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Abstract

Purpose: 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.

Design/methodology/approach: This paper uses a systematic literature review methodology to review journal articles published in the 10-year period from 2006 to 2015. Each selected study is analyzed using a rigorous review framework of four primary elements including "decision", "information", "modelling approach", and "context".

Findings: 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. The value of information is subject to contextual supply chain parameters, and varies in accordance with the characteristics of the information. Furthermore, the focus of existing literature is on "information availability" in supply chain decisions; the impact of important information characteristics such as accuracy, timeliness, and completeness, has not been extensively studied. Especially the research on information timeliness and its influence on supply chain decisions is limited.

Research limitations/implications: Findings of this paper are based on reviewing the literature with specific key phrases and a specific time frame (2006-2015). Furthermore, the paper includes only peer-reviewed journal articles. Despite these limitations, the authors believe that this review provides a good representation of the existing research on value of information in the supply chain domain and provide an avenue for further research in this direction.

Originality/value: Previous review papers on the value of information focus on inventory decisions in the literature up to 2005. This paper continues the work, yet with a broader scope that includes decisions on facility, inventory, transportation, sourcing, and pricing. Furthermore, we study the impact of information characteristics on value of information, which is a missing dimension in the previous reviews. Finally, based on reviewed articles, we developed a step-wise framework to evaluate the value of information in supply chain decisions.

Keywords: value of information, supply chain decision, information accuracy, information timeliness, information completeness, literature review

Paper type: Literature review

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1. Introduction

Over the past two decades, information[2] sharing and Information and Communication Technology (ICT) have been widely discussed as the main enablers to improve the supply chain performance, and to prevent critical supply chain problems such as bullwhip effect (Lee et al., 1997). Access to more information in a supply chain can be however very challenging in practice. Firstly, information sharing requires high level of trust between collaborating parties in the chain (Ebrahim-Khanjari et al., 2012). In addition, the access to information is not cost-free and may require significant investments in the ICT infrastructures to gather and share data (Lee et al., 2000). Meanwhile, several recent studies show that despite substantial investments in ICT systems, many organizations have failed to obtain the expected improvements in their supply chain performance (Fawcett et al., 2011). This might primarily imply that the investment in gathering and sharing information per se does not guarantee enhanced supply chain performance (Wu et al., 2006). It is particularly important to clearly understand which information is needed to share in a supply chain and how that information may contribute in 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. Firstly, 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). The second definition which is also 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 the improvement in one or several Key Performance Indicators (KPIs) achieved through the use of the information comparing with the base scenario in which the information does not exist (Ketzenberg et al., 2006; Davis et al., 2011; Ganesh et al., 2014b). In this paper, we will adopt the later 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 et al., 2015). However, a recent review of literature on this topic is lacking. Additionally, 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 et al. (2003). They presented a review of studies on the impacts of sharing production information on the supply chain dynamics up to 2003. As a reference framework, they categorized the 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 et al. (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 affecting factors are dependent on the context and how the information is utilized in the decision-making problems. Another review that focused on the topic of VOI is presented by Ketzenberg et al. (2007) in which they investigated 27 papers up to

[2] In practice, information is described as data that has been processed. Similarly to Nelson et al. (2005) and Pipino et al. (2002), the terms data and information are interchangeable in this paper, unless specified.

2005 and introduced a framework to explain how supply chain parameters influence the value of information sharing in "inventory replenishment decision". 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 the 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 10-year period from 2006 to 2015. Moreover, while inventory decision is the focus in the aforementioned reviews, this paper broadens the scope by considering decisions in the other supply chain areas, i.e. facility (location and design), transportation, sourcing and pricing. In addition, we emphasize on the impact of information characteristics on VOI, which is a missing dimension 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, shared information from different supply chain actors). This information usually have heterogeneous characteristics and these characteristics may highly influence the VOI in the chain (Sellitto et al., 2007; Hazen et al., 2014). For instance, although the availability of final consumer demand is important to inventory planning by a distributor, the "timeliness" – or the timing that the information becomes available for use – is also important to make decisions for optimal supply chain planning. More discussion on the key information characteristics is presented in Section 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 a road map for future research based on the findings from the literature. Finally, we propose a framework as a guidance tool to evaluate the VOI in supply chain decisions.

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: to establish a clear focus of the review
- (ii) locating studies: to define the method to locate as much as possible the relevant studies to the review questions
- (iii) study selection and evaluation: to assess if a study does actually address the review questions using a set of criteria
- (iv) analysis and synthesis: first to decompose each study into parts and explain how the parts relate to the others, then to 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: to report the results of the review

The introduction section explained the motivation and the context of this review. The research questions are formulated as "how the value of information has been addressed/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). After that, we present the review framework which includes the factors used in analyzing the selected literature (i.e. step iv). Section 3 is dedicated for discussing the results from the review (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 10-year period from 2006 to 2015. Conference proceedings are excluded in our search. The literature search was performed on two databases - Scopus and Web of Science, which cover a majority of journals in the field of supply chain management research. The focus was on the articles whose objective is to assess the VOI in supply chain decisions.

To locate relevant studies from the databases, we used a combination of terms associated with value of information and supply chain management research, as follows:

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

and the search located 124 studies. In order to reach the articles that do not use the phrase "value of information", an additional search was performed with keywords that are semantically close to "value" (i.e. profit, cost, benefit, saving, surplus). The second search criteria was set as

[(("information" <u>and</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))]

within limited subject areas (i.e. business, management, engineering, decision science, economics, engineering and mathematics). The second search brought 110 studies. The process of combining the results from the two searches and reading abstracts shortened the list to 71 journal articles.

