The benefits of supply chain visibility: A value assessment model

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1. Introduction

Market globalisation, intensified competition and stronger emphasis on customer satisfaction are generally considered to be the main reasons for the growing interest in Supply Chain Management (SCM) by both academics and practitioners (e.g. Gunasekaran et al., 2001; Webster, 2002). In this competitive environment, the profitability of the focal company – that firm identified by consumers as being 'responsible' for the specific product or service and the coordination of material and information flows –depends strongly on its ability to manage complex relationships with its business partners (Caridi et al., 2010a). Visibility has therefore become a key issue in SCM research (Yu et al., 2001), because it affects the performance of the whole supply chain (SC) (Choi and Sethi, 2010). Moreover, visibility can be considered an enabler for strong SC relationships: indeed, Spekman et al. (1998) identified three possible intensity levels for interactions in a SC relationship, shifting from cooperation (visibility on essential information and long-term contracts) to coordination (implementation of visibility mechanisms such as EDI and JIT) and full collaboration (which also includes a high level of trust and a common vision of the future).

Despite significant interest in the matter, having access to accurate and timely information is a challenging issue in global SCs. In this regard, a key role is played by new Information and Communication Technologies (ICTs) (Moinzadeh, 2002; Nudurupati and Bititci, 2007). The adoption of several technologies, e.g. Radio Frequency Identification (e.g. Balocco et al., 2011; Ramudhin et al., 2008), Enterprise Resource Planning (e.g. Green et al., 2007) and Electronic Data Interchange (e.g. Choe, 2008; Perego and Salgaro, 2010; Balocco et al., 2010) could increase the level of visibility along the chain, leading to a strong interest in these solutions in recent years (Choi and Sethi, 2010). However, since companies must devote a lot of energy and resources to the introduction of ICTs, managers need to fully understand the benefits for the company in order to be confident that the investment will be worthwhile. Several empirical studies have been conducted since the 1950s (Ackoff, 1958), and a large number of tools and techniques have been proposed to help companies assess the value of ICT investments (e.g. Anandarajan and Wen, 1999; Bassioni et al., 2005; Brun et al., 2006; Dehlin and Olofsson, 2008). According to Brun et al. (2004), ICT value assessment (VA) can be defined as a methodology for evaluating the impacts (i.e. costs, benefits) of a certain ICT solution, thus assisting managers to select the technology that best suits their specific situation.

Several authors have acknowledged the importance of evaluating the benefits of visibility in terms of operations and SC outcome improvement (e.g. Kulp et al., 2004; Wang and Wei, 2007) as well as in terms of planning effectiveness (e.g. Petersen et al., 2005). However, a model designed to measure the benefits of improved visibility is still missing (Caridi et al., 2010b). This paper aims to fill

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this gap by presenting a structured method and the associated tools to support an evaluation of the benefits (i.e. improvements in SC performance) related to the visibility of useful information regarding SC partners. The research project presented in this paper is exploratory, and describes the first attempt to construct a theory in the field of supply chain visibility. The method and tools (hereafter called the model) are based on the literature and were further developed through a focus group that included managers from nine "focal" companies, each one a leader in its respective SC. Finally, the paper illustrates an application of the model to a real SC, thus exploring its applicability in a practical context.

The paper is organised as follows. Section 2 presents a summary of the literature. Sections 3 and 4 describe the research objectives and associated methodologies. Section 5 describes the model and Section 6 presents the case study to which the model was applied. Finally, Section 7 presents the conclusions and discusses future research paths.

2. Literature review

The literature review is organised in three sections: the first presents a review of scientific contributions relating to definitions of SC visibility; the second discusses papers that deal with the benefits of visibility; and finally, the third section describes papers on VA methods.

2.1. Definitions of SC visibility

SC visibility relates to the ability of the focal company, i.e. the supply chain leader, to access/share information related to the SC strategy and the operations of SC partners. SC visibility is a commonly used expression in the SCM and logistics community (Francis, 2008), but its meaning is still somewhat ambiguous and several definitions have been proposed (see Table 1 for some examples).

All of the definitions in the literature relate SC visibility to information sharing, but the concept of SC visibility goes beyond simple access to certain information flows related to SC processes. Several definitions refer to the properties of the shared information. Many authors view SC visibility as strongly related to the usefulness of the exchanged information, which should be relevant and meaningful (e.g. Kaipia and Hartiala, 2006; McCrea, 2005; Schoenthaler, 2003; Tohamy, 2003). For illustrative purposes, Kaipia and Hartiala (2006) define SC visibility as "the sharing of all relevant information between SC partners, even over echelons in the chain". Other studies have suggested looking at other properties of the exchanged information, e.g. accuracy, trustworthiness, timeliness, and usability (e.g. Closs et al., 1997; Mohr and Sohi, 1995).

Another critical issue is the identification of the SC processes that are the most affected by visibility, in order to better define which information flows should be shared. Lancioni et al. (2000) and Maltz (2000) believe visibility can positively affect manufacturing, transaction activities, planning, supplying, and evaluation. Other authors (Kulp et al., 2004; Wang and Wei, 2007) focus more on forecasting, planning, scheduling, and execution. Barratt and Barratt (2011) analyse the role played by internal and external information-sharing in improving operations. Rojas and Frein (2008) focus on coordination under demand uncertainty. Zhang et al. (2011) analyse the impact of SC visibility on inventory management, whereas Marchet et al. (2012) explore its effects on transportation.

Despite the large number of authors studying SC visibility, a comprehensive metric for evaluating the level of visibility is seldom provided. The recent articles by Caridi et al. (2010a, 2010b, in press) attempt to harmonise the assortment of papers described above, by providing a unique metric for measuring the quantity, accuracy and freshness of useful information flows exchanged in complex supply networks.

2.2. Benefits of SC visibility

The primary purpose of SC visibility is to improve company performance (Wang and Wei, 2007; Pidun and Felden, 2012), also by supporting the decision-making process (Kulp et al., 2004). Several initiatives and programmes have successfully incorporated the concept of performance improvement enabled by visibility (Choi and Sethi, 2010), e.g. Quick Response (e.g. Vaagen et al., 2011), Efficient Consumer Response (e.g. Wood, 1993), Vendor Managed Inventory (e.g. Marques et al., 2010) and Continuous Replenishment (e.g. Yao and Dresner, 2008). As a natural consequence, many authors suggest evaluating the benefits of visibility in terms of SC performance improvements (Kulp, 2002; Lee and Wang, 2000; Yu et al., 2001), e.g. cost, quality, service level, flexibility, and time (see Table 2).

Despite the large number of articles, research on the benefits of visibility is still mainly theoretical. The main performance indicators affected by visibility improvements have been identified, but most studies focus on only one or on a subset of the impacted performance indicators. Moreover, most of the scientific papers on the benefits of visibility attempt to analyse the dyadic relationships between retailers and manufacturers (Li et al., 2005), and even in these cases only a few benefits have been measured quantitatively. For illustrative purposes, Lee et al. (2000) developed a linear model to assess the inventory reduction and cost savings achievable through information-sharing between retailers and their upstream suppliers. Table 3 summarises the main types of SC relations studied in the literature and the performance indicators affected by visibility in each case.

Some important limitations in the extant literature can be identified. The first limitation is related to the players involved in the analysis. With a few notable exceptions (e.g. Barratt and Oke, 2007), the authors mentioned above studied information sharing between manufacturers and retailers, whereas suppliers were generally excluded from the analysis. Second, most of the above mentioned models explore the benefits of having visibility on downstream players (e.g. manufacturers having access to information owned by retailers), but limited attention has yet been

Table 1
Definitions of SC visibility.

Definition	Reference
Visibility means that important information is readily available to those who need it, inside and outside the organisation, for monitoring, controlling, and changing SC strategy and operations, from service acquisitions to delivery	Schoenthaler (2003)
[Visibility is] the extent to which actors within a SC have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit	Barratt and Oke (2007)
[Visibility is] the ability to be alerted to exceptions in SC execution, and [to] enable action based on this information	McCrea (2005)
[Visibility is] capturing and analysing SC data that informs decision-making, mitigates risk, and improves processes	Tohamy (2003)

Table 2
Overview of the papers that address the impact of visibility on SC performance.

Performance	Performance indicator	Papers
Cost	Distribution cost	Bartlett et al. (2007), Gustin et al. (1995)
	Inventory cost	Barratt and Oke (2007), Beamon (1999), Chen et al. (2000), Ding et al. (2011), Gavirneni (2002), Lee et al. (2000), Ryu et al. (2009), Sahin and Robinson (2005), Yu et al. (2001), Wu and Cheng (2008), Zhang et al. (2011)
	Stock out cost	Clark and Hammond (1997), Kulp et al. (2004)
	Shortage cost	Lee et al. (1997a, 1997b, 2000, 2004), Yu et al. (2001), Disney and Towill (2003a, 2003b)
	Back order penalty cost	Cachon and Fisher (2000)
	Total cost	Lee et al. (2000), Zhao et al. (2002), Wu and Cheng (2008)
Quality	Supplier quality level	Bartlett et al. (2007)
	Internal quality level	Bartlett et al. (2007)
	External quality level	Tse and Tan (2012)
Service level	On time delivery	Beamon (1999), Prajogo and Olhager (2012), Zhou and Benton (2007)
	Customer response time	Beamon (1999), Zhou and Benton (2007)
	Product availability	Barratt and Oke (2007), Ryu et al. (2009)
Flexibility	Volume flexibility	Beamon (1999), Prajogo and Olhager (2012)
	Mix flexibility	Beamon (1999)
	New product flexibility	Beamon (1999)
Time	Manufacturing lead-time	Handfield and Bechtel (2002), Jayaram et al. (1999)
	New product development time	Handfield and Bechtel (2002), Jayaram et al. (1999)
	Cycle time	Kulp et al. (2004)
	Responsiveness	Barratt and Oke (2007)

Table 3
Types of SC relations studied for evaluating the benefits of visibility.

