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Improving landside operations of an air cargo terminal

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Abstract

This paper deals with the triplet issue of shipment consolidation, route planning and capacity-constrained pick-up and delivery nodes, due to a limited number of loading/unloading docks, with dynamic and stochastic arrivals of goods to an air cargo terminal. Because of the complexity, interconnection and interdependency of all three problems, a policy-based approach for solving the system-wide problem is considered. Results from a discrete-event simulation model show that a policy based on consolidating shipments from the point of view of the ground handlers, which are the nodes with the highest workload, is the policy with the best compromise between total distance travelled and average shipment throughput times.

Keywords: air cargo hub; city-logistics; shipment consolidation; third-party logistics

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1. Introduction

Airports are one of the most critical nodes in international trade networks as well as critical hubs for the economic development of a country. Since international airports concentrate a great proportion of cargo value flow into and out of a country (35% of global cargo flows based on value – IATA 2017), the operational performance of an airport is a key factor in the logistic capabilities of a nation and, consequently, in the competitive advantage of a country with respect to other nations (The World Bank, 2018).

In Europe, the proportion of weight moved by air is 0.8% compared with the 26.7% value of goods of all transport modes (European Comission, 2018); for this reason, airports attain added value with logistics operators with a better flow of goods, i.e. shorter throughput times, instead of exclusively through price competition. Thus, it is increasingly important for international cargo airports to improve their performance in terms of throughput times without a high impact in the costs of moving cargo through their facilities.

Air cargo hub operations (air cargo terminal operations – Feng et al., 2015) can be divided into two main systems: the landside and the airside. Landside operations deal with the interchange of cargo between logistics operators and the airport's ground handlers (GH), which receive cargo from the landside, sort the cargo and then deliver it to the corresponding aircraft (the airside). Landside operations are notoriously difficult to manage as they are comprised of various interconnected and interdependent processes and many agents with possible conflicting goals, as it will be explained in the next section. Because of this, many studies have investigated some parts of the problem in a separate manner, e.g., logistics provider freight consolidation (Leung et al., 2009) or truck scheduling in ground handler terminals (Ou et al., 2010); however, to the best of our knowledge, a systems-wide investigation of the landside air cargo terminal operations has not been developