Supply Chain Visibility Ledger

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***Abstract*:** *Improved situational awareness, also known as Supply Chain Visibility, contributes to better decisions with the ability to synchronize processes and reduce costs. It requires data sharing by events of for instance positions, speed, and direction of vessels, trucks, barges, and trains, and Estimated Time of Arrival (ETA) and – Departure (ETD) of these transport means. Whereas the data structure is called 'event', the progress of the physical processes is expressed by 'milestones'. These milestones are related to (groups of) physical objects, modelled as Digital Twins. Groups of Digital Twins are those that are offered at a given time and place for transport and have to be available together at another time and place, also called shipment or consignment. Such shipments and consignments are uniquely identifiable between a customer and Logistics Service Provider; Digital Twins of different or the same shipment(s) can be regrouped into other shipments. Based on this Digital Twin approach and business transactions representing shipments or consignments, this paper presents a Supply Chain Visibility Ledger propagating events with milestones.*

Keywords: *supply chain visibility, distributed ledger, blockchain, semantic technology*

1 Introduction

The lack of or limited situational awareness of the various stakeholders involved in supply and logistics chains causes unnecessary delays and - waiting times, fines imposed by customers for delays, and unnecessary priority shipment for products required by a customer, and stock reduction (Parjogo & Olhager, 2012), (Urciuoli & Hintsa, 2018) (Caridi, Moretto, Perego, & Tumino, 2014). These all lead to higher costs, increase the carbon footprint, and contributes to waste. In general, improved situational awareness will contribute to decision making (Endsley, 1995). (Near) real-time supply chain visibility addresses these issues.

However, supply and logistics chains can be complex. International supply chains involve many enterprises and authorities, each with their heterogeneous IT systems either tailored Commercial Off The Shelve (COTS) or proprietary developed. Data is duplicated by messages between these systems, including various formats and implementation guides of open standards (Hofman, 2018). Many of these systems are not yet able for real-time processing of events generated by physical assets (IoT – Internet of Things). Different solutions are being developed addressing these issues, each with their (proprietary) interfaces. Tradelens and the Electronic Product Code Information System (EPCIS (Global Systems One, 2014)) are two examples. Identity mechanisms supported with delegation (iShare, 2019) are introduced to access the status of logistics chains. These various solutions have a so-called publish and subscribe (Erl, 2005) model in common, for instance in a bilateral collaboration or based on delegations.

This paper provides an alternative solution for real time status sharing between all stakeholders in supply and logistics networks by Distributed Ledger Technology (DLT). Subscription mechanisms are based on transactional relations between stakeholders and the associations between the various physical objects, like a container transported by a vessel.

Additional rules are specified by which status information is propagated downstream in chains towards the final destination, especially the predicted status to address the aforementioned issues.

First of all, supply chain visibility is analyzed and illustrated by two use cases. Secondly, the solution is specified illustrated with a first demonstrator. Finally, the relation with available standards is analyzed and conclusions are presented.

2 Supply chain visibility

This section introduces the concept of supply chain visibility, illustrated with two typical use cases. The first use case demonstrates supply chain visibility for direct transport, meaning there is one transport operation. The second one demonstrates transshipment of containers via a port and coordination issues involved.

2.1 A generic approach to supply chain visibility

Supply chain visibility can be defined as 'awareness of and control over end-to-end supply chain information – including insight in sources of data and whereabouts of goods – enabling agile, resilient, sustainable as well as compliant and trusted supply chains' (Wieland & Wallenburg). Other definitions state 'the ability to be alerted to exceptions in supply chain execution' or 'capturing and analyzing supply chain data that informs decision-making, mitigates risk, and improves processes' (Caridi, Moretto, Perego, & Tumino, 2014). Basically, it supply chain visibility is about improving decision-making by increased situational awareness (Endsley, 1995). Supply chain visibility has many advantages in terms of costs and time (Caridi, Moretto, Perego, & Tumino, 2014) based on process synchronization. It reduces inventory and contributes to customer service by on-time delivery and providing customer visibility. Process synchronization requires sharing of knowledge of the location of physical objects, and in case these physical objects are transport means, their speed and direction, any relation between physical objects like a container transported by a truck, and a prediction of a time for completing a particular logistics operation. These times can be various, like:

- For transport operations, the following predicted times are relevant:
    - Estimated Time of Arrival (ETA) of a transport means at a location, e.g. a vessel in a port.
    - Estimated Time of Departure (ETD) of a transport means, or the combination of the Actual Time of Arrival (ATA) and a predicted duration of a call of a transport means at a location.
- For transshipment operations, the estimated discharge and loading times of cargo objects like containers of and on transport means are relevant. An estimated discharge time provides for instance an indication for the next transport leg to pick up the cargo objects.

These types are basically relevant for synchronizing different transport operations, or what can be called 'transport legs', of a logistics chain. Any disturbances caused by for instance accidents, incidents, lack of qualified personnel, weather conditions, and maintenance of both on physical assets used to facilitate transport operations and the infrastructure used (e.g. roads and inland waterways with locks), will influence these transport operations. They will cause delays that have to be known to the next transport leg.

Administrative procedures may also cause delays. Examples are missing documents or data of a particular shipment like a Certificate of Origin, lack of a confirmation by an authority like a customs release, a physical inspection of cargo by a customs authority, and payment of the previous transport leg. Providing authorities supply chain visibility, improves their decision processes, which may lead to less or unnecessary delays (Urciuoli & Hintsa, 2018), (Caridi, Moretto, Perego, & Tumino, 2014) and contribute to safety (Hofman, Spek, & Ommeren, 2018). Supply chain visibility may include both data of cargo and their itinerary with estimate times of arrival.

Thus, process synchronization of transport operations also has to meet particular condition imposed by formal procedures, optionally providing additional data (optional multiple filing reference), and agreements between stakeholders involved, like specified by for instance the INCOTERMS used in international transport. The INCOTERMS specify for instance which of the stakeholders has to pay for which part of a logistics chain. An example is 'free delivered' mostly applied in eCommerce where a shipper pays transport charges.

2.2 Direct transport

Direct transport is a single modality transport by one carrier between a shipper's and a consignee's location, for instance from a supplier of material to a production plant of a customer or delivery of consumer products to a cross-docking center of a retail chain. Road transport is the main modality used for direct transport; most other transport modalities require additional transshipping for pickup and last mile delivery of cargo. There are two options for arranging transport, specified by the INCOTERMS 'ex works' and 'free delivered': either the shipper organizes and pays the transport (free delivered) or the consignee (ex works). Transport is according to national or international CMR conditions, with an accompanying document representing the contractual agreement (the 'CMR'). When accepting the cargo, a carrier is able to make notes regarding the condition of the cargo; a consignee can do the same at the destination. These notes can include for instance damage remarks and losses of packages.

Direct transport considers two milestones, namely the pickup and acceptance and the drop off and delivery of the cargo by a carrier. Sharing of the milestone of the drop off is called 'Proof of Delivery', which can trigger payment of transport charges and products delivered to a consignee. Before picking up the cargo, a carrier may inform a shipper of its ETA. Sharing an ETA may reduce waiting time of a carrier and allow a shipper to prepare the cargo at a proper gate (Hofman & Rajagopal, 2015). In-between pickup and drop off, shipper and consignee are both interested about the Estimated Time of Arrival and any deviations (too late or too early; (Urciuoli & Hintsa, 2018)): a shipper to inform its customer upon request and a customer to synchronize its processes with the arrival of the cargo. Concluding, there are four milestones:

- ETA of a truck at the premises of a shipper;
- Pickup of the cargo by the carrier;
- ETA of the truck and its cargo at the premises of the consignee
- Drop off of the cargo by the carrier.

Sharing these milestones is on basis of contractual relationships. A carrier shares this information with his customer, either a shipper ('free delivered') or a customer ('ex works'). In case a shipper acts as customer to a carrier, that shipper might inform its customer, acting as consignee, of for instance an ETA and any deviations. The carrier and the consignee will inform a shipper of the Proof of Delivery. In case a consignee acts as customer of a carrier, the carrier will inform the consignee of ETA of its truck at the premises of the shipper, pick up and (deviations of) an ETA at the premises of the consignee. The consignee will inform the shipper of the Proof of Delivery.

2.3 Container transshipment in a port

A more complex case is that of transhipment of containers via a port like the port of Rotterdam. Transshipment consists of arrival of a vessel in a port, discharge of containers, and on-carriage of these containers to the hinterland. Various enterprises are involved utilizing different modalities for on-carriage. Furthermore, there are a number of conditions that have to be met, before on-carriage can take place. These conditions are known as 'released' and have to be known to a carrier for on-carriage and a terminal where a container is transhipped. Release consists of:

- Commercial release – transport charges for sea transport are paid. In case the INCOTERMS are 'free on board', a consignee or his agent will pay transport charges. Basically, a shipping line and forwarder acting as consignee's agent share the commercial release status, including their banks.
- Customs release – a container is released by customs for its next transport leg. Customs issues a release to the shipping line responsible for sea transport. This customs release may require an declaration for the next customs procedure issues by the consignee or his agent, e.g. transit, import, or (temporary) storage under customs regime.
- Discharged – a container is physically present at a terminal of a stevedore.

