



# Can digital ecosystems mitigate risks in sea transport operations? Estimating benefits for supply chain stakeholders

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## Abstract

Decision-making supported by digital ecosystems has been increasingly studied during recent years, especially due to improved technical capabilities to collect, store, and analyze large amounts of data. The literature recognizes that these systems can reduce response time of managers and enhance a cost-efficient recovery of supply chains. However, there is a lack of methodological frameworks to evaluate the benefits of these platforms. In addition, there is still little understanding of the risks in ocean container transport and their implications for supply chains. This paper proposes and applies a mathematical model for evaluating the impacts of digital platforms, with a focus on solutions to mitigate risks in sea transport operations. The model is based on scenarios and decision tree models to evaluate the impacts of a supply chain digital ecosystem on full containers shipped from Asia to Europe implemented by four companies. Results show monetary savings per scenario in the range from €3448 to €79,242. The most significant savings are expected on unplanned transshipments, cargo damage, export inspections, container detention, and container release.

**Keywords** Digital ecosystems · Decision trees · Container shipping · Shipping risks · Supply chain management

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## 1 Introduction

Supply chains are complex environments in which several private and public stakeholders interact to ensure the shipping of goods globally (Gunasekaran et al. 2004). Optimal coordination and performance can be enhanced by means of digital environments, or so-called ecosystems, to enable information exchange, visibility, and improved decision-making capabilities (Thatcher 2017; Chang and West 2006; Fawcett and Waller 2011). According to the American Production and Inventory Control Society (APICS), a digital ecosystem allows managers to “safely connect, practically manage, and efficiently analyze data from billions of unique products, customers, and transactions around the globe—instantaneously and on demand” (Thatcher 2017). In particular, the increased visibility that can be achieved in a supply chain with a digital ecosystem can shorten reaction time in risk-based decision-making (Heckmann et al. 2015). Monitoring data from sensors in real time can be used to detect gaps between supply chain planning and execution, and thereby generate alerts to operators and management teams (Park et al. 2013; Liu et al. 2007). This is especially true in ocean transportation, where the complexity of operational risks may undermine the scheduling reliability of port terminals, liner services, and thereby, supply chain actors (Notteboom 2006).

The existing literature enlists plenty of studies claiming benefits of supply chain ecosystems (Blackhurst et al. 2005; Caridi et al. 2014; Kim and Lee 2010; Swift et al. 2019). Sharing information within a supply chain improves performance, for instance, by minimizing the bullwhip effect as well as inventory costs (Yu et al. 2001; Lee and Wang 2005; Lee and Whang 2000; Lee et al. 2000; Kim et al. 2016). Likewise, these systems can improve organizational performance and product availability and flexibility (Barratt and Oke 2007). Kim and Lee (2010) used structural equation modeling to prove how information technology enhances joint decision-making, and thereby supply chain responsiveness and market performance.

Nevertheless, most of these studies focus on strategic benefits, not operational ones. In addition, risks in ocean container transport and implications for supply chains have been significantly understudied in the literature (Fransoo and Lee 2013). Hence, this paper aims to develop and apply a framework to identify and evaluate operational risks and supply chain implications. To that effect, we attempt to assess the potential benefits of digital supply chain ecosystems, with a focus on enhanced risk-based decision-making in sea transport operations.

The methodology is demonstrated through multiple case studies of companies shipping cargo between China and the Netherlands. The focus of the cases is on the maritime leg of supply chains, indicated by experts as problematic in terms of visibility, accounting for about 6–10% of costs wasted as a result of inaccurate, poor, or lacking information (Thai 2007; Aichlmayr 2003).

The remainder of this manuscript is organized as follows: after the introduction, the literature reviewed is presented. Specifically, this paper enlightens previous work upon risks in global supply chains, supply chain digital ecosystems, and benefits addressed by previous research. Thereafter, the methodology applied



is explained, and results are quantified and expounded. Finally, the findings are summarized and discussed considering potential implications for practitioners and researchers.

## 2 Risks in maritime shipments

The globalization trend has pushed several companies to move their manufacturing activities offshore, especially to Asian countries. The logistics to be arranged in global shipments to ensure timely operations is quite complex, since there are multiple stakeholders involved and several processes to be arranged and efficiently synchronized (Willis and Ortiz 2004). First of all, traders need to arrange and coordinate shipments between import and export countries. This task requires interaction with several actors, i.e., manufacturers, port terminals, handling companies, transporters, ocean carriers, customs brokers, customs administrations, etc. (Willis and Ortiz 2004). To avoid shipment delays, shippers are challenged to find and ensure transport capacity by contracting ocean liner companies, while establishing routines to synchronize the exchange of information among all these actors, e.g., cargo and consignee data, shipping instructions, and an estimation of time of arrival. In some cases, small–medium-sized shippers tend to outsource these operations to a nonvessel operating common carrier (NVOCC) (Fransoo and Lee 2013). In this case, the NVOCC issues a contract with the shipper and takes the responsibility to either ship the cargo on shipping capacity they have purchased in advance, thus assuming themselves shipping market risks,<sup>1</sup> or find ocean vessel capacity by contracting ocean carriers and sometimes terminal operators (Fransoo and Lee 2013). The presence of so many actors, the greater length of supply chains, and the need to exchange information and synchronize operations increase the vulnerability of maritime shipments to several risks with severe implications on performance (Peck 2006; Willis and Ortiz 2004). Supply chain risks have been addressed in previous literature in terms of unexpected events that can hit demand, supply, flows of materials, information, finances, etc. (Viswanadham and Gaonkar 2008; Manuj and Mentzer 2008). Risks that typically affect the maritime legs of supply chains are several and exacerbate into schedule unreliability (Notteboom 2006), e.g., time delays, strikes, queues in port terminals, piracy, extreme weather conditions, etc. Sometimes risks may happen less frequently but with more severe consequences, halting the supply chain for a longer time. These risks include natural catastrophes, economic disruptions, acts of terrorism, etc. (Kleindorfer and Saad 2005).

Other risks that appear in global supply chains are security or compliance risks (Khan and Burnes 2007; Ni et al. 2016). Customs administrations need to ensure the safety and security of countries by verifying the content of the shipments against the export and import declarations submitted by shippers. Risks to be prevented include illegal smuggling of weapons, drugs, nuclear or radioactive materials, and other prohibited items in containers (Willis and Ortiz 2004). Customs officers have to

<sup>1</sup> Thus the name nonvessel owning but “common carrier” nevertheless (NVOCC).



distinguish legitimate from illegal trade and hinder any shipments that could constitute a threat to national security. Hence, different nonintrusive inspection technologies to screen containers without opening them and with a low rate of false positives are being evaluated (Urciuoli 2016).

### 3 Digital ecosystems

Use of digital ecosystems and big data analytics is seen as an effective tool to optimize the efficiency of supply chains (Provost and Fawcett 2013). A digital ecosystem can be seen as a collaborative digital environment in which different entities can connect and exchange information by pushing or pulling information amongst them. Since the 1990s, a shift has been seen from client–server applications<sup>2</sup> to peer-to-peer grids,<sup>3</sup> mobile and ad hoc networks, service-oriented architectures (SOAs)<sup>4</sup>, and lately, swarm intelligence<sup>5</sup> (Chang and West 2006). SOAs are seen as a strategic approach to information technology (IT) to enable information exchange among different companies while maintaining flexibility and high interoperability. Actors involved in information exchange in a supply chain have two main roles: publishing and providing a service or, sometimes, even merely requesting services from a brokering server (Chang and West 2006; Kumar et al. 2007).

In a supply chain, a digital ecosystem is a platform where data can be collected from different supply chain actors (e.g., suppliers, logistics providers, manufacturers, intermodal terminals, carriers, etc.), rearranged, and distributed back through distinct published services feeding into the applications of the single stakeholders that are part of a supply chain (Heikkurinen et al. 2013). Since the same data are relevant to several stakeholders, the digital ecosystem becomes a community of agents pushing and pulling data, where clients can be servers at the same time, and without a centralized control or a fixed architecture (Chang and West 2006); For instance, to provide real-time visibility of shipments data, elements such as purchase orders, booking number, bill of lading number (B/L number), container numbers, vessel International Maritime Organization number (IMO), etc. need to be collected from several stakeholders before the position of a container can be conveyed to the supply chain actor requesting it (Urciuoli 2018).

Several experts agree that visibility and information sharing are fundamental tools to enhance the management of supply chain risks (Blackhurst et al. 2005; Lee and Wang

<sup>2</sup> A distributed application where a piece of software is preinstalled in a computer or portable device that, through the Internet or an off-line network, can communicate and exchange data with a server (e.g., the client sends a request and the server responds with the information requested).

<sup>3</sup> Also a distributed computing application but different from client–server applications (centralized system); the server's functionalities are distributed across networks of computers (decentralized).

<sup>4</sup> Characterized by three roles: service providers, service requesters, and brokers. The provider creates the services and publish these in the registry of the broker. The requester can search and find the service and thereby invoke it.

<sup>5</sup> In a self-organized architecture, any computer/device in the network can share information and create and publish services.



2005; Caridi et al. 2014; Yu and Goh 2014). Blackhurst et al. (2005), having interviewed several executives, found that visibility is a key issue for dealing with disruptions. Lack of accurate information flows lead to production inefficiencies, emphasizing the importance of integrating supply chain information systems and enhancing visibility (Rupp and Ristic 2000). Apart from disruptions, operational risks can also be monitored and dynamically counteracted, maximizing responsiveness and flexibility, i.e., quickly preventing, detecting, and recovering from critical disruptions (Sheffi 2005; Finch 2004; Blackhurst et al. 2005). This is performed by systematically measuring and comparing differences between predetermined key performance indicators, measured during supply chain planning, and execution (Liu et al. 2007; Otto 2003; Bodendorf and Zimmermann 2005; Christopher and Lee 2004). Liu et al. (2007) developed a model based on Petri nets, where basic patterns can be analyzed and thereby detected. Other approaches include the use of fuzzy logic and agent technology (Bodendorf and Zimmermann 2005).

#### 4 Potential benefits of digital ecosystems

Disruptions affect performance negatively, and losses can assume different magnitudes depending on three factors (Blackhurst et al. 2005): type and time-length of the disruption and mitigation measures or strategies adopted by companies. The final outcome that is relevant for the supply chain includes additional costs due to interruptions in business operations or other undesirable consequences such as delayed deliveries or lost sales (Svensson 2002). These additional costs are a direct function of the level of complexity, leanness, globalization, and specialization of the supply chain (Pfohl et al. 2010; Peck 2006).

Operational risks bring less visible monetary losses but more frequently and, sometimes, in such an underhanded manner that businesses may erroneously ignore them. In other cases, the interconnectedness of risks and their ramifications across multiple stages and actors of the supply chain makes the quantification of the impacts difficult; For instance, if containers arrive late at the port of import and miss the connecting inland transport, they need to be stored and wait for the next vessel. This implies additional storage costs, travelling time, and sometimes, demurrage costs charged by port terminals (Fransoo and Lee 2013). In addition, additional losses appear at the end of the supply chain in the form of penalties for contract breaches or simply unfulfilled demand.

Finally, personnel costs should also be considered. Decreasing complexity to handle risks implies that personnel can (1) easily work with multiple tasks and (2) solve problems quickly and cost-effectively before risks develop into major ones, sometimes irreversible (Ravulakollu et al. 2018; Bevilacqua et al. 2017).



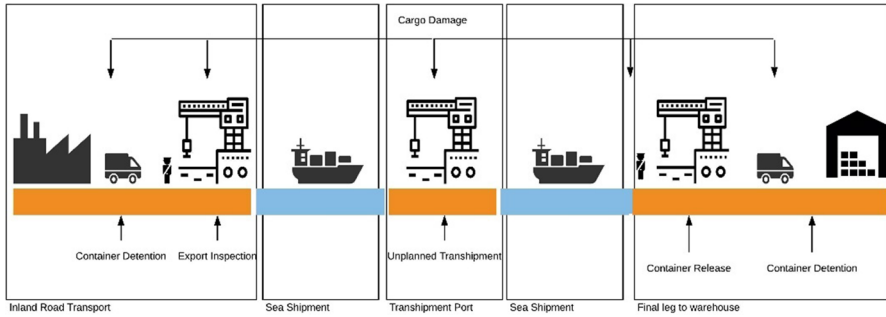


Fig. 1 Risk events identified in trade lane

## 5 Model

To determine how a digital ecosystem could impact a supply chain, diverse methodologies were employed in this study. First, the literature related to digital ecosystems and risk management was reviewed. Next, another literature review was performed to identify the main supply chain processes in international shipments and thereby typical risk events disrupting supply chains. Finally, four cases were used to collect and analyze data. The cases consist of trade lanes where full containers are shipped from factories in Asia to receiving warehouses in Europe.

### 5.1 Main scenarios identification

A plethora of risks can take place in a supply chain. To streamline the process of identifying the most important risks, a qualitative screening of classes of scenarios was performed to spatially separate, structure, and prioritize potential events (Haimes et al. 2002). The main assumption of this phase was to see systems as hierarchical in nature (Haimes et al. 2002; Haimes 2002). Hence, the trade lanes in the four case studies were split into five overarching classes: inland road transport from factory to exporting port, sea shipment, transshipment port, sea shipment, and final leg to warehouse. By means of workshops and interviews with selected experts from the cases, the following main scenarios were established (Fig. 1):

1. Cargo damage
2. Container detention
3. Export inspection
4. Unplanned transshipment
5. Container release



## 5.2 Data collection and analysis

Four main case studies with shipments on trade lanes from China to Europe were used to collect data:

- The first company is the largest international health and beauty retailer in Asia and Europe, with over 3 billion customers, partnering with 13 retail brands.
- The second manufactures and sells document-printing technology products in more than 160 countries, with headquarters in the USA.
- The third is a global computer, phone hardware, and electronic manufacturing company.
- The fourth distributes and retails consumer electronics and information technology products.

All the above cases include (1) an inland export leg, where containers are moved from factories to a port terminal by truck, (2) a sea shipment, and (3) an import leg, where cargo is moved from port of import to final destination in the Netherlands. As part of the above cases, additional data were collected and analyzed from four companies working in the logistics and freight-forwarding sectors and in charge of the shipments of the main case companies. These were a global-market leader in the freight-forwarding sector (managers from Netherlands, Hong Kong, and Shanghai), two logistics service providers, and one distribution company working in the Netherlands with urban, regional, and national distribution.

Data were collected by means of semistructured interviews and workshops. Interviews were prepared with a protocol, recorded, and transcribed for further elaboration and analysis (Miles et al. 2014). Questions were mostly of an exploratory nature, hence trying to understand processes and key risk events in the supply chain. Other literature was screened to prepare the interview protocol as suggested by Eisenhardt (1989) and Yin (1994).

At the end of the interviews, following the techniques for data reduction, the main risk events were identified and tree diagrams constructed to display the evolution of the risks and the operational implications for the companies involved (Miles et al. 2014). During this phase, the respondents estimated costs and probabilities of the tree diagrams. Thereafter, focus-group sessions were used to validate these tree diagrams. All findings derived from the interviews were discussed within the team and thereafter validated with the respondents (Miles et al. 2014).

Data analysis was carried out in four steps:

- *Identification of main scenarios and initial events* This phase aimed at filtering relevant risks according to classes defined by analysts. The interviews were used to create initial scenarios and main initiating events (Haimes et al. 2002).
- *Decision tree diagrams* Once the main initiating events were identified, decision tree diagrams were used to visually represent all possible end-states stemming from the initial events (King 1973). Decision tree diagrams are recommended to systematically identify main events and thereby quantify possible outcomes, especially when lack of data could be a concern (Kim and Koehler 1995). The



decision tree diagrams were constructed by asking experts to give examples of typical normal scenarios and deviations from normal-operations scenarios (Kim and Koehler 1995). The constructed decision trees for each of the main scenarios identified are expounded in annex 9.3.

- *Development of state equations* In correspondence with the tree diagrams, the main probabilities and corresponding costs were identified and modeled in the state equations. For each end-state, an expected monetary cost is computed, i.e., an average of the different courses of action, weighted by the respective probabilities assigned to the branches of the tree. Data collection was performed to gather existing statistics available at companies or, when not available, judgmental probabilities from the panels of experts (Kim and Koehler 1995; King 1973; Berger et al. 2004).
- *Impacts assessment* Assessment of the impacts was performed by means of a panel of experts. To ensure normative and substantive goodness, experts were chosen based on their knowledge of the digital platform as well as the main bottlenecks experienced during shipments (Winkler and Murphy 1968). Thereafter, the experts were asked to estimate how probabilities were going to be affected. The identified values were based on the common agreement of the panel.

### 5.3 State equations

Each state within the identified scenarios can be modeled with a state equation. The Appendix reports the state equations used for each of the tree diagrams. In the same appendix, notations and indices are illustrated to clarify the parameters used in the state equations. The following equation represents the expected monetary cost of each end-state of risk events:

$$\text{EMC}(\theta_j^i) = \prod_{k=1}^b (P_k^{i,j}) \sum_{k=1}^b (C_k^{i,j}) = \prod_{k=1}^b (P_k^{i,j}) \sum_{k=1}^b (f_k^{i,j} + C_{hr} t_k^{i,j}), \quad (1)$$

where EMC = Expected Monetary Cost,  $\theta_j^i$  = end state  $j$  of risk event  $i$ ,  $i = [cd, cdt, ei, ut, cr]$  = set of identified risk events (definitions in annex, Sect. 9.1),  $j = 1, \dots, n$ , where  $n$  is the number of end states in each tree diagram,

$$C_k^{i,j} = f_k^{i,j} + C_{hr} t_k^{i,j} = \text{Operating costs,}$$

$f^{i,j}$  = Fixed Costs identified for risk even  $ti$ , end-state  $j$ ,

$C_{hr} t_k^{i,j}$  = Variable costs, given as additional time multiplied by cost of time in hours,

$k = 1 \dots b$  = Number of branches in the end-state considered,

hr = Hours.





## 5.4 Impacts assessment

The supply chain digital ecosystem to be assessed was developed by a team of software engineers. The solution consisted of a combination of software and hardware, delivering the following supply chain services:

- *Real-time tracking services* real-time data collected by gathering several types of shipment information<sup>6</sup> at different points of the supply chain. Data sources consisted in pdf documents made available by stakeholders, automatically parsed by using text recognition software, as well as other data retrieved from port community systems. Additional data were gathered by means of container security devices [Global Positioning System (GPS) position, door opening/closing logger, Global System for Mobile communications/General Packet Radio Service (GSM/GPRS) modem], databases, and manual data-upload functionalities. Records related to customs scanning and inspection activities could be logged by manual data-upload functionalities.
- *Exception alert services* these services generate alerts based on a deviation between actual and target performance or status. The alerts were sent via email.
- *Reporting services* real-time milestone reporting provides reports on a weekly/monthly basis of main key performance indicators set in the platform. Examples of indicators include timing of occurrence of milestone events and any discrepancies compared with normal operations. The reporting services could be accessed via a web platform available for computer or mobile devices.

To evaluate impacts of the above services, the costs of AS IS versus TO BE states were compared by means of experts' judgements. In this aspect, the interviewed experts were asked first to select which parameters of the decision trees were expected to be affected, i.e., which probabilities ( $P_k^{i,j}$ ) and costs ( $C_k^{i,j}$ ), and then to estimate the expected impacts in three situations: low ( $l$ ), medium ( $m$ ), and high ( $h$ ) impacts, i.e.,  $P_k^{i,j,m,h}$  and  $C_k^{i,j,m,h}$ . On this basis, the resulting expected monetary costs for the three scenarios (low, medium, and high) could be obtained by the following equation:

$$EMC^{l,m,h}(\theta_j^i) = \prod_{k=1}^b (P_k^{i,j,m,h}) \sum_{k=1}^b (C_k^{i,j,m,h}) = \prod_{k=1}^b (P_k^{i,j,m,h}) \sum_{k=1}^b (f_k^{i,j,m,h} + C_{hr}^{i,j,m,h}). \quad (2)$$

The economic benefits,  $\Upsilon$ , can be derived as the difference between expected costs and the normal operations scenario given in [Eq. 1].

$$\Upsilon^{l,m,h} = \Delta EMC(\theta_j^i) = EMC(\theta_j^i) - EMC^{l,m,h}(\theta_j^i),$$

<sup>6</sup> E.g., purchase order, shipping instructions, shipping details, master bill of lading, house B/L, commercial invoice, packing list, certificates, etc.



**Table 1** Experts' opinions on potential impacts of digital ecosystem

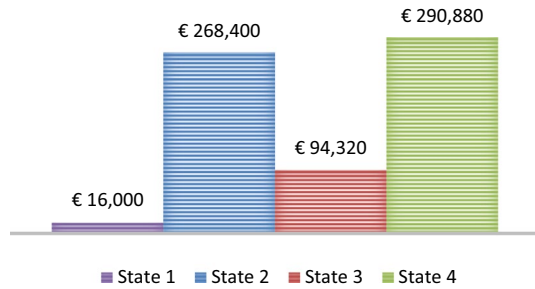
Parameter	Low ( <i>l</i> ) (%)	Medium ( <i>m</i> ) (%)	High ( <i>h</i> ) (%)
$\epsilon_k^{i,j,m,h}$			
$P_{ci}$	0	0	0
$P_{cp}$	0	0	0
$P_{ms}$	0	0	0
$P_{df}$	25	50	75
$P_{dp}$	40	50	60
$P_{ot}$	0	0	0
$P_{si}$	97	98	100
$P_{pd}$	0	0	0
$P_{pi}$	0	0	0
$P_{pu}$	0	0	0
$P_{ps}$	0	0	0
$P_{td}$	0	0	0
$P_{ut}$	0	0	0
$P_{wi}$	85	87.5	95
$\mu_k^{i,j,m,h}$			
$t_{nt}$	60	70	80
$t_{ntd}$	88	90	95
$t_{ns}$	60	70	80
$t_{dm}$	98	99	100
$t_{pi}$	0	0	0
$t_r$	0	0	0
$\pi_k^{i,j,m,h}$			
$C_{ie}$	70	80	90
$C_{df}$	0	0	0
$C_{dl}$	0	0	0
$C_{dff}$	0	0	0
$C_{ra}$	98	50	100
$C_{hr}$	0	0	0

$$\begin{aligned}
 Y^{l,m,h} &= \prod_{k=1}^b \left( P_k^{i,j} - P_k^{i,j,m,h} \right) \sum_{k=1}^b \left( C_k^{i,j} - C_k^{i,j,m,h} \right), \\
 &= \prod_{k=1}^b \left( P_k^{i,j} - P_k^{i,j,m,h} \right) \sum_{k=1}^b \left[ \left( f_k^{i,j} - f_k^{i,j,m,h} \right) + C_{hr} \left( t_k^{i,j} - t_k^{i,j,m,h} \right) \right].
 \end{aligned}
 \tag{3}$$

To determine the potential changes of probabilities,  $P_k^{i,j,m,h}$ , and costs/time parameters,  $f_k^{i,j,m,h}$ ,  $C_{hr}t_k^{i,j,m,h}$ , experts were asked to evaluate what proportion of the original parameters ( $P_k^{i,j}$ ,  $f_k^{i,j}$ , and  $C_{hr}t_k^{i,j}$ ) would be affected after implementation of the supply chain digital ecosystem. The following notation is used:



**Fig. 2** Expected monetary costs of cargo damage (AS IS)



$$\begin{cases}
 \varepsilon_k^{i,j,m,h} = \text{reduction of probabilities} \rightarrow P_k^{i,j,m,h} = \varepsilon_k^{i,j,m,h} \cdot P_k^{i,j} \\
 \mu_k^{i,j,m,h} = \text{reduction of time units} \rightarrow t_k^{i,j,m,h} = \mu_k^{i,j,m,h} \cdot t_k^{i,j} \\
 \pi_k^{i,j,m,h} = \text{reduction of fixed costs} \rightarrow f_k^{i,j,m,h} = \pi_k^{i,j,m,h} \cdot f_k^{i,j}
 \end{cases}$$

Table 1 presents the way in which the panel of experts rated the above parameters.

## 6 Results

This section reports the findings for each of the scenarios identified, namely cargo damage, container detention, export inspection, unplanned transshipment, and container release.

