Real-time supply chain – a blockchain architecture for project deliveries

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Real-time supply chain - a blockchain architecture for project deliveries

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Abstract

Real-time tracking and tracing are important in providing a unified view of global supply chains consisting of several parties. This paper illustrates the needs and requirements for managing supply chains in multi-company project environments by adopting various tracking and tracing technologies. This kind of tracking and tracing is especially needed within distributed architectures engaged in project-based businesses, where several vendors are involved in a single project. Such tracking and tracing data can be used extensively to generate key performance indicators, which can be used to measure and control supply chain processes. This paper also proposes a pilot system of a cloud-based portal for real-time tracking and tracing of logistics and supply chains. This portal is formed by the combination of RFID, IoT and blockchain technology into an integrated real-time view. RFID (Radio Frequency Identification) and IoT (Internet of Things) provides real-time information or data, while blockchain technology is used to provide a chain of immutable transactions. The architecture of the proposed portal system is connected to transport companies, tracking devices, consolidation points and suppliers. The pilot study also illustrates the benefits and advantages of such a portal system.

Keywords: supply chain management; real-time; blockchain; key performance indicators

1. Introduction

Global industries are facing problems in building a trusted real-time view of their supply networks [1]. This is a challenge for project-based businesses, where tracking and tracing in their logistics supply networks depends on several vendors, transportation companies and distribution centres, some of them infrequent or even one-timers [2] [3].

Supply and logistics chain are nowadays critical to support the entire life-cycle of the extended manufacturing enterprise [4]. Tracking systems are used to identify the last known position of the shipment and inform the next actor or the received in advance [5] [6]. These systems are widely used by large shipping companies, but for distributed industries such as project-based businesses, e.g. machine building, construction, shipyards, managing a large number of connected shipments has not been possible. Without a reliable tracking system, it is almost impossible to find delivered items and often items considered as lost or stolen. The information is needed by project managers to maintain real-time visibility of the flow from the production process to transportation and material management.

The demand for tracking and tracing of items in supply networks has been recognized by several industries [7] [8]. The academic community along with standardization organizations are also actively making efforts to develop global identification methods for items and products. The standard procedures developed so far are mainly concerned with the identification of items, and as such do not directly define any connection to real-time tracking systems. The complexity of project-based supply chains in global industry has produced an increasing interest in improving their manageability [3]. Due to the diversity of product variants, together with the necessity to improve product traceability, a lot of information about the items is needed.

In practice, there are several tracking systems available through GPS (Global Positioning System), GTIN (Global Trade Item Number) [9], RFID (Radio Frequency Identification) [10, 11], and barcode variants. However, many of these systems are partial solutions and do not provide a unified architecture. Many existing tracking systems are not able for example to identify the contents within a container which has been opened or where the contents are lost or stolen, etc. In order to tackle such misalignments in the logistics channel, state-of-the art technologies, including IoT (Internet of Things) [12, 13], Industrial Internet Platform [14] and trackers [15] are needed to be developed for sustainable production processes. These tools are needed to be cost effective and at the same time provide the needed data or information.

In order to maintain the authenticity and security of such data, blockchain technology can be integrated with such tools. Blockchain technology provides the necessary data authenticity and security in the logistics channels in immutable transactions. Before proceeding towards real-time tracking and tracing technology [16], it is crucial to analyse its possible cause and effects. The overall performance of the tracking technology supports successful project delivery. Based on the above requirements, this research study identifies the following three objectives:

(1) to identify both the functional and non-functional requirements of logistics in project business

(2) to introduce a framework for supply chain performance measurement based on decision time horizon and data aggregation matrix

(3) to develop a portal system by integrating RFID, IoT and blockchain technologies for logistics tracking and tracing in project business.

The remainder of this paper is organized as follows: Section 2 introduces the background and related works on this problem. The requirements of the project logistics context are outlined in Section 3, while Section 4 illustrates the method, and then section 5 demonstrates the proposed system and key-performance indicators. The requirements are collected from a case company, and a proposed architecture to fulfil these needs is presented. Finally, the conclusions section shows how real-time data can be used in managing the supply chain.

2. Related work

2.1 Project logistics

Project-based businesses such as construction, shipbuilding, power plants and machinery often operate in global multi-factory environments [2]. Customer sites are located far from production plants; materials are shipped from suppliers directly to customer sites or via consolidation points. Supplier networks may change from project to project as the scope of supply or local content requirements vary [17]. Key performance indicators related to the supply chain support the project overall success. Contracts may have heavy penalties for late project delivery and this is stressed throughout the supplying network during the execution phase.

Large construction projects logistics have a large number of shipments consisting of several deliveries, each with schedule dependency on some work phase. For example, engine and propulsion related deliveries for a cargo shipbuilding project may include hundreds of container boxes, which need to be installed during the exact phase of the overall shipbuilding project. For such a project, hundreds of suppliers may be involved, with each part being crucial for installation and commissioning. Dispersed data storage and a variety of data sources give the possibility to use big data to produce up-to-date performance information along the network.

A technological solution for supply chain data collection is to build a system which collects supply chain information from suppliers, transport companies, consolidating warehouses and customer delivery (Fig. 1). GS1 SSCC type of standardized labelling [18] should bring unified identification for multi-actor systems, and tracking devices may be used for expensive and sensitive key component deliveries. The data is collected and stored on a centralized database system, which links connections between data elements (Fig. 2).

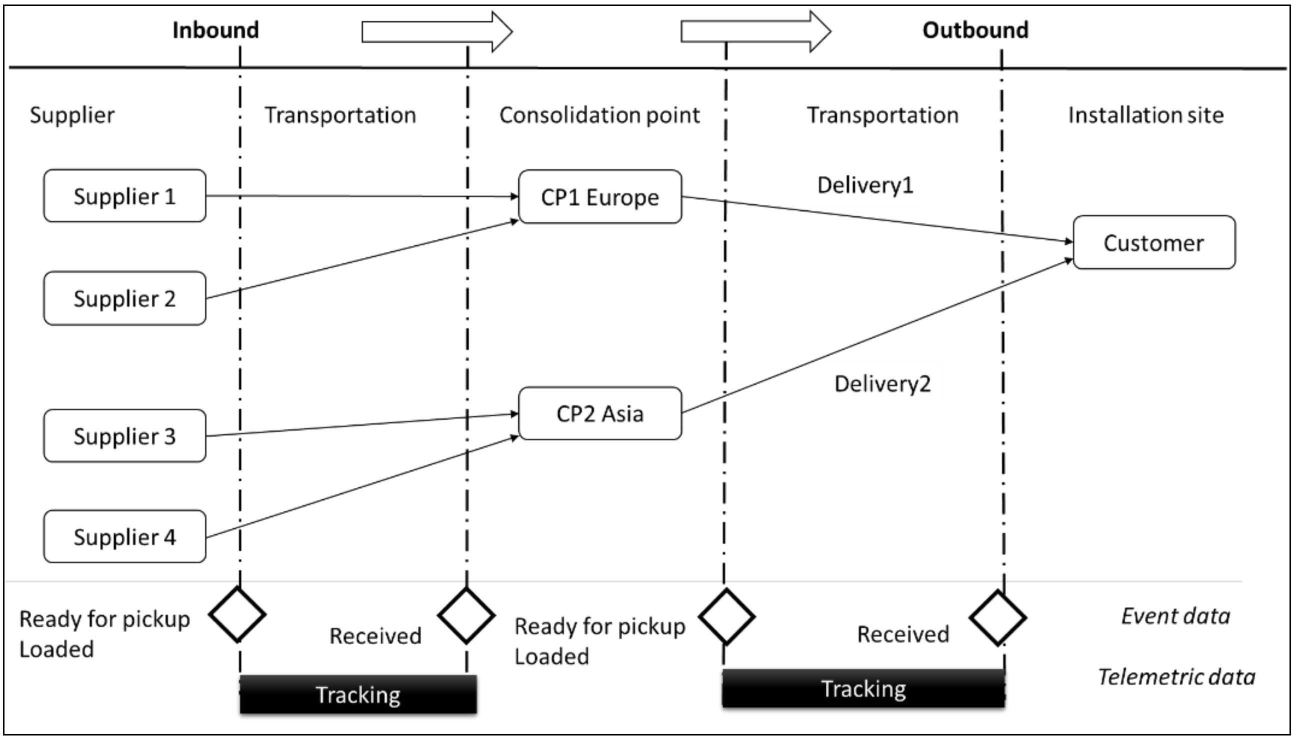

Fig. 1. Supply chain transactions in multi-vendor project logistics (source: authors).