Figure 1 visualizes the formal relations of the various roles involved in transhipment. The arrow points from a customer to a service provider, where customs also acts as a type of customer based on legal obligations. Sharing the relevant release information can be organized via the shipping line that is aware of commercial – and customs release, and physical availability of a container based on its contractual relation with the stevedore. This release status can be shared with the forwarder that shares it with its carrier. Formally, a carrier can inform a forwarder on its ETA at a terminal for picking up a container, whereas a forwarder synchronizes this information with a stevedore. We have to note that current practice is to directly synchronize between a carrier and stevedore; we will show however that a distributed ledger can serve as a technology supporting this synchronization according contractual relations.

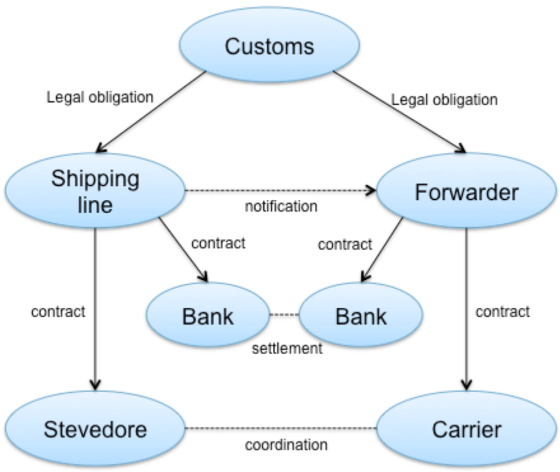

Figure 1: value chain for container transshipment in a port

On top of sharing this release information, also other milestones similar to those of direct transport need to be shared. For instance, the ETA of a vessel at a terminal is relevant for synchronization with departure of the previous vessel at that terminal[1] and the ETA of a truck at a terminal needs to be shared. Furthermore, a forwarder would like to inform its customer, the consignee, of arrival of the cargo at its final destination. In case there is one transport leg between a port and the final destination, an ETA of that leg can be shared via a forwarder to the consignee. In case of more than one transport leg, i.e. on-carriage is split into two (or more) transport modalities, the forwarder might also require to inform the first transhipment hub and the carrier from that hub to the final destination.

3 Towards a Supply Chain Visibility Ledger

Like indicated, the underlying business case is that of process synchronization of all stakeholders and improved decision making. The use cases demonstrate the type of milestones that might be shared amongst the various stakeholders. This section presents an ontology for data structures and the rules for sharing these milestones in supply and logistics networks. A demonstrator supporting the use case of direct transport illustrates the implementation of the rules and the ontology.

3.1 General concepts

Conceptual, transactional relations formulate the subscription to events. A transactional relation is defined in two ways. First of all, a customer and a service provider share an order like shipment of particular cargo, a service provider informs a customer of the status of that order by sharing relevant milestones. Relevant milestones are those of direct transport, potentially extended with intermediate locations relevant to the customer like the location of border crossing or an (air)port where responsibility for transport is handed over (see the use case of port transshipment). The second type of transactional relation is based on an enterprise providing data like a customs declaration to an authority and waiting for status information of that authority. The data will have a unique identification, e.g. a Movement Reference Number for a customs declaration, and contains identifications of one or more physical objects subject. In this proposal, an enterprise acts service provider and an authority as customer.

Secondly, the concept ‘Digital Twin’ is introduced (Boschert & Rosen, 2016): a Digital Twin is a data representation of any physical object, e.g. a container, a truck, a vessel and a product. Any subscription, either an order or a declaration, considers at least one Digital Twin. The concept ‘Digital Twin’ will be elaborated when specifying an ontology as a basis for data structures in the ledger.

3.2 The choreography for sharing events

The interaction choreography (Object Management Group, 2011) of a customer and service provider is depicted as sharing events based on relevant order - and declaration data. Since, however, the Supply Chain Visibility Ledger does not support ordering, customers enter relevant order data that needs to be confirmed by service providers. Note that any service provider can have a customer role in its turn. Furthermore, any service provider can insert associations between physical objects, thus creating links between orders with their customers and their service providers. For instance, customer orders can be bundled into one shipment by for instance stuffing pallets of those customer orders into one container (LCL or Less than Container Load). On the other hand, pallets of one customer order can be shipped by two or more containers.

[1] https://www.portofrotterdam.com/nl/tools-services/pronto

Figure 2 shows the choreography supported by the Supply Chain Visibility Ledger. It has basically two flows, the first of entering orders and creating associations between Digital Twins (see next section on data structures), and the second for sharing events. Events can be submitted by any actor, either in its role as customer or service provider. Each actor, e.g. an organization or a Digital Twin, can have both roles, where in general a Digital Twin will have the role of service provider.