### 6.1 Cargo damage

During transportation, cargo is exposed to physical stresses in form of shocks, vibrations, and acceleration that could cause damage and therefore lower the quality of the products in transit. Likewise, changes in environmental conditions, such as temperature, moisture, or humidity, may also deteriorate the quality of the products stored in containers; For instance, time delays or sudden changes of environmental conditions, e.g., temperature and humidity, could speed up the deterioration process of perishable goods, e.g., medicines, vegetables, fruit, etc. As a result of the interviews performed, four AS IS end-states could be identified (Fig. 11, Annex 9.3.1):

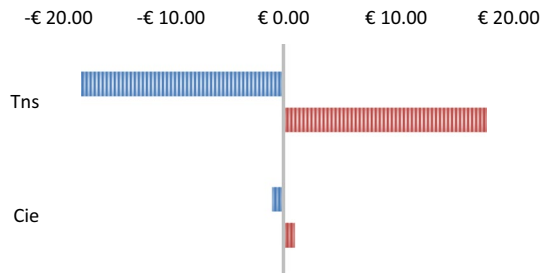
- *State 1* Cargo is not damaged; hence it arrives to destination free of quality issues.
- *State 2* Cargo is damaged during transportation, and when delivered, it is not usable. The costs incurred by the actors are related to lost sales, insurance excesses and rate increments, investigation operations to claim and identify liabilities, and the setup of a new order and shipment.
- *State 3* Cargo is damaged during transportation, but when it arrives to destination, it can be resold at a lower price. In this case, actors experience a limited



**Table 2** High, medium, and low impacts on cargo damage risk (TO BE) expressed as expected monetary costs (EMC)

	High	Medium	Low
$\theta_1^{ei}$	€1600	€3200	€4800
$\theta_2^{ei}$	€174,040	€182,080	€188,120
$\theta_3^{ei}$	€93,672	€93,744	€93,816
$\theta_4^{ei}$	€288,288	€288,576	€288,864
Tot	€557,600	€567,600	€575,600
Savings	€60,000	€50,000	€42,000

**Fig. 3** Sensitivity analysis of parameters in cargo quality risk event (expected cost variation €/container)



loss of the value of the cargo; costs related to the identification of liabilities as well as insurance excesses and increments also need to be considered.

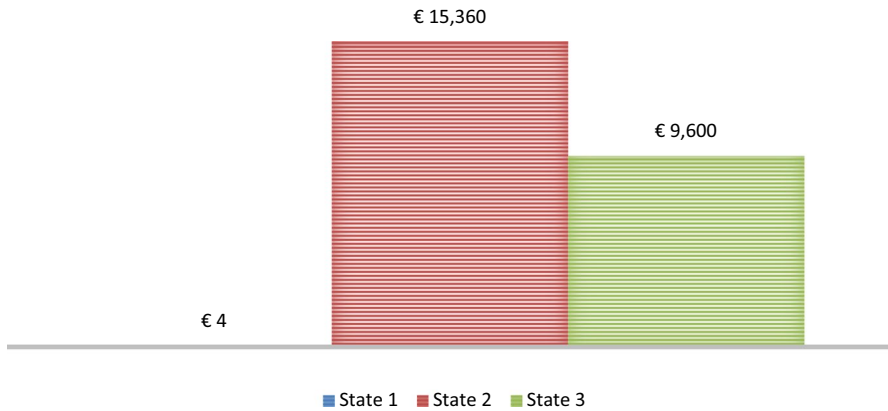
- *State 4* Cargo is damaged during transportation, and when it arrives to destination, it needs to be repaired before it can be sent to the market. The costs involved in this scenario include repair costs, costs for liabilities claim, lost sales (time delay to market), and insurance costs.

The costs associated with the four states identified for this risk are shown in Fig. 2. State 4 appears to be the most expensive, followed by states 2 and 3. The total expected monetary costs for this risk event amount to €617,600.

In the TO BE situation, experts believe that the supply chain digital ecosystem may affect mostly State 2, where products are not usable anymore and a new shipment needs to be planned. Within this state, the time-to-market required for a new shipment and its related costs can be reduced,  $T_{ns}$ . Likewise, the costs for exchanging information,  $C_{ie}$ , can be significantly reduced by exploiting the capability to push information automatically to stakeholders rather than having operators engaged in several phone calls requesting the status of the shipment from multiple actors. Table 2 presents the potential impacts of the platform on cargo damage risks. Potential savings range between 6.8% and 9.7% of the total expected costs, quantifiable to €42,000 up to €60,000.

On a sensitivity analysis, the time required for a new shipment clearly has a greater impact on the total expected costs (Fig. 3).





**Fig. 4** Container detention expected monetary costs (AS IS)

**Table 3** Container detention—expected impact on costs (TO BE)

	High	Medium	Low
$\theta_1^{\text{cdt}}$	€0	€1	€1
$\theta_2^{\text{cdt}}$	€5280	€6720	€8208
$\theta_3^{\text{cdt}}$	€1104	€2160	€3168
Tot	€6384	€8881	€11,377
Savings	€18,580	€16,083	€13,587

## 6.2 Container detention

Interviewed companies pointed out the issue of detaining containers outside the port domain. Detention charges are applied for the storage or holding of containers outside a terminal when a designated free time passes. This event was modeled in a tree diagram, where three AS IS end-states were identified (Fig. 12, Annex 9.3.2):

- *State 1* Truck is not delayed, and no detention fee is charged.
- *State 2* Truck is delayed, and detention fee is charged.
- *State 3* Truck is delayed, but despite the delay, the container is returned on time, and no detention fee is applied.

As shown in Fig. 4, State 2 is the most expensive end-state (when containers incur a detention fee), and the total expected costs of this scenario amount to €24,964.

In the TO BE situation, experts agree that use of a visibility platform can affect two main parameters: costs for the information to be exchanged to monitor the status of the shipment in real time,  $C_{ic}$ , and probability for returning the container within the detention free time-window,  $P_{dp}$ . The exception alert services of the digital ecosystem can alert users when free time-windows are close to being exceeded. Users can also put into place measures to avoid the fee, e.g., forward the alerts to a transport carrier reminding them to speed up operations and return



the container. Possible impacts are more significant in this case, ranging between 54.4% and 90.9% (Table 3).

A sensitivity analysis was performed on two parameters:  $C_{ie}$  and  $P_{dp}$ . However, no differences were discovered, and average impacts on costs were limited to €± 3 per container.

### 6.3 Export inspection

In case export customs select containers for inspection, the container is likely to miss the ship and need to be stored at the port terminal, awaiting for the next one (Fig. 13, Annex 9.3.3). During the storage time, there is also a risk of the container exceeding the demurrage free time-window and a fee being required to be paid to the port. Next, when a new vessel approaches the port and the container is loaded, information about the new vessel needs to be shared with the export freight forwarder. According to the interviewed managers, this is not always the case. If the information is not given, the formal container documents from the freight forwarder at exit may not contain the correct vessel details, leading to higher costs to track the shipment in the importing country. Consequently, the import freight forwarder will have to spend time to rematch the documentation, and the export procedure will be more complex and time-consuming. Six AS IS states are possible (Fig. 13, Annex 9.3.3):

- *State 1* Customs do not select the containers for inspection. Containers are loaded and depart.
- *State 2* Customs select containers for inspection, and vessel is not missed. Hence, containers are loaded on time and depart to destination.
- *State 3* Customs select containers for inspection, and ship is missed. Due to delayed loading, containers incur demurrage fees. Containers are loaded onto a new vessel, and correct vessel information is communicated to operators.
- *State 4* Customs select containers for inspection, and ship is missed. Due to delayed loading, containers incur demurrage fees. Containers are loaded onto a new vessel, but no vessel information is communicated to operators.
- *State 5* Customs select containers for inspection, and ship is missed. Despite delayed loading, containers do not incur demurrage fees. Containers are loaded onto a new vessel, and vessel information is communicated to operators.
- *State 6* Customs select containers for inspection, and ship is missed. Despite delayed loading, containers do not incur demurrage fees. Containers are loaded onto a new vessel, but no vessel information is communicated to operators.

Total costs of this scenario were estimated at €29,324. The different costs associated with each of the six states identified are shown in Fig. 5. As shown, States 1 and 6 are, in order, the most expensive ones.



