A DEMONSTRATOR FOR INTERCONNECTING INDEPENDENT MATERIAL FLOW SIMULATION MODELS IN THE AIR CARGO SUPPLY CHAIN USING THE IATA ONE RECORD STANDARD

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ABSTRACT

In this paper we demonstrate the concept of a digital twin for the air cargo transport chain which is based on data provided via the new IATA ONE Record standard (1R). Using ONE Record data which is based on the linked data concept enables overarching optimization without the necessity to build interfaces to many legacy systems or share sensitive data between supply chain partners. Real shipment data was transformed into the 1R format and stored in GraphDB from where it was retrieved with SparQL to feed a simulation model built with Siemens Plant Simulation. The concept shows how certain activities can be used the predict the near-term workload of the downstream supply chain partners. For the outbound ground handling process an information advantage of 15 minutes for 85% of all ULDs or even 30 minutes for 40% of all ULDs can be achieved.

KEYWORDS

value of information; air cargo; logistics; digital twin; discrete event based simulation

1. INTRODUCTION

Air Cargo shipments represent about a third of global trade when measured in value (IATA 2016). Despite the relevance there is not a lot of research in air cargo compared to aviation in general or passenger transport. In this paper we focus on the forwarder-airline-driven air cargo supply chains and do not consider the Integrator business model or airmail or other air transport concepts for goods. The air cargo supply chain is characterized by volatile demand with changing and flexible supply chain partners. Compared to passenger services and other industries air cargo is lagging in digitization (Feng, Li & Shen 2015b). Message forwarding which is the current standard in data exchange between the supply chain partners has some deficits, esp. in cases where changes to the shipment or the transport plan occur. IATAs ONE Record (1R) standard aims at resolving these deficits. While past research mostly focused on the optimization of one partner, we conceptualize a digital twin that helps to optimize the supply chain. Due to the volatility in demand, but also short-term operational changes a digital twin improves the short-term allocation of resources and thereby improves quality of service and lead times.

The objective of this paper is to demonstrate how 1R data can be used to build a digital twin of the air cargo supply chain and how this digital twin can be used for short-term workload predictions. From the complete end-to-end-air transport chain which is covered by the concept and 1R in this paper we focus with our demonstration on the on-airport activities and partners (Figure 1).

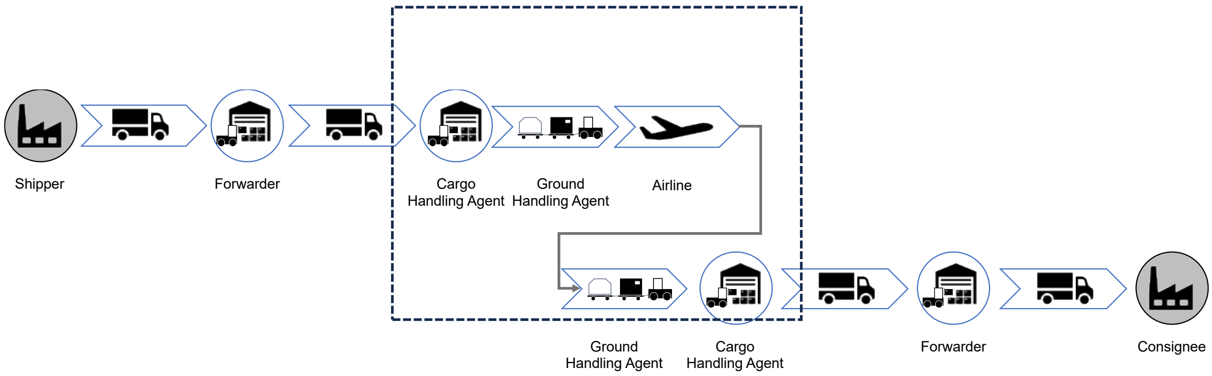


Figure 1: Simplified Air Cargo Transport Chain (dotted line indicates the focus area - (Source: authors representation)

The paper is structured as follows. Section 2 contains the literature review on air cargo and digital twins in logistics. This is followed by an in-depth description of the air cargo supply chain, its partners and processes as well as in introduction to the ONE Record standard, the underlying architecture and a description of the digital twin itself (section 3). Section 4 presents the results which is followed by the discussion in section 5 and the limitations in section 6. The last section summarizes the findings and provides an outlook on future research (section 7).

2. LITERATURE REVIEW

A comprehensive overview of air cargo operations research is given by Feng, Li & Shen (2015b) while Morrel & Klein (2019) or Schäfer (2020) present a detailed overview of all aspects of air cargo. Merkert (2022) presents a keyword map of relevant literature of the last 60 years.

Research addresses primarily the airline or cargo handling agent perspective with the objective to optimize airline strategy (Dewulf, Meersman & Van de Voorde 2019), airline revenues (Chao & Li 2017, Eren et al. 2023, Vancroonenburg et al. 2014, Popescu et al. 2006, Feng, Li & Shen 2015a), networks (Lee, Zhang & Ng 2019, Heinitz, Hirschberger & Werstat 2013, Huang, Xiao & Liang 2022, Janić 2022), airlines choices from a forwarder perspective (Chu 2014, Taner 2022) or load planning (Brandt & Nickel 2019, Lee et al. 2021). Bombelli & Fazi (2022) as well as Romero-Silva & Mota (2022) analyze the potentials of a cooperation between the ground handlers and forwarders to optimizing truck scheduling with the help of a central coordinator.

Material Flow Simulation, a sub-type of discrete event-based simulation, is used for analyzing real systems that have many influencing business-related and stochastic factors. Setting up a simulation model is done by abstracting a real system and building a model from it. Then, various input parameters are tweaked in experiments and the results are compared. In the domain of air cargo, simulation studies look at systems of warehouse, landside, or airside operations. Relevant works include Cao et al. (2011), DeLorme et al. (1992), He, Morris & Qin (2010), Nsakanda, Turcotte & Diaby (2004), Lee et al. (2006), Ou, Zhou & Li (2007), Romera-Silva & Mujica Mota (2021), Suryani, Chou & Chen (2012), Sencer & Karaismailoglu (2022). These known models focus solely on the air cargo handling terminals to either identify bottlenecks or evaluate benefits of technical improvements. Wong, Mo & So (2020) develop a digital twin for air cargo loading operations. Pérez Bernal et al. (2012) use a simulation software to model a forwarder-to-consignee air cargo supply chain for the airport of Zaragoza, Spain. They conclude that double-digit savings are possible if an overarching simulation model would be used.

Digital twins have been used in other industries for a long time, e.g. the aerospace industry, in general with a focus on installations or equipment (Haße et al. 2019, Tuegel et al. 2011). A digital twin uses constantly updated data and is also adapted according to the changes in reality (e.g. exchange of a certain machinery or any kind of extension) (Rosen et al. 2015). To enable the digital twin functionality provision of data from various systems, formats and owners is a challenge (Bazaz, Lohtander & Varis 2019). Haße et al. (2019) and Korth, Schwede

& Zajac (2018) describe a digital twin in the field of logistics while Franke, Hribernik & Thoben (2021) research the topic of interoperability in logistics.

To the best of our knowledge a digital twin of an air cargo transport chain that comprises of multiple stakeholders does not exist.

With the invention of 1R as a new form of data exchange the relevant and constantly updated data to build a digital twin becomes available. RDF and graph data models can be used to create interoperability between the distributed 1R data and a local simulation model.

As 1R itself is under development real-life 1R data is not available yet. Therefore, the authors had to transform real-life air cargo handling data into the 1R format to then use it as a data feed for the digital twin experiments.

2.1. CONCEPT OF AN 1R-DRIVEN DIGITAL TWIN OF THE AIR CARGO TRANSPORT CHAIN

2.1.1. AIR CARGO PLAYERS AND PROCESSES

Today's air cargo transport chain is centered around the contractual relationship which is defined by the airway bill (AWB). Typically, a shipper does not directly contract an airline, but hires a forwarder to organize the transport, so the AWB is set between the forwarder and the airline. As most tradelanes (origin-destination-combinations) are served by multiple airlines and air cargo does not represent a constant transport volume, the air transport chain is part of a volatile and flexible network, meaning a shipper might use multiple forwarders while the forwarders use multiple airlines (even for the same, recurring shipments).

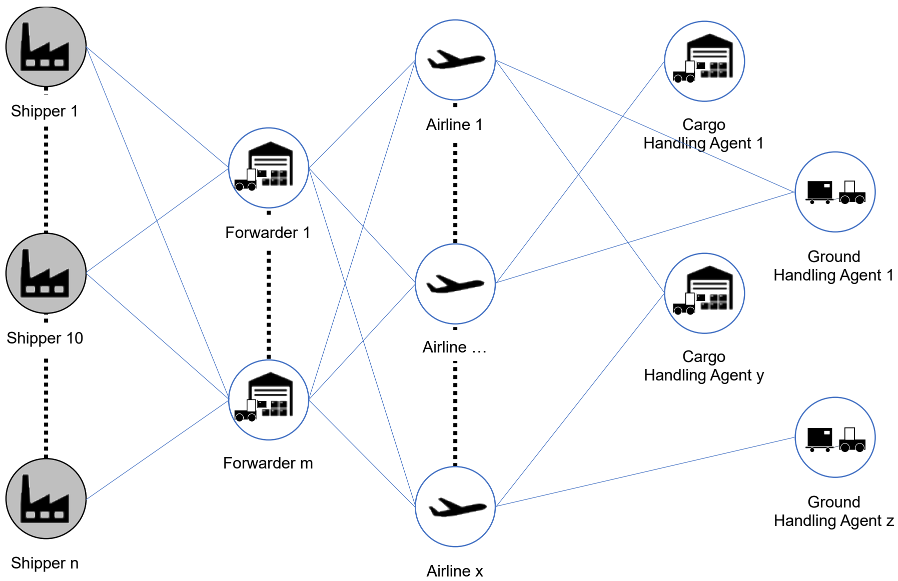


Figure 2: Complex network structures in the air cargo transport chain (Source: authors representation)

Forwarders and airlines most of the times outsource parts of their offer to several logistics service provider. While the air transport is the core value proposition of an airline all other surrounding services like ground handling, warehouse handling, road transport (Road feeder services RFS) are typically outsourced to other companies. The forwarders also heavily rely on outsourcing. This leads to more complex contractual situations than the 2-party-contract of the AWB indicates (figure 2).

IATA's master operating plan (MOP) describes the necessary material handling and documentary processes on a high-level-basis (IATA, 2019). The air transport from shipper to consignee is split into 19 main processes (with multiple sub-processes) which are either carrier-(airline) or forwarder-driven processes. Morrell & Klein (2019) describe the processes in more detail, specifically regarding ULDs and warehouse handling processes. Although company-specific differences in handling exist, the authors use the generic process described in the MOP as a baseline for the simulation model.

Different than in manufacturing supply chains with recurring transports under the same contractual terms AWBs cover individual transports only (as identical transports are rare).

For all companies involved in the air transport chain basic (physical) information about the shipment is essential for the correct identification and handling of the shipment (e.g. shipper, consignee, number of pieces and the weight). Because of security and customs regulation further data (e.g. a customs code or a basic cargo description) is needed to process the shipment.

Data exchange in air cargo is relying on CargoIMP and CargoXML, formats derived from EDIFACT, and a plentitude of individual solutions (cf. figure 3). Both formats revolve around messages portraying the contents of the air waybill document (FWB and xFZB) with limited capacities around that. These were originally designed for communication between the forwarder and the airline and form the backbone of this bilateral data exchange. Since the air waybill does not cover all needs that air cargo has today – consider track and trace needs, evolving dangerous goods regulation, or subcontracting – various individual solutions exist to enhance these. This includes IATA standards, such as eDGD, but also a lot of company- or provider-solutions such as web APIs, community systems, but also emails, phone calls, and telefax.

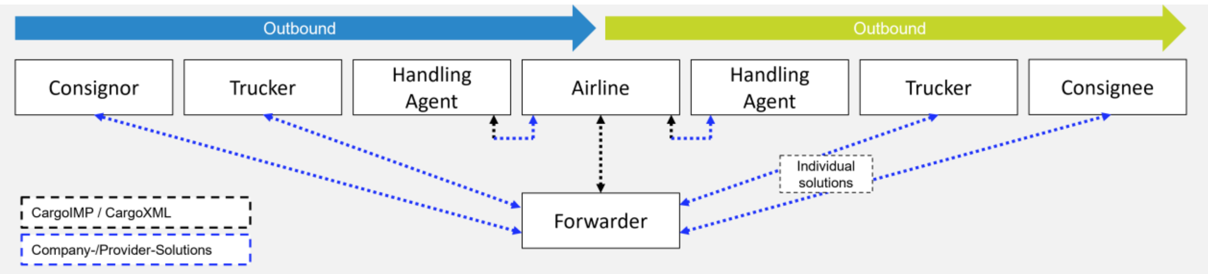


Figure 3: Current data exchange in air cargo (Source: authors representation)

All of this causes a fractured landscape of data pools along the air cargo supply chain that – while loosely basing on air waybill data – are too diverse to accurately and standardized retrieve process data from them.

2.1.2. THE ONE RECORD DATA MODEL AND ITS APPLICABILITY ON PHYSICAL AIR CARGO PROCESSES

ONE Record (1R) is an upcoming data transmission standard to share air cargo shipment data on piece level. Replacing the prevalent, restrictive EDI messaging, 1R is designed as a layer on top of the various IT systems used by supply chain partners, connecting the data pools and serving as authoritative source of truth.

The ONE Record standard aims connect the various data pools along the supply chain which exist independently, creating an internet of logistics, as stated by Blaj et al. (2020). It is built upon the W3C standard RDF (Resource Description Framework), which is a data model portraying relationships between webhosted resources as directed graphs. Data is described as subject-predicate-object, forming a triple. Every participant hosts and manages their own data, while consuming all data they need to access. Data is hosted on a per-resource basis. Each resource, being a node in the graph, has a weblink and can be accessed by standardized API-calls, to create, change or retrieve it. In total, the 1R defines 154 types of nodes, and 528 types of edges to describe properties of and relationships between the nodes.

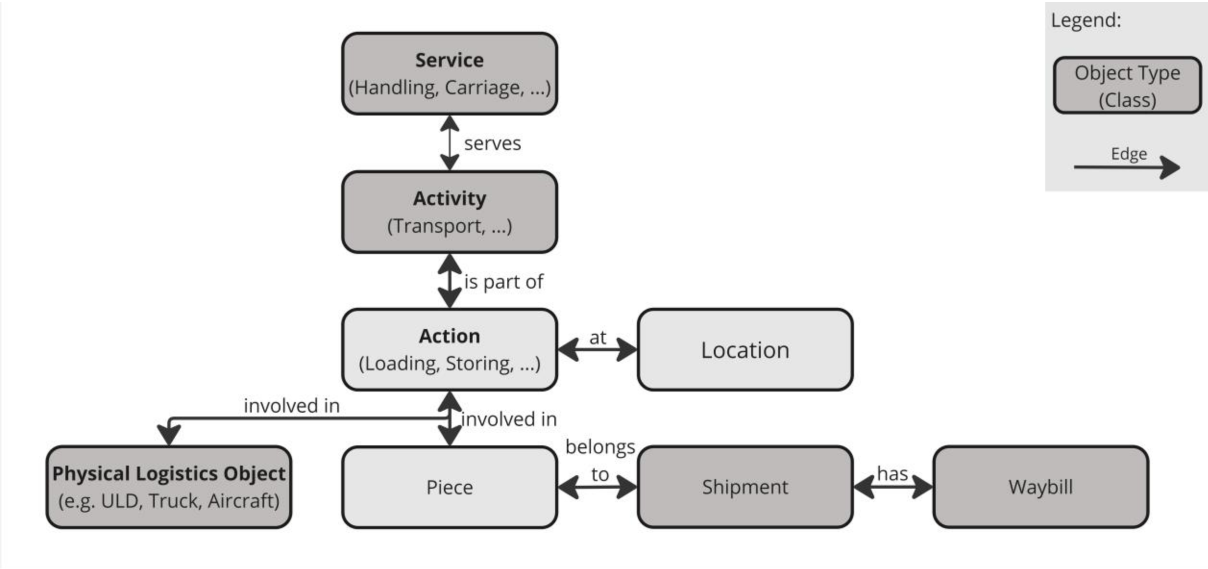


Figure 4: Logical data model of ONE Record 3.0.0[1] (Source: authors representation)

In the center of 1R is its cargo ontology, which defines the vocabulary and data model for the air cargo industry based on pieces, the physical world and processes. The core design principle is piece-centricity and physics-orientation (figure 4), meaning that each physical object and especially the pieces have digital equivalents in data traffic. These hold identifiers, dimensions, weight, handling requirements and all other physical parameters that their twin in the real world possesses in practice. This is in stark contrast to the document driven approach of CargoIMP and CargoXML, where this information is only available consolidated within a digital air waybill. Spanning from the piece, the data model includes objects to describe the relevant contractual data of the air waybill and airline booking parameters but are now limited to just non-physical parameters. In addition, processes are described as actions, where pieces and other physical objects interact with each other, that are part of a larger activity. This includes the Transport Movement activity covering Loading actions for flights and truck transportation, the Unit Composition activity including Composing actions for build-up and break-down processes and the Storage activity with Storing actions to describe storage times. These activities, in turn, are consolidated as services to be executed on a specific waybill – for example as part of a ground handling service. Further features include customs and security information, insurance information, and internet-of-things data, which are irrelevant for this project at the current state.

2.1.3. ONE RECORD CONNECTOR FOR MATERIAL FLOW SIMULATIONS IN AIR CARGO

[1] Full model visualization available on GitHub: https://github.com/IATA-Cargo/ONE-Record/blob/master/2023-12-standard/Data-Model/

Air cargo process simulation depends on pieces, physical objects, and process parameters. As such, the ONE Record connector is built on pieces, physical logistics objects, actions, activities, and services available as RDF-data. From the relationship nodes between the objects, the material flow inside, to and from the warehouse can be derived. Required descriptive nodes are the weight and destination per piece, the security status, and the times of actions performed on the pieces.

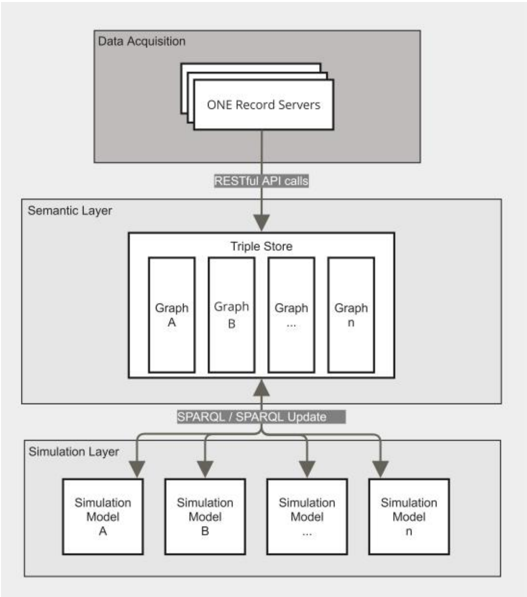


Figure 5: Architecture (Source: authors representation)

The proposed architecture is composed of three layers, namely the data acquisition layer in form of the network of ONE Record servers, the semantic layer holding the triple store, and the simulation layer running the simulation models (figure 5). For layer intercommunication, the approach relies on SPARQL and SPARQL Update. Both are W3C-standardized languages for querying and updating RDF data, respectively. The database server, as central layer, serves as provider of inter-model semantic interoperability as well as feeding the models with live data.

At simulation start, the database server fetches operational data using subsequent GET-Requests for every required resource. It is assumed that security permissions for access are present, but even partial data suffices in case access is denied. The returned JSON-LD files are parsed as triples and stored in a graph database, tailored towards handling RDF-data. In the proposed approach, the database includes separate, dedicated subgraphs for each connected simulation model. Upon completion, the separate instances of the simulation software running on the model server fetch the required input data by sending predesigned SPARQL-queries to the RDF4J-endpoint of the graph database. The database returns the query results as comma-separate-values, which are parsed and stored into the control tables of the simulation models. During the simulation run, the simulation models may routinely query the graph database for updates, while updating the graphs of connected simulation models by posting SPARQL Update queries against their respective endpoint in the graph database.