A number of papers list "value of information", "big data" or "data mining" in their keywords list. The potential association among these phrases was recognized. Since knowledge and techniques in the fields of big data analytics, particularly data mining, have been applied widely in various supply chain functions (Frehe et al., 2014; Olson, 2015; Wang et al., 2016), the third search was performed with the search criteria as

[(("big data" <u>or</u> "data mining") <u>and</u> (logistics <u>or</u> supply chain)) <u>in</u> (abstract, title, keywords)],

which resulted in 22 articles. During the screening, the articles whose research objectives are on technical aspects were written off. Finally 11 articles that address VOI were selected.

In total, 82 journal articles over the period 2006-2015 were selected for analysis-and-synthesis step in this paper. 13 out of 82 articles discuss the VOI from a general supply chain management perspective; 69 articles study the VOI in a specific supply chain decision-making context. Section 3 will focus on discussing the findings from these 69 articles. Figure 1 shows the timely distribution of the selected articles in this review. The figure highlights an increasing number of publications in the last 3 years 2013, 2014 and 2015. The number of VOI articles found under big data and data mining search was limited until 2013, and it is in growing phase.

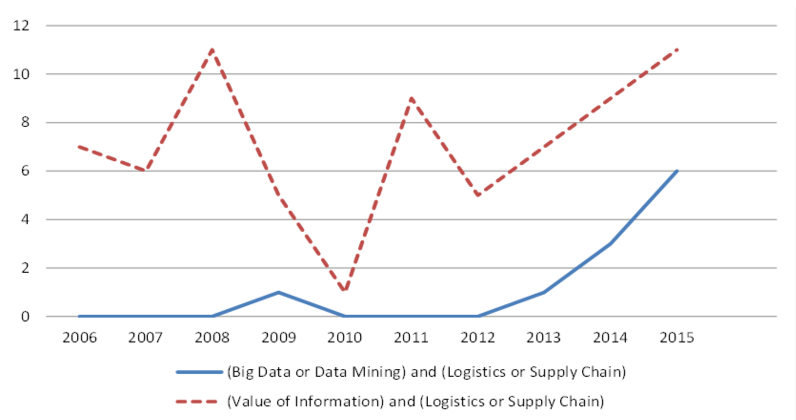


Figure 1. Time distribution of reviewed articles

2.2 Review framework

The dimensions along which the articles were analysed in this paper are integrated into a framework with four primary elements as shown in figure 2. These elements are explained in the following.

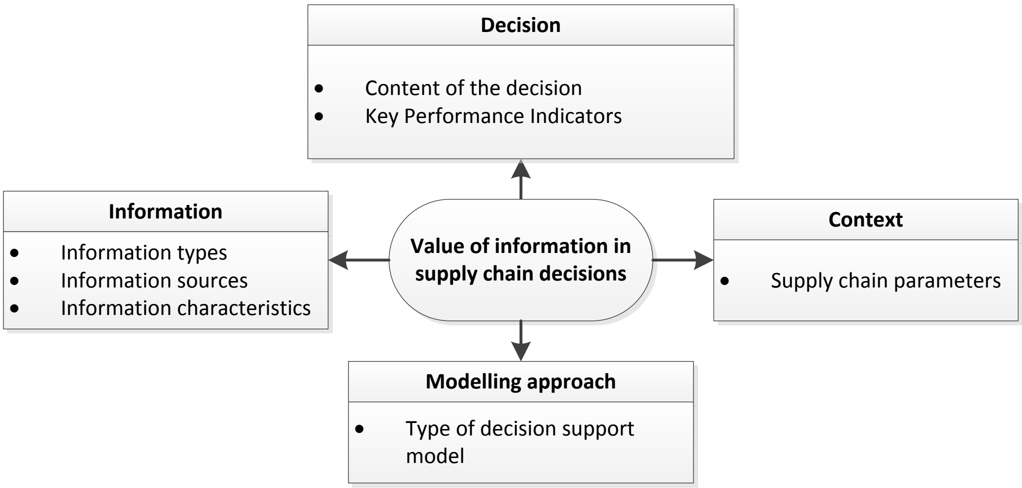


Figure 2. Review framework

Decision

Supply chain decisions utilize the information to improve the KPIs of the supply chain. The decision element defines the content of the decision (i.e. what is decided?), and what are the targeted KPIs in the decision. In this review paper, the taxonomy of supply chain decisions is grounded on five determinant drivers of supply chain performance introduced by Chopra & Meindl (2013): 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. The example changes are the change in the role, location, capacity, and the 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 concerns inventory review policies, order quantity, and order timing; (ii) capacity allocation refers to the 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 relates to joint replenishment policies among chain members to improve the chain-wide efficiency, e.g. Vendor Managed Inventory.
- Transportation decisions concern the movement of inventory between point to point in the supply chain. This category also includes decisions on warehouses internal transportation and distribution processes.
- Sourcing decisions determine who will perform a particular supply chain activity in short term or long term. The example decisions are in-house/outsource production and supplier selection.
- Pricing decisions are about the strategies (e.g., differential pricing or discounting) to define the price of products and services provided by the company.

Information

The information element identifies the type of the information that is used in the decision-making, the source of 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 will extend the categorization based on our review as further discussed in Section 3.

