linked with research on how to increase the dynamic VOI generated from big data in such a multi-actor context.

- *Modelling approach: more diverse and complementary methods in evaluating VOI*
Prescriptive analytical modelling and optimization are the dominant modelling approaches in evaluating VOI in the literature. However, simulation methods are appropriate, especially to evaluate VOI in real cases, due to their capability to capture the high complexity and uncertainty in supply chains (Chatfield, Hayya, & Harrison, 2007; Govindan et al., 2017). The use of simulation models are therefore suggested because VOI is subject to different supply chain factors. Besides discrete-event simulation, multi-agent simulation (MAS) particularly suits multi-actor contexts in which agents (i.e. actors in the chain) interact with each other in a co-operative manner to accomplish a common goal (Behdani, 2012). Nevertheless, a specific challenge for MAS is to define decision rules and model the heterogeneous characteristics of agents. Here is where the simulation can benefit from predictive analytics such as data mining. This enhances the simulation due to clustering, patterns and relations discovery from historic (big) data (Zhong et al., 2016). This also implies further research towards multi-method frameworks for evaluating VOI in the supply chain domain (Nguyen et al., 2017). Therefore, we suggest the following question:

(5) *How complementary multi-method modelling approaches (especially, using predictive and prescriptive models) can be developed to assess the value of information in supply chain decisions?*
For instance, to evaluate the VOI in information-sharing models for facilitating collaborative transportation, MAS allows the modelling of uncertain parameters at each collaborating actor's facilities, such as unloading and loading time, travel time, etc. In addition, frequent order patterns and frequent trajectory patterns can be extracted from historic transportation orders by data mining (Zhong et al., 2015). These patterns can be integrated in the simulation to define the environment and actor behaviour settings in the collaboration.

4.2. A step-wise research approach to study VOI in the supply chain domain

In addition to the aforementioned gaps, a well-defined step-wise approach to assess the VOI is also lacking in the literature. Therefore, based on the reviewed articles, such an approach is presented in Fig. 6. Combining the review framework and this step-wise approach helps future researchers identify the necessary elements and steps in their studies. To evaluate the value of an information type (i.e. additional information), we need to compare the base scenario, which is defined based on the existing information in the supply chain process (i.e. base information), with information scenarios, which are developed considering different intrinsic characteristics of the additional information. Tables 2 and 5 work as general guidelines in defining different information scenarios. Table 2 supports modelling different information characteristics, and Table 5 is a reference for selecting the relevant information type for different decisions. One piece of information might be utilized in more than one decision in the supply chain. For instance, the inventory level information of a retailer can be used for material ordering and also for arranging the distribution route from a central warehouse. In that case, the VOI would be the cumulative VOI for different decisions.

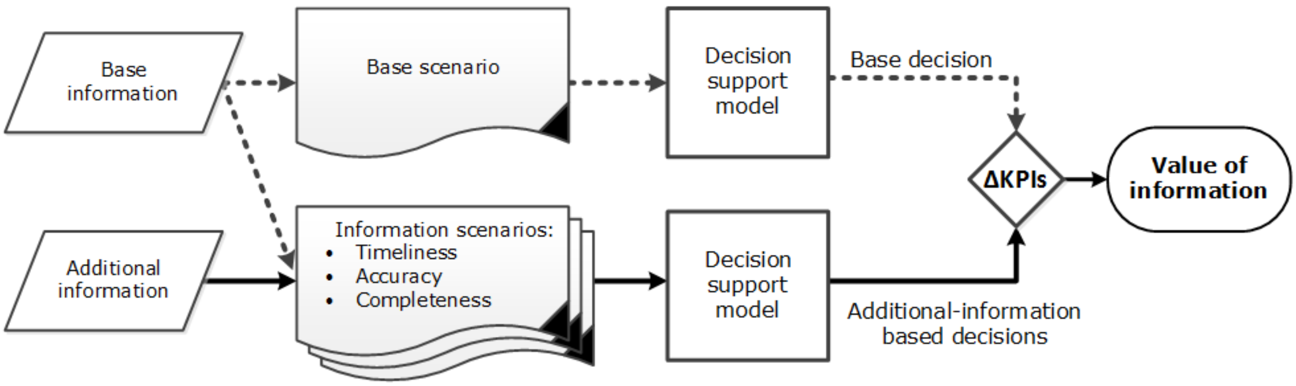

Fig. 6. Step-wise approach to assess the VOI in supply chain decisions.

5. Conclusion

The purpose of this paper was to provide an overview of existing research on VOI in supply chain decisions. We performed a structured overview on how the values of different information types have been studied in different supply chain decisions, which modelling approaches are used, and what are the influential factors on the VOI in each case. In total, 93 articles published in peer-reviewed journals from 2006 to 2017 were analysed using a rigorous review framework. The findings indicate that the current literature on VOI is rich in inventory decisions, yet insufficient in other supply chain areas, and research on the VOI in integrating and coordinating interdependent supply chain processes is still limited. In addition, the impact of information characteristics such as accuracy, completeness, and especially timeliness has not been examined extensively. Based on the insights from our literature analysis, we have also provided an agenda for future research. We especially suggest further research on the impact of information characteristics on the VOI, on analysing the dynamic VOI in supply chain multi-actor settings, and on developing multi-method modelling approaches, particularly combining data mining and simulation, to better evaluate the value of (big) data in real industrial cases. We hope that this review encourages further reconceptualization and model building as well as new studies in the merging domain of data-driven decision making in supply chains. Data-driven decision making has increasingly become a determinant of competitive advantage for each company and each supply chain. Particularly in the big data context, evaluating the value of big data is a challenge (Zhong et al., 2016). We notice that many research papers cover the problems of collecting and analysing big data, yet do not map and examine the value of the extracted information from big data to specific supply chain decisions. Identifying the decisions helps to identify the right data and information with the right characteristics and the right big data analytics method to use. Evaluating the value of the information is useful to adjust the costs of collecting and analysing against the benefits resulting from improved supply chain processes and operations.

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