2.1.4. DIGITAL TWIN OF A FORWARDER HUB

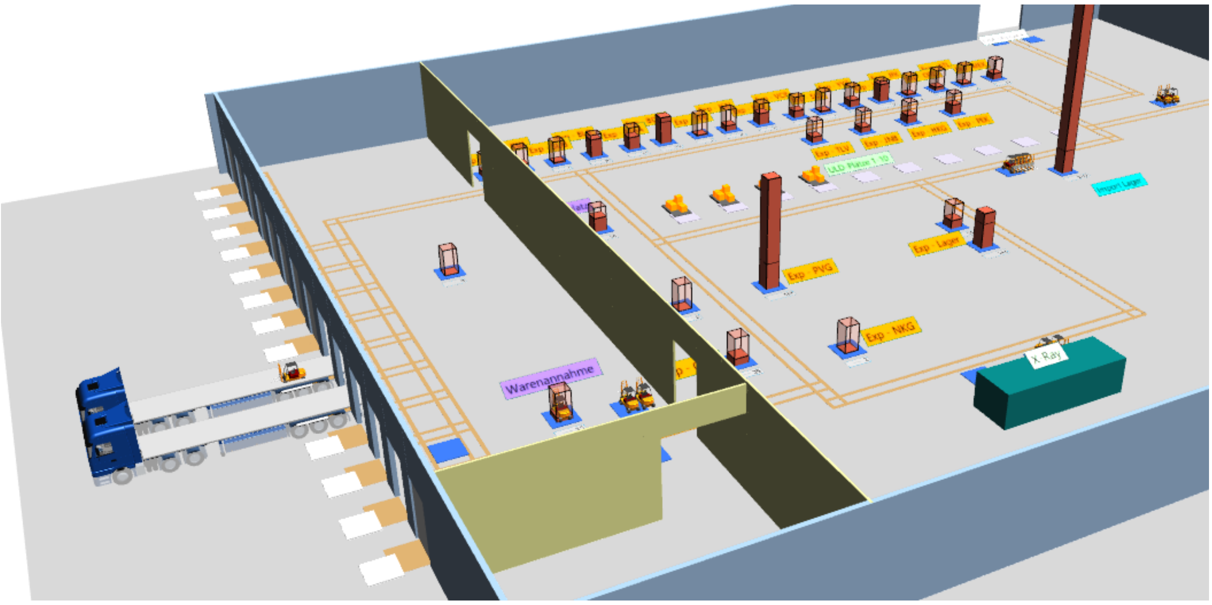


Figure 6: 3D model screenshot (Source: authors simulation model)

The presented demonstrator considers a single forwarder handling facility that is located at Frankfurt Airport built with Siemens Plant Simulation 2201 (figure 6). The model simulates the flow of import and export shipments on piece level, which are handled in the same area. It is operated by four control units, namely truck control, import control, export control and ULD control. Where truck control creates and sinks movable units in the form of pieces, import and export control handle the overall flow of these pieces through the warehouse. On trucks dropping off shipments at the warehouse, the model operates in a push fashion; on trucks picking up shipments at the warehouse, the model operates in a pull fashion. All trucks are created by the simulation based on pre-defined events holding the historical or planned timeslot of the trucks. The ULD control is a special case since it only applies for shipments arriving in ULDs in import or shipments to be packed on ULDs in export. In Import, it is triggered by the push of an ULD arriving at the warehouse; in export, it is triggered by the pull of an approaching latest acceptance time limit when the finished ULDs leave warehouse.