Type of SC relation	Performance affected by visibility	Paper
Two tier SC – 1 supplier and 1 buyer	Service level	Bourland and Powell (1996)
	Stock out cost	Clark and Hammond (1997)
	Shortage cost	Lee et al. (1997a, 1997b, 2000, 2004), Yu et al. (2001), Disney and Towill (2003a, 2003b)
	Inventory cost	Bourland and Powell (1996), Clark and Hammond (1997), Gavirneni et al. (1999), Chen et al. (2000), Disney and Towill (2003a, 2003b), Gavirneni (2002), Lee et al. (1997a, 1997b, 2000, 2004), Moinzadeh (2002), Sahin and Robinson (2005), Yu et al. (2001)
	Quality (supplier quality level; internal quality level); total cost; service level	Bartlett et al. (2007)
Two tier SC – multiple suppliers and multiple buyers	Inventory cost, back-order penalty cost	Cachon and Fisher (2000)
	Total cost; service level (product availability)	Zhao et al. (2002)
	Inventory cost; flexibility; responsiveness; quality	Barratt and Oke (2007)
	Service level (on time delivery); flexibility	Prajogo and Olhager (2012)
		Zhou and Benton (2007)
Multiple tier SC	Inventory cost	Ding et al. (2011)
	Product availability	Ryu et al. (2009)
	Inventory cost	Chen (1998)
	Inventory cost	Li et al. (2001), Ryu et al. (2009)
	Quality (external quality level)	Tse and Tan (2012)

explicitly paid to visibility on upstream SC members (e.g. retailers having access to information flows owned by manufacturers). Third, most papers consider information flows relating to sales and demand forecasting, without evaluating the benefits of sharing additional information flows (e.g. order status, production residual capacity, and production plan). Finally, the existing models provide an incomplete evaluation of the benefits enabled by visibility.

2.3. *Value assessment methods*

In order to reap the benefits of SC visibility, which have been extensively illustrated in the previous sections, the adoption of Information and Communication Technology is often required (Wei and Wang, 2010). Since such solutions can be quite expensive, it is important to be able to evaluate the achievable benefits quantitatively in order to support the decision-making process. Since the 1950s, several empirical studies have generated a range of methods to help companies with the Value Assessment (VA) of ICT investments (Table 4 shows some notable works).

Despite the large number of papers on the topic of VA, researchers have yet to fully address the lack of methods that can be easily applied to the evaluation of visibility impacts on complex networks. The existing models provide useful insights about different ways of assessing benefits related to SC visibility, such as the importance of considering both tangible and intangible benefits (e.g. Narasimahn et al., 2003), which should be measured both ex ante (e.g. Anandarajan and Wen, 1999; Bassioni et al., 2005) and ex post (e.g. Murphy and Simon, 2001). Although all of these models provide meaningful ideas about VA, most of them are incomplete, as they analyse a single technology (e.g. eProcurement in Ronchi et al., 2010 and in Narasimahn et al., 2003; RFId in Miragliotta et al., 2009; ERP in Murphy and Simon, 2001) and there is a limited level of model generalisability to other technologies. In this regard, the model proposed by Brun et al. (2006) proved to be interesting: although currently applicable to APS systems, it can be easily extended to other technologies. Moreover,

Table 4
VA methods for ICT investment (recent noteworthy examples).

Paper	Focus of the method	Short description
Ronchi et al. (2010)	eProcurement	Quantification of the impact of endogenous (e.g. targets, invested resources) and exogenous (e.g. organisational inertia) factors and characteristics of eProcurement systems (e.g. architecture, functionalities) on financial and organisational performance.
Miragliotta et al. (2009)	Radio Frequency Identification (RFId)	Analytical model to assess the costs and benefits of Radio Frequency Identification (RFId) applications in the fast moving consumer goods (FMCG) supply chain.
Dehlin and Olofsson (2008)	ICT	Analysis of the overall implementation process to quantify impacts in terms of costs, benefits and risk. The evaluation includes strategic, tactical and operational benefits.
Brun et al. (2006)	Advanced Planning and Scheduling (APS)	Analysis of the causes affecting SC performance and the value of implementing an APS system, by evaluating the influence on benefits and quantifying them.
Bassioni et al. (2005)	ICT	Ex-ante approach based on the Balanced Scorecard analysis in order to assess the impact of ICT investments on critical success factors for the company and investigating the existing relationships between different critical success factors.
Narasimahn et al. (2003)	eProcurement	Comparison of the tangible and intangible benefits (e.g. time, cost, flexibility, etc.) and different costs (e.g. hardware, software, implementation, etc.) of different systems through an AHP approach.
Murphy and Simon (2001)	Enterprise Resource Planning	Quantification of the value of an ERP system that combines the quantification of tangible and intangible benefits. The paper quantifies each by assessing the cash flow value, with the goal of calculating the net present value of the investment.
Anandarajan and Wen (1999)	ICT	Ex-ante comparison of different solutions in terms of Net Present Value and Internal Rate of Return, estimating tangible and intangible costs (e.g. hidden costs, development costs) and benefits (e.g. production costs, sales costs, marketing costs, R&D costs, etc.).

it can be used to evaluate (ex ante or ex post) both tangible and intangible benefits. Therefore, using the model proposed by Brun et al. (2006) as a starting point, this paper provides a useful discussion on assessing the value of SC visibility.

3. Research objectives

The previous sections have shown that a general VA model for SC visibility has not yet been developed. The purpose of this research project is to provide an initial exploratory contribution to theory building, in order to fill in some gaps in the supply chain visibility literature. More specifically, this paper describes the development of a model (comprising a method and a set of tools) for the assessment of the benefits of visibility in complex SCs.

The analysis was based on the perspective of the SC focal company. More specifically, the model is intended to support the measurement of the benefits the SC leader obtains by improving the degree of visibility on its supply network, which includes all suppliers of goods and services, from raw material producers to first tier suppliers. Extension of the model to include an assessment of the value of visibility on internal and downstream SCs is reasonably straightforward (see Section 7).

In order to measure the level of visibility on the inbound supply network, the Caridi et al. (2010b) metric was used, since it provides an acceptable measure of visibility in complex supply networks. The basic idea is that visibility is related to the ability of the focal company to access the significant, reliable and meaningful information owned by its SC partners, neglecting additional information that is not useful in the decision-making process. The visibility metric proposed by Caridi et al. (2010a) considers both the amount of information available to the SC focal company (which is assessed as the number of information items available to the focal company compared to the total number of useful pieces of information that could be exchanged) and its quality, in terms of freshness – i.e. the degree of information "synchronisation" with business partners (e.g. Barratt and Oke, 2007; Gustin et al., 1995; Mohr and Sohi, 1995; Zhou and Benton, 2007) and accuracy – i.e. the degree of conformity of the shared information with its actual value (e.g. Gustin et al., 1995; Kaipia and Hartiala, 2006; Barratt and Oke, 2007; Mohr and Sohi, 1995; Zhou and Benton, 2007). Further details about this metric are provided in Annex A.

In order to develop the VA model for assessing the value of visibility, three sub-goals were identified. The first sub-goal was to develop cause-effect maps (i.e. the visibility VA tools) that show the main classes of visibility benefits and their determinants. These cause-effect maps are based on the literature (e.g. Barratt and Oke, 2007; Beamon, 1999; Chen et al., 2000; Ding et al., 2011; Gavirneni, 2002; Lee et al., 2000; Ryu et al., 2009; Sahin and Robinson, 2005; Yu et al., 2001; Wu and Cheng, 2008; Zhang et al., 2011), and were discussed and adjusted (where necessary) during focus group sessions, which involved nine experts (see Section 4). The second sub-goal was to propose a new VA method, developed by combining the VA procedure introduced by Brun et al. (2006) and the AHP methodology, in accordance with the approach used to compare benefits in the model proposed by Narasimahn et al. (2003). The last sub-goal was to explore the model applicability in a real context.

4. Research methodology

Multiple research methodologies were used to reach the objectives described in the previous section. Fig. 1 illustrates the methodologies that supported each phase of the research process. The details and results of the literature review are described in Section 2 above, whereas the purpose of the following paragraphs is to provide further details about the focus group and the case study approach.

4.1. Focus group

The VA model was developed on the basis of the main findings in the literature regarding the variables that impact SC performance, the relationships between them and VA models for ICT investments. A focus group that included experts from nine companies was then organised in order to understand the perspective of practitioners, with the final goal being to discuss model usability, diagnostic support and adherence to reality. Three meetings were arranged, each of which lasted three hours. During the meetings, the cause-effect maps and an interview guide covering all of the steps in the VA method were shared and discussed in detail with the experts.

The nine companies invited were chosen because of their initiatives toward improving visibility on their external networks,

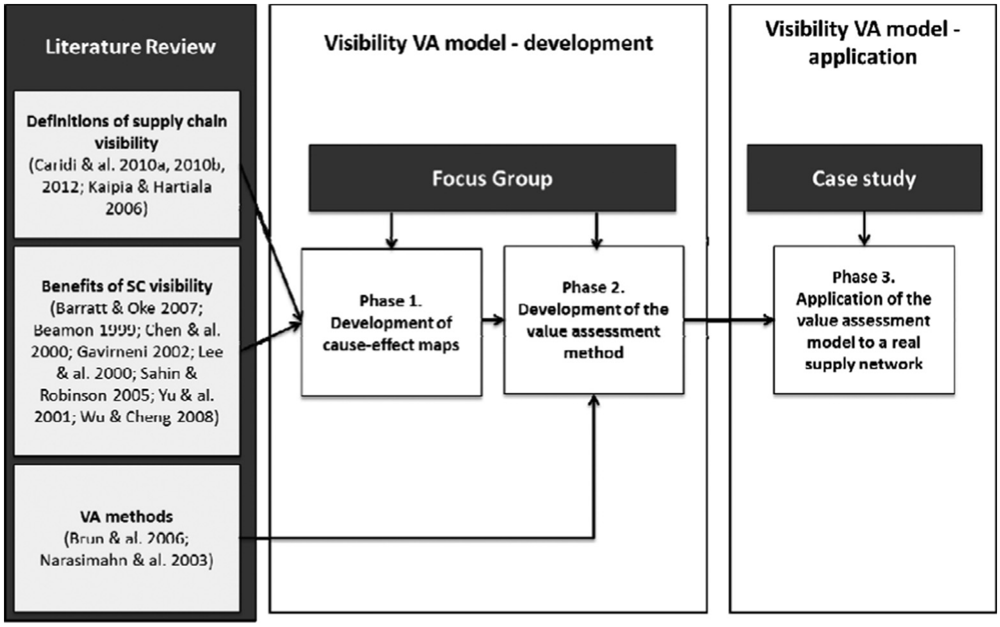

Fig. 1. Research process and related methodologies.

Table 5
Quality criteria for the case study.