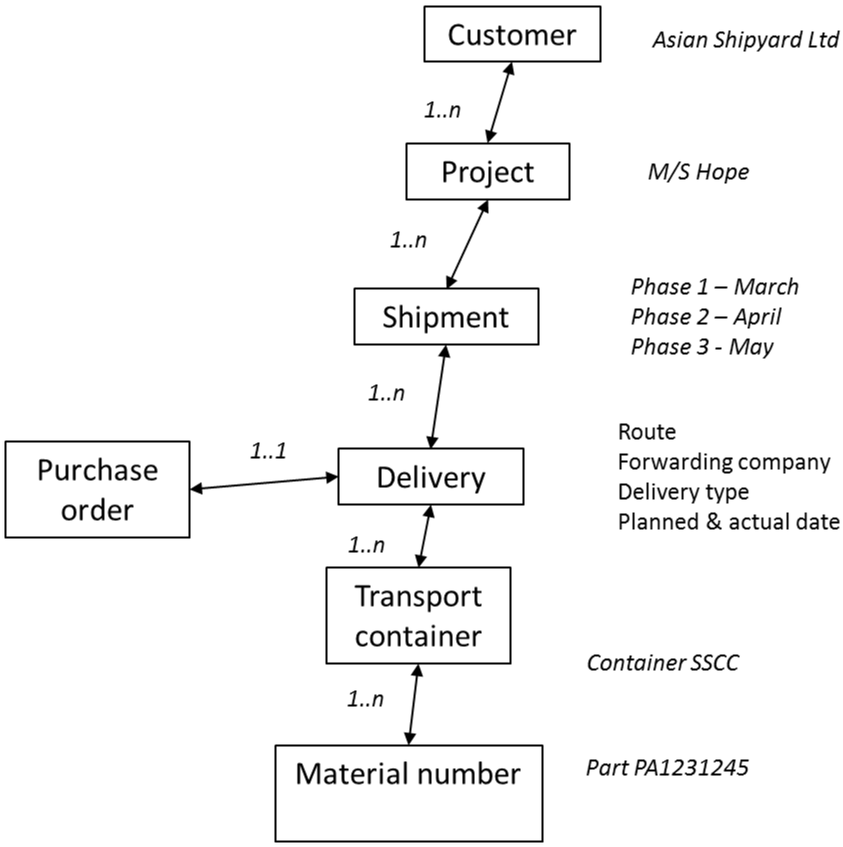

Fig. 2. Data model for project logistics (source: authors).

In the case of synchronized production and logistics (SPL), the processing, moving and storing of raw material, WIP and finished product in a manufacturing unit demand operational level integration and need a high level of information sharing to improve overall performance [19]. In order to maintain agility and synchronization in supply chains and to promote the collaborative management of supply chain disturbances, it is necessary to exchange information promptly throughout the supply chain [20]. To improve overall reliability between demand and supply, a joint effort between different functional units such as logistics, marketing, sales and executive management on the one hand, and between different business units on the other, is necessary [21, 22].

2.2 Blockchain technology in the supply chain

In recent days, blockchain has been receiving more attention in a variety of industries, which range from the financial sector to health-care, to, utilities to the government sector. The reason for this attention is that applications in these industries are worked only through a trusted intermediary [23]. By adopting blockchain it is possible for these industries to operate in a decentralized way, without the need for a verification system, but achieving the same amount of reliability. In addition, the use of cryptography in blockchain ensures information security [24]. If offers a large accounting ledger to record all transactions made by users.

Blockchain supports distributed peer-to-peer network architecture to improve security and scalability in manufacturing [25]. In addition, the integration of blockchain technology with agent technology guarantees data reliability and provides accurate front-line resource execution for different stakeholders [26]. This technology works as a distributed digital ledger system which ensures the transparency, traceability and authenticity of information, along with smart contractual relationships within global supply chain networks. It is basically a disruptive technology for the design, organisation, operation and general management of supply chains [27].

Blockchain technologies [28] provide promising possibilities to build distributed supply chain transaction records [29-33]. Generally, blockchain is understood as an immutable digital ledger of records, which has been organized in data blocks connecting to each other. Blockchains are secure due to decentralized cryptographically secure transaction mechanisms provided by decentralized computer networks operating together for block creation and verification processes [28]. Applications of blockchain in the supply chain ensure the secure storage of all transaction information. By incorporating blockchain, shipments can be tracked, the origin and destinations authenticated, and proof of all transactions can be stored and not manipulated [26].

With respect to the security point of view, blockchain is considered the most prominent technology [34-37]. Although the application of blockchain technology in the supply chain and logistics is still at its initial phases, this technology can surely be remodelled and implemented in the supply and logistics sector [36, 38-39]. This technology is being implemented in more widely than others, starting from open manufacturing [25] and real estate in order to ensure fraud prevention [40] to clinical trials [41] and entrepreneurship innovation [35]. When adopting blockchain, supply chain managers are able to have safer, more transparent, traceable and efficient virtual transactions of their operational processes [34, 36]. The overall implementation of blockchain in global supply networks can be summarized as presented in Table 1.

Table 1. Application of blockchain in global supply networks.

No.	Author(s)	Industry segment/area	Contributions
1	Tse et al. [42]	Food supply chain	Blockchain technology is applied to manage and track information in the food supply chain. It monitors and audits the food supply chain to record and authenticate the transactions.
2	Madhwal et al. [43]	Aviation supply chain	Application of blockchain assists in maintaining inventory of aircraft parts and to monitor performance with the objective of reducing the risk of parts coming from the black market.
3	Badzar [44]	Transportation and logistics	Blockchain in logistics increases supply chain transparency and improves contractual coordination in transportation contracts and improves overall service management within companies.
4	Tian [45]	Agri-food supply chain	Both RFID and blockchain technology are utilized to effect traceability with trusted information in the entire agri-food supply chain and to guarantee food safety through sharing authentic data of agri-food in production, processing, warehousing, distribution and selling links.
5	Korpela et al. [46]	Digital supply chain	Integration between Cloud database and blockchain technology is proposed to establish

			an interoperable digital supply chain to achieve disruptive transformation of information/data for various organizations and systems.
6	Kshetri, [36]	Multi-case study	IoT and blockchain-based solutions are deployed with the objective of fulfilling supply chain requirements such as cost reduction, improving quality, higher speed, less dependability, risk reduction, improving sustainability and flexibility, and increasing transparency and accountability.
7	Bocek et al. [47]	Pharmaceutical supply-chain	Integration of IoT and blockchain is performed in order to assert data immutability and public accessibility of temperature and humidity records of the medicines in the pharmaceutical supply-chain with reduced operational costs.
8	Leng et al. [48]	Agricultural supply chain	A public blockchain is implemented to the agricultural supply chain system to study the dual chain structure and take into account the security of transaction information and the privacy of the enterprise information system.
9	Lee and Pilkington [49]	Consumer electronics industry	The study analyses the overall impact of blockchain technology on the supply chain management of the consumer electronics industry with the aim of making this industrial segment a more transparent, safer, and more honest place.
10	Sivula et al. [50]	Construction industry	This research study highlights the opportunities of blockchain technology in the logistics chain of the construction industry. A case example is illustrated to provide extended customer value, transparency and an enhanced service network in the construction industry.
11	Casado-Vara et al. [23]	Consumer industry supply chain	Supply chain management through the blockchain model is proposed to enable the concept of a circular economy and to coordinate all the transactions that take place in the supply chain.
12	Rico et al. [51]	Megacity supply chain	Blockchain technology is used to support the search and negotiation phase of a logistics contract. A detailed data architecture and incentive structure of decentralized retailer-logistics are also implemented through blockchain technology.

The most well-known applications of blockchain are related to cryptocurrencies, but increasingly also in digital asset management. Trade-processing and settlement is an obvious continuation of payments. As data immutability is verifiable, this may be used for signing transactions or verifying the authenticity of an item, contract or right to use. These features are looked at especially in government registers and medical industries [52]. Industrial uses reported in the literature include open manufacturing environments [53], IoT connectivity [54], origin authenticity [55] and product safety [56].

The possible advantages of blockchain systems are:

(1) Decentralized management of the system as all participants share the need for immutable data and transparency of the process [29].
(2) The data can include transaction data on a high level or detailed documentation related to products, custom processes or release of payments.
(3) Improved trust through increased supply chain visibility and fraud detection [29].
(4) A shared and scalable network providing a basis for mutual interest [32].

This digital technology is leveraging new relationship models through the entire supply chain network and transforming and remodelling the relationships between all members of logistics and supply chain systems [56]. Although the application of blockchain has gained in relative pace over various segments in recent years, its application in logistics and supply chains has not yielded sufficient research cases.

This research study therefore tries to fill this research gap, notably by helping to understand individual blockchain adoption behaviour in the logistics and supply chain network. Previous supply chain implementations have been targeted for generic purpose shipping or consumer goods types of items. The novelty of the approach presented in this paper is that special consideration is given to requirements of project logistics. The contribution is the demonstration how in practice logistics data originating from various dispersed sources and integrated into a real-time view. More specifically, a blockchain-based architecture is proposed, which is supported by RFID, IoT and Cloud-based data security and tracking systems. This framework supports increased traceability and transparency in logistics and supply chain networks.

2.3 Performance measurement

The performance measurement revolution has been under discussion for a long time. Neely et al. [57] claimed that several internal and external pressures together with enabling information technology have been driving the trends and changing the focus from purely financial metrics toward operations [58]. Performance measurement frameworks are changing from periodic management review toward operational tools. According to Bititchi et al. [59], performance measurement is also challenged by the turbulence of the environment, the demand for sustainability measurements, increased share of services compared to physical distribution, and the need to acknowledge the network beyond the enterprise. The widely used Supply Chain Operations Reference model (SCOR) combines business process mapping methods with performance metrics. According to Estampe et al. [60], companies refer to several models in the performance evaluation process.

Performance measurement systems are also changing the focus from control of the system to learning from the system [57]. This means that performance systems are not built for periodic repeatable management decisions but as an enabling knowledge base for ad hoc questions and decisions. An important long-term trend is the transition from performance measurement to performance management [58]. The maturity of the performance management system is evaluated by its capability to deliver value [61-62]. The value creating capability of the system is connected to the use of big data in performance measurement and management.

Real time supply chain application can enable new aspects for performance measurement. The root causes of high-level performance indicators, trends or patterns may be analysed by analysing smaller entities. For example, the on-time delivery performance of a company may be analysed by seeing related supplier on-time delivery performance, common parameters such as project types, or customer locations.

Performance measurement is typically periodically operated based on aggregated snapshots. Monthly or weekly reports are performed on predefined organizational units (sourcing channel, factories and business areas). The tools of big data are targeted for analysing streams of data and making decisions in a time-scale which is not predefined by reporting periods. Ad hoc analyses and testing hypotheses for decision-making are examples of short-term actions.

Some examples of how to use real-time data streams for supply chain decision-making include the following:

- Route planning for trucks in real-time
- Quality management by analysing customer feedback and delivery issues on-line
- Profitability analysis for trucks, routes and stock-keeping units
- Order patterns and customer behaviour over time
- Risk management analysis based on orders and current status of deliveries

In terms of period, data is generated in several layers. Fig. 3 shows time-layers and data element examples for each. Typically, companies use aggregated metrics on a monthly or weekly level. These key performance indicators are linked to the strategic goals of supply chains, certain levels of lead-time, on-time delivery performance or costs. A more precise level is the daily level, which is typically supported by Enterprise Resource Planning (ERP) systems and operational logistics information systems such as Warehouse Management Systems (WMS) and Transportation Management Systems (TMS). This means information on the level of hours. Not all companies use key performance indicators at this level, as it requires operational level IT systems on the shop floor and truck fleets. The most detailed level of performance data comes from machines, where each transportation package or truck may be tracked several times in a minute, and vibration, shock or other sensory measurements are processed.

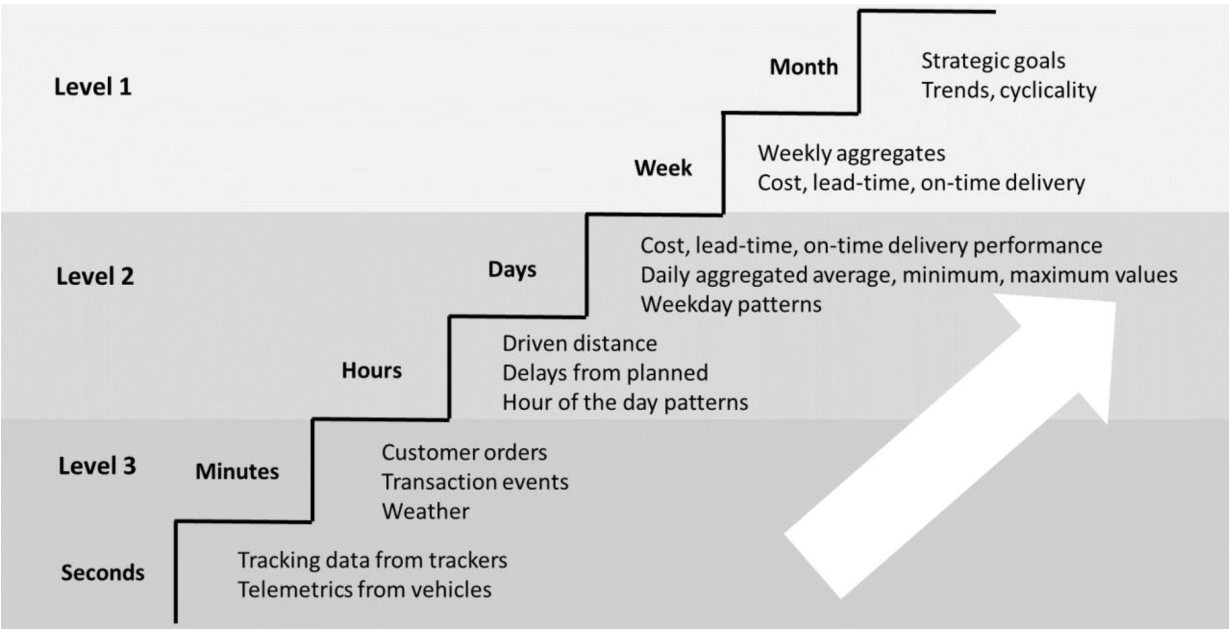

Fig. 3. Levels of period in performance analysis.

3. Research method

This research is based on a case study approach along with an extensive literature survey to fulfil the predefined research objectives. The case study was suitable for exploring supply networks within a project-based company engaged in the energy business in Finland. The necessary data collection process was designed to address the research objectives. Data were collected from the case company, represented by executives, business managers and IT experts in the field of supply chain and logistics, product designers and engineers, and project managers. From the collected data, various requirements, both functional and non-functional, were identified. This kind of exploratory research method was applied to provide a proof of concept of combining several promising technologies to deliver a real-time project view. Software design and engineering techniques were applied to implement and integrate the elements.

Proof of concept developed during the implementation project was not based on simulation or mathematical model but tested on actual project logistics environment. In order to facilitate the case company's logistics and supply chain with real-time status updates, an online portal was developed. This portal is operated by the Cloud and integrates various technologies such as RFID, IoT, GPS and blockchain. Various data related to the case company's supply chain such as customers, projects, shipments, deliveries, handling units, etc., are populated on this portal. From this portal, supply chain stakeholders are able to visualize relevant tracking and tracing data of their shipped items. Technologies such as RFID, bar code and IoT provide data as received from various sensors attached to the delivery items, while blockchain technology ensures authenticated and secured data transactions between supply chain stakeholders.

4. Requirements for project logistics

The purpose was to collect realistic requirements from a project-based company for the actual implementation of real-time supply chain architecture. The functional and non-functional requirements were analysed by using interviews with the project managers, transport managers and purchasing managers of a machine building company working with shipyards and marine projects.

4.1 Functional requirements

The main functional requirement was to create a framework to facilitate the creation and use of tracking data in non-centralized supply chain networks.

Client

- The purpose of the client application is to provide a secure, non-centralized way to create package tracking information
- The tracking number should be linked to transaction events in the supply chain using a safe method
- The reference number can be input manually or by using barcode or RFID tags
- Up-to-date information can be retrieved by using the reference number
- A decentralized data system for the creation of tracking data is enabled

Integration

- The tracking numbers generated can be linked to external data such as purchase order number, shipment number or sales order number
- External data sources can be integrated as transaction event sources such as transportation company provided APIs by using standardized methods
- External IoT tracking devices or a link to real-time data streams should be provided

Portal

- Collects data from decentralized supply chain transaction data and links it to a centralized searchable data storage
- Provides a search view for multiple views: project shipments, tracking numbers, purchase orders, project name
- Connects supply chain key performance metrics in the data view

4.2 Non-functional requirements

According to the analysis phase of the requirement collection, this planned real-time supply chain system should satisfy both the manufacturers and their suppliers within the project supply networks. Each participant should have a view of the material flow. The planned system should support an environment with features of:

- More than 5000 vendors using the system for the creation of shipment, some frequent suppliers and some one-timers
- More than 100 projects running simultaneously
- Average shipping time between 8 to 30 days between distribution centre and outbound project site location (Fig. 4)
- Project materials shipped in 1 to 4 shipments during the phase of the project
- Each project having 50 to 200 material handling units (boxes, containers), each container containing possibly hundreds of components (Fig. 5).

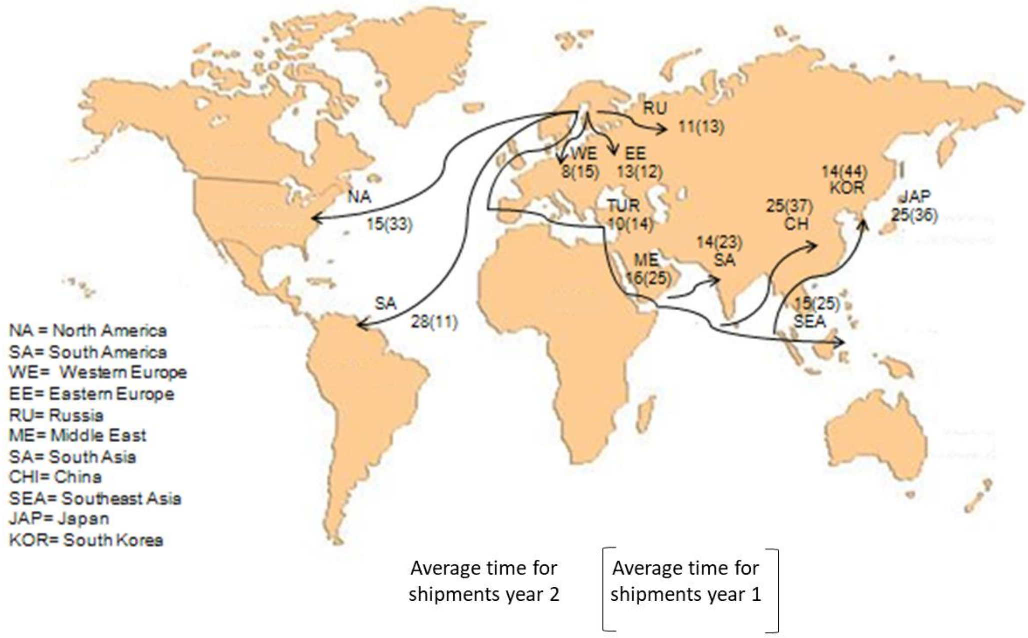

Fig. 4. Average shipment durations for project logistics, collected from a machine building company.

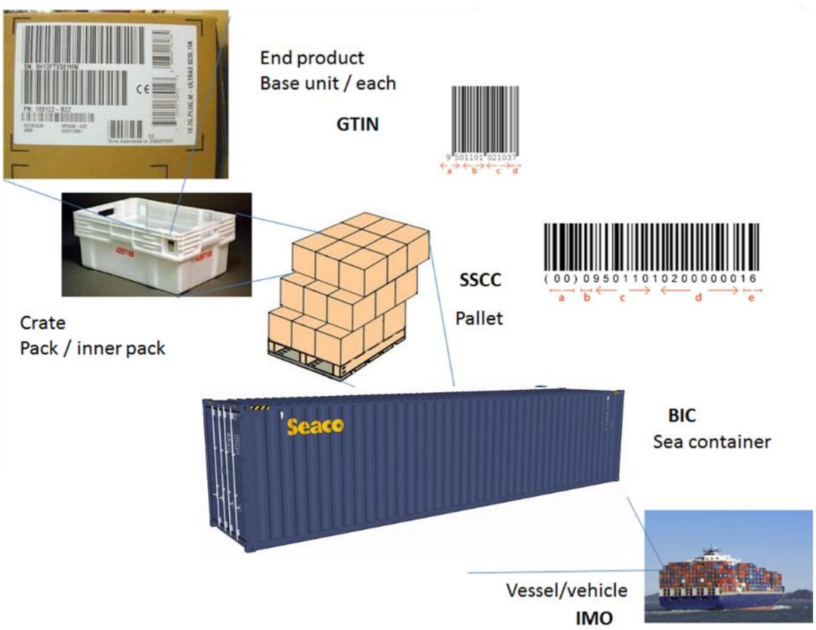

Fig. 5. Package hierarchy linking product, inner pack, pallets, containers and vessel/vehicle.

5. Proposed system

A Real-Time Supply Chain architecture (RTSC) was developed to implement the functionality of the decentralized project logistics. The main components in the implementation were (1) a blockchain component providing a method to create and verify the authenticity of transactions from the supply chain, (2) RFID and barcode client for transactions, (3) IoT and tracking device interface, (4) user interface on a cloud portal, and (5) key performance indicator view for supply chain management. Each of the components of the RTSC is explained in the following sub-sections.

5.1 Blockchain architecture

The architecture of the blockchain composed of blocks is presented in Fig. 6, containing transaction information of the logistics items. Each transaction in the logistics and supply chain, including the creation of a package, transportation order, confirmation of shipping time, pick-up of goods, custom processing, or receiving goods, should be presented as a block. Each of the blocks within the architecture is connected with each other by hash. The preceding blocks are connected to each other in the blockchain. This part is implemented by using Ethereum. Ethereum is an open source platform for developing blockchain applications [63]. It is a generic purpose transaction-based state machine and has good APIs for developers. The system is based on blockchain using an intrinsic digital token called "Ether". "Ether" can be broken into smaller units such as "Wei" (1E-18 Ethers). This token is needed to provide a payment (also referred to as gas) for the network of computers providing the proof-of-work: the calculation of the hash to create and verify the blocks. The payment of this fee is needed when using existing networks. Another possibility would be to create a private network and invite members who share the same supply chain related interest. In the pilot, we used a public test network.

Ethereum Virtual Machine (EVM) within the blockchain architecture operates as a runtime environment for smart contracts. The blockchain application (Tracker app) communicates with EVM and the network and provides a limited set of methods such as *InitiatPackage* and *transferPackageOwnership* (Fig. 6). These methods are implemented in the Tracker App component and by calling the Ethereum node component.

Decentralized Application (DApp) as part of the blockchain architecture is used to develop applications using front-end (HTML+CSS+JS) webpage and back-end (Solidity Smart contract) programming code. The communication with the back-end code, which includes the smart contracts, would be deployed as EVM bytecode in the blockchain. The interaction between the front-end code and the back-end Ethereum client/blockchain was implemented by using web3.js over JSON RPC, as seen in Fig.6.

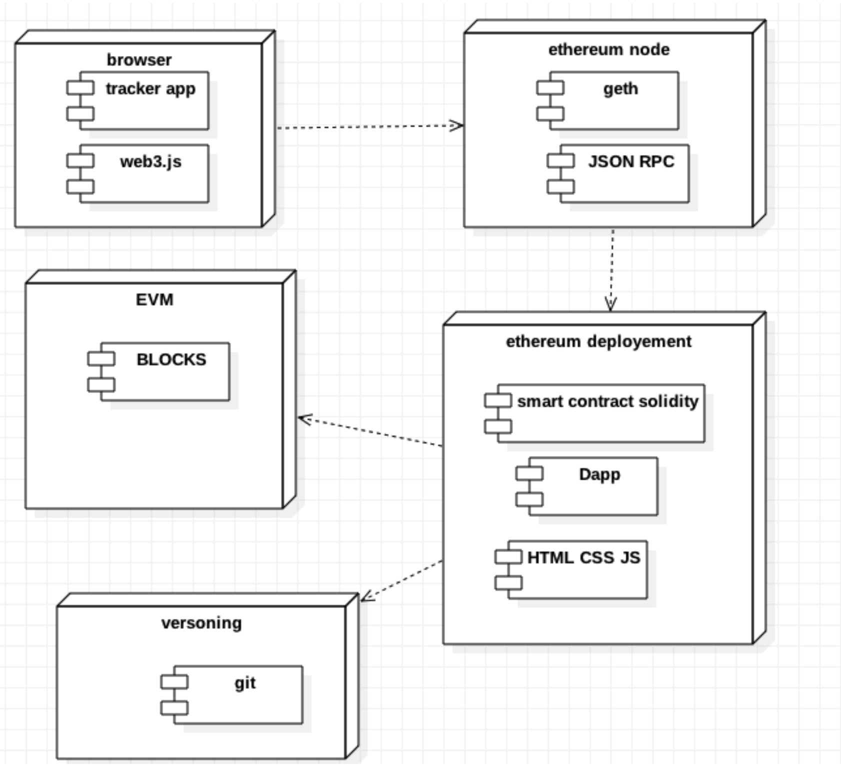

Fig. 6. Components of the blockchain architecture, which is an integral part of the developed software.

Smart contracts as part of the Ethereum deployment block within the blockchain architecture can be defined as 'a computerized transaction protocol that executes the terms of a contract' [71]. According to Cong and He [64], smart contracts can be defined as follows: "smart contracts are digital contracts allowing terms contingent on decentralized consensus that are tamper-proof and typically self-enforcing through automated execution". Smart contracts can increase contractibility and facilitate the exchange of various instances such as money, property, shares, service, or anything of value in an algorithmically automated and conflict-free way, while avoiding the services of an intermediary [65]. Smart contracts as deployed on Ethereum offer secure logistics management and can be applied to different scales with easy adaptability in several logistics environments through immutable programme [65].

In the supply chain network, one of the critical stages is to form a contractual agreement between parties. Any dispute within the contractual agreement that results from fraud, misunderstanding, and performance failures may not only destroy the supply chain partnership but also disrupt supply chain activities with a prolonged time for resolution [66]. By implementing such smart contracts in logistics and supply chain network this can resolve many of the problems arising. Smart contracts is a basically a computer protocol intended to facilitate, verify, or enforce contractual obligations following necessary contractual clauses such as rights, agreements, penalties, etc. [67]. The adoption of smart contracts not only clarifies the contractual rules and penalties, but also enforces those rules and penalties automatically, which contributes to improving compliance, mitigating risk, and increasing efficiencies across the enterprise [67].

Within smart contracts, predefined rules and regulations of a contractual agreement are converted to computer codes, which are then stored and replicated on the computer system and supervised by the network of computers that run the blockchain [66]. The application of smart contracts in a blockchain-based supply chain can help logistics companies to achieve real-time information exchange, money, property, or anything of value in a secured, transparent, and conflict-free way, while avoiding the services of an intermediary [68]. This results in reducing transaction time and costs in logistics companies.

A simplified example how smart contracts are used in the pilot implementation can be illustrated by a Solidity contract. Figure 7 shows the key principles and Appendix 7 outlines the source code for contract. Package object is introduced containing an id, current owner, address and assigned ownership for the received. A new package identity is born with initiatePackage method where initiator becomes the current owner. Then current package handler can be transferred to next one in the chain by using method tranferPackageOwnership. This transaction is the main contractual element. Other supporting methods in the contract are getPackageOwnershipHistory to see previous steps of the shipment and currentOwner to see who is handling the package at this point.

Sending and receiving organizations can use *transferPackageOwnership* function in the smart contract to sign and approve the delivery at each step. Smart contracts are used to monitor when approval signatures are required from both the sending and receiving party. This allows decentralized handover and enables the use of automation in releasing letters of credits or insurance, for example. Ethers support on smart contracts provides a flexible platform for use of more complicated future scenarios, which are not yet known.

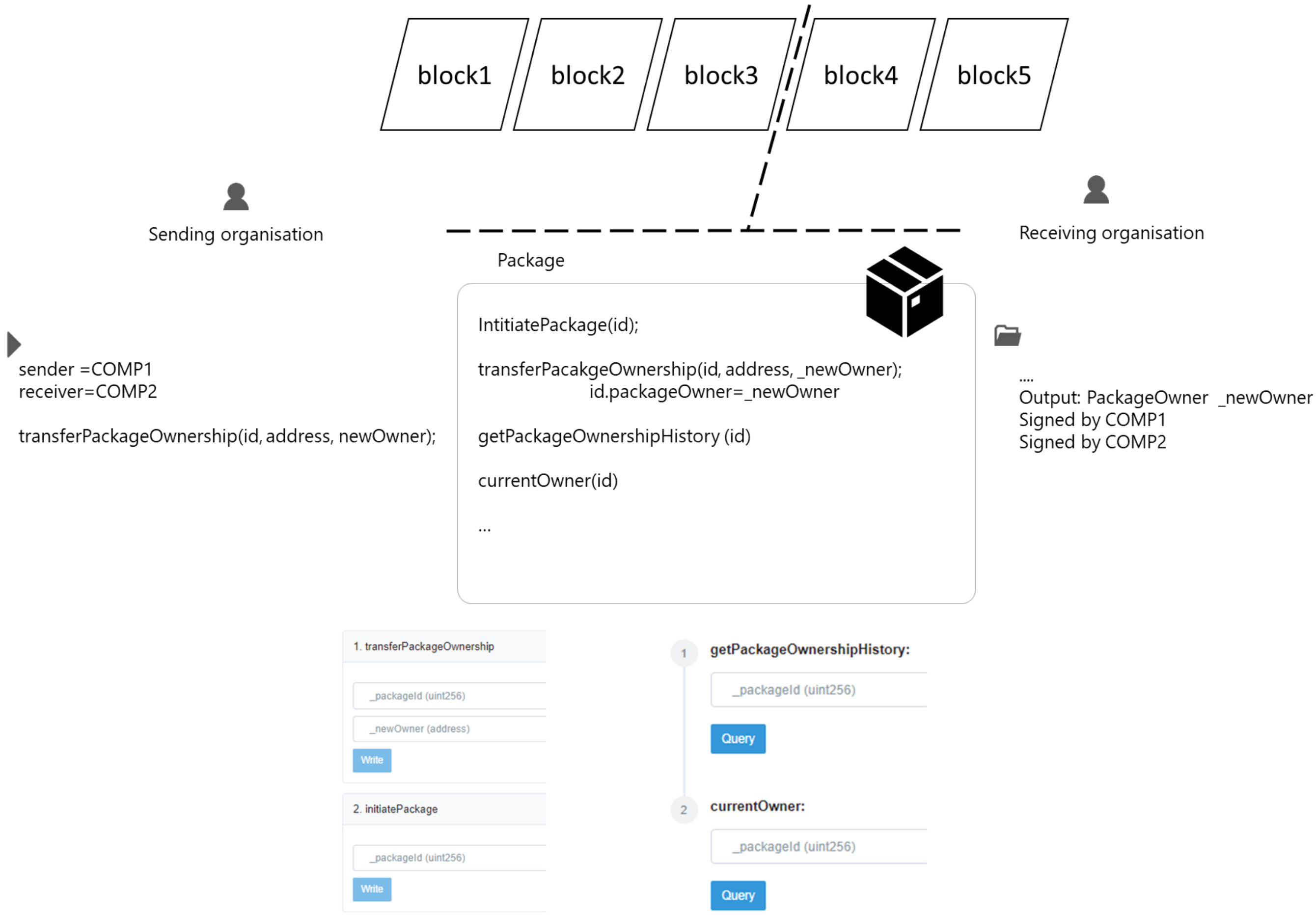

Fig. 7. Supply chain via blockchain and Solidity smart contract architecture.