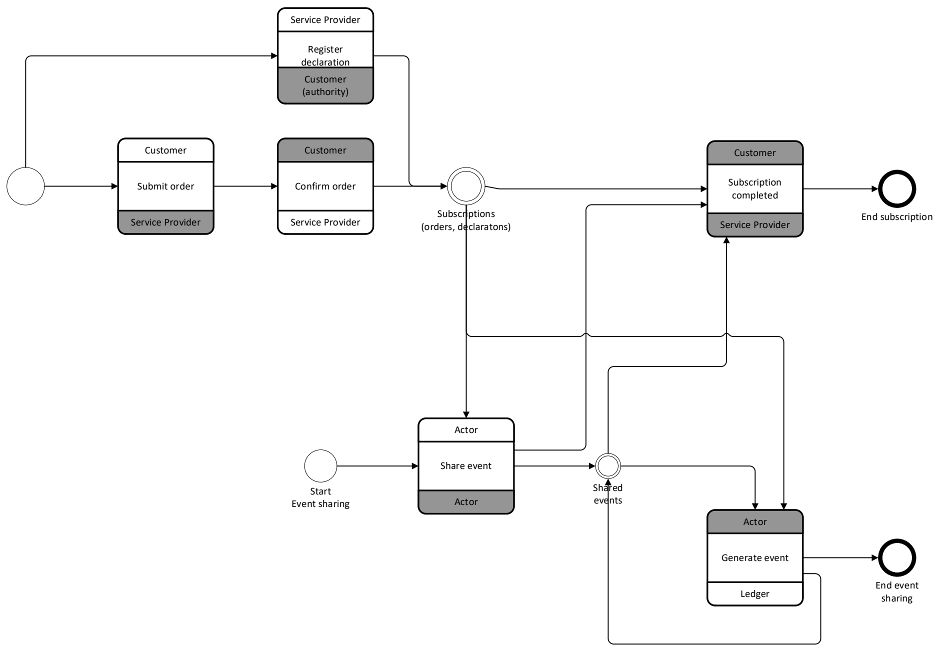

Figure 2: choreography supported by the supply chain visibility ledger

The flow to register subscriptions consists of five steps:

- A customer submitting an order to the ledger;
- A service provider confirming the order, thus establishing a subscription;
- A service provider submitting a declaration to the ledger;
- Completion of a subscription: either all cargo of one customer order has been delivered at its (required) destination or an authority has shared the status information. Completion is triggered by identifying that a shared event is the final one: the place of the cargo object given by the event is identical to the place of delivery of the cargo object in the order, all cargo objects mentioned in the order have this place, and the time of arrival of the cargo in the place of delivery equals (within a time interval) the time of delivery mentioned in the order.

In an ideal world where everyone uses a Supply Chain Visibility platform or ledger, associations between any two Digital Twins are entered with an event submitted by the actor making this association, e.g. load a container on vessel. The following actions are feasible for the subtype ‘general –‘ and ‘bulk cargo’ as a subtype of ‘cargo’:

- Combine general – or bulk cargo of different customer orders into one order to a service provider, containers of different shippers are transported by the same vessel,
- Split general – or bulk cargo of one customer order to different orders with one or more service providers.
- A combination of both, namely splitting general – or bulk cargo of one customer order to different orders and combining it with general – or bulk cargo of other customers orders.

An actor can submit an event to the ledger in its role as customer or service provider, as shown in figure 2 by ‘share event’. The role of the actor submitting the event should be part of the event, resulting in the following actions:

1. If a service provider submits an event to the ledger (activity ‘share service provider event’) an event is shared with a customer based on a confirmed order only if the place of a Digital Twin in an event equals the place of acceptance, - delivery or some intermediate place mentioned in the customer order. A cargo object of an event can only be linked to customer orders that are not yet completed. In case a cargo object can be associated to two (or more) orders, it can only be associated to the one that is either not yet completed, or where the timestamp of the milestone given by the event is within the time interval between time of acceptance and – delivery and the place is either the place of acceptance or delivery of an order. This case represents that the same container is transported from a port to the hinterland that can re-appear the same day in the port.
2. If a customer shares an event to the ledger, this event should relate to an object or an identification mentioned in an order of that customer that serves as subscription. The event is directly accessible by the service provider. There are different cases like a forwarder sharing a customs – and a commercial release with a carrier or a shipping line sharing a commercial release with a terminal. In both cases, the event has to contain uniqueness of its provenance, customs and a bank respectively. A carrier can thus only pick up a container after a terminal as authenticated the customs release. Record integrity of the releases needs to be provided.

An event submitted by a service provider or customer is always stored in the ledger. It can trigger a new event, either submitted to a service provider or a customer. In its turn, this new event is also stored and can trigger generation of a new event. Whenever it is not possible to generate a new event, the process of sharing events ends. It means that none of the following conditions can be met that are implemented by ‘generate event’:

1. Event is received by a customer. The following rules are validated for generating a new event:
    a. The receiving customer acts as service provider in an order that contains the Digital Twin of the received event. A new event is generate to that customer. The condition is formulated as: <u>IF</u> The Digital Twin in the received event occurs in an order of that customer in its role as service provider <u>AND</u> (<u>IF</u> (the milestone is departure and the place in the event place of acceptance in the order <u>AND</u> the time of the milestone is in the period mentioned in the order) <u>OR</u> (the milestone is arrival and the place of the event is the place of delivery in the order <u>AND</u> the time of the milestone is in the period mentioned in the order) <u>OR</u> the milestone is pass and the intermediate place is in the order) <u>THEN</u> generate new event to the customer of the order.
    b. The Digital Twin is associated with another Digital Twin that appears in one or more order. There are two cases identified for these orders (they can be formulated in more detail like the rule before):
        i. The receiving customer acts as customer. The only relevant situation for generating a new event is where the milestone of the received event is arrival at place of acceptance in the next order. In case the milestone is an ETA prediction, the next leg represented by the order can be informed in case the ETA does not fit with the time period for start of the next leg.

ii. The receiving customer acts as service provider. The service provider will generate a new event to a customer as described by the first part of ‘share event’.

2. Event is received by a service provider. If the service provider also can act as customer, i.e. it has outstanding orders with other service providers, the event will be shared with those service providers that have the place of acceptance or – departure and the Digital Twins that are concerned as part of the order with them. The time of release also has to fit with the period mentioned in the order.

Sharing a release like a customs – or commercial release is only feasible if that release refers to a particular place, for instance a terminal. Thus, it is not sufficient to specify only a release milestone, but also where the release takes place.

3.3 Data structures

The data structures for the interactions are based on an ontology of all data that can be shared. The concept of ‘Digital Twin’ (Boschert & Rosen, 2016) is core to this ontology: a Digital Twin is a representation of any physical object in the real world with information. As the following figure shows, transport means and cargo are the main subtype of Digital Twin. Cargo in its term has the subtypes of equipment (e.g. containers, trailers), general cargo consisting of number and types of packages (e.g. pallets), bulk cargo (e.g. liquid bulk like palm oil) and transport means (e.g. a truck with its trailer on a ferry or railway wagon). A Digital Twin has an identifier like a container number or Automatic Identification System (AIS) identification. A business transaction, which is an instance of a business service, has a unique identification and so will have orders and events. Actors have one of two roles in a business transaction: customer or service provider. The role can be modelled by a property of the association or as a separate list of potential roles, since other roles like shipper, forwarder, and carrier can act as customer and/or service provider.

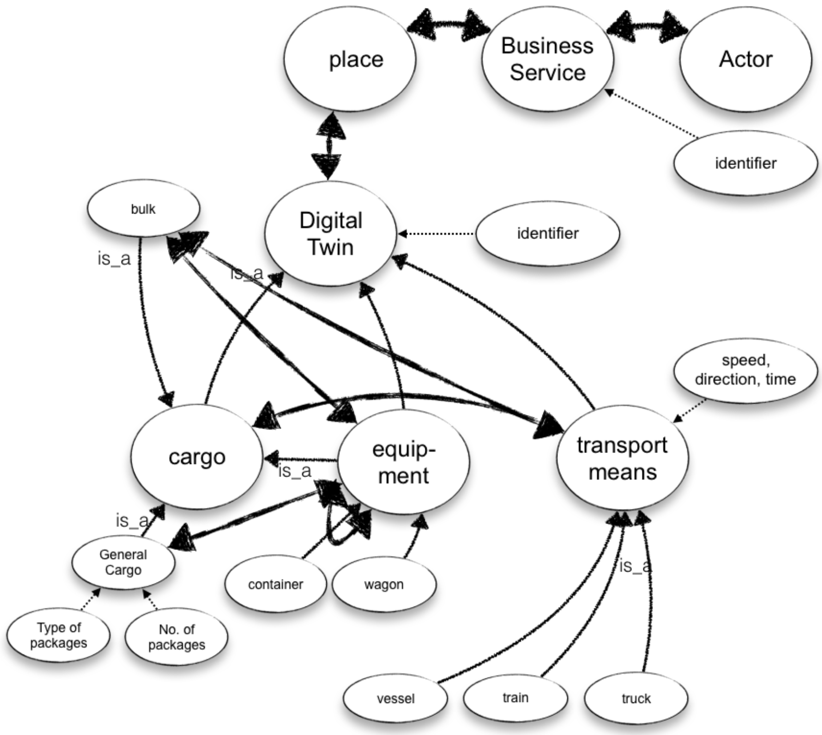

Figure 3: an ontology for supply chain visibility

Each Digital Twin has an association with ‘place’, where place represents physical locations like terminals, warehouses, (air)ports, and distributions centres. Two types of places are foreseen for transport: the place where transport starts (place of acceptance) and where the service is completed (place of delivery). In some cases, these places have different names like port of loading and discharge for sea transport or pickup and drop off for road transport. Additionally, an intermediate place is required like border crossing place. Each of these places is represented by an association with the following properties:

- An agreed or planned time with an uncertainty expressed by a period. A timetable of a transport means like a train can for instance have a planned time. A flight schedule is a similar construct.
- A timetable, voyage scheme, route, or flight may have a unique identification. It expresses a sequence of places that are called upon by a transport means.
- The estimated time at which a particular Digital Twin will be arrive or depart from a place, with an uncertainty.
- The actual time of arrival or departure.

A turnaround period can be expressed as the difference between a time of departure and arrival. The route of each instance of a Digital Twin can thus be configured by customer orders containing the instance of a Digital Twin, e.g. a container and its various transport legs. It may also be the case that within a customer order, a customer not only requires data on the start and end of the transport leg, represented as place of acceptance and – delivery, but also an intermediate place like place of border crossing, for instance to decide on the customs procedure at crossing.

Conceptual structure		
Data properties	Order	Event
Actor		
customer	x	x
service provider	x	x
identifier	x	x
Digital Twin		
Identifier	x	x
Digital Twin - place of acceptance		
alternative role	x	x
planned time	x	
estimated time		x
actual time		x
Digital Twin - place of delivery		
alternative role	x	x
planned time	x	
estimated time		x
actual time		x
Digital Twin - intermediate place		
alternative role	x	x
planned time	x	
estimated time		x
actual time		x
Place - name	x	x
General cargo - equipment	o	o
number of packages		x
planned stuffing time	x	
actual stuffing time		x
planned stripping time	x	
actual stripping time		x
Cargo - transport means	o	o
planned loading time	x	
actual loading time		x
planned discharge time	x	
actual discharge time		x

Implementation structure		
Implementation structure	Order	Event
Actor		
customer	x	x
service provider	x	x
identifier	x	x
milestone		x
timestamp		x
encrypted hash		o
provider of the hash		o
Digital Twin		
Identifier	x	x
type of Digital Twin	x	x
place of acceptance	x	
time of acceptance	x	
place of delivery	x	
time of delivery	x	
intermediate place	o	
time at intermediate place	o	
place		x
time		x
Speed (transport means)		o
Direction (transport means)		o
Digital Twin associaton	o	o
time	o	x

Figure 4: conceptual and implementation data structures

Associations between the subtypes of Digital Twin represent that a subtypes are contained by or contains another subtype. Such an association also has properties like the number of packages of general cargo that is contained by a container or the volume of bulk cargo carried by a vessel. Time is another property of these associations, i.e. the planned and actual time of constructing or deleting the association like the planned time of loading or discharge of a container from a vessel.

Primarily, the milestones ‘arrive’, ‘depart’, ‘construct’, or ‘delete’ are foreseen. The construct and delete milestone will be made specific to an association:

- Stuff or stripping of general cargo in container(s);
- Load or discharge cargo from a transport means.

Secondly, milestones like ETA or release are identified, where a customs can provide a customs release and another stakeholder a commercial release based on payment of transport charges by a bank.

This ontology is the basis for a data structures, one for orders and the other for events. These data structures can be processed by the activities in the choreography according to a data matrix for each activity in the choreography (figure 4). According the specification of that activity, a customer or service provider can store (initiating role) or retrieve the data on the ledger.

For implementation purposes, this conceptual data structure can be further simplified. The subtypes of Digital Twin can be 'type of Digital Twin' and 'place of acceptance' and '-delivery' can become properties of a Digital Twin. The aforementioned milestones are part of the implementation structure. Figure 4 also shows the implementation structure (x: data is required; o: data is optional). This latter structure allows visibility of all types of Digital Twins, including sharing their milestones. Also, the provenance of particular milestones has to be traceable. A hash of the event is inserted, where the hash is encrypted with the private key of the one that has submitted the event. Since such an event can have a relative low amount of data, a generated string can be inserted in the event that is used to calculate the hash.