Design test	Operationalised through
Construct validity	Multiple sources of data Multiple interviews with managers Interviewees were allowed to review draft case and give feedback (direct involvement of managers with the analysis; brainstorming session with managers in three departments to assure better consistency of the results)
External validity	The population of interest was specified (most important suppliers)
Reliability	Adoption of a standardised interview protocol Constructs well defined in the literature (e.g. KPIs)

making it possible to gather additional information on the relationships between visibility and performance metrics. All of the companies that participated are large multinational firms (from 2000 to 400,000 employees) with complex global SCs, representing a variety of different industries (i.e. electronic devices, technology and consulting, home appliances, fashion manufacturing, automotive, cables, and oilfield services). SC managers were considered to be the most appropriate participants.

The focus group is considered to be an appropriate methodology for the fine-tuning and validation of a model, as it allows viewpoints that are in agreement with the primary views of the interviewer, as well as those that are not, to be grasped (Frankland and Bloor, 1999; Langford and MacDonagh, 2003). Moreover, this methodology creates a collaborative and creative atmosphere (Barbour, 1999) and has proved to be appropriate for acquiring direct feedback from experts (Andic et al., 2012). The focus group meetings were conducted in such a way as to generate a natural, unrestricted discussion on the subject, which was observed and guided by the interviewers (Andic et al., 2012).

4.2. *Case study*

In the third phase of the research, the model was applied to a case study in order to explore its applicability (i.e. usability, quality of the provided results) in a practical context (Brun et al., 2006). The case study methodology was chosen, since it has often been found to be the best way to proceed during the early and exploratory research phases (Yin, 2003). In this study, case research is used with a positivist philosophical perspective, which sustains that reality, meaning a true state of affairs, can be ascertained by research, and that the object of the research is independent of the researcher (Annells, 1996). The single case study methodology is considered to be appropriate, as it produces a detailed level of understanding of the observed phenomena (Bartlett et al., 2007). The case selection strategy was driven by the need to analyse a representative case, exemplifying both company and industry attributes (Seuring, 2008; Yin, 2003); the selection of a case that is at the same time both representative and specific can be considered a good way of uncovering more information and obtaining more profound insights (Flyvbjerg, 2006). To maximise the utility of the information gathered from a single case, the case was selected on the basis of expectations about information content, using an information-oriented selection approach (Flyvbjerg, 2006).

The focal company selected operates in the aerospace industry, and was chosen because the inbound SC is very complex and is critical to the success of the focal company. Although the proposed model is also appropriate for simple SCs, a complex network was chosen because there is a greater need for visibility if the entire network is to be optimised in such an environment while improving visibility is more challenging. In addition to these general considerations, the focal company selected for the case study is representative in several other respects:

- The company recently implemented an extensive organisational change in the SC department. As a consequence, management is highly committed to the exploration of different options for optimising the inbound supply chain.

- The company's competitiveness is strongly dependent on its supply network, but the current financial crisis has impacted the economic health of many of the small companies in its inbound network, thereby making the company more interested in frequent, interlinked collaboration with its suppliers.
- The company currently has quite a low level of visibility on its supply network. Using the visibility metric proposed by Caridi et al. (2010a,2010b), the overall visibility level of the focal company on its supply network is 2.15 on a scale of 1–4 (1=minimum; 4=maximum).

In order to summarise the main decisions made during the case study, Table 5 lists the quality criteria, based on the recommendations of Yin (2003).

Since the company uses an Engineer to Order (ETO) approach and the supply chain can differ significantly depending on the product, the unit of analysis used was the whole supply chain of a single product. Information was collected in 2011 through 12 face-to-face interviews with supply chain, purchasing and operations managers, along with written questionnaires and a review of internal documents in order to obtain a broader perspective. Data triangulation was assured through the use of direct observations and multiple investigators (Eisenhardt, 1989). In fact, 2–3 researchers were involved in each interview, making it possible to compare different perceptions of the problem as well as to handle the large quantity of contextual data and to achieve greater confidence in the research findings. The interviews lasted 1–3 h each. Since the company purchasing department is responsible for controlling the whole chain, a representative from this department played a pivotal role in contacting other units and was involved in all of the interviews. Additional details about the departments involved in each interview and the topics discussed are presented in Section 6.1.

Interviews were conducted by following an interview guide (see Annex B). Each session was recorded and summarised in the form of a report. The researchers coded the information collected using a cross-verification method. First of all, the researchers' notes were collected in a single file to prevent any loss of information. Then, the results obtained by the different researchers were compared in order to converge upon a common output, resulting in an objective view of the case and driving data reduction. Systematic coding was also used to avoid bias and to validate interpretations. Following this analysis, the company was again contacted in order to obtain any missing information.

Quantitative data shared during the interviews (e.g. current level of visibility on suppliers) were collected prior to the interviews by means of written questionnaires: 22 buyers in charge of managing the relationships with major suppliers provided the quantitative data needed for the as-is analysis.

5. Visibility value assessment model

5.1. Value assessment tools

Caridi et al. (2010a) suggest four types of information flows on which the focal company could be interested in gaining visibility:

- *Transactions/events*: information communicated when an event takes place.
- *Status information*: information describing the status of some resources/ processes.
- *Master data*: information related to product features.
- *Operational plans*: information about future company plans.

Table 6
Information flows included in the model.

Type of information	Information flow
Transactions/events	ASN – Advanced Shipping Notice
Status information	Order status
	Production residual capacity
	Inventory level
	Supplier internal quality
Master data	SKU (Stock Keeping Unit) features
	Component features
Operational plans	Production plan
	Delivery plan
	Demand forecast (marketing/sales plan)

Table 7
KPIs included in the cause–effect maps.

Process	KPIs
Inventory management	Raw materials inventories
	WIP stock inventories
	Finished products inventories
Customer service	On time delivery (OTD)
	Delivery lead time
	Customer visibility
	Finished product quality
	Product availability
Finance	Order-to-cash
Source	Supplier switching cost
	Source lead time
	Purchasing cost
Handling	Handling efficiency
	Workforce saturation
Warehouse management	Warehouse saturation
Production execution	Production lead time
	Production cost

On the basis of the literature review (Bracchi et al., 2001) and the focus group discussions, ten major information flows in the suggested categories were identified and analysed individually (see Table 6).

Secondly, a subset of KPIs to be included in the cause-effect maps were identified and categorised in accordance with the processes to which they relate, as shown in Table 7. The KPIs included in Table 7 were selected on the basis of the literature on SC visibility (see Table 2) and were validated by the focus group.

For each information flow, a map was created that shows the KPIs affected by an improvement in the quality and/or quantity of the focal company's visibility on that information flow in its inbound supply network (hereinafter referred to as visibility improvement). Such maps have a twofold purpose: they allow the identification of the KPIs potentially affected by visibility improvements, and they explain the reasons why KPI improvements are generated, raising confidence in the quality of the results. The maps were created so as to be applicable to companies in different industries, and should therefore be adapted to the specific company context before being used.

For illustrative purposes, the cause-effect map related to the "Order Status" information flow is shown in Fig. 2. On the map, the information flow is represented by a black box, the final KPIs by grey boxes and the processes within dotted boxes. The other cause-effect maps are presented in Annex C, while Annex D includes a description of each of the linkages in the causal map shown in Fig. 2 (order status) and provides details about both the type (positive or negative) and the trigger of the impact.

The content of the ten cause-effect maps can be summarised by showing the relationship between information flows and KPIs (see

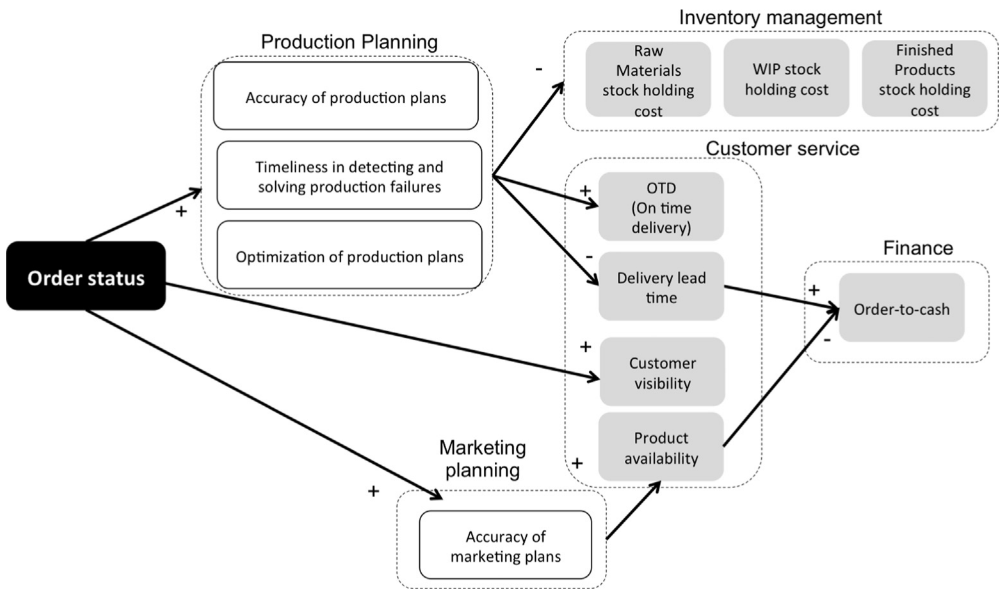

Fig. 2. Example of cause–effect map – Order status.

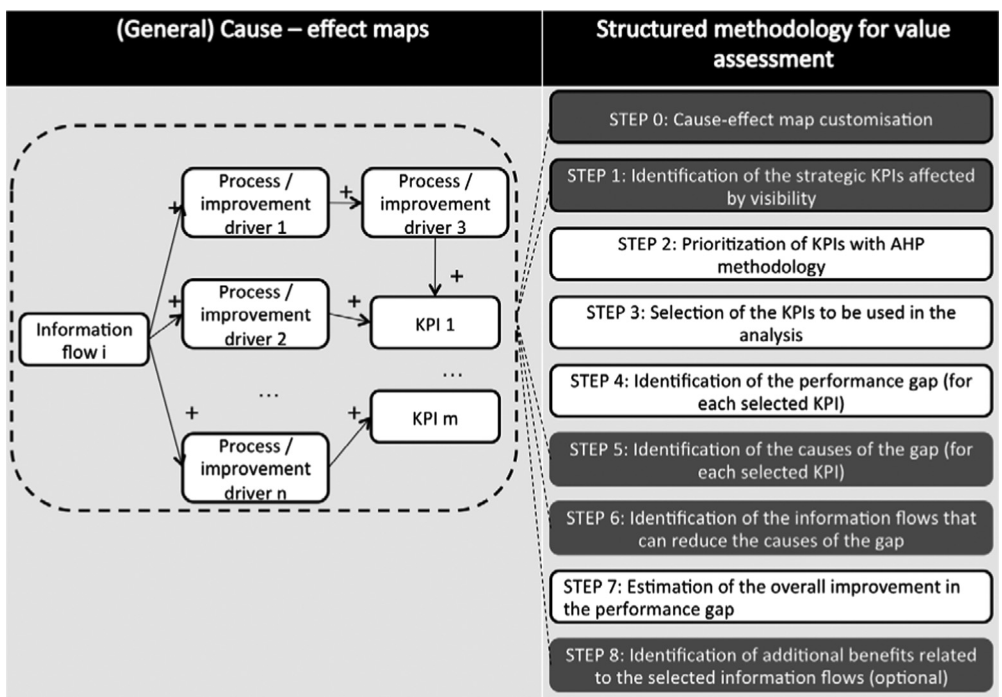

Fig. 3. Visibility VA method.