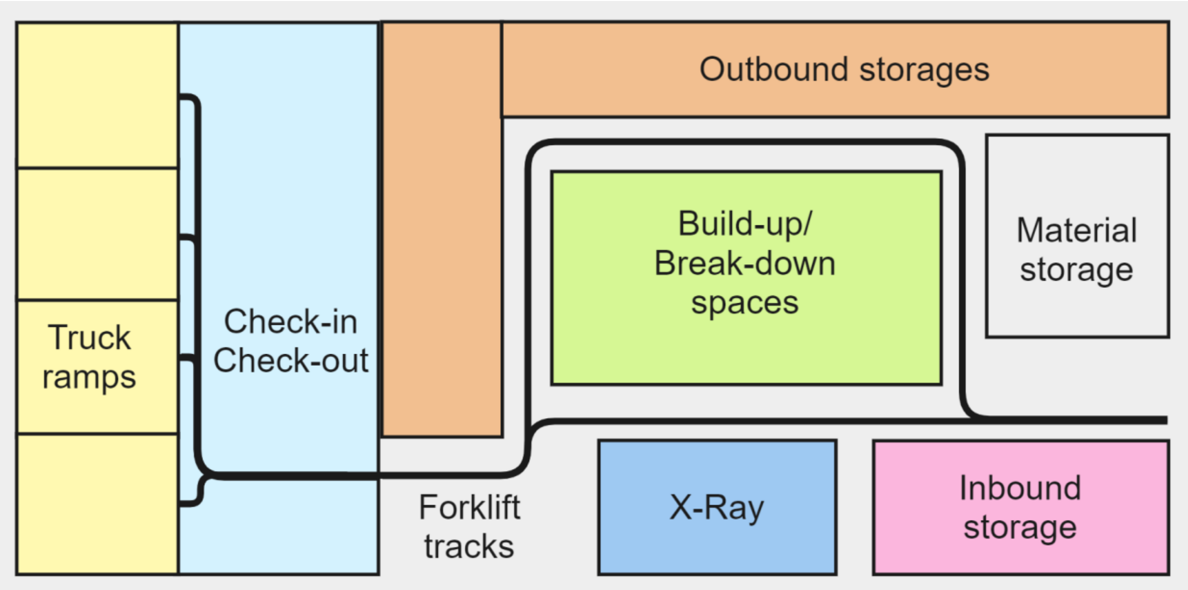


Figure 7: Schematic depiction of the model layout (Source: authors representation)

The warehouse covers consolidation and deconsolidation, loading and unloading, security screening, storage processes and the movement in-between stations. The processes are triggered through the abovementioned control units. Processes take time and require resources that are restricted, such as space at any station or labor for all processes except storage. Figure 7 depicts the model layout. As a core feature, the model portrays the build-up and break-down processes in high detail, including retrieving/collecting, composing/decomposing, and netting. Furthermore, it comprises four truck ramps that are used for incoming, outcoming and airport-internal trucks interchangeably. Pieces are stored in 28 sub-storage spaces based on forwarder company and flight destination or origin. Security screening including dark alarms through X-Ray, sniffing and explosive detection dogs is included. Each process happens in dedicated areas of the warehouse, which are connected through forklift tracks. The operation of movement by forklift as well as labor is controlled by shift plans.

The model is capable of realistically depicting warehouse KPIs. This includes the throughput in terms of AWBs, total weight and total pieces; Truck dock occupation and truck waiting times; Workforce and forklift utilization. These model-produced KPIs were used for data-based validation based on reporting data from February and March 2023. Additionally, the model and its parametrization were visually validated by the warehouse operator.

The current model operates on historical data of 32,694 pieces of export and import freight handled in February 2023 by the depicted company. It originates from six partially independent data pools (cf. table 1) and includes, next to the shipment information, also trucking data. Due to redundancies, the total dataset has some duplicate and contradictory information. On the contractual side, the pieces are consolidated as 8,879 house air waybills and 3,923 master/direct air waybills. The dataset includes relevant meta data in form of weight per piece, the time and type of performed security checks and an indicator for build-up/break-down as well as forwarder, airline company and flight destination. On the physical side, information of 1,611 trucks from forwarders and 1,175 airport-internal trucks is part of the dataset with their onload described on a per-house air waybill level.

Data set	Relevant content	1R 3.0.0 classes used
AWB data	AWB number, flight destination, ULD indicator, forwarder, carrier	Waybill, Location, LogisticsService, ActivitySequence, UnitComposition, Party, Company
Warehouse receipts export	Pieces, HAWB number, AWB number, gross weight, store-in date, store-out date, external truck number, internal truck number	Piece, Shipment, Waybill, Value, Storing, Storage, Loading, OtherIdentifier
Warehouse receipts import	Pieces, HAWB number, AWB number, gross weight, store-in date time, store-out date time, external truck number, internal truck number	Piece, Shipment, Waybill, Value, Storing, Storage, Loading, OtherIdentifier
Security checks	Pieces, security check type, security check date time	Piece, Check
External trucks	External truck number, registration date time, loading/unloading date time	Loading, TransportMovement, Location
Airport internal trucks	Internal truck number, loading/unloading date time	Loading, TransportMovement, Location

Table 1: Dataset and mapping to ONE Record classes (Source: authors representation)

The semantic layer operates on the ONE Record Datamodel 3.0.0 RC4 and comprises 1,431,595 RDF triples. With the data only present in csv files, custom pipelines were developed to convert and clean the input data. GraphDB was chosen as database software. During conversion of the six datasets into a combined ONE Record graph, 52 different properties and 18 different classes were used. The mapping to the logical data model of figure 4 is listed in table 1. Communication between GraphDB and external ONE Record servers has been successfully trialed, but not implemented yet. At the current stage it is of little value due to the as per time of writing still changing API specifications and the lack of real available ONE Record data.

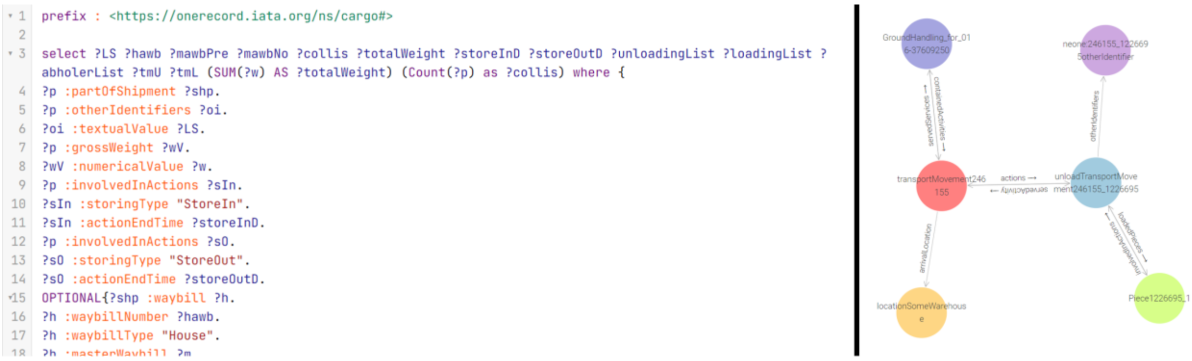


Figure 8: Sample SPARQL query and excerpt of the total graph (Source: authors representation)

A set of dedicated queries retrieve simulation-relevant data using the RDF4J-SPARQL endpoint of the database software is used on a per-element level. A sample query and an excerpt of the data structure is provided in Figure 8. The queries run on simulation start, retrieving and converting data into simulation-understandable tables within seconds. Truck dock elements are fed with load lists and information about the consolidation state of pieces (on ULD or loose). The storage area and security checks are operating on piece-level information about the destination and to-be-performed checks. Build-up/break-down processes are triggered by build-up and break-down plans. In contrast to directly feeding the elements with data from the six sub-tables, using ONE Record ensures the elimination of contradictory information as a single source of truth. Furthermore, implementation of the standard for operating a simulation model proved to be very simple in comparison to complex analyses of proprietary data formats from handling systems.

3. RESULTS

Based on the 1R-transformed input data the utilization of resources, process and waiting times and storage levels can be retrieved from the simulation to optimize the forwarder operation (e.g. reduce the number of staff or to achieve more constant storage levels).

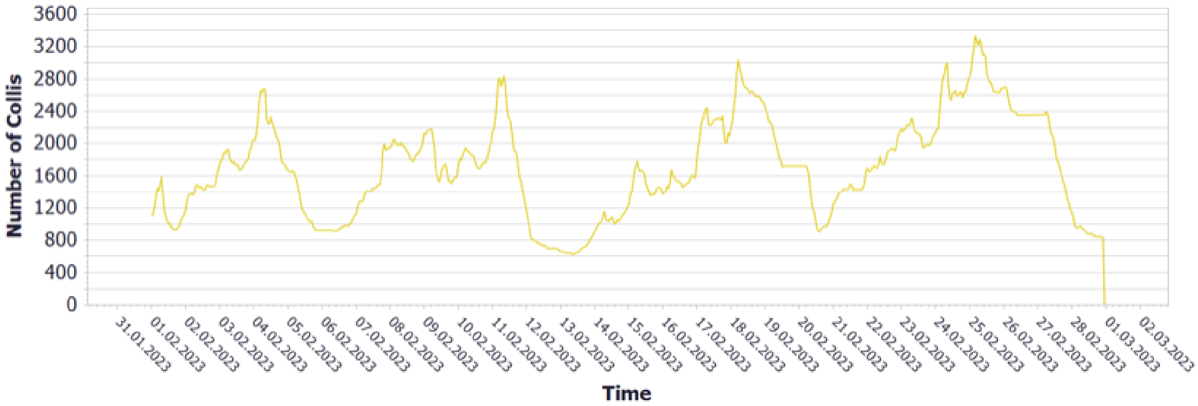


Figure 9: Number of pieces in storage (Simulation results - Source: authors calculations)

For the scope of this paper, we focus on processes and events that are visible in 1R while representing valuable information for downstream supply chain partners.

In the outbound process the start of the build-up process (B/U) can be identified in 1R when an AWB is linked with an ULD. BUPs (Built-Up Pallets) thereby represent ULDs that are build-up at the forwarder. Today, the ground handling agent as the downstream supply chain partner gets a transport order once the B/U is complete and the finished ULD is ready to be picked up at a designated handover area. Based on our simulation results the ground handling agent would be informed about upcoming ULDs (which will be transport orders once finished) at least 15 minutes earlier then today for more than 85% of the ULDs. For 40% of the ULDs the advantage is 30 or more minutes (Figure 10).