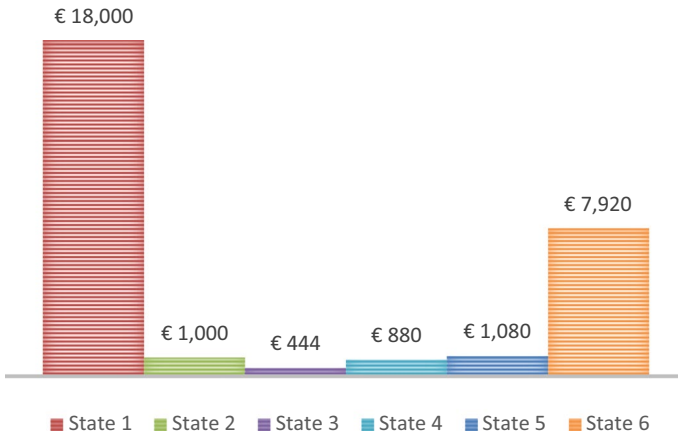


Fig. 5 Overview expected costs of export shipment event (AS IS)

Table 4 Overview of base cost and potential impacts (TO BE)

	High	Medium	Low
$\theta_1^{ei}$	€1800	€3600	€5400
$\theta_2^{ei}$	€100	€200	€300
$\theta_3^{ei}$	€165	€276	€451
$\theta_4^{ei}$	€0	€2	€5
$\theta_5^{ei}$	€190	€361	€519
$\theta_6^{ei}$	€4	€29	€55
Tot	€2259	€4468	€6730
Savings	€27,065	€24,856	€22,594

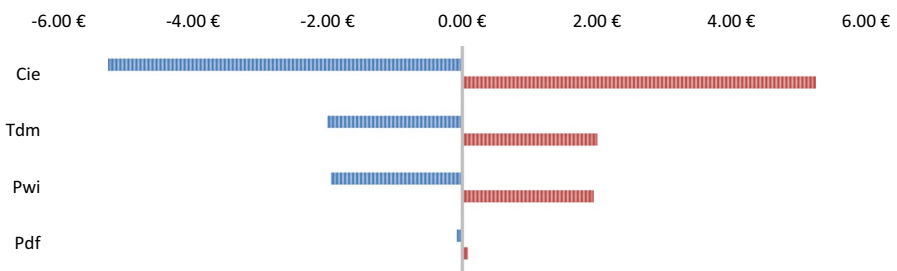


Fig. 6 Tornado diagram on parameters affected (€/container)

In the TO BE situation, experts expect the developed ecosystem to lower costs of information exchange (by means of exception alert services),  $C_{ie}$ , and probabilities of incurring demurrage fees,  $P_{df}$ , while the probability of receiving information about the new vessel,  $P_{wi}$ , increases. Table 4 presents the costs of the scenarios under low, medium, and high impacts of the ecosystem.



According to these results, total expected costs range between €2259 and €6730. Hence, compared with the base expected costs, savings range between 77.05% and 92.30%. A final sensitivity analysis on the parameters expected to be affected by the IT platform is shown in Fig. 6. The cost of information exchange is the parameter majorly affecting final costs, followed by time spent for matching documents, probability of delivering wrong information, and finally, probability of incurring demurrage fines.

#### 6.4 Unplanned transshipment

This event concerns the sea-to-sea transshipment of a container; For example, a container loaded at Yiantian and bound for Rotterdam may be transshipped at the port of Singapore for operational reasons. Transshipment can be scheduled and, although shippers may have the capability to arrange intermodal transport themselves, this is usually the job of the carrier; For instance, transshipments from a deep-sea vessel to another deep-sea or to a feeder vessel may take place, given the hub-and-spoke network of the shipping line. However, sometimes, unscheduled transshipments can happen without notifications. According to the interviewed experts, during loading–unloading operations, containers could be unloaded for remarkshalling purposes and then left on the terminal or even reloaded onto the wrong vessel. If left on the ground, containers will need to wait for the next vessel. If they are loaded onto the wrong vessel, containers may unexpectedly arrive at an unknown port, requiring involved stakeholders to arrange an additional feeder or inland transport to final destination. This may result in additional delays, handling costs, and even additional data to be exchanged to figure out where the container is located and recover it. Hence, the identified AS IS states are (Fig. 15, Annex 9.3.4):

- *State 1* Shipment goes as planned, and no unexpected transshipment takes place. The shipment arrives on time at the right destination.
- *State 2* In case of an unexpected transshipment, stakeholders manage to receive a warning from the transshipment port. Consignees arrange new transport, and the vessel arrives at the correct port of destination (PoD) but late, at an unknown date.
- *State 3* Stakeholders receive a warning from the transshipment port. Shippers arrange new transport, but the vessel arrives at a different port. Economic losses are substantial as a new feeder vessel or inland transport must be arranged. In addition, arrival at the correct port will be significantly delayed.
- *State 4* Stakeholders receive a warning from the transshipment port, but due to lack of communication with logistics actors, new transport cannot be arranged. The containers wait for longer time, until a new vessel picks them up and delivers them to the PoD. Arrival at PoD will be significantly delayed.
- *State 5* A transshipment takes place, but due to lack of communication, stakeholders do not receive any warnings from the transshipment port. Containers





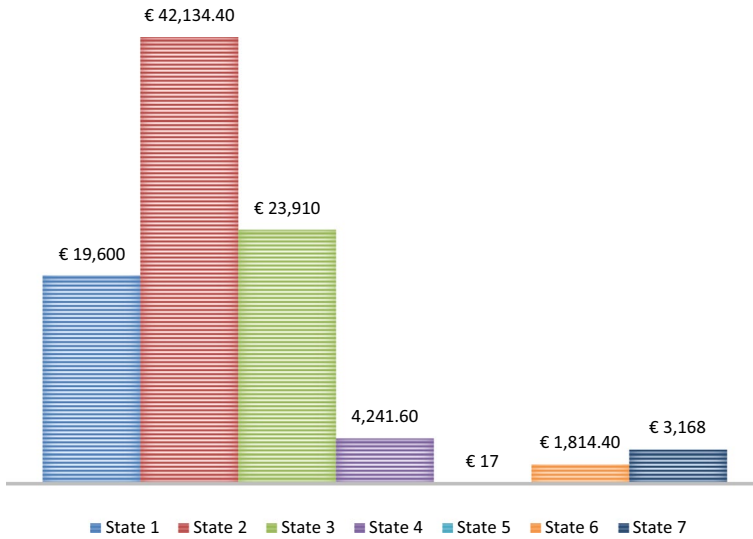


Fig. 7 Costs analysis, unplanned transshipment (AS IS)

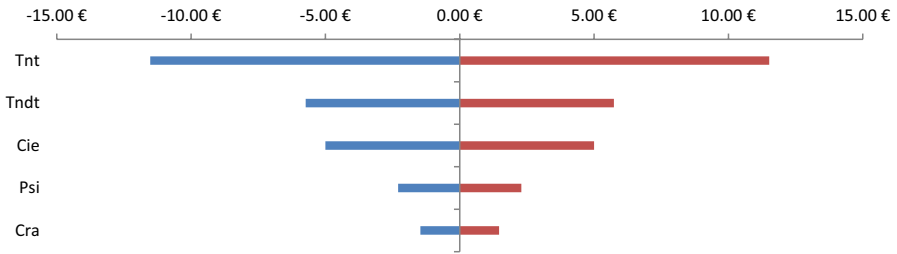
Table 5 Potential impacts (TO BE)

	High	Medium	Low
$\theta_1^{ut}$	€1960	€3920	€5880
$\theta_2^{ut}$	€9875	€14,468	€18,964
$\theta_3^{ut}$	€2803	€4320	€5142
$\theta_4^{ut}$	€952	€1415	€1868
$\theta_5^{ut}$	€0	€1	€1
$\theta_6^{ut}$	€32	€93	€185
$\theta_7^{ut}$	€21	€71	€128
Tot	€15,643	€24,288	€32,169
Savings	€79,242	€70,597	€62,716

wait for a longer time, until they are loaded onto a new vessel arranged by the shipper. Thereafter, containers are delivered to the correct PoD still on time.

- *State 6* A transshipment takes place, but due to lack of communication, stakeholders do not receive any warnings from the transshipment port. Containers wait for a longer time, until they are loaded onto a new vessel. Containers finally arrive at the correct PoD but significantly delayed.
- *State 7* A transshipment takes place, but stakeholders do not receive any warnings from the transshipment port. Containers wait for a longer time, until they are loaded on a new vessel. Yet, containers arrive at a different port, requiring additional time to arrive at destination as well as costs for arranging a feeder or inland transport. Shipment will be significantly delayed.





**Fig. 8** Tornado diagram on parameters affected by ecosystem (€/container)

Total expected costs of this scenario was about €94,885. Most expensive states are: State 2 (€42,134) and State 3 (€023,909) (Fig. 7).

In the TO BE scenario, experts believe that the ecosystem can lower (1) time to arrange new transport,  $T_{nt}$  and  $T_{ntd}$ , (2) costs of replanning activities,  $C_{ra}$ , and (3) costs for information exchange,  $C_{ie}$ . While (4) the probability of information reaching stakeholders on time,  $P_{si}$ , is expected to increase. A digital ecosystem can shorten time and costs for replanning a shipment, including new sea transport and intermodal connections ( $C_{ra}$ ). Normally, operators need to make phone calls, find and collect necessary documents, and fax these to the right operators. Alternatively, ecosystem services provide a real-time alert in case of transshipment problems and thereby direct access to all data necessary to arrange a new shipment. Some is uploaded in the platform by different actors, hence simplifying data sharing and costs for exchanging information. Under low, medium, and high impacts of technologies, potential savings were computed in the range between 66.1% and 83.5% (Table 5).