Annex E). Once again, the KPIs were grouped by process, thereby highlighting which internal processes could be improved by improving visibility on suppliers. Some KPIs could be improved by increasing visibility on several information flows (e.g. order-to-cash, delivery lead time), whereas others are influenced by just one specific information flow (e.g. production lead time, warehouse saturation). From a different perspective, a good level of visibility on some information flows (e.g. production plan, demand forecast) can lead to considerable benefits on several KPIs involved in multiple processes; conversely, other information flows (e.g. SKU features) are much more specific, and need to be exchanged only when specific processes are to be improved (in the example, handling and warehouse management).

5.2. Value assessment method

As explained above (see Sections 3 and 4), the literature review and the cause-effect maps were used to formulate a new VA method, specifically for the assessment of the benefits of SC visibility. Fig. 3 lists (on the right) the nine steps (from 0 to 8) of the VA method. The grey-coloured blocks highlight the phases directly supported by the cause-effect maps developed by the authors.

The framework of the method is based on the work of Brun et al. (2006). The inclusion of the cause-effect maps – and the related tools – in Steps 0, 1, 5, 6, and 7 customises the method for the evaluation of SC visibility. In addition, in order to prioritise

KPIs in step 2, the AHP methodology is proposed, according to Narasimahn et al. (2003).

The VA approach consists of 9 steps.

- Step 0: *Cause–effect map customisation*. The maps should be adapted to include industry and/or company-specific features.
- Step 1: *Identification of the strategic KPIs affected by visibility*. The checklist created from the maps (see Annex E) should be used to identify the KPIs that do not currently satisfy company's performance targets. Appropriate metrics should be defined for these KPIs; where applicable, financial metrics are recommended.
- Step 2: *Prioritisation of KPIs*. This phase aims to identify which KPIs are a priority. The final output consists of the list of the KPIs selected in the previous phase, ranked in order of their strategic importance.
- Step 3: *Selection of the KPIs to be used in the analysis*. On the basis of the ranking completed in the previous step, the KPIs to be included in the analysis should be selected. As the analysis is time-intensive, the authors recommend focusing on only the most important KPIs in order to reduce the level of effort required to complete the VA process. The steps described below (from 4 to 8) should be performed for each KPI identified in this step.
- Step 4: *Identification of the performance gap (for each selected KPI)*. The performance gap is the difference between the current performance level and the target. As-is performance should be considered in addition to the performance gap since saturation effects often exist (i.e. the poorer the as-is performance, the higher the expected KPI improvement).
- Step 5: *Identification of the causes of the gap (for each selected KPI)*. This phase is intended to determine the "causal factors" (e.g. supplier's delay, unreliable production plan) that explain the performance gap. The cause–effect maps are intended to help managers identify the causes of the gap, since they show some of the processes/factors (i.e. the ones related to visibility) that affect performance. The managers involved should identify n causes, which determine the existing gap between the current and the target value. For each cause, a "weight of influence" (P_i, $0 < P_i \leq 100\%$) on the performance gap, i.e. how much the cause affects the gap, should be provided; the weights must sum to 100%.
- Step 6: *Identification of information flows that can reduce the causes of the gap (for each selected KPI)*. The cause–effect maps help identify the information flows that can potentially contribute to eliminating or reducing the causes of the gap, thus improving the KPI. The expected reduction in the occurrence of each cause (ΔC_i) should be assessed in consultation with the managers involved.
- Step 7: *Estimation of the overall improvement in the performance gap (for each selected KPI)*. The overall percentage reduction in the performance gap is calculated as a weighted average of the cause factor reductions identified by the managers.

$$\Delta \text{Gap} = \sum_{i=1}^{n} P_i \Delta C_i \ [\%] \tag{1}$$

  where ΔGap is the reduction in the performance gap (percentage); i is the index for the causes of the gap; n is the total number of causes of the gap; P_i is the weight of influence assigned to the cause i ($0 < P_i \leq 1$); ΔC_i is the (percentage) reduction in the cause i due to improved visibility.
- Step 8: *Identification of additional benefits related to the selected information flows (optional; for each selected KPI)*. The cause–effect maps may suggest additional benefits related to the selected information flows may be obtained. The analysis might therefore be extended to include other KPIs affected by the selected information flows. Although these KPIs were not considered to be strategic during the first step of the procedure, the company may choose to include them in the analysis as well (only in relation to the selected information flows).

6. Case study in the aerospace industry

6.1. Application of the visibility VA model

The purpose of the case study was to explore the applicability of the VA method in a practical context by evaluating the benefits that a focal company can gain through better visibility on the information flows in its supply network. The company is part of a multi-national group, a leader in the aerospace sector, which has a total workforce of over 85,000 employees and 18 billion euros in revenue. It has about 400 first-tier suppliers, of which 22 are considered to be more important in terms of volume of purchases (representing about 70% of total purchases).

The company currently has a rather low level of visibility on its suppliers: using the visibility metric proposed by Caridi et al.

Table 8
Departments involved and topics addressed in each interview.

Interview	Departments	Topics
1	Purchasing	Introduction – analysis of the level of visibility
2	Purchasing	Introduction – analysis of the level of visibility by studying the buyers' questionnaire
3	Purchasing Supply chain	Cause effect map customisation
4	Purchasing Operations	Cause effect map customisation
5	Purchasing Supply chain	Identification of the strategic KPIs affected by visibility
6	Purchasing Supply chain	Prioritisation of KPIs using the AHP methodology
7	Purchasing Supply chain	Selection of KPIs for analysis
8	Purchasing	Identification of performance gaps
9	Purchasing	Identification of performance gaps
10	Purchasing	Identification of the causes of the gaps, identification of the information flows that can reduce the causes of the gaps
11	Purchasing Supply chain	Identification of the causes of the gaps, identification of the information flows that can reduce the causes of the gaps
12	Purchasing Supply chain	Sharing and validation of the results

(2010a, 2010b), the overall visibility level the focal company has on its major suppliers is 2.15 on a scale of 1–4 (1 = minimum; 4 = maximum). The assessment model was used to evaluate the benefits related to "perfect visibility" (i.e. having access to all useful information flows) on the 22 major suppliers.

Table 8 lists the topics and the departments involved in each interview.

Step 0: *Cause–effect map customisation*. The validity of the cause–effect maps was confirmed by the managers involved in the analysis. However, since the company has an "ETO – Engineer to Order" policy and operates in an industry where spare parts management is routine, some modifications were required. For illustrative purposes, Fig. 4 shows the adapted cause–effect map for the "order status". Because of the ETO policy, the KPI "inventory of finished goods" is not significant, and was therefore discarded. Moreover, visibility on order status does not support the marketing planning process; when the company buys raw materials and components, the order has in fact already been signed. Spare parts management proved to be particularly important in the industry, and was therefore added as a separate item.

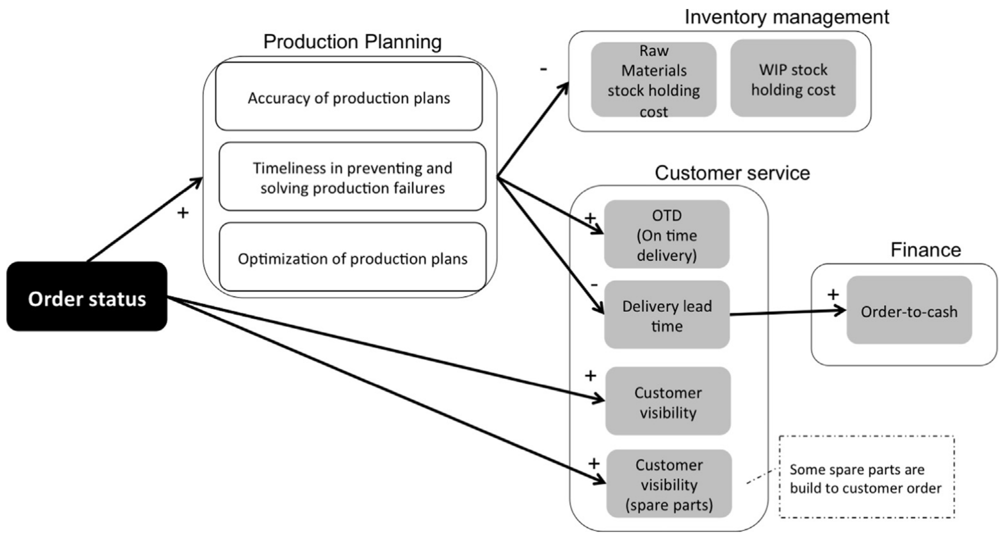

Fig. 4. Case study (aerospace company) – Order status map.

Table 9
Case study (aerospace company) – set of KPIs impacted by visibility and relative importance.

Process	KPI	Importance obtained through AHP analysis
Inventory management	**Raw materials stock holding cost**	**10.1%**
	WIP holding cost	**6.1%**
	Spare parts stock holding cost	2.0%
Customer service	On time delivery	16.0%
	Delivery lead time	2.7%
	Customer visibility	9.2%
	Customer visibility on spare parts	9.7%
	Spare parts availability	**11.0%**
	Timeliness in providing maintenance services	**9.5%**
Finance	Order-to-cash	1.5%
Source	Supplier switching cost	0.8%
	Source LT	0.8%
	Purchasing cost	1.5%
Handling	Handling efficiency	1.1%
	Workforce saturation	3.0%
Warehouse management	Warehouse saturation	1.5%
Production execution	**Production lead time**	**3.5%**
	Production cost	4.5%
Engineering	Engineering cost	5.5%

Table 10
Case study (aerospace company) – performance gaps.