About 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 enabled warehousing information. (ii) Chain-internal relates to information sharing among actors in the chain. (iii) Chain-external includes that information that originates from the 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 different terms such as information quality dimensions (Miller, 1996; Gustavsson & Wänström, 2009), information value attributes (Sellitto et al., 2007; Herrala et al., 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 et al., 2003; Hazen et al., 2014) (see 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 et al., 2005).

Table 1. Definition of intrinsic characteristics of information

Characteristic	Definition
Accuracy	How accurate the 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.

Context

The context element 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) organizes these factors and introduces new factors (i.e. number of facilities in the supply chain, inventory review policies, product perishability) into their framework as introduced in the introduction. For instances, demand variance is an indicator of the level of uncertainty in the supply chain; capacity is relevant to the responsiveness of the supply chain, etc.

Modelling approach

In general, a study about VOI is equivalent to the study about how the information is used to improve the decision-making in the supply chain. The modelling element connects the decision element and the information element by indicating how the decisions are made, with- and without the information. 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 information of the supply chain. (ii) Predictive models utilize the output of descriptive models to project the future state information of the supply chain. (iii) Prescriptive models use the outputs from descriptive and predictive models to determine the most appropriate decision to improve the supply chain performance. Particularly in the field of VOI, prevalent predictive modelling techniques include data mining and forecasting; prescriptive modelling techniques include optimization, simulation, and multi-criteria decision-making.

3. Findings

The results from studying the articles will be presented based on the review framework. We will first discuss in general the findings about the information element, the context element, and the modelling approach element in Sections 3.1, 3.2, and 3.3 respectively. Section 3.4 starts with an overview of the supply chain decisions. After that, each sub-section of section 3.4 is dedicated to reviewing the decisions in a specific supply chain area, particularly on which information types are used in the decisions, and how information characteristics affect the VOI.

3.1 Information

Information types

Since this paper covers a broader scope of supply chain decisions, the information model presented by Huang et al. (2003) was extended to include more information types that have been studied between 2006 and 2015. Eight groups of information are shown in figure 3 from left to right: (i) Demand, (ii) Inventory, (iii) Planning, (iv) Product, (v) Manufacturing process, (vi) Transportation process, (vii) Return-product, and (viii) Supply. Process information is split into manufacturing process and transportation process because these two groups have distinct values in the decisions of two different areas - inventory and transportation - as discussed later the section 3.4. The value of return-product information has received growing attention due to recent developments of reverse supply chains (Karaer & Lee, 2007; Flapper et al., 2012; Ruiz-Benitez et al., 2014).

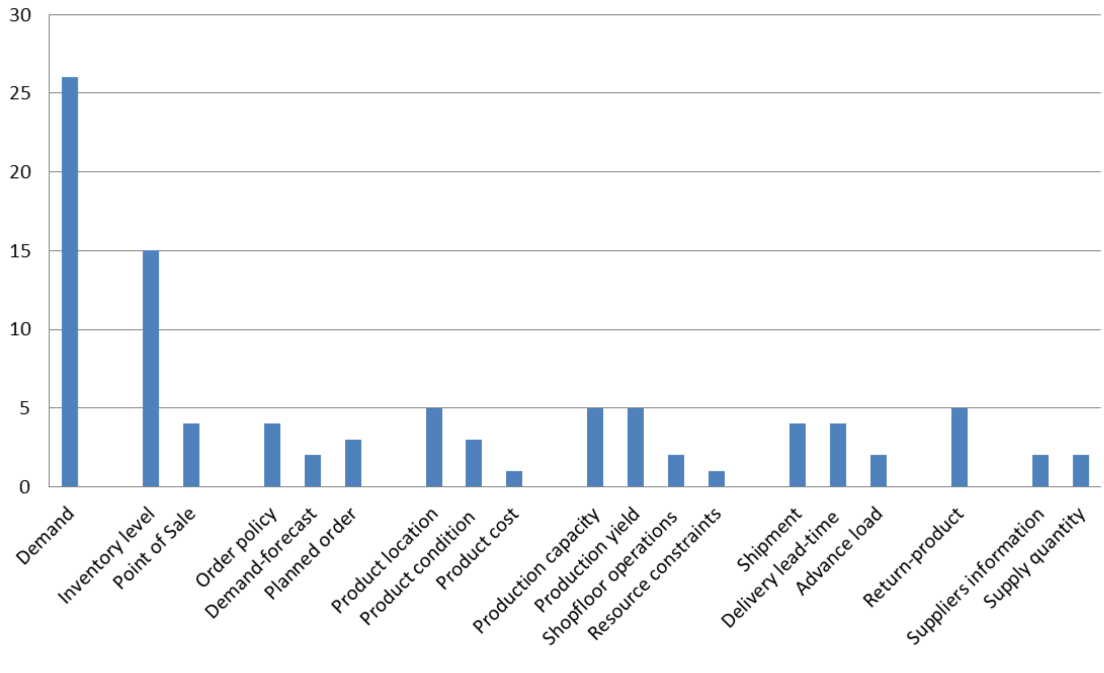


Figure 3. Number of articles per information type

Information sources

In terms of information sources, chain-internal information sharing has been the focal point of the literature (which covers about 72% of the articles). Information can be shared from downstream to upstream in the chain such as demand information (Viswanathan et al., 2007), or reversely such as manufacturer's production capacity information shared to retailers (Bakal et al., 2011), or between actors in the same chain 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 et al., 2015). The receivers of the data need to process the data to extract the desired information, see for an example of the information processing in Jonsson & Mattsson (2013). Most of company-internal information are generated from sensing, tracking, and tracing technologies. Examples are RFID data in warehouses and shopfloor (Zhong et al., 2015), shipment data (Flamini et al., 2011), product location (Bryan & Srinivasan, 2014) and condition data (Ketzenberg et al., 2015). We found no article discussing the VOI from the chain-external information sources.

Information characteristics

Characteristics of information are not explicitly discussed in the majority of reviewed articles. Most of existing papers investigate the value of information only based on "information availability" (see figure 4). In other words, these studies consider and compare two scenarios: the decision-making with- and without the information. Despite a long list of information characteristics as mentioned, this review found out that indeed the three intrinsic characteristics - completeness, accuracy, timeliness - are expressly deliberated the most. These characteristics have been modelled differently in the literature (see table 2). Timeliness is modelled by parameters that indicate the timing of obtaining the information in advance to the decision-making. Inaccuracy is incorporated by adding information errors, which usually follow statistical distributions, to the actual values. Information inaccuracy can occur due to 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 have been explored, yet research on information timeliness is still in its infancy, as already suggested more than a decade ago by Huang et al. (2003).

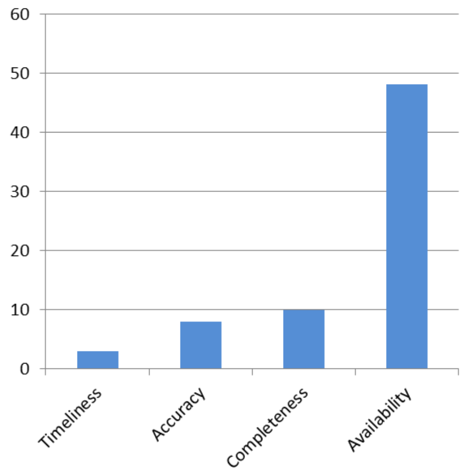


Figure 4. Number of articles per information characteristic

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

<table>
<tr><th>Characteristic</th><th>Article</th><th>Types of information</th><th colspan="2">Modelling</th></tr>
<tr><td rowspan="3">Timeliness</td><td>(Liu et al., 2009)</td><td>Product location (tracking)</td><td colspan="2">q-period lagged information (q = 0, 1, 2, …; q = 0: real-time information)</td></tr>
<tr><td>(Tjokroamidjojo et al., 2006)</td><td rowspan="2">Advance load information</td><td colspan="2" rowspan="2">Number of days in advance that the information is shared</td></tr>
<tr><td>(Zolfagharinia & Haughton, 2014)</td></tr>
<tr><td rowspan="8">Accuracy</td><td>(Ketzenberg, 2009)</td><td>Demand, Yield, Capacity</td><td colspan="2">A probability p (0, 0.05, 0.25, 0.5) that inaccuracy occurs in randomizing the information (p = 0: accurate information)</td></tr>
<tr><td>(Flamini et al., 2011)</td><td>Product location</td><td colspan="2">Randomizing measurement errors (follow a uniform distribution)</td></tr>
<tr><td>(Cannella et al., 2015)</td><td>Inventory level</td><td colspan="2">Adding error as a percentage of the record</td></tr>
<tr><td>(Kaman et al., 2013)</td><td>Shop-floor operations</td><td colspan="2">Randomizing errors between actual and observed states (follow a uniform distribution)</td></tr>
<tr><td>(Cui et al., 2015)</td><td>POS, Replenishment policy</td><td colspan="2">Adding decision deviations (follow a normal distribution) to the order quantity which is based on the replenishment policy</td></tr>
<tr><td>(Kwak & Gavirneni, 2015)</td><td>Demand</td><td colspan="2" rowspan="3">Adding information errors (follow a normal distribution) to the actual values</td></tr>
<tr><td>(Ketzenberg et al., 2015)</td><td>Product condition</td></tr>
<tr><td>(Rached et al., 2015)</td><td>Demand, Delivery lead-time</td></tr>
<tr><td rowspan="11">Completeness</td><td></td><td></td><td>Partial information</td><td>Complete information</td></tr>
<tr><td>(Ketzenberg et al., 2006)</td><td>Demand, Return quantity, Recovery rate</td><td>A limited number of information signals to limit the range of the variables</td><td>Infinite number of information signals</td></tr>
<tr><td>(Chen et al., 2007)</td><td>Inventory, Demand, Capacity</td><td>Sharing 1 or 2 types of information</td><td>Sharing 3 types of information</td></tr>
<tr><td>(Larbi et al., 2011)</td><td>Content of inbound trucks in a sequence</td><td>A small number of inbound trucks</td><td>A very large number</td></tr>
<tr><td>(Liu & Kumar, 2011)</td><td>Inventory level</td><td>Weekly and mix of weekly/daily</td><td>Daily sharing</td></tr>
<tr><td>(Bakal & Akcali, 2006)</td><td>Yield rate</td><td>Different supports of the uniform distribution, e.g. (0, 1), (0.4, 0.6)</td><td>Uniform distribution with very small interval</td></tr>
<tr><td>(Karaer & Lee, 2007)</td><td>Inventory level</td><td rowspan="5">The information only includes mean and variance of the distributions</td><td rowspan="5">Detailed values</td></tr>
<tr><td>(Mukhopadhyay et al., 2008)</td><td>Product cost</td></tr>
<tr><td>(de Brito & van der Laan, 2009)</td><td>Demand, Product return</td></tr>
<tr><td>(Cheong & Song, 2013)</td><td>Yield</td></tr>
<tr><td>(Wagner, 2015)</td><td>Demand</td></tr>
</table>

3.2 Context

The value of an information type can be affected by many supply chain factors. For examples, the value of demand information is influenced by production capacity, product substitution, product lifetime, order batch size, lead-time, etc. We summarize the trends of the effects in table 3.

The trends are consistent in most of the articles, e.g. the VOI is positively proportional to the values of cost components. In order to understand the contradictory findings in a few cases, it is essential to analyze how the factor is related to the changes in KPIs achieved from using the information in decision-making. 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) - 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 – model B. 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.

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***
(Choudhury et al., 2008)	Inventory level	Demand uncertainty	x			
		Network size (number of retailers)			x	
		Production capacity	x			
(Byrne & Heavey, 2006)	Demand	Production capacity			x	
(Bakal et al., 2011)	Production capacity (supplier)	Production capacity	x			
(Ganesh et al., 2008)	Demand	Product substitution			x	
(Ganesh et al., 2014b)	Demand	Product substitution			x	
(Yan & Pei, 2015)	Demand	Product differentiation			x	
(Ferguson & Ketzenberg, 2008)	Demand and Inventory level	Product lifetime		x		
(Hussain & Drake, 2011)	Demand	Order batch size		x		
(Davis et al., 2011)	Inventory level	Capacity			x	
		Penalty cost				x
		Demand uncertainty			x	
(Ruiz-Benitez et al., 2014)	Return product quantity	Shipping cost			x	
		Decay rate of product	x			
(Chiang & Feng, 2007)	Inventory level	Holding cost	x			
(Kaman et al., 2013)	Shopfloor operations	Holding cost	x			
(Rached et al., 2015)	Demand and delivery lead-time	Holding cost	x			
(Bendre & Nielsen, 2013)	Lead-time	Lost-sale cost	x			
(Karaer & Lee, 2007)	Return product location and quantity	Lead-time of reverse channel	x			
(Zolfagharinia & Haughton, 2014)	Advance load	Service radius and trip length	x			
(Flapper et al., 2012)	Advance return	Return time	x			
(Ketzenberg et al., 2013)	Unattended POS (vending machine)	Demand uncertainty	x			
(Ferguson & Ketzenberg, 2006)	Product condition	Demand uncertainty	x			
(Ketzenberg et al., 2015)	Product condition	Demand uncertainty			x	
(Shang et al., 2010)	Demand	Logistics system	VOI is significant when the logistics systems is flexible to enable flexible ordering			
(Cho & Lee, 2013)	Demand	Lead-time	VOI is significant when lead-time is shorted than the seasonal period			
(Babai et al., 2015)	Demand	Autoregressive demand parameter	VOI is significant when the parameter is less than 0.7			
(Xue et al., 2011)	Supply quantity	Review policy	VOI depends on the inventory review policy			

3.3 Modelling approach

Table 4 summarizes the types of decision support models used in the reviewed articles. approximately 7% of the articles employ predictive models including forecasting methods (de Brito & van der Laan, 2009; Scott, 2015), data mining (Lin et al., 2009; Yi, 2014), and big data analytics (Zhong et al., 2015). 52% of the articles use prescriptive analytical models, which are based on mathematical models, game theory, and probability theory. For example with game theory, actors' quantitative decisions (e.g. order quantity, pricing) are adjusted correspondingly to the information received from other actors. Optimization models (29%) are also employed: heuristics, dynamic-, integer-, stochastic-, and mixed-integer programming. A limited literature (12%) applied simulation in their studies; discrete-event simulation is used the most among these articles.

It should be noted that the selection of a modelling approach can 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 which requires the most detailed information) is found not necessarily leading to the highest VOI.

Table 4. Employed decision support models in the reviewed articles

Type of decision support model	*Articles*
Analytical	(Axsäter & Viswanathan, 2012), (Babai et al., 2015), (Lin & Tsao, 2006), (Giloni et al., 2014), (Bakal et al., 2011), (Ketzenberg et al., 2006), (Hsiao & Shieh, 2006), (Chen & Lee, 2009), (Jakšič et al., 2011), (Kwak & Gavirneni, 2015), (Liu et al., 2009), (Cho & Lee, 2013), (Ganesh et al., 2014b), (Ganesh et al., 2014a), (Ganesh et al., 2008), (Karaer & Lee, 2007), (Shang et al., 2010), (Salzarulo & Jacobs, 2014), (Yao & Dresner, 2008), (Cannella et al., 2015), (Wu & Edwin Cheng, 2008), (Cui et al., 2015), (Rached et al., 2015), (Chiang & Feng, 2007), (Xue et al., 2011), (Ruiz-Benitez et al., 2014), (Bakal & Akcali, 2006), (Chen et al., 2012), (Wagner, 2015), (Lee & Cho, 2014), (Yang et al., 2012), (Ha & Tong, 2008)
Game theory	(Mukhopadhyay et al., 2008), (Yan & Pei, 2012), (Yan & Pei, 2015), (Wu et al., 2011)
Dynamic programming	(Ketzenberg et al., 2015), (Davis et al., 2011), (Ketzenberg, 2009), (Kaman et al., 2013), (Ferguson & Ketzenberg, 2008), (Ketzenberg et al., 2013), (Bendre & Nielsen, 2013), (Flapper et al., 2012)
Integer programming	(Chen et al., 2007), (Thomas et al., 2015), (Krikke et al., 2008), (Tjokroamidjojo et al., 2006)
Stochastic programming	(Bryan & Srinivasan, 2014), (Cheong & Song, 2013)
Mixed-integer programming	(Zolfagharinia & Haughton, 2014)
Heuristics	(Ferguson & Ketzenberg, 2006), (Dettenbach & Thonemann, 2015), (Viswanathan et al., 2007), (Larbi et al., 2011), (Flamini et al., 2011)
Data mining	(Yi, 2014), (Lin et al., 2009)
Big data analytics	(Zhong et al., 2015)
Forecasting	(de Brito & van der Laan, 2009), (Scott, 2015)
Monte Carlo simulation	(Sohn & Lim, 2008)
System dynamics	(Hussain & Drake, 2011)
Discrete-event simulation	(Liu & Kumar, 2011), (Byrne & Heavey, 2006), (Schmidt, 2009), (Choudhury et al., 2008), (Jonsson & Mattsson, 2013), (Kim et al., 2008)

3.4 Decision

Traditionally, the primary motivation in evaluating the VOI is that information is a way to replace physical inventories in the chain (Tan et al., 2002; Borgman & Rachan, 2007). Therefore, it is not surprising that in the literature, a large number of articles study the VOI in inventory decisions (see figure 5). It is observed that transportation is the second major area. There is a limited literature in sourcing and pricing decisions and no works on facilities decisions. Table 5 summarizes the supply chain decisions from the uses of information in each supply chain area.

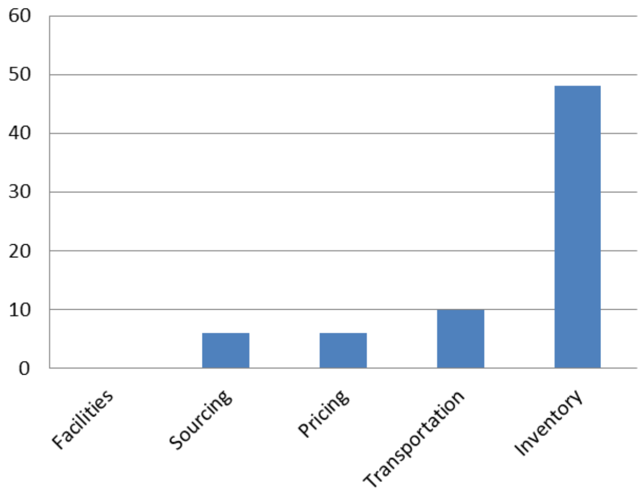


Figure 5. Number of articles per supply chain area

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	(Babai et al., 2015), (Xue et al., 2011)	Demand, Supply quantity
	Reorder point	(Shang et al., 2010), (Liu & Kumar, 2011), (Salzarulo & Jacobs, 2014), (Schmidt, 2009)	Demand, Inventory level
	Safety stock	(Schmidt, 2009)	Demand
	Order frequency/timing	(Axsäter & Viswanathan, 2012), (Yao & Dresner, 2008), (Bryan & Srinivasan, 2014), (Lin & Tsao, 2006), (Viswanathan et al., 2007), (Ketzenberg et al., 2013), (Ketzenberg et al., 2015)	Demand, Inventory level, POS, Planned order from downstream, Location of product, Production lot freezing and plan
	Order quantity	(Hussain & Drake, 2011), (Cannella et al., 2015), (Jonsson & Mattsson, 2013), (Bendre & Nielsen, 2013), (Cheong & Song, 2013), (Chiang & Feng, 2007), (Bakal et al., 2011), (Ketzenberg et al., 2006), (Ketzenberg et al., 2015), (Chen et al., 2007), (Ferguson & Ketzenberg, 2006), (Cui et al., 2015), (Ferguson & Ketzenberg, 2008), (Jakšič et al., 2011), (Rached et al., 2015), (Dettenbach & Thonemann, 2015)	Demand, Inventory level, POS, Demand-forecast, Planned order, Supply lead-time, Supply quantity, Shipment position, Yield distribution, Production capacity, Product location, Product condition
	Order-up-to level	(Giloni et al., 2014), (Wu & Edwin Cheng, 2008), (Choudhury et al., 2008), (Chen & Lee, 2009), (Kwak & Gavirneni, 2015), (de Brito & van der Laan, 2009), (Cho & Lee, 2013), (Liu et al., 2009), (Davis et al., 2011), (Ganesh et al., 2008), (Ganesh et al., 2014b), (Ganesh et al., 2014a)	Demand, Inventory level, Planned order, Return product probability, Product location, Shipment position
Capacity allocation		(Flapper et al., 2012), (Byrne & Heavey, 2006), (Karaer & Lee, 2007), (Ketzenberg, 2009), (Thomas et al., 2015), (Sohn & Lim, 2008), (Kaman et al., 2013), (Salzarulo & Jacobs, 2014), (Ketzenberg et al., 2006)	Demand, Inventory level, POS, Advance return, Return product visibility, Recovery yield, Production capacity, Resource constraints in production, Shopfloor operations
SC coordination		(Yao & Dresner, 2008), (Chen et al., 2007), (Ferguson & Ketzenberg, 2008), (Choudhury et al., 2008), (Thomas et al., 2015), (Viswanathan et al., 2007)	Demand, Inventory level, Planned order, Production capacity, Resource constraints in production
Transportation decision			
Service network design		(Shang et al., 2010)	Demand
Scheduling of services		(Ruiz-Benitez et al., 2014), (Larbi et al., 2011), (Flamini et al., 2011), (Tjokroamidjojo et al., 2006)	(Inventory level) Return-product quantity, Shipment (products types and quantities, sequences), Product location, Advance load
Vehicle routing		(Yi, 2014), (Flamini et al., 2011), (Zolfagharinia & Haughton, 2014), (Krikke et al., 2008), (Zhong et al., 2015)	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)	Suppliers' reliability, Supplier's production cost, Product quality
Modifying sourcing contract terms	(Wagner, 2015), (Lee & Cho, 2014), (Ha & Tong, 2008)	Demand, Inventory level
Pricing decision		
Determining wholesale price	(Mukhopadhyay et al., 2008)	Product cost
Postponing pricing decision	(Bakal & Akcali, 2006)	Yield rate
Determining real-time price	(Scott, 2015)	Real-time demand (load)
Determining prices in competing retailers	(Yan & Pei, 2012, 2015), (Chen et al., 2012)	Demand, Demand-forecast

3.4.1 Inventory decisions

Inventory decisions are categorized into replenishment, capacity allocation and supply chain coordination. Replenishment decisions have six sub-categories: inventory reviewing policy, reorder point, order quantity, order timing, order-up-to level, and safety stock. Upon inventory decisions, major interests are in the traditional types of information including Demand, Inventory, Planning and Manufacturing process as shown in Table 5. There has been also rising interest in evaluating the value of Product information, Transportation process information and Return-product information. For instances, product condition information captured by sensing devices improves order-quantity decisions in perishable supply chains by reducing the product spoilage uncertainty (Ferguson & Ketzenberg, 2006, 2008; Ketzenberg et al., 2015). Product location information from tracking devices is also valuable as it diminishes the uncertainty about replenishment arrival time, especially in the case 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). Return-product quantity information is useful in the decision-making on production plan of new products (Karaer & Lee, 2007).

Regarding information accuracy, inaccurate inventory records is 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, the inaccurate inventory-level information shared by retailers has no more value to the supplier. In another study by Cannella et al. (2015), inaccurate inventory records may eradicate the bullwhip-effect avoidance features resulted from the collaborative information sharing of inventory level. Ketzenberg et al. (2015) indicate that products' travel time and temperature information is useful in inventory issueing policy when the errors are less than 14% of the actual values. Note that these figures are subjective to supply chain parametric settings.

Concerning information completeness, partial information in some cases can perform almost as well as complete information. In the 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's yield rate information (i.e. only mean and variance are known) can be sufficient in determining the newsvendor's regular ordering quantity; however the partial information cannot replace the complete information in a strategic decision of selecting reliable suppliers because an improvement of 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). Real-time tracking information of product location allows a cost-effective policy on order quantity and timing, while the lagged information in 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 employed. A few articles studying perishable products 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 could not be seen separately. It is noteworthy to emphasize that the impact of information on KPIs may look inconsistence in some cases. For instance in evaluating the VOI in terms of reducing inventory costs, Rached et al. (2015) conclude that the gains from sharing simultaneously demand information and warehouse-retailer lead-time information are not cumulative; whereas Ketzenberg et al. (2006) suggest that investing in an additional type of information (among two types: demand and return-product) results in an additional payoff. The difference between these findings lies on how the information helps to reduce the costs. In Rached et al. (2015), both demand and lead-time play the same role on order-quantity decision to reduce the retailer 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 on the order-quantity decision. Thus, the additional information type will allow an additional retailer holding cost reduction.

3.4.2 Transportation decisions

The value of different information types are studied in different transportation and distribution decisions including service network design, scheduling of services, vehicle routing and empty vehicle repositioning. Lumsden & Mirzabeiki (2008) indicate product location information as a critical information type for all supply chain members; it is mainly used to optimize vehicle routing and scheduling (Flamini et al., 2011; Yi, 2014). Product location information enabled by RFID is also useful in decisions on repositioning empty vehicles. 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) utilizes the shipment information of inbound trucks in optimizing cross-docking scheduling. Besides supporting inventory decisions, inventory-level information also helps to coordinate the joint transportation (i.e. routing and scheduling of services) and inventory decisions (Krikke et al., 2008; Ruiz-Benitez et al., 2014).

The effect of information timeliness in transportation decisions is discussed by 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 trucking industry, and show that the value of 3-day ALI is merely slightly higher than the value of 2-day ALI. In other words, significant cost improvement can be achieved with 2-day ALI.

Examining information completeness in the case of scheduling cross docking operations, Larbi et al. (2011) indicate that knowing the content of 14 next 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 correspondingly to the level of information obtained.

Flamini et al. (2011) quantify the value of information 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 employed routing algorithms.

3.4.3 Sourcing decisions

In sourcing decisions, information is used in selecting suppliers or modifying sourcing contract terms. Concerning the selecting suppliers, Lin et al. (2009) propose a data-mining based framework which gathers the big data of suppliers' characteristics and shipment records to cluster potential ones into primary and secondary supplier groups. On more tactical decision on short-term sourcing, Wu et al. (2011) study the benefits to a buyer when her suppliers share their product quality information; based on the information, the order quantities are adjusted. 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 contracting 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 can be significant as 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 contract (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 to knowing only the mean and variance of the demand distribution. The analytics show that with the 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 address the VOI in pricing decisions. 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 her 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. 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. Bakal & Akcali (2006) study the value of perfect yield rate information in making pricing decision in automotive parts remanufacturing industry. Since the perfect yield information is difficult to attain, the authors suggest a strategy of postponing pricing decisions to deal with the random yield.