3.4 Demonstrator of a Supply Chain Visibility Ledger

A first demonstrator is developed for a case where a shipper has outsourced a shipment to a forwarder and the latter utilizes a carrier. The demonstrator does not implement the property 'time', implying that all identifiers of shipments/consignments and Digital Twins are unique. Secondly, the demonstrator reflects the real world assumption that not all actors utilize the ledger. It implies that the choreography is extended by adding the association between Digital Twins of an order in which an actor has the role of service provider and those orders in which it has the role of customer. This latter extension results in the time sequence diagram shown by figure 5. Another simplification shown by this figure is the implementation of two milestones, namely load and discharge of Digital Twin(s). These milestones are generated by the carrier and propagated to the shipper via the ledger.

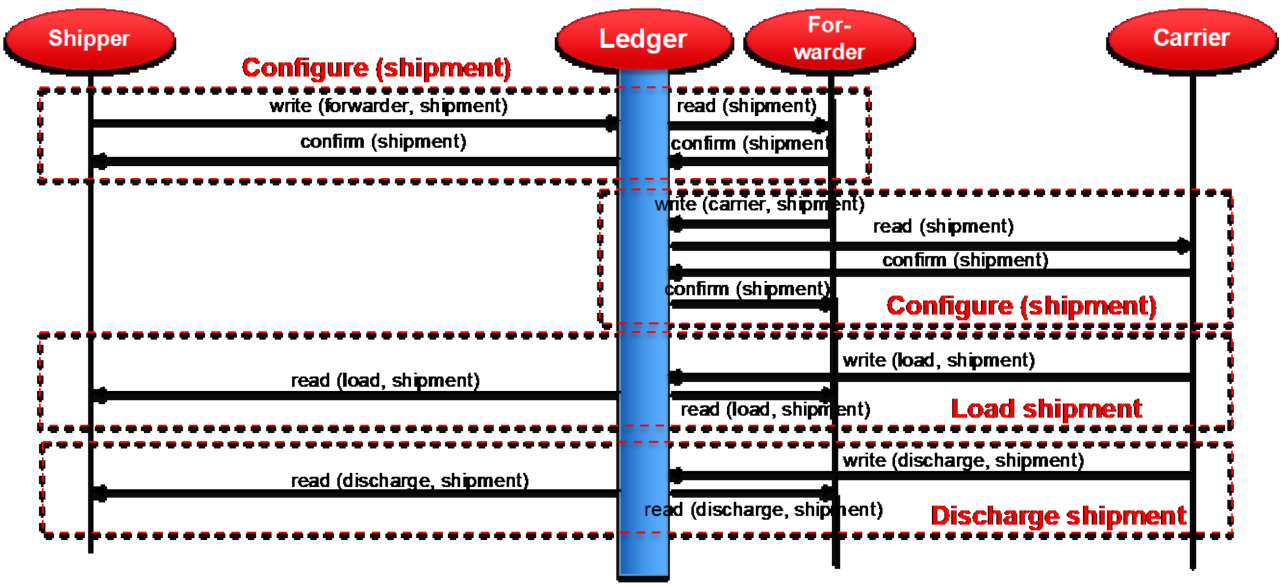

Figure 5: time sequence diagram for the demonstrator

Transaction confidentiality is an important aspect of the Supply Chain Ledger. It considers two aspects, namely the ability that only an intended recipient is able to read the data (Hofman, Spek, & Ommeren, 2018) and it is impossible for users of the ledger to trace back which users shared particular data. Transaction confidentiality makes the ledger completely private, thus supporting commercial sensitivity. Each user has a keypair acting as its identity that is verifiable. Transaction confidential is achieved by a user, which we will call submitter and is intending to share data with another user, generating a new identity, i.e. keypair[1]. Payload data is published to the ledger via this new identity, where the data and a signature created by the submitter are encrypted with a symmetric key. Details for unlocking data, the so-called payload unlocker, are shared with an intended recipient by creating yet another identity, i.e. keypair[2]. Each recipient also creates a new identity, i.e. keypair[3], for receiving the data. The payload unlocker contains keypair[1] and a signature of the original submitter of the data proving the integrity of the symmetric key, where the signature is made by encrypting the symmetric key of keypair[1] by the private key of the submitter. The public key of the submitter can also be shared in the payload unlocker, but could also be shared otherwise.