5.2 RFID and barcode client for transactions

The users manually enter the basic logistics related transactions. For this purpose, mobile clients are using both web user interfaces and native Android apps, which are implemented to help in creating new shipments and changing the status of shipments. Each transaction is linked to:

- generated label ID (barcode, QR code or RFID representation)
- user-id
- timestamp
- GPS location of the device

Blockchain generation is done in the Ethereum network by using these elements, and a copy of the processed blockchain is stored on the cloud portal, which is implemented on SalesForce. The generated label id also works as an identifier used on the ERP system, where purchase orders are maintained. Fig. 8 displays the tracking system using mobile user interfaces for tracker/HU functions.

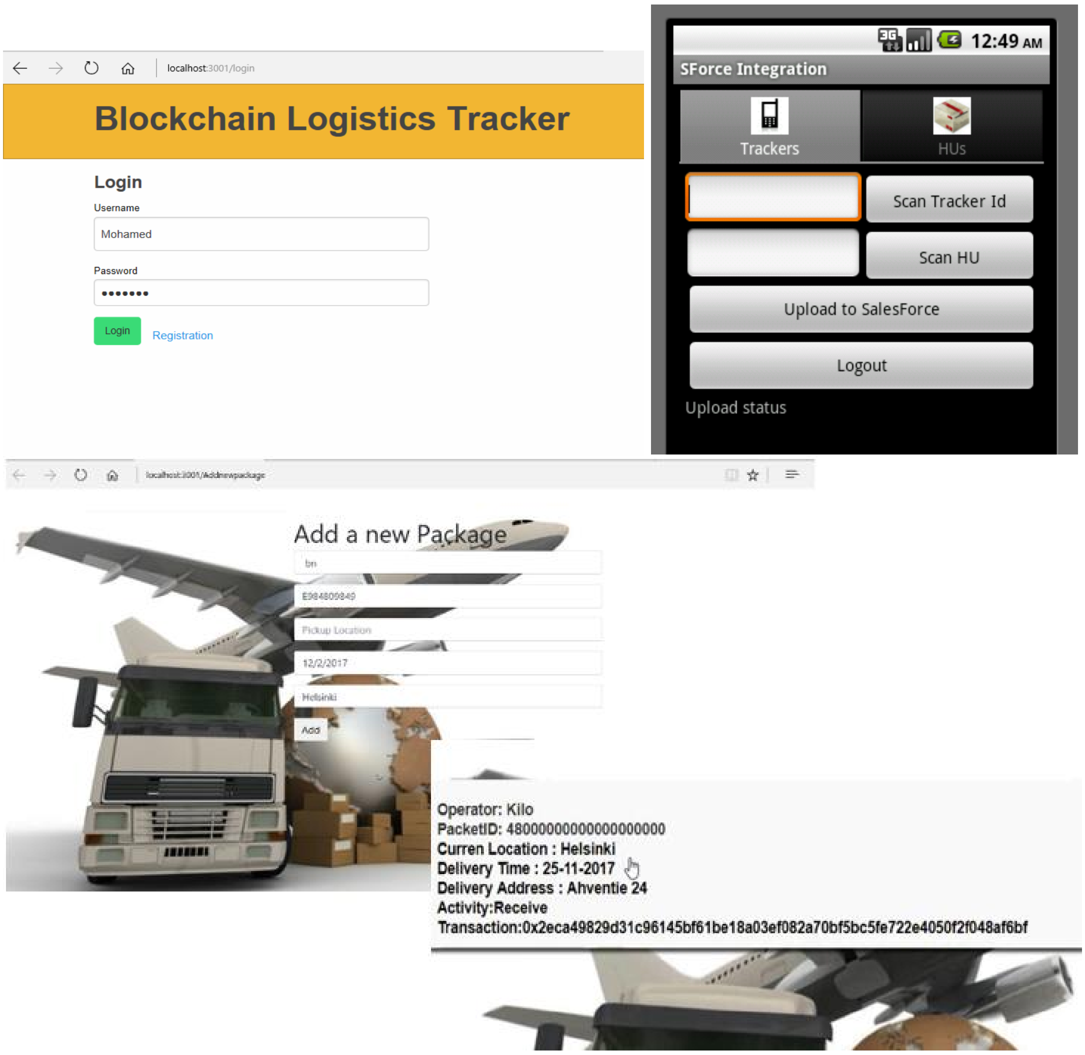

Fig. 8. Tracking system mobile user interfaces for tracker/HU function.

From the performance point of view, use of Ethereum blockchain technology solves the problem of verification within a reasonable response time. The test was not a simulation but instead we tested transactions in Kovan test network provided by Ethereum. This test setup would probably emulate a shared private network with geographically distributed multiple users.

During the pilot tests, Kovan testnet work was used to for blockchain transactions. Kovan is a testnet for Ethereum applications using Parity's Proof of Authority consensus engine. Ether mainnet has some 7000 nodes running transactions, but during out tests Kovan network had significantly lower number of active nodes, probably only 10 nodes.

The processing time for generation of a new block in Kovan network is 4 seconds (block time), but it does not require paying fees for transaction processing. The server-side storage for each independent node running a full Etherum node is currently 120 GB in light mode and 3.1 TB in full node mode. In practice creation of a new block and verification of existing blocks can take between 15 to 30 seconds depending on network situation.

These performance figures show that blockchain does not solve the need for fast data queries. A suggestion for architecture from this experience is that cache memory should be used in transactions for user interface which do not need be verified. For fast access a local storage needs to be used for clients, which requires some 500 MB capacity depending on the history length of valuable transactions. In case of logistics, the value of transactions may decrease to zero once packages have been successfully received in their destinations.

The performance of the test network could be improved to some extent, although Ethereum based systems have a performance limit which keeps the number of new block creation in the range of tens per second. For this reason, safety critical creation and verification process should be triggered as separate transactions which are processed in parallel. Forthcoming developments, such as Etherum 2.0 may improve the situation significantly in the future.

5.3 IoT tracking devices

In addition to manual entry of transaction changes, external data sources are supported by using an interface, which receives transaction data from IoT tracking devices and transportation companies providing vehicle information on-line. In addition, external data source type of messages are signed by using Ethereum and linked with a label identifier.

- Truck IoT - Transport companies transmit case status changes via text files in the UN EDIFACT standard format to notify about transportation changes. EDI status messages can contain an http-link for vehicle level positioning tracking data (Fig. 9).
- Tracking devices - For larger and more expensive goods, battery operated trackers can be used to provide telemetric information on cargo status and ambient environment (temperature, humidity, vibration and opening of the cargo handling unit).
- Automatic Identification System (AIS) data - Can be polled for sea vessels and linked with container numbers to label IDs. Automatic events can be triggered on arrival within the proximity of a geo-fenced zone.

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UNA:+.?
UNB+UNOC:3+ 5790001103651+ 146537+110414:1255+1818
UNH+0001+IFTSTA:D:99B:UN:EAN002
BGM+77+11033106550201+9
DTM+137:201103310655:203
NAD+CA+ Transport Company Ltd::100
NAD+CZ+Vendor::100
CNI+1+38383537
*STS+1+13*
RFF+ACL:24
DTM+7:201103300000:203
FTX+ZZZ+1++http://10.0.1.204/tracking-device/.
UNT+11+0001
UNZ+1+1818
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Fig. 9. EDI status message example from an external data source.

5.4 User interface on cloud portal

Data visualisation is an important part of using real-time data tracking and tracing in the supply chain. Recent developments of visualisation components, and the use of geographical information systems and cartograms give new possibilities for data visualisation. “War rooms”, equipped with large displays and mobile management cockpits for tablet computers can visualise a large quantity of data in a user-friendly form for decision makers.

A cloud portal view was built on top of SalesForce platform (Fig. 10). Data hierarchy to link customers, purchase orders, projects, shipments, deliveries and handling unit level information is maintained on a centralized level. The details tracking data, such as the exact tracking history of a container or GPS tracking date, is stored here, as well as a copy of each blockchain transaction.

Linking high-level objectives and respective performance attributes with lower level performance metrics is the key item which an analytical approach can bring to supply chain performance measurement. Data are available as fresh streams and producing more detailed views is possible and decision-making can be accelerated.

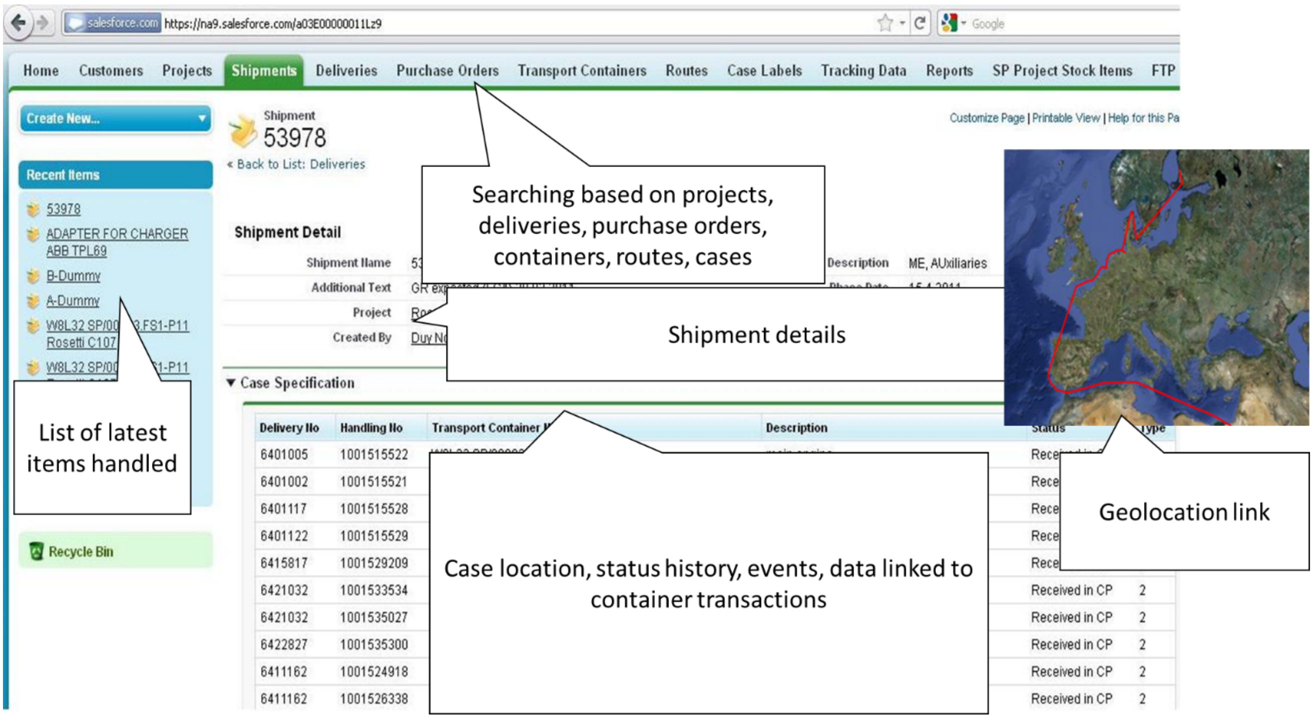

Fig. 10. Cloud portal providing a view of supply chain traceability.

5.5 Key performance indicators and managerial use cases

Key performance indicators for project business are typically analysed on an annual level for corporate level reporting and on a project level for project execution purposes. Some typical metrics for this project business include:

- Project logistics cost
- Delivery time
- Number of deliveries
- On-time delivery
- Percentage of perfect deliveries
- Rush delivery costs

Annual enterprise level figures depend a lot on ongoing project volumes and the phase of each project. For this reason, a rolling time horizon shows recent developments and trends faster. Enterprise figures accumulate from independent projects directly. For project logistics planning and execution, real-time data is important to make any adjustments. When all projects and their status - either latest transaction event or actual location data - are known, they can be monitored in the supply chain. An important aspect is to compare planned performance with the actual level. Based on experience and past data, algorithms may be built to identify potential risks and exceptional behaviour in terms of suppliers, transportation companies, transport routes or cargo type. (Table 2)

Table 2. Solution functionality and link to key performance indicators.

Solution functionalities	**Performance attributes**
Overall supply chain objectives	Supply chain reliability • Perfect order fulfilment Supply chain responsiveness • Order fulfilment cycle time Supply chain management cost • Supply chain management cost
Participants	Project planning - Planned shipments - Purchase orders for suppliers -
	Suppliers - Order confirmations - Packing information - Delivery status information
	Transport companies - Status messages - Tracking locations
Observation points	- Identify critical deliveries - Monitor overall cost
Analysis dimensions	- Project number - Subsystem - Transport company - Supplier - Geographical area
Actions	- Alternative transportation - Change supplier - Replacing orders

The level of data aggregation and decision time horizon can be presented in a quadrant (Fig. 11). Traditional high-level supply chain performance metrics are at the top part of the picture (1). What the big data approach can bring is a detailed view combined with external metrics. Tactical key performance measurement (2) and operational local metrics (3) on a daily and hourly level concentrating on shorter term decision making are in the diagonal of the axis. Pattern analysis (4) typically depends on short time range data accumulation and can be used in short term and tactical decisions. Forecasting of demand behaviour (5) is also in the same class, with the decision time horizon probably on a weekly or monthly level. Data granulated to a monthly level may be used for short-term operation decisions to check assumptions and give alerts for exceptional behaviour.

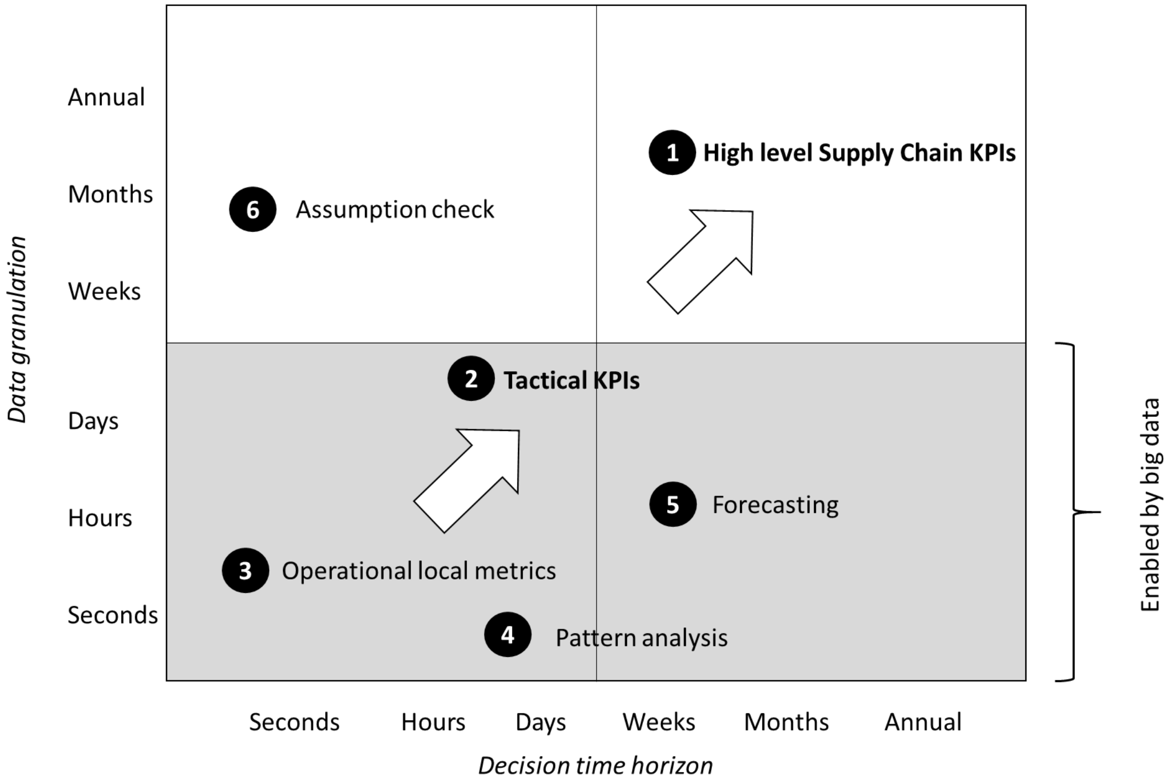

Fig. 11. Framework: Decision time horizon and data aggregation matrix for SC performance measurement.

The real life-applications from this pilot experience are expected to become standard features of logistics information systems in the future. The presented blockchain-based design and management of production system supported by RFID, IoT and Cloud portal ensures real-time information visibility to production system related stakeholders. This production system offers trusted and authenticated information transfer from one party to the next. In the case of supply chain and logistics management, this novel approach offers real-time data tracking and tracing in the supply chain. The RFID technology used in this system can be used to track supply and logistics items that also help to determine real-time status information of the shipments. In addition to RFID technology, IoT is used in this decision aid model to provide on-line vehicle information of the transportation companies. It can also be used to provide identification data for the sea vessels and linked with container numbers to label IDs.

It is critical for logistics companies to visualize real-time data of their shipments. To keep such an objective in mind, this developed system worked on a Cloud portal, which was built on the SalesForce platform. This portal provides data hierarchy that is maintained on a centralized level and has links to customers, purchase orders, projects, shipments and deliveries. Detailed tracking data of any shipment, such as the exact tracking history of a container or GPS tracking date is stored in this portal as well as a copy of each blockchain transaction.

The developed system can be used to measure the key performance indicators for typical project business. Such key performance indicators are typically analysed for business level reporting and on a project level for project execution purposes. The real-time data obtained from the developed portal is used to measure the overall performance of project logistics planning and execution. Based on the collected data (e.g. logistics cost, lead-time, number and location of deliveries, number of projects, etc.), an algorithm might be built to identify and forecast potential risks and exceptional behaviour of supply and logistics deliveries, optimal transportation routes, or cargo types.

6. Conclusions

Ultimately, what trusted real-time data does for supply chain performance management is the acceleration of the decision-making loop. The control mechanism from the performance metrics has remained similar – the loop has accelerated, and the data provides a valuable source for learning the details and micro-mechanisms of the operations. The real-time supply chain should not be considered a separate set of novel analytics tool but rather a possibility to add resolution to an existing structured approach.

Speed to derive actionable insights from the data is essential. The operational use of supply chain performance measurement becomes closer to an OODA loop – originally developed for the military [69]. Measurement is part of the Observe – Orient – Decide – Action loop. The reference could be a fighter plane pilot observing the sky, seeing another plane – focusing on that and still observing the surroundings, then deciding and taking action in following the target. In the context of supply chain management, top-level metrics are used to observe the overall situation and interpret it by considering the current business circumstances. When some external information or sudden change in metrics occurs, the management may orient and investigate the next levels of metrics for detailed analysis. Typically, in this stage, external reporting dimensions are added – does this change occur only in certain types of location, with certain suppliers, or on weekdays only? Hypotheses may be developed and tested with past data. Then it is time to decide what to do and implement action. Each part of loop provides feed forward to the next phase, and feedback is received every time a loop has been run. (Fig. 12).

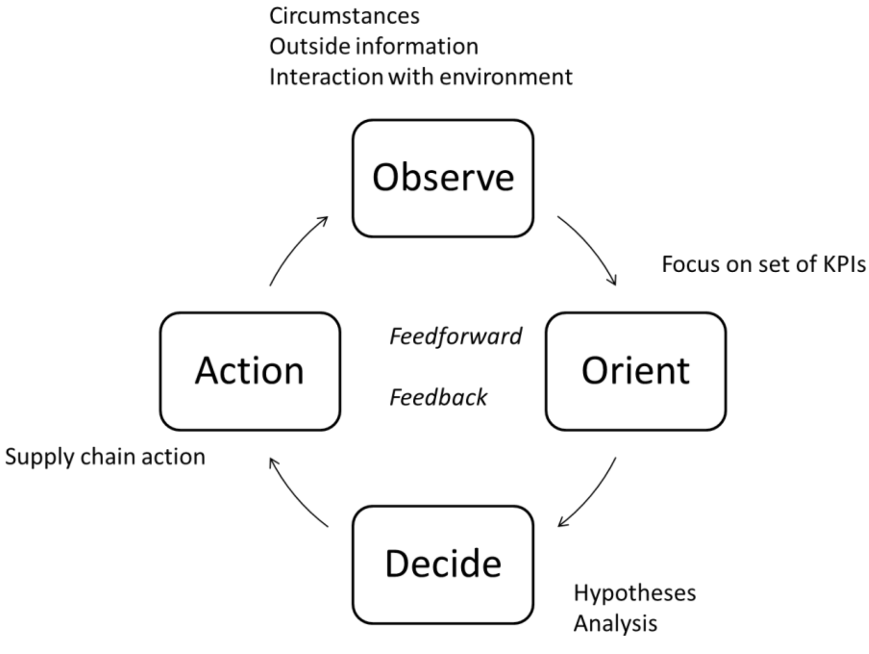

Fig. 12. OODA loop in performance measurement.

The main conclusion of this study is that the current IT and communication infrastructure within suppliers, own delivery centres, warehouses, and transport companies enable development towards real-time visibility in the supply chain. There is no single technology rather than a combination of various systems and processes to support the requirements. We believe that such system should include the following aspects:

- A portal system to collect the information into a centralized location and provide the information based on request to all participants involved.

- An integration system for communication between transport companies by using standardized messaging platforms (EDI messages, AIS satellite tracking for vessels, EDI/XML based web-service integrations, etc.) and connect these to the blockchain.
- A transaction monitoring system on each event during the logistics chain by using RFID and bar code systems, using blockchain to sign these transactions and link each one to the chain.
- The use of IoT tracking devices for expensive goods.
- Visualisation of the supply chain within the portal by using maps and key performance indicator data.

Based on the experiences from piloting the RTSC system, such an integrated system can be realized around existing technologies. Use of trusted immutable data can bring value to supply chain analytics and performance measurement. Large quantities of data enable precision and the ability to see patterns in more detail below the aggregated metrics. The velocity of the data streams make it possible to accelerate the decision making speed. Combining data sources into reporting dimensions and triangulating observations from different data sources adds value for users.

The managerial implications from this study are the encouraging of project-based businesses to build their own supply chain portals and integrate multiple data sources for building visibility and transparency. Blockchain can be used towards a cloud manufacturing system to secure data sharing in a peer-to-peer distributed network platform [70]. Blockchain and smart contract technology implementations show good potential for safety and security related transactions, but the actual response rate for database related queries is too slow and local storage needs quite high. For this reason, the architecture should support parallel processing and use of local caches.

Future research should focus on building standardization and larger inter-operational pilots, where ERP and transport management systems are integrated into a blockchain-based system of multiple parties. More complicated smart contracts should be tested in the field of supply chains based on good experience from the signing process.

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Appendix 1. Smart contract example.

```
pragma solidity ^0.5.11;

contract PackageOwnership {
  constructor() public {

  }

  struct Package {
    uint id;
    address packageOwner;
    uint ownershipAssignedAt;
    address[] packageOwnerArr;
    uint[] ownershipAssignedAtArr;
    bool exists;
  }

  mapping (uint => Package) internal packages;

  function initiatePackage(uint _packageId) public {
    address[] memory packageOwnerArr;
    uint[] memory ownershipAssignedAtArr;

    packages[_packageId] = Package(_packageId, msg.sender, now, packageOwnerArr, ownershipAssignedAtArr, true);
    packages[_packageId].packageOwnerArr.push(msg.sender);
    packages[_packageId].ownershipAssignedAtArr.push(now);

    emit PackageInitiated(_packageId, msg.sender);
  }

  function transferPackageOwnership(uint _packageId, address _newOwner) public
    isPackageOwner(_packageId)
    differentOwner(_newOwner)
  {
    packages[_packageId].packageOwner = _newOwner;
    packages[_packageId].ownershipAssignedAt = now;

    packages[_packageId].packageOwnerArr.push(_newOwner);
    packages[_packageId].ownershipAssignedAtArr.push(now);

    emit PackageOwnershipTransferred(msg.sender, _newOwner);
  }

  function getPackageOwnershipHistory(uint _packageId) public view returns(uint[] memory, address[] memory) {
    Package memory p = packages[_packageId];

    return (p.ownershipAssignedAtArr, p.packageOwnerArr);
  }

  function currentOwner(uint _packageId) public view returns(address) {
    return packages[_packageId].packageOwner;
  }

  event PackageOwnershipTransferred(address indexed _oldOwner, address indexed _newOwner);
  event PackageInitiated(uint indexed _packageId, address _owner);

  modifier isPackageOwner(uint _packageId) {
    require(packages[_packageId].packageOwner == msg.sender, "Only the owner of this package can invoke.");
    _;
```

```
  }

  modifier differentOwner(address _newOwner) {
    require(msg.sender != _newOwner, "New owner's address must be different from current owner's.");
    _;
  }
}
```