4. Research agenda and research approach

In this paper, we review the VOI literature in the 10-year period from 2006 to 2015. Each article has been explored based on four elements of the review framework – decision, information, modelling approach, and context. Grounding on the literature and the findings from the previous section, in this section we proceed with discussing opportunities for future research under each element of the review framework.

- *Decision*. The current VOI literature is rich on assessing the VOI in inventory decisions, yet other areas of supply chain management such as transportation are not adequately explored in the literature. Especially with increased use of advanced ICTs to facilitate inter-organizational information exchange in logistics (Buijs & Wortmann, 2014), there is need for further research on how to make the utmost uses of these information in strategic, tactical and operational decisions in the chain. In addition, the existing literature on VOI has not fully captured the interdependence among chain processes and how information may support coordinating the interdependencies between different processes in the chain. 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.

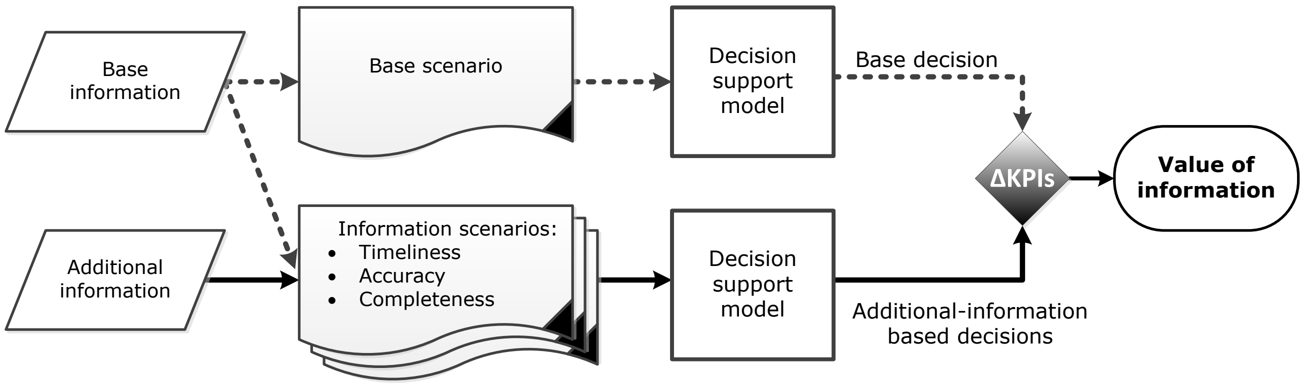
- *Information.* The main focus of the literature has been on the information availability; the importance of information characteristics in determining the VOI is generally lacking in the existing literature. Especially timeliness is an information characteristic that is not adequately addressed.

  Another research direction concerns the requirements for information characteristics by decision-makers. As discussed in the section 3.4, value of shared information in several cases is still significant despite of being inaccurate to some extent, or being incomplete, or being shared 2 days in advance in stead of 3 days. Because accurate/complete/timely information is costly and requires manual efforts, a better understanding of how accurate/complete/timely the information should be to be useful in supply chain decisions can loosen the requirements of information characteristics, thus lower the cost and effort.
- *Context.* A large amount of VOI literature studies dyadic supply chains (Montoya-Torres & Ortiz-Vargas, 2014). Since the number of actors in the supply chains grows fast, analysing VOI in a multi-actor context becomes necessary. Moreover, the VOI in a multi-actor context can be very dynamic. Information characteristics are subject to actors' behaviors. Having dissimilar goals and capabilities of information gathering, sharing and processing, their information-sharing approaches are diverse on which information to share, when and how much to share, and how accurate it will be, etc. This diversity creates the dynamic values of information sharing, which is primarily influenced by information characteristics.
- *Modelling approach.* Prescriptive analytical modeling and optimization are the dominant modeling aapproaches in evaluating VOI in the literature. However, simulation methods are appropriate, especially to evaluate VOI in the real cases, due to its capability to capture the high complexity and uncertainty in the supply chains (Chatfield et al., 2007). The use of simulation models are therefore suggested. 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. It enhances the simulation due to clustery, patterns and relations discovery from historic (big) data. Schoenherr & Speier-Pero (2015) suggest that the skills and knowledge in predictive analytics and big data have become a valuable asset to researchers in the field of supply chain management.

A step-wise research approach

In addition to aforementioned gaps, a well-defined step-wise approach to assess the VOI is also lacking in the literature. Based on reviewed articles, such an approach is presented in figure 6. To evaluate the value of information we need to compare the base scenario – which is defined based on the existing information in the supply chain process – with information scenarios – which are developed considering different intrinsic characteristics of information. Table 2 and 5 can work as general guidelines in defining different information scenarios. Table 2 would support modelling different information characteristics. Table 5 can be a reference for selecting the relevant information type for different decisions. It is noteworthy to mention that one piece of information might be utilized in more than one decision in the chain. For instance, the inventory level information of a retailer can be used for material ordering and also for arranging the distribution tour from a central warehouse. In that case, the value of information would be the cumulative value of information for different decisions.

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



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