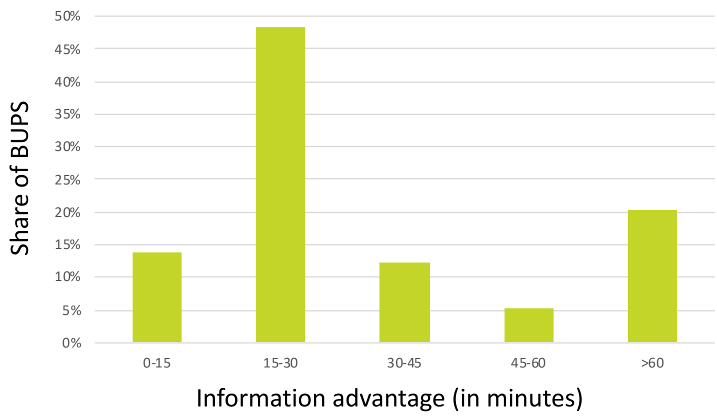
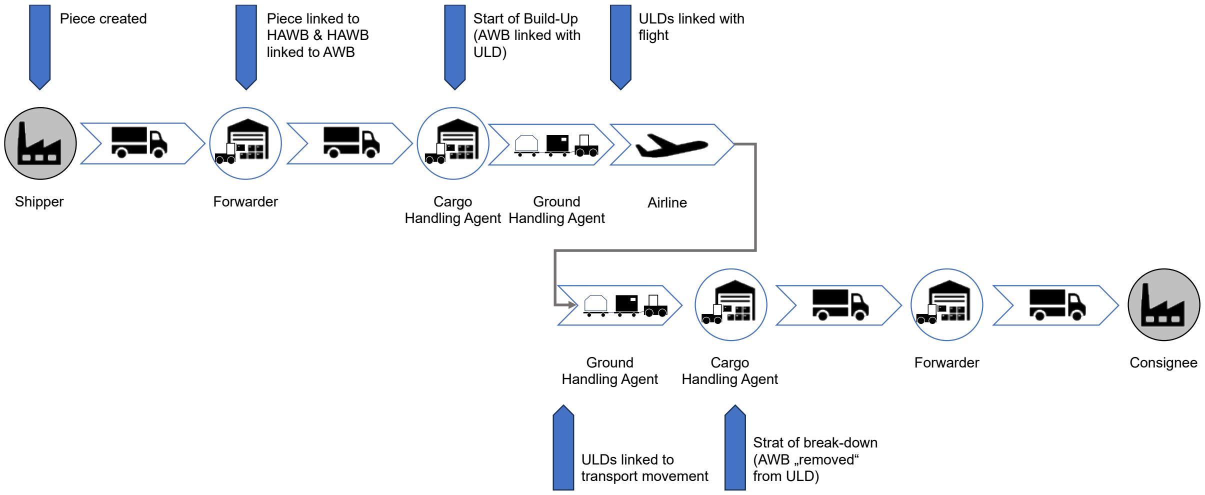


Figure 10: Information advantage based on the identification of a started B/U (Simulation results - Source: authors calculations)

4. DISCUSSION

The forwarder hub simulation model shows potential benefits for the downstream supply chain partner, in this case the ground handling agent. As consolidation and deconsolidation activities are transparent in 1R, these events indicate the future workload for the downstream partner and allows for a better resource planning and allocation. A sample of relevant (de-)consolidation events is shown in Figure 11.



The methodology and architecture used for the forwarder hub can be easily extended to the

Figure 11: Sample of relevant de-/consolidation events in the air cargo transport chain (Source: authors representation)

full air transport chain. The other processes can be derived from IATA's MOP if more detailed information is not available.

Related to the most important partners next to the forwarder model a model for the air cargo handling agent (e.g. the warehouse where the airline handling takes place) and a model for the ground handling agent need to be developed. While an overarching model which covers the whole air transport chain is relevant for scientific research and to analyse effects and impacts at the various partners, from an industry perspective separated models are preferable as only the respective partners know their available resources and can decide about their operational strategies to cope with bottlenecks or peaks.

Beside the benefits from a short-term workload prediction (for all partners, based on different processes) the digital twin serves all use cases of classic simulation approaches: Users can assess the impact of process automation, autonomous vehicles, and different operational strategies.

4.1. LIMITATIONS

As One Record data and structures are not available today, the twin reflects potential benefits which cannot be validated as a direct comparison is not possible. To feed the twin with 1R-style data, existing shipment data had to be transformed according to the 1R data model. It is thereby assumed that all the data used will be available in 1R.

The concept assumes full adaption of the new standard by all major forwarders and airliners. Being an international business, it is understood that adaption speed will differ and it has to be seen which share of non-adopters is acceptable to still be able to calculate benefits.

The research focuses on the classic, forwarder-driven air cargo transport chain and is not applicable to integrator or airmail operations. The model reflects the processes at an European air cargo hub and is based on IATA's MOP. Different processes and structures could apply at other airports. Additionally, effects from bottlenecks or otherwise limited resources which impact the process and lead times have so far not been regarded.

5. CONCLUSION

Due to the structures in air cargo transport chains information exchange is important. 1R has the potential to serve as an industry-wide standard that contains all relevant data elements. This data can be used to feed digital twins of the complete or partial processes in the air transport chain (e.g. of one partner) without the need to connect multiple legacy systems or IT-systems of other partners.

As 1R servers, data exchange and respective data are not available, because the new standard is still in development, shipment data from a forwarder hub had to be transformed into 1R-style data first. The data was transformed into RDF triples and stored in a GraphDB. The data was retrieved with SparQL and inserted into a standard simulation software.

It could be demonstrated with the digital twin of the forwarder hub that valuable information – here workload prediction – could be derived from 1R data which helps the downstream partner – the ground handling agent – to create an event-based short term workload prediction (which allows for a more efficient resource allocation). Based on the results the ground handling can achieve an information advantage of 15 minutes for 85% of all ULDs or even 30 minutes for 40% of all ULDs.

With the help of the planned integrated digital twin further use cases can be analysed and the results for other supply chain partners and processes evaluated.

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