The final sensitivity analysis shows that the ecosystem has higher impacts on time to setup new transport both for sea and inland modes,  $T_{nt}$  and  $T_{ntd}$  (Fig. 8).

## 6.5 Container release

This scenario deals with import customs processes and operations at port of entry in Europe (Rotterdam). Customs inspections are performed to prevent the exploitation of supply chains to perpetrate prohibited actions. This process consists of two stages: the first is a screening of the containers, and the second is a physical inspection of the containers' content, typically concerning only a small sample of containers randomly selected by customs officials or flagged by the customs risk management system. This second stage depends on the risk analysis performed by customs, where the screening's results and data submitted by brokers for customs import or transit are analyzed. Before physically inspecting a container, officers need to check the presence of gases. Toxic gases could be developed for two main reasons. First reason is cargo has gone through fumigation processes, i.e., gaseous fumigants used to eliminate all possible pests in it (e.g. exotic organisms, parasites, insects, termites, etc.). The presence of residual fumigants generates dangerous concentrations of gases representing a health danger to operators exposed



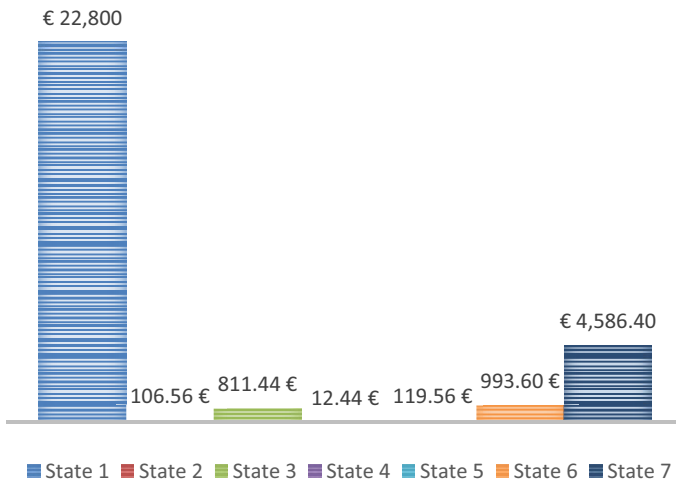


Fig. 9 Costs associated to status release container event (AS IS)

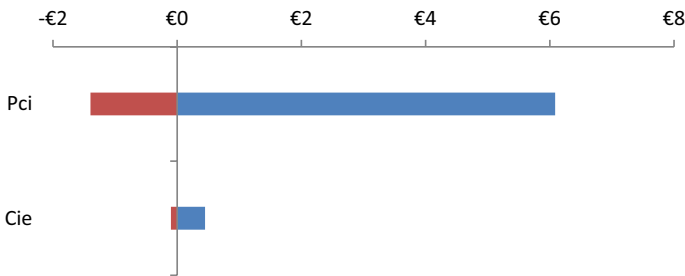
to them. Another reason is that products consume oxygen in the container and develop  $\text{CO}_2$  due to respiration processes or biochemical, microbial, and other decomposition processes that take place during transportation. These processes may develop faster when containers are moved across long distances and consequently are subjected to substantial variations of temperature and humidity/moisture (e.g., sea transportation). Within this event, a total of seven AS IS states have been identified (Fig. 15, Annex 9.3.5):

- *State 1* Container is not selected for customs inspection, and therefore it can transit to next inland destination.
- *State 2* Container is selected for customs inspection, presence of gases is detected, and it is decided to ventilate the container. After ventilation, officers discover illicit items or any other possible infringements, and therefore the container is seized.
- *State 3* Container is selected for customs inspection, presence of gases is detected, and it is decided to ventilate the container. After ventilation, officers do not discover any infringements, and therefore the container is released.
- *State 4* Container is selected for customs inspection, significant presence of gases is detected, and it is decided to transport the container to a degassing chamber and sanitize the internal atmosphere. When container is back, officers discover illicit items or any other possible infringements, and therefore the cargo is seized.
- *State 5* Container is selected for customs inspection, significant presence of gases is detected, and it is decided to transport the container to a degassing chamber. When container is back, officers do not discover any infringements, and therefore containers are released.



**Table 6** High, medium, and low impacts on container release event (TO BE)

	High	Medium	Low
$\theta_1^{cr}$	€19,380	€19,760	€20,140
$\theta_2^{cr}$	€126	€135	€145
$\theta_3^{cr}$	€796	€797	€799
$\theta_4^{cr}$	€15	€16	€17
$\theta_5^{cr}$	€118	€118	€118
$\theta_6^{cr}$	€1185	€1282	€1380
$\theta_7^{cr}$	€4428	€4445	€4463
Tot	€26,046	€26,554	€27,062
Savings	€4464	€3956	€3448

**Fig. 10** Sensitivity analysis on variables affected by ecosystem (€/container)

- *State 6* Container is selected for customs inspection, and no significant presence of gases is detected. Opening the container, officers discover infringements, and therefore the container is seized.
- *State 7* Container is selected for customs inspection, and no significant presence of gases is detected. After physical inspection, officers do not discover infringements, and therefore the container is released.

The total cost of this scenario was estimated at €30,510. State 1 is the most expensive state of the seven analyzed, and it can be assumed as the normal situation when the container is selected for x-ray screening. Next, States 7 and 6 have significant costs in case containers are inspected but no degassing is required. The rest of the states examined have very low costs, ranging between €23 and €811, given that degassing is not required so often (Fig. 9).

In the TO BE situation, digital ecosystem impacts are expected to affect only two variables: cost of information exchange,  $C_{ie}$ , and probability of customs inspections,  $P_{ci}$ . Hence, under low, medium, and high impacts of technologies, potential savings in the range between 11.3% and 14.6% were computed (Table 6).



**Table 7** Impacts on five scenarios identified

	Costs savings					
	% Costs reduction (high, medium, low) (%)			Monetary savings (high, medium, low impacts) (€)		
Export inspection	92.30	84.76	77.05	€27,065	€24,856	€22,594
Container detention	90.95	64.42	54.43	€18,580	€16,083	€13,587
Unplanned transshipment	83.51	74.40	66.10	€79,242	€70,597	€62,716
Container release	14.63	12.97	11.30	€4464	€3956	€3448
Cargo damage	9.72	8.10	6.80	€60,000	€50,000	€42,000

A sensitivity analysis shows that cost of information exchange is still the most important factor contributing to potential savings identified within this scenario (Fig. 10).

## 7 Discussion and conclusions

Supply chain companies are looking at advanced digital ecosystems as potential support to management that could lead to improved operations and therefore to competitive advantage. However, understanding about how such systems can actually impact benefits is still lacking. In particular, ocean container transport has been indicated as a source of major delays in supply chains, yet the implications to stakeholders have not still been quantified. This study shows how a risk-based decision tree approach could be profitably exploited to shed more light on this issue (Haimes 2015; King 1973; Kim and Koehler 1995).

The findings reported in this paper demonstrate that the developed methodology can be successfully and systematically applied to identify and compute the potential benefits of supply chain digital ecosystems. Contrary to previous research (Lee and Wang 2000, 2005; Yu et al. 2001), our results focus on shipment disruptions and potential benefits in the form of time and costs savings. The outcome of the analysis quantitatively reaffirms claims that improved visibility can bring benefits (Caridi et al. 2014; Blackhurst et al. 2005). Likewise, the methodology emphasizes the importance of understanding potential reductions of time to manage disruptions. In essence, as previously suggested in earlier research (Bodendorf and Zimmermann 2005), improved visibility and preprogrammed intelligence rules can speed up the reaction of managers and thereby the recovery of the supply chain.

Another important finding of this study regards the improved understanding of the most important scenarios and risks in ocean container transport and the monetary impacts on their business. In addition, it was also possible to rank these scenarios in terms of cost savings, percentage of costs reduction, and monetary savings (€). An interesting result is that what really drives the business case is not the effectiveness of the system alone in reducing a cost but instead its combined impact on the initial cost of the scenario analyzed; For instance, cargo damage has a low percentage reduction,



but monetary savings are high, despite the low effect of the solution. The other way round, the scenario where digital solutions were estimated to be more effective, i.e., export inspection, is not the most beneficial in terms of monetary savings (Table 7).