KPI	Definition	Gap	Gap (%)
Spare parts availability	Pieces available/pieces requested	40%	40
Raw materials stock holding cost	Average stock value in the last three months	€100 million	25
Timeliness in providing maintenance services	Times when maintenance services were provided later than promised	30	30
WIP holding cost	Average WIP value in the last three months	€20 million	13
Production lead time	Number of working days	20 days	30

Similar analyses were conducted for all of the maps, thereby producing a tailored version of each map for the case study. The customisation of the maps proved to be very simple, corroborating the authors' judgment that these tools are both efficient and usable.

Steps 1 and 2: *Identification of the strategic KPIs affected by visibility and prioritisation of KPIs.* Based on the general checklist reported in the rows of Table 9, the KPIs that do not currently satisfy the company performance targets were identified. As a result of the cause-effect map customisation, KPIs on spare parts management and product engineering were added, while KPIs relating to the finished product stock level were excluded (see Table 9). Moreover, in order to prioritise the KPIs, the AHP approach was used. A brainstorming session with three company managers was conducted in order to ensure the consistency of the results, and a comparison of all KPI dyads was performed (see Table 9).

Step 3: *Selection of the KPIs used in the analysis.* In agreement with the managers, the selection of the KPIs was based on two basic criteria. First, the importance of the KPI for the company, which was evaluated in Step 2; second, qualitative evaluation of the time and cost of the analysis, which are related to – among other aspects – the difficulties involved in measuring the KPI based on the information already available to the company. As a result, the five KPIs listed in bold type in Table 9 were selected. Specifically, "customer visibility (spare parts)" and "customer visibility" were excluded from the analysis because the direct involvement of customers would have been required, which was not recommended at this stage in the analysis. Moreover, "production lead time" was chosen over "production cost" because the company was not willing to share sensitive data with the analysts; "on time delivery" and "engineering cost" were both excluded for the same reason.

Step 4: *Identification of the performance gap (for each selected KPI).* For each of the five KPIs, the performance gap between the current value and the desired one was identified (see Table 10) through multiple direct interviews with the company's managers.

Steps 5–8: *Identification of the causes of the gap, identification of the information flows that can reduce the causes of the gap,*

Table 11
Case study (aerospace industry) – VA – results.

KPI	Original gap	Gap reduction (KPI improvement)	Information flows
Spare parts availability	40%	13.3%	Supplier internal quality; component features; production residual capacity; order status; inventory level; production plan
Raw materials stock holding cost	€100 million	€29 million	Order status; ASN; delivery plan; production residual capacity; production plan; procurement plan; demand forecasting; inventory level
Timeliness in providing maintenance services	30%	4.4%	Production residual capacity; production plan; order status; ASN component features
WIP holding cost	€20 million	€6.3 million	Supplier internal quality; ASN; order status; inventory level; delivery plan
Production lead time	20 days	6.5 days	ASN; order status; production residual capacity; inventory level; production plan; delivery plan; component features

		Production lead time						
		GAP: 20 days	**Current value: undisclosed** / **Target value: undisclosed**					
		Causes of the gap						
		Lack of component/equipment availability	**Workforce saturation exceeded**	**Handling inefficincy**	**Poor supplier performance (deliveries, quality)**	**Inefficiency in assembly line setting**	**Failures in the indutrial engineering process**	**Inefficiency of aircraft configuration management**
Cause weight (%)		**25%**	**10%**	**10%**	**15%**	**10%**	**15%**	**15%**
INFORMATION FLOWS (all 22 major suppliers)	ASN – Advanced Shipping Notice	x			x			
	ORDER STATUS	x			x			
	PRODUCTION RESIDUAL CAPACITY	x			x			
	INVENTORY LEVEL	x			x			
	PRODUCTION PLAN	x			x			
	DELIVERY PLAN	x			x			
	COMPONENT FEATURES						x	
Reduction in the cause occurrence (%)		**70%**	**0%**	**0%**	**80%**	**0%**	**20%**	**0%**
Weighted reduction of cause occurrence (%)		32.50%						
Gap reduction (days)		6.5 days						

Fig. 5. Case study (aerospace company) – Value Assessment – production lead time.

estimation of the overall improvement in the performance gap (for each selected KPI), and identification of additional benefits related to the selected information flows. For the sake of brevity, only the analysis carried out for "production lead time" is described in detail, although the results obtained for all of the KPIs are summarised in Table 11.

Company managers believe that production lead time is negatively affected by seven main causes (see Fig. 5); two of these (i.e. lack of component/equipment availability, poor supplier performance) are directly related to suppliers' behaviour, and can therefore be improved through better visibility on the upstream SC. Specifically, the interviewees believe that visibility (i.e. timely access to accurate information) on ASN (Advanced Shipping Notice), order status, production residual capacity, inventory level, production plan, and delivery plan can improve the KPI because this visibility improvement would enable a 70% reduction in component/equipment stock-outs and an 80% reduction in problems related to supplier performance (e.g. late arrivals). Moreover, visibility on changes to component features allows for the proper definition of product and process engineering, thus leading to a 20% reduction in engineering failures. The combination of these effects leads to a 32.5% expected reduction in the causes of the gap. The direct involvement of managers in the analysis and critical discussion of the results facilitated the review of the draft case and the gathering of feedback.

Table 11 summarises the results of the VA method for the case study. The assessment showed that the gap for the five KPIs can be reduced toward the target value by 14.8–33.3% by improving visibility on the inbound supply chain. By analysing the information flows that have a greater impact on the company's KPIs, order status was shown to have an impact on all the five KPIs considered in the analysis; in addition, production plan, production residual capacity, inventory level, and ASN impact four out of five KPIs. This insight suggests that the company ought to focus on those information flows when investing in improving visibility on its inbound supply chain.

6.2. Discussion

The application of the model to a real company, which is interested in improving visibility on its supply network, was valuable for clarifying the model's pros and cons. A final brainstorming session was conducted as part of the case study in order to obtain feedback from the company's managers, thus improving construct validity. The managers generally reported a good level of satisfaction with regard to the quality of the results, and the following items were brought up:

- The method provided clear and easy-to-understand indications about the level of SC visibility. Moreover, cross-analyses between the importance (i.e. a combination of priority and volume of purchases) of suppliers and the level of visibility the focal company has on them helped in the development of roadmaps for continuous improvement.
- The model results helped to identify the priorities (in terms of either processes or information flows) for future projects that aim to increase the level of SC visibility.
- The results provided clear insights about both quantitative and qualitative KPIs, as has been suggested in the literature about the impact of visibility (e.g. Beamon, 1999; Zhou and Benton, 2007), and in the literature on VA methods (e.g. Murphy and Simon, 2001; Narasimahn et al., 2003; Ronchi et al., 2010). Quantitative KPIs can be a useful tool for improving the assessment of cash flows of an investment – as, for example, suggested by the VA method proposed by Anandarajan and Wen (1999) – whereas qualitative KPIs might be used to take into account more soft and intangible elements – as argued by Ronchi et al. (2010) and Brun et al. (2006). The consideration of both tangible and intangible benefits proves significant in value assessment models, as has been previously suggested (e.g. Brun et al., 2006; Murphy and Simon, 2001).

  Based on the feedback obtained, the model presented in this paper is consistent with the following basic principles, which reflect the features suggested in the literature that a good VA model should have (e.g. Fink, 2006; Vaidya et al., 2004):

(1) Usability: The cause–effect maps proved to be easily customisable, as the time required to adapt them to the specific context was significantly less than the time required to perform an ad-hoc analysis from scratch. Moreover, the modular structure of the method supported by the maps means that it can be used to obtain results with varying levels of confidence depending on the amount of effort expended. In other words, the method can be used to provide a good approximation of

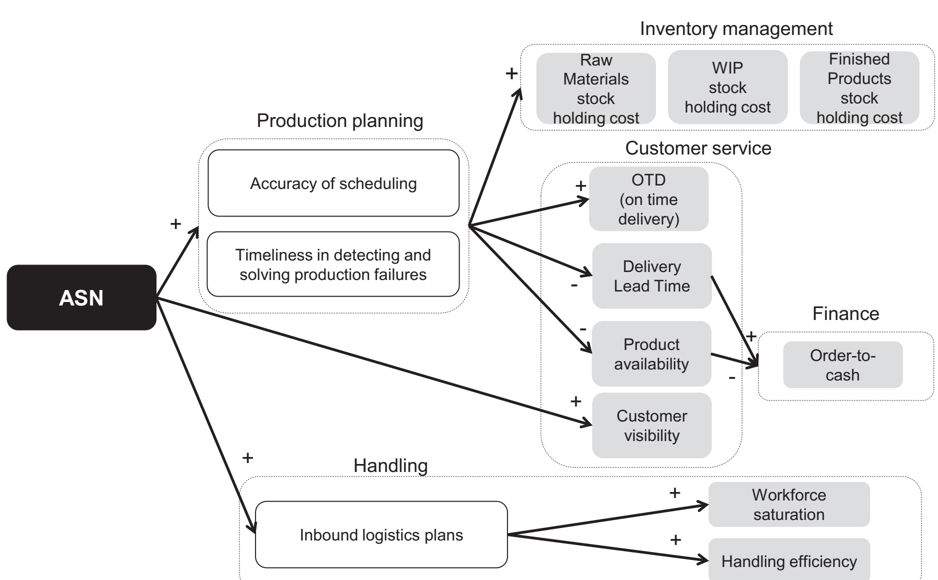

Fig. C1. Cause–effect map – ASN..

the benefits of visibility with a limited amount of effort, and can then be refined to obtain more reliable results.

(2) Diagnostic support: The model not only helps to identify the potential benefits of visibility, but it also helps the user identify how the benefits can be achieved and why, which is of the utmost importance for managers according to Fink (2006). The contribution of individual pieces of information to the overall benefit is clearly shown (see Fig. 5), ensuring good diagnostic capability and clearly demonstrating to managers the most effective way to improve visibility.