A second important aspect of the Semantic Ledger Technology is its validation of input data. Rules can be formulated in SHACL (World Wide Web Consortium, 2017) and validated using standard software components. A rule could be for instance for events that if the type of Digital Twin is ‘container’, the ‘identifier’ should have a particular format (4 letters, nine digits, and a check digit based on an algorithm), meaning that the software can validate container numbers given by an event. Another rule would be that the event should at least contain one Digital Twin of type cargo or transport means and their subtypes. These SHACL rules are stored on the ledger and can be accessed by anyone. Thus, data structures are separated from software code of the APIs provided by the Supply Chain Visibility Ledger.

4 Discussion

This section briefly discusses potential extensions of the Supply Chain Visibility Ledger and positions it with respect of (proprietary) Application Programming Interfaces (APIs). The ledger is also positioned in a context with other solutions, used by enterprises and authorities.

The proposed Supply Chain Visibility Ledger supports particular physical actions represented by milestones. Since IoT enables not only location based services, but also other types of services like monitoring the condition of cargo, the milestones can be extended. Cargo conditions can for instance be detected by temperature sensors to signal that the temperature exceeds a maximum or is lower than the minimal allowed setting which can be relevant to the quality of the cargo, shock sensors that can be used to trace potential damage to packages, seals that signal unauthorized opening of the cargo, especially containers, and weighing assets that detect the actual gross weight of cargo, for instance at loading a container on a vessel. The ledger can be used to share these sensor readings.

The assumption is that the ledger does not contain details of orders like container gross weight, delivery conditions, and transport charges. Such a data set may reflect a transport document like a CMR for road transport or a Bill of Lading for sea transport. The ledger can be used to share links to this data set reflecting access control, including a hash of the data set to assure record integrity.

In this paper, the ledger supports milestones that reflect the start and completion of an order between a customer and service provider, i.e. the place and time of acceptance and delivery. Additionally, intermediate places can be given for which milestones are required. A service provider can decompose a customer order in various transport legs and the customer might require to be informed of the status of each leg. Additional settings can be given in the order or can be considered as configurations of the ledger by a customer. This extension requires further elaboration.

The design and the demonstrator assumes an ideal world, where all users integrate with one Supply Chain Visibility Ledger. These users can be enterprises and authorities that require and share milestones of the physical processes. In the real world, we will have many Supply Chain Visibility Ledgers and – Platforms, each with their users and business model. Enterprises that do business with each other, can use different ledgers or platform and authorities don’t wish to integrate with all ledgers and platforms. First of all, authorities will develop their ledger or platform, secondly, privately operated ledgers have to configure the proper subscriptions for authorities, and thirdly, all ledgers and platforms have to be interoperable, i.e. they have to be able to share data. The latter consists of two parts:

- Technical interoperability – the ledgers and platforms have to be able to communicate with each other.
- Functional interoperability – the ledger – and platform services have to be identical to allow users to share events. Functional interoperability requires agreement on the configuration of subscriptions and events with milestones.

Technical – and functional interoperability has to be standardized and adopted by each ledger - and platform provider. There are already (proprietary) supply chain visibility interfaces like the Open Trip Model (OTM[2]), Tradelens[3], and the Electronic Product Code Information System (EPCIS (Global Systems One, 2014)). These interfaces differ in functionality, e.g. OTM stems from road transport and expands to other modalities, Tradelens supports visibility of container transport by sea, and EPCIS is generic similar to the solution presented by this paper and needs to be configured with semantics. They are incompatible and a proposal is to develop one standard based on these inputs. Any implementation choices also need to be represented as options, like the provenance of a milestone.

5 Conclusion and further work

Distributed Ledger Technology (DLT) can reduce complexity and automatically provide supply chain visibility to all stakeholders in a controlled manner by automatically propagating and - generating events. Complexity reduction is achieved by avoiding that individual stakeholders need to develop, implement, and maintain software for processing incoming events and generating new events. Two use cases formulate rules for such a distributed ledger, namely direct transport and transshipment in a port, resulting in a demonstrator implementing part of the functionality.

Transaction confidentiality is an important feature of the proposed visibility ledger. This paper briefly describes this topic. It has been developed as an extension to DLT, that is called Semantic DLT. Publications on this topic are in production.

The discussion illustrates that we are far away for creating an open infrastructure for supply chain visibility. A demonstrator of a Supply Chain Visibility Ledger can create awareness of the potential of Distributed Ledger Technology implementing the choreography. It can also be an instrument to further develop, validate, and improve specifications of an open supply chain visibility infrastructure and help steering a discussion to initiate governance of such an infrastructure. Validation of the demonstrator and extending the functionality can be in close collaboration in different use cases with users, both business and authorities. The validation would lead to formalization of the choreography, the semantic model, data structures for all interactions, and various implementation choices that have to be made.

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