Note that the events where major impacts are identified are those happening far away from the stakeholders' premises, where visibility of information is more difficult, unreliable, and leading to major costs to companies in case of deviations from normal operations. This emphasizes the importance of categorizing risks based on distance gaps between origin and destination (Manuj and Mentzer 2008; Viswanadham and Gaonkar 2008). In addition, based on findings from Figs. 6, 8, and 10 and Table 1, major impacts were expected on the timing necessary to rearrange a shipment as well as the cost for exchanging information (Bodendorf and Zimmermann 2005). This emphasizes the importance of communication and real-time visibility in managing risks as well as the improved capabilities of stakeholders to react to events with the support of digital ecosystems (Bodendorf and Zimmermann 2005; Liu et al. 2007). The same conclusions could be deduced from the sensitivity analysis performed on the parameters identified by the experts.

In view of the results achieved in this study, the potential for future research can be expounded. The decision tree modeling expounded in this paper could be used in combination with real-time data to enhance the predictive capabilities of digital ecosystems, as recommended by Kim and Koehler (1995). Another potential goal in future research would be to use the technique adopted to stimulate discussions about new services to be included in digital ecosystems and thereby predict potential benefits and pricing.

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## Appendix

### Indices

cd = cargo damage (risk event)  
 cdt = container detention (risk event)  
 cdl = container delivery delay (risk event)  
 cr = container release (risk event)  
 ci = customs inspection  
 df = demurrage fee  
 dl = damage loss



$dm$  = documentation matching  
 $ei$  = export shipment (risk event)  
 $h$  = hours  
 $ie$  = information exchange  
 $ms$  = missed ship  
 $ns$  = new shipment  
 $pd$  = product damage  
 $pu$  = product usable  
 $td$  = truck delayed  
 $r$  = repair  
 $ut$  = unplanned transshipment (risk event)  
 $wi$  = wrong information

### Parameters

Probabilities:

$P_{ci}$  = Probability of Customs Inspection  
 $P_{cp}$  = Probability of containers arriving at correct port  
 $P_{ms}$  = Probability of Missed Ship  
 $P_{df}$  = probability of picking up container outised free demurrage time-window  
 $P_{dp}$  = probability of detention time passed  
 $P_{ot}$  = Probability of containers shipped to buyer on time  
 $P_{si}$  = Probability of information passed to stakeholders  
 $P_{pd}$  = Probability product damage  
 $P_{pi}$  = Probability containers are physically inspected  
 $P_{pu}$  = Probability product still usable  
 $P_s$  = Probability container is screened  
 $P_{td}$  = probability of truck delayed  
 $P_{ut}$  = probability of unplanned transshipment  
 $P_{wi}$  = Probability of giving wrong information or missing information

Time factors:

$T_{nt}$  = Time for new sea transport arranged [hours]  
 $T_{ntd}$  = Time for new inland transport arranged [hours]  
 $T_{ns}$  = Time for a new shipment [hours]  
 $T_{dm}$  = Time for documentation matching [hours]  
 $T_{pi}$  = Time to perform physical inspection of containers [hours]  
 $T_r$  = Time to repair [hours]

Fixed costs:

$C_{ie}$  = Cost for information exchange [€]  
 $C_{df}$  = Cost of demurrage fee [€]  
 $C_{dl}$  = Cost of damage loss  
 $C_{dtf}$  = Cost of detention fee [€]  
 $C_{ra}$  = Cost of replanning activities [€]



Others

$C_h$  = Cost of time [€]

$N$  = containers moved annually

### Risk events tree diagrams and state equations

Decision tree diagrams are used to facilitate decision-making in the presence of uncertain variables and complicated structures (Hillier Frederick and Lieberman Gerald 2005; King 1973). They can be used qualitatively but also quantitatively by means of probabilistic assignments of events and end-states. Another advantage of decision trees is that, in business decision contexts, there could be lack of necessary data, e.g., relative frequency statistics or outcomes from previous events (Kim and Koehler 1995; King 1973). Tree diagrams can be extremely useful to gather estimates of probabilities from experts, and thereby formally summarize them into potential end-states as single numerical measures (King 1973). The combined probabilities and costs of the sequence of branches in the tree, i.e., events and decisions made leading to the end states, constitutes the expected monetary cost of each alternate course of action. This expected value can also be seen as an average of the different courses of action, weighted by the respective probabilities assigned to the branches of the tree.

The next sections in this annex show the constructed decision tree diagrams for the five scenarios considered, i.e., cargo damage, container detention, export inspection unplanned transshipment, and container release. In the same section, the formulas used to compute the expected monetary costs are expounded.

#### Cargo damage

Figure 11.

The total scenario expected costs were calculated according to the following state equations:

$$EMC(\theta_1^{cd}) = (1 - P_{pd}) * C_{ie} * N$$

$$EMC(\theta_2^{cd}) = P_{pd} * (1 - P_{pu}) * (C_{dl} + C_{ie} + C_h * T_{ns}) * N$$

$$EMC(\theta_3^{cd}) = P_{pd} * P_{pu} * P_{pr} * (C_r + C_{ie} + C_h * T_r) * N$$

$$EMC(\theta_4^{cd}) = P_{pd} * P_{pu} * (1 - P_{pr}) * (C_{vl} + C_{ie}) * N$$

#### Container detention

Figure 12.





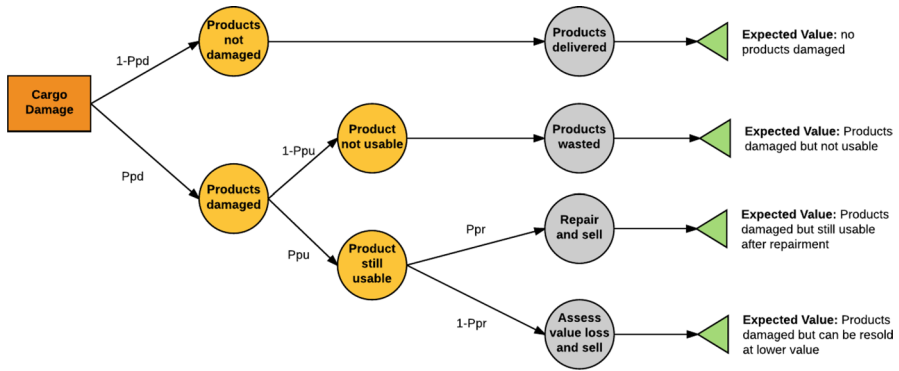


Fig. 11 Cargo damage

$$EMC(\theta_1^{ctd}) = (1 - P_{td}) * C_{ie} * N$$

$$EMC(\theta_2^{ctd}) = P_{td} * P_{dp} * (C_{ie} + C_{df}) * N$$

$$EMC(\theta_3^{ctd}) = P_{td} * (1 - P_{dp}) * C_{ie} * N$$

### Export inspection

Figure 13.

Probabilities and related costs were assessed by accessing available data put at disposal by the case company. The total scenario expected costs were calculated according to the following equations:

$$EMC(\theta_1^{ei}) = (1 - P_{ci}) * C_{ie} * N$$

$$EMC(\theta_2^{ei}) = P_{ci} * (1 - P_{ms}) * C_{ie} * N$$

$$EMC(\theta_3^{ei}) = P_{ci} * P_{ms} * P_{df} * (1 - P_{wi}) * (2C_{ie} + C_{df}) * N$$

$$EMC(\theta_4^{ei}) = P_{ci} * P_{ms} * P_{df} * P_{wi} * (2C_{ie} + C_{df} + T_{dm} * C_h) * N$$

$$EMC(\theta_5^{ei}) = P_{ci} * P_{ms} * (1 - P_{df}) * (1 - P_{wi}) * (2C_{ie}) * N$$

$$EMC(\theta_6^{ei}) = P_{ci} * P_{ms} * (1 - P_{df}) * P_{wi} * (2C_{ie} + T_{dm} * C_h) * N$$



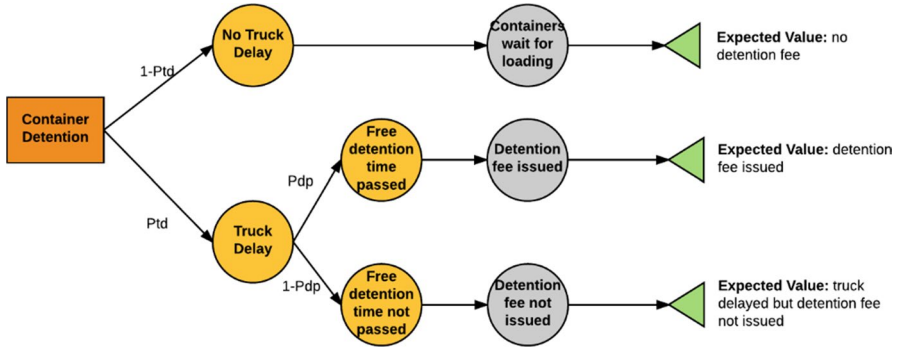


Fig. 12 Container detention tree diagram

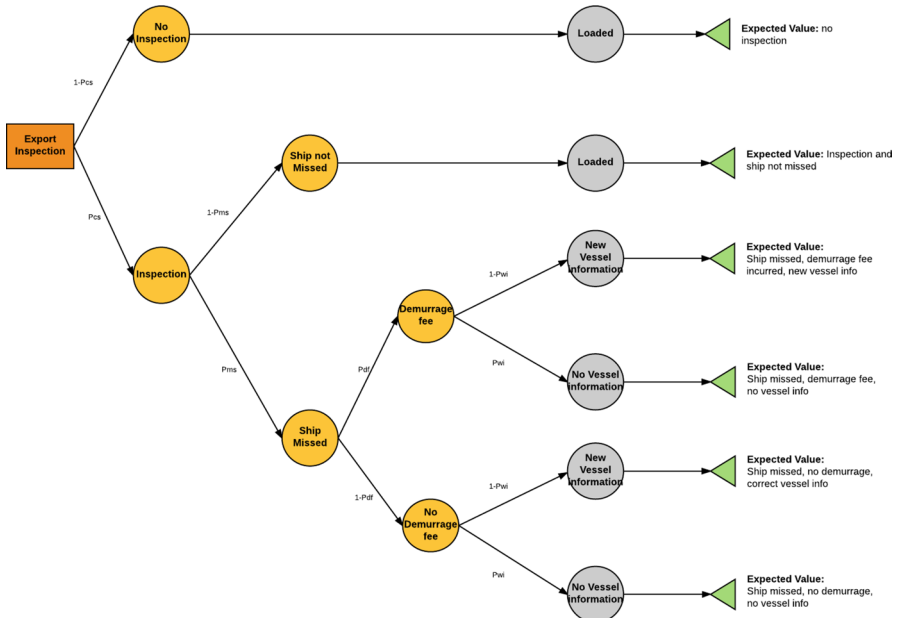


Fig. 13 Export inspection

### Unplanned transshipment

Figure 14.

For this risk event, seven states were identified:

$$EMC(\theta_1^{ut}) = (1 - P_{ut}) * C_{ic} * N$$



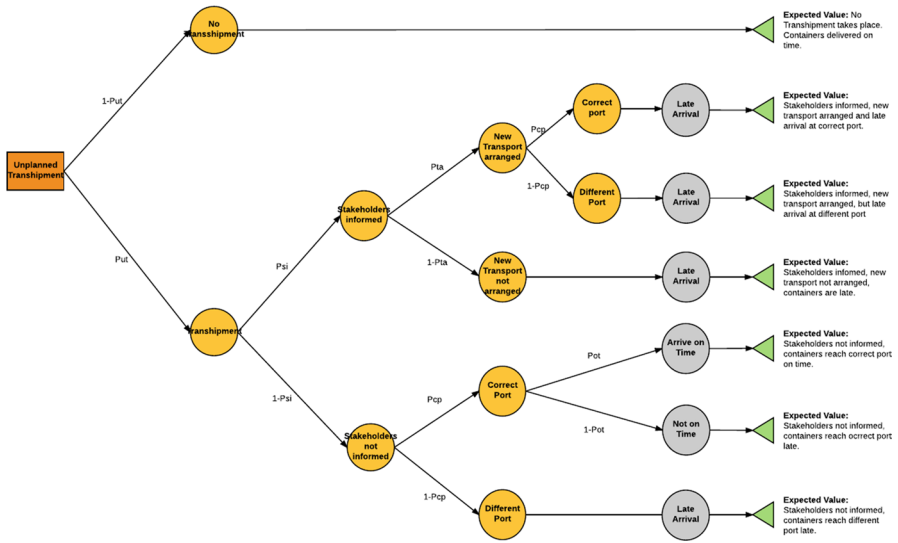


Fig. 14 Unplanned transshipment tree diagram

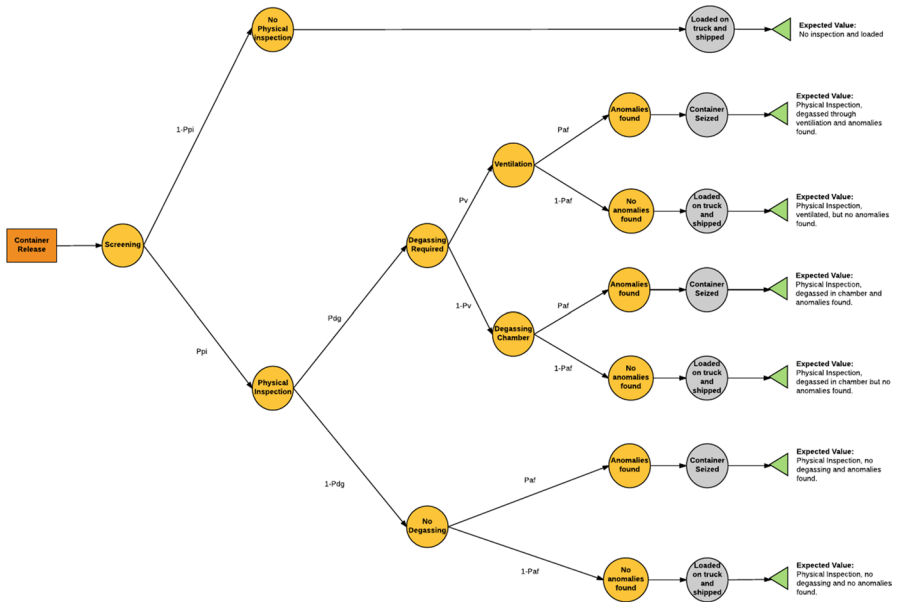


Fig. 15 Diagram tree container release event

$$EMC(\theta_2^{ut}) = P_{ut} * P_{si} * P_{ta} * P_{cp} * (C_{ie} + C_{ra} + C_h * T_{nt}) * N$$



$$EMC(\theta_3^{ut}) = P_{ut} * P_{si} * P_{ta} * (1 - P_{cp}) * (C_{ie} + 2 * C_{ra} + C_h * T_{ntd}) * N$$

$$EMC(\theta_4^{ut}) = P_{ut} * P_{si} * (1 - P_{ta}) * (C_{ie} + C_h * T_{nt}) * N$$

$$EMC(\theta_5^{ut}) = P_{ut} * (1 - P_{si}) * P_{cp} * P_{ot} * C_{ie} * N$$

$$EMC(\theta_6^{ut}) = P_{ut} * (1 - P_{si}) * P_{cp} * (1 - P_{ot}) * (C_{ie} + C_{ra} + C_h * T_{nt}) * N$$

$$EMC(\theta_7^{ut}) = P_{ut} * (1 - P_{si}) * (1 - P_{cp}) * (C_{ie} + C_{ra} + C_h * T_{ntd}) * N$$

## Container release

Figure 15.

$$EMC(\theta_1^{cr}) = P_s * (1 - P_{pi}) * (T_{pi} * C_h + C_{ie}) * N$$

$$EMC(\theta_2^{cr}) = P_s * P_{pi} * P_{dg} * P_v * P_{af} * (T_{pi} * C_h + C_{ie} + C_{pi} + T_v * C_h + C_h * T_{ns} + C_{vl} + C_f) * N$$

$$EMC(\theta_3^{cr}) = P_s * P_{pi} * P_{dg} * P_v * (1 - P_{af}) * (T_{pi} * C_h + C_{ie} + C_{pi} + T_v * C_h) * N$$

$$EMC(\theta_4^{cr}) = P_s * P_{pi} * P_{dg} * (1 - P_v) * P_{af} * (T_{pi} * C_h + C_{ie} + C_{pi} + T_{dc} * C_h + C_h * T_{ns} + C_{vl} + C_f + C_{dc}) * N$$

$$EMC(\theta_5^{cr}) = P_s * P_{pi} * P_{dg} * (1 - P_v) * (1 - P_{af}) * (T_{pi} * C_h + C_{ie} + C_{pi} + T_{dc} * C_h + C_{dc}) * N$$

$$EMC(\theta_6^{cr}) = P_s * P_{pi} * (1 - P_{dg}) * P_{af} * (T_{pi} * C_h + C_{ie} + C_{pi} + C_h * T_{ns} + C_{vl} + C_f) * N$$

$$EMC(\theta_7^{cr}) = P_s * P_{pi} * (1 - P_{dg}) * (1 - P_{af}) * (T_{pi} * C_h + C_{ie} + C_s) * N$$

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