7. Conclusions and future developments

7.1. Concluding remarks

This paper is part of a broader research project whose aim is to investigate the relationships between SC visibility, context variables (i.e. virtuality and complexity) and SC performance (Caridi et al., 2010a, 2010b, in press). This paper specifically focuses on the development of a model (i.e. method and tools) for quantifying the benefits of visibility improvements in terms of impact on SC performance. The model is based on the existing literature and was fine-tuned with the support of a focus group consisting of nine practitioners. The model was then applied to the SC of a focal company in the aerospace industry to explore its applicability in a practical context.

The model was found to be efficient since it can easily be customised in accordance with the desired level of effort (e.g. which suppliers and which KPIs to focus on). Moreover, limited effort was required to adapt the tools (e.g. cause–effect maps) to the specific context. The model also proved to be effective in supporting the estimation of KPI improvements and it was shown that the cause–effect maps and the related tools can help the user identify how and why the benefits might be achieved. The method

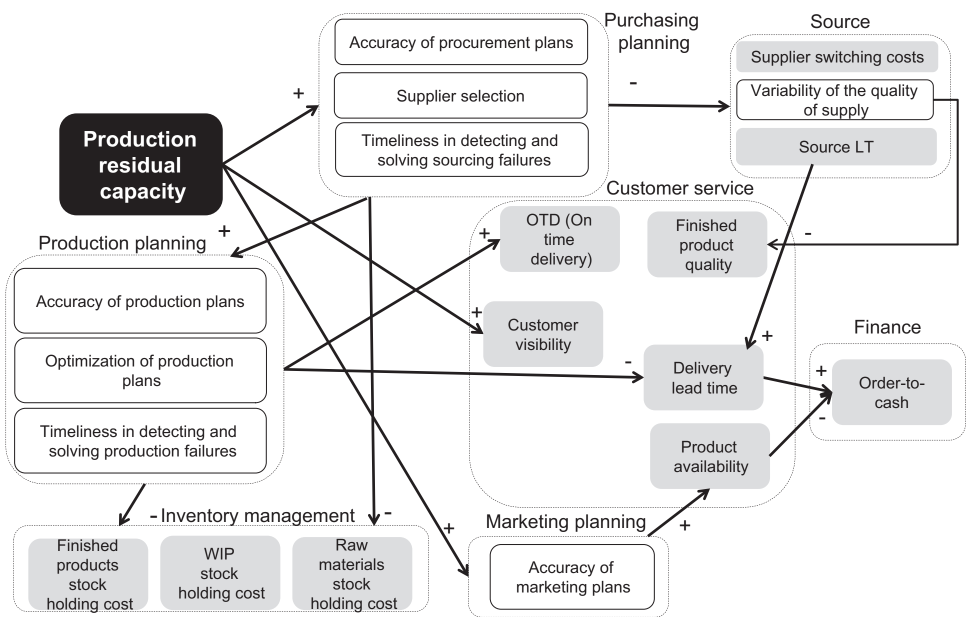

Fig. C2. Cause–effect map – production residual capacity..

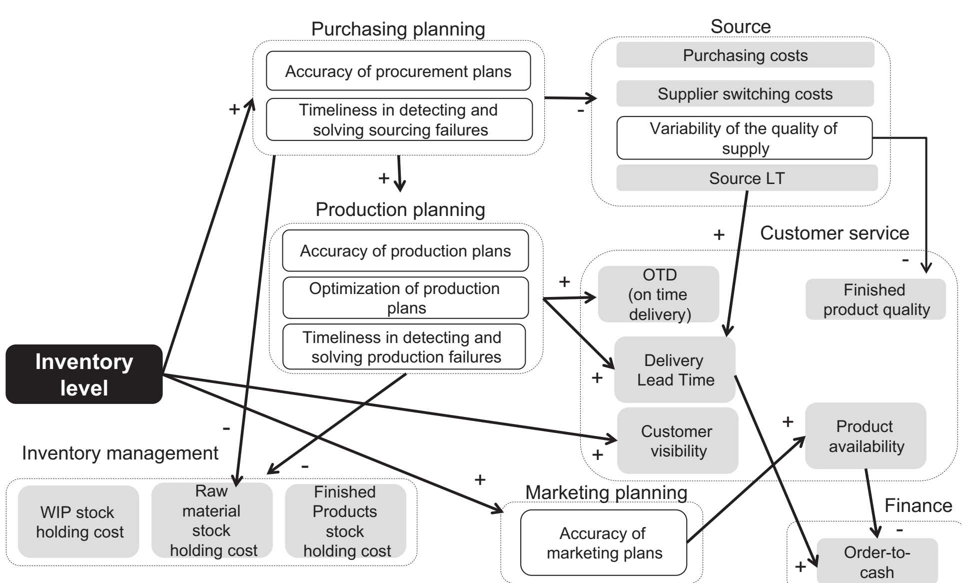

Fig. C3. Cause–effect map – inventory level..

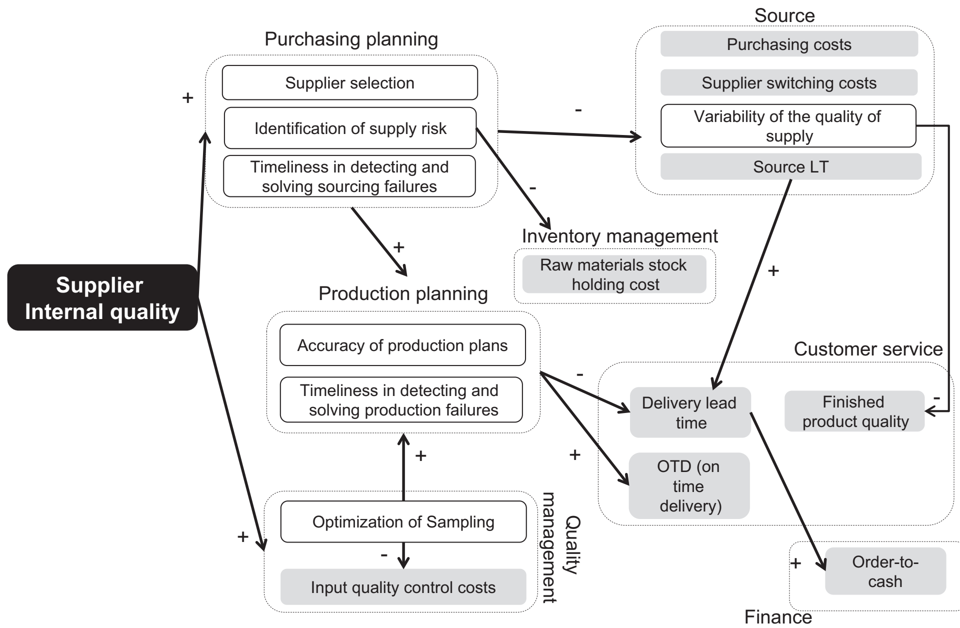

Fig. C4. Cause–effect map – supplier internal quality..

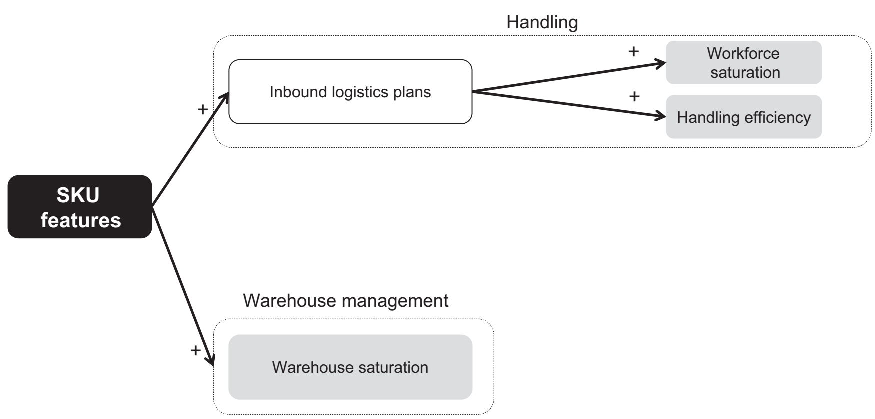

Fig. C5. Cause–effect map – SKU features..

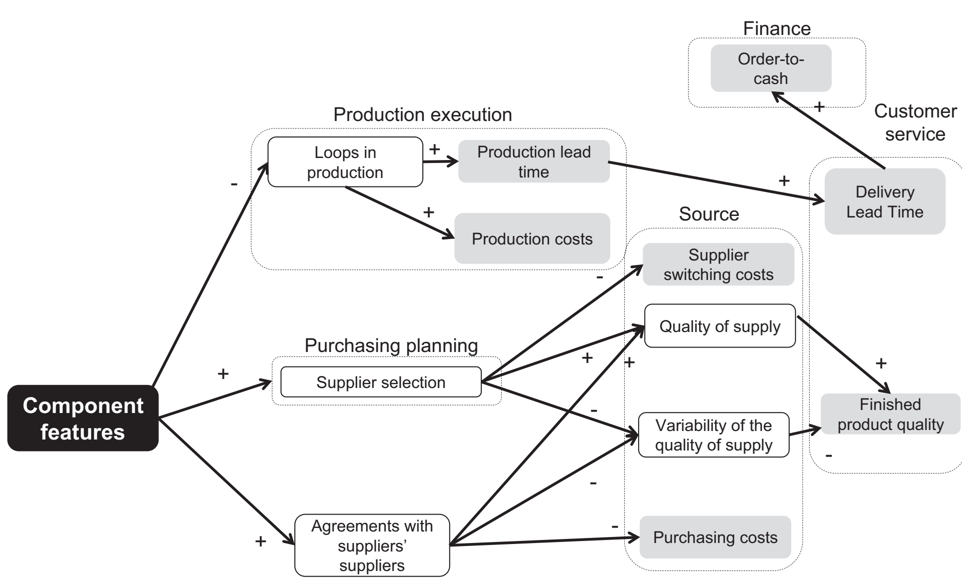

Fig. C6. Cause–effect map – component features..

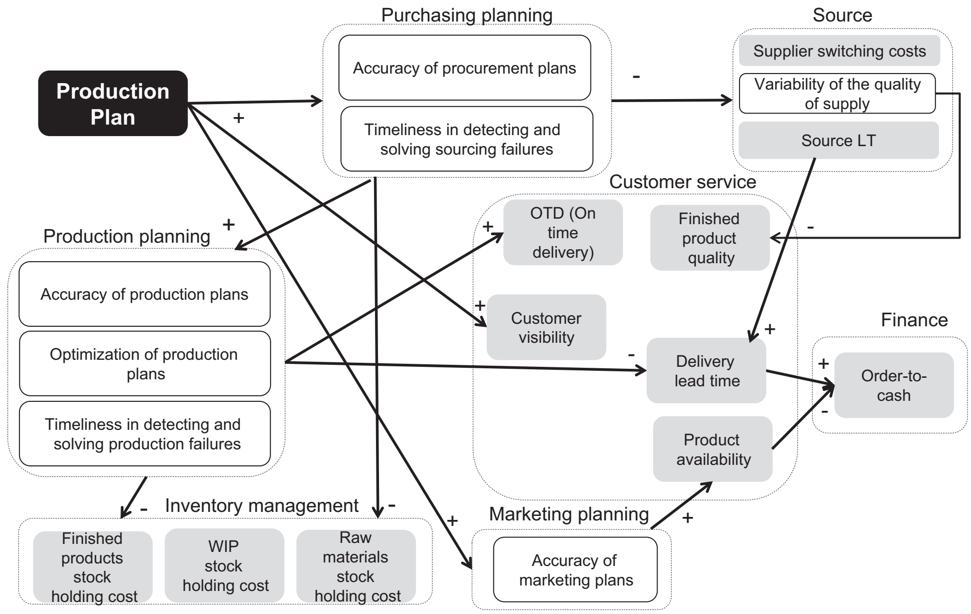

Fig. C7. Cause–effect map – production plan..

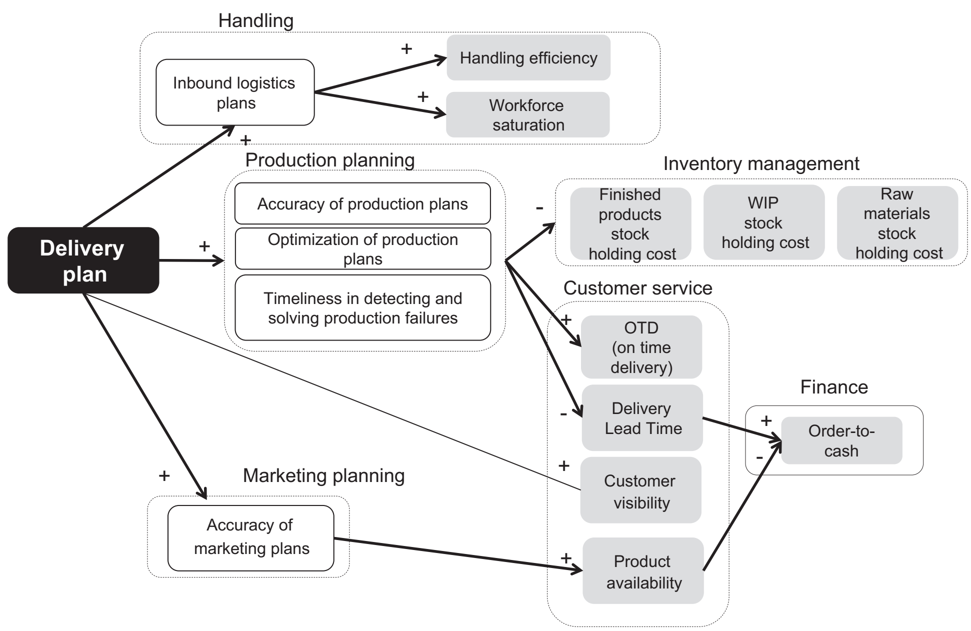

Fig. C8. Cause–effect map – delivery plan..

can be applied in different contexts following the same interview guide, therefore generating results characterised by a similar level of reliability.

7.2. Contributions to knowledge

The results presented in this paper are important for both researchers and practitioners. For the former, the paper provides a structured model (method and tools) for the assessment of the benefits that may be attained through improvements in visibility in complex supply networks. The most important aspect of this research is the method: despite the current lively debate about the importance of SC visibility, methods for assessing the value of visibility are still rudimentary, as they focus only on specific KPIs and enabling technologies. The tools, i.e. maps illustrating the cause–effect relationships between information flows and SC KPIs, represent an additional original contribution to knowledge, revealing insights into the positive effects of different information flows on the main SC processes.

For practitioners, the paper presents how the model can be used in the "ex-ante" evaluation of projects intended to improve SC visibility (e.g. implementation of ICT enabling visibility). The model can be used to assess benefits and can therefore be a valuable tool in helping to reduce barriers to adoption. Furthermore, since the model makes it possible to evaluate the benefits related to single suppliers (or clusters of suppliers), it can help a

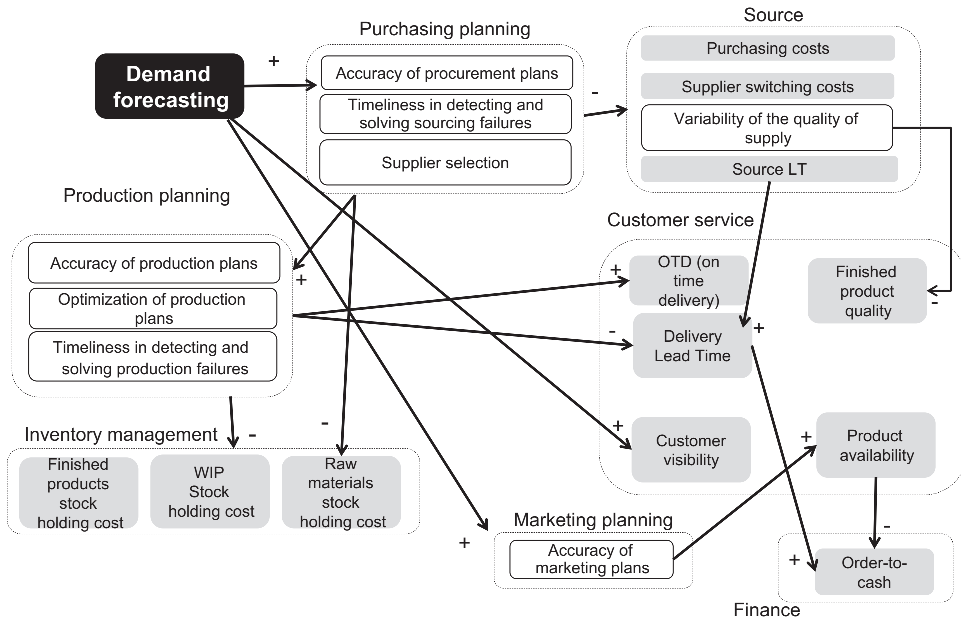

Fig. C9. Cause–effect map – demand forecasting..

company to identify which suppliers it should involve in projects for improving visibility, or in even stronger relationships (e.g. coordination or full collaboration). Moreover, the model can be used to clarify which information flows have the greatest impact on a company's KPIs.

7.3. Future research

Some paths for future research to overcome the limitations of the current study can be identified. First, the tools should be extended by developing cause–effect maps related to internal (i.e. the facilities owned by the focal company) and outbound networks. This would also require new metrics for evaluating the level of visibility on the internal and outbound networks. Metrics for the outbound supply chain have been proposed recently by Caridi et al. (in press), and the authors are currently working on extending the causal maps. Second, the impact of context and operational variables (i.e. size, market velocity, and demand variability) on both the current level of visibility and the benefits of increased visibility should be investigated. Moreover, since the ability of ICT to support visibility on supply chains requires large investments by all of the parties involved (focal company and suppliers), the VA model should be extended to include the assessment of performance benefits from a supplier perspective.

Lastly, the model should be applied to other companies in different industries so as to provide practitioners with useful data and benchmarks relating to the value of SC visibility: generalisability might be achieved by assessing other specific cases – based on industry or company features – which would also contribute to a wider understanding of the phenomenon.

Annex A. Metric used to measure supply chain visibility

The procedure used to evaluate the visibility index *VIS* involves three steps.

First, twelve judgments for each node k ($J_{k,x,y}$) need to be collected based on the three qualitative scales, where:

- $x \in \{q, a, f\}$, q=quantity, a=accuracy, and f=freshness;
- $y \in \{t, s, m, o\}$, t=transactions, s=status, m=master data, and o=operational plans.

The collected judgments are then combined – using the geometric mean – to create a synthetic evaluation of the visibility that the focal company has on each node. The quantity and quality of the shared information are assessed separately, and then combined to evaluate the visibility index *VIS* on node k.

$$VIS\_Quantity_{\ k} = \sqrt[4]{j_{k,q,t} \cdot j_{k,q,s} \cdot j_{k,q,m} \cdot j_{k,q,o}} \tag{A.1}$$

Eq. (A.1): *Visibility index – Quality*

$$VIS\_Quality_{\ k} = \sqrt{\sqrt[4]{j_{k,a,t} \cdot j_{k,a,s} \cdot j_{k,a,m} \cdot j_{k,a,o}} \cdot \sqrt[4]{j_{k,f,t} \cdot j_{k,f,s} \cdot j_{k,f,m} \cdot j_{k,f,o}}} \tag{A.2}$$

Eq. (A.2): *Visibility index – Quantity*

$$VIS_{\ k} = \sqrt{VIS\_Quantity_{\ k} \cdot VIS\_Quality_{\ k}} \tag{A.3}$$

Eq. (A.3): *Visibility index – Quality and quantity for a single node*

Finally, the overall visibility that the focal company has on its inbound supply chain is assessed. The contribution of each node is weighted on the basis of the node distance from the focal company, on the basis of its significance in terms of the value of the supplied goods, and how critical it is, which is measured on a qualitative scale based on the Kraljic matrix (Kraljic, 1983).

Therefore, the visibility index *VIS* is defined as follows:

$$VIS = \sum_{k=1}^{M} (VIS_k W_k) \tag{A.4}$$

Eq. (A.4): *Overall visibility index* where VIS_k is the visibility that the focal company has on node k; M is the number of nodes; W_k is the weight assigned to node k in relation to its distance from the focal company ($W_{d,k}$), criticality ($W_{c,k}$) and significance ($W_{s,k}$).

More specifically, the weight $W_{d,k}$ depends on the "distance" between the connected nodes and on the number of suppliers included in each node. The distance from the focal company is measured by considering the vertical integration of the nodes that are on the path between the node itself and the focal company.

$$W_a = W_{d,k} n_k = \begin{cases} n_k & \text{for first} - \text{tier supplier} \\ \left(1 - \frac{\sum_{l \in I_k} AV_l}{S_{m,FC}}\right) n_k & \text{for suppliers belonging to tier } N, \text{ with } N \geq 2 \end{cases} \tag{A.5}$$

Eq. (A.5): *Measure of the distance from the focal company* where a is a connection exiting from node k; n_k is the number of suppliers included in node k; $W_{d,k}$ is the weight of node k, assessed on the basis of its "distance" from the focal company. If k belongs to the first tier, then $W_{d,k}=1$, otherwise it depends on the vertical integration of the nodes that are on the path between the node itself and the focal company; I_k is the set of nodes along the path from k to the focal company; l is a node belonging to I_k; AV_l is the added value of node l; m is the first-tier node belonging to I_k; $S_{m,FC}$ is the volume of sales from the node m to the focal company FC.

The criticality weight $W_{c,k}$ is evaluated based on the well-known Kraljic matrix (Kraljic, 1983). More specifically, a four-response scale is used to measure the criticality of a supply chain node, combining the impact on profits and the supply risk. Finally, the significance weight $W_{s,k}$ is calculated on the basis of supplier sales within the considered supply network (cf. Eq. (A.6))

$$W_{s,k} = \begin{cases} \frac{S_{k,FC}}{\sum_{n \in N_1} S_{n,FC}} & \text{for first} - \text{tier supplier} \\ \frac{S_{k,e}}{\sum_{i \in N_z}} W_{s,n} & \text{for suppliers belonging to tier } N, \text{ with } N \geq 2 \end{cases} \tag{A.6}$$

Eq. (A.6): *Measure of the significance weight* where $S_{b,c}$ (e.g. $S_{k,FC}$, $S_{n,FC}$, $S_{k,e}$, $S_{i,e}$) are the sales by supplier b to company c; n belongs to the set of first-tier nodes, N_1; i belongs to the set of z-tier nodes N_z; e is the $(z-1)$-tier node belonging to I_k.

Table D1
Information flows considered in the model – Order status links.

Arrow beginning	Arrow tip	Type of impact	Description
Order status	(Production planning) • Accuracy of production plans • Timeliness in detecting and solving production failures • Optimisation of production plans	+	More information available about suppliers' order status allows the focal company to improve the accuracy of production plans due to a reduction in unexpected stock-outs of raw materials and components. Should a failure occur (e.g. due to the lack of a required component/raw material), this information flow allows the failure to be recognised in advance, and therefore the company can immediately work to find a solution. Finally, the focal company can prepare the production plan on the basis of real data, instead of using average values, thus anticipating or postponing production accordingly.
(Production planning) • Accuracy of production plans • Timeliness in detecting and solving production failures • Optimisation of production plans	(Inventory management) • Raw materials stock holding cost • WIP stock holding cost • Finished products stock holding cost	–	A firm can improve its inventory management process, thus reducing the average inventory level, due to a better understanding of production needs since it can buy, produce and stock exactly what it needs. Better timeliness in detecting and solving production failures implies a reduction in the use of safety stock of raw materials and finished products. As a consequence, the likelihood of missing parts in the assembly line decreases, as does, in turn, the WIP (work-in progress) level. When production plans are not optimised, the WIP level increases in order to avoid stock-outs in case suppliers' lead time is longer.
(Production planning) • Accuracy of production plans • Timeliness in detecting and solving production failures • Optimisation of production plans	(Customer service) • OTD (On time delivery)	+	Provided that production plans respect customers' needs, the higher their quality (i.e. optimisation, accuracy), the better the company punctuality (i.e. on time delivery). Moreover, timeliness in detecting and solving production failures improves OTD because of a reduction in internal lead time uncertainty.
(Production planning) • Accuracy of production plans • Timeliness in detecting and solving production failures • Optimisation of production plans	(Customer service) • Delivery lead time	–	A firm can reduce its delivery lead time by reducing the amount of time wasted in manufacturing because of planning failures. If an error occurs, detection timeliness reduces internal lead time.
(Customer service) • Delivery lead time	(Finance) • Order-to-cash	+	The order-to-cash, i.e. the amount of time from arrival of the customer order to payment, includes the delivery lead time. Therefore, a reduction in delivery lead time leads to an improvement in the order-to-cash KPI.
Order status	(Customer service) • Customer visibility	+	Better visibility on order status allows the focal company to provide more reliable information to customers.
Order status	(Marketing planning) • Accuracy of marketing plans	+	The marketing department can develop more reliable plans because of the possibility of more accurately estimating the capability of the SC to meet the proposed plans.
(Marketing planning) • Accuracy of marketing plans	(Customer service) • Product • Availability	+	More accurate marketing plans help increase product availability, thus reducing or possibly eliminating gaps between service level and customer expectations.
(Customer service) • Product • Availability	(Finance) • Order-to-cash	–	If a stock-out occurs, the order-to-payment (i.e. cash) time increases, because the customer usually pays for the product only once it has been received. Therefore, higher product availability ensures shorter order-to-cash time.

For diagnostic purposes, the overall visibility index *VIS* can be split according to information quantity and quality, and type of information.

Annex B. Interview guide

- Step 0: *Cause–effect map customisation*
  For each information flow, the cause–effect map is analysed with the interviewee so that it can be adapted to company-specific features.
- Step 1: *Identification of the strategic KPIs affected by visibility*
  (In the back-office, the researcher prepares the list of KPIs obtained from the final maps.) The interviewee is asked to select the KPIs that do not satisfy the company's target. For each of those KPIs, the interviewee specifies the metric. Where applicable, financial metrics are recommended.
  The researchers and the manager evaluate whether to carry forward to the next VA method steps all of the KPIs on the list (in which case Step 2 is skipped) or to select a subset of strategic KPIs to focus on (this selection is carried out in Step 2). The output of this evaluation is the number *N* of KPIs that will be considered in the next steps of the method. The decision is made mainly on the basis of the trade-off between obtaining a more precise VA result and the cost of the assessment, both of which are a function of the amount of time devoted to the analysis.
- Step 2: *Prioritisation of KPIs*
  The interviewee is asked to rank the set of KPIs according to their strategic relevance. When the number of KPIs is high (more than 10), the Analytic Hierarchy Process (AHP) methodology (Saaty, 2008) could be used to facilitate a couple-wise comparison. The AHP method can be used in two different ways: by collecting individual ideas from multiple interviewees and comparing them in the back office or by collecting ideas from multiple interviewees through consultation, where people are free to discuss different perceptions of the problem. Depending on the hierarchical level of the people involved, the researcher may select the preferred method for collecting this information.
- Step 3: *Selection of the KPIs used in the analysis*
  Based on the ranking completed in the previous step, the *N* KPIs to be included in the analysis are selected. The steps described below (from 4 to 8) are performed for each KPI selected in this step.
- Step 4: *Identification of the performance gap (for each selected KPI)*
  For each KPI, the researcher obtains (i) the as-is value and (ii) the target value set by the company. Finally the researcher calculates the performance gap as the difference between the target and as-is values.
- Step 5: *Identification of the causes of the gap (for each selected KPI)*
  For each KPI, the interviewee is asked to identify the causes of the performance gap. Information system queries can support the interviewee in identifying the causes and these are strongly recommended. During this step, the researcher may re-analyse the customised cause–effect maps, since they contain useful information about the possible causes of the gaps.
  Once the interviewee has identified all of the possible causes, they must provide a "weight of influence" in the range (0–100%) for each one. The weights must sum to 100%.
- Step 6: *Identification of the information flows that can reduce the causes of the gap (for each selected KPI)*
  (In the back-office, the researcher identifies the information flows which might affect the performance gap for each KPI using the customised cause-effect maps.)

Table E1
Information flow – KPI matrix.

			Information flows									
			Transactions/ events	Status information				Master data		Operational plans		
			ASN	*Order status*	*Production residual capacity*	*Inventory level*	*Supplier internal quality*	*SKU features*	*Component features*	*Production plan*	*Delivery plan*	*Demand forecast*
KPIs	Inventory management	*Raw material stock holding cost*	X	X	X	X	X			X	X	X
		WIP stock holding cost	X	X	X	X				X	X	X
		Finished product stock holding cost	X	X	X	X				X	X	X
	Customer service	*OTD – On time delivery*	X	X	X	X	X			X	X	X
		Delivery lead time	X	X	X	X	X		X	X	X	X
		Customer visibility	X	X	X	X				X	X	X
		Product availability	X	X	X	X				X	X	X
		Finished product quality			X	X	X		X	X		X
	Finance	*Order-to-cash*	X	X	X	X	X		X	X	X	X
	Source	*Supplier switching cost*			X	X	X		X	X		X
		Source lead time			X	X	X			X		X
		Purchasing cost				X	X		X			X
	Handling	*Handling efficiency*	X					X			X	
		Workforce saturation	X					X			X	
	Warehouse management	*Warehouse saturation*						X				
	Production execution	*Production lead time*							X			
		Production cost							X			

For each KPI, the interviewee is asked to evaluate the expected percentage reduction in the occurrence of each cause under the assumption that all of the information flows affecting the performance gap are available.

- Step 7: *Estimation of the overall improvement of the performance gap (for each KPI)*
(In back-office, the researcher calculates a weighted average of the expected percentage reduction in the performance gap for each KPI, by using the judgments collected in Step 6 and the weights collected in Step 5):

$$\Delta \text{Gap} = \sum_{i=1}^{n} P_i \Delta C_i \ [\%], \tag{B.1}$$

Eq. (B.1): *Measure of the reduction in the performance gap*where ΔGap is the reduction in the performance gap (percentage) identified in Step 4; i is the index of the causes of the gap; n is the total number of causes of the gap; P_i is the weight of influence assigned in Step 5 to cause i ($0 < P_i \leq 1$); ΔC_i is the percentage reduction in cause i due to the improved visibility identified in Step 6).

The researcher shares the result of his/her analysis with the interviewee and collects his/her comments.

- Step 8: *Identification of additional benefits related to the selected information flows (optional; for each selected KPI)*
(In the back-office, the researcher considers the information flows identified in Step 6 that affect performance gaps, and identifies possible additional benefits (i.e. improvements in additional KPIs) related to them on the basis of the cause–effect maps. The analysis might also be extended to include other KPIs affected by the selected information flows.)

The researcher shares the list of additional KPIs with the interviewee and they decide whether to include them in the analysis (from Step 4 onward), based on the trade-off between precision of the VA results and the cost of the assessment, both of which are a function of the amount of time spent on the analysis.

Annex C. Cause–effect maps

See Figs. C1–C9 here.

Annex D. Information flows considered in the model – Order status links

See Table D1 here.

Annex E. Information flow – KPI matrix

See Table E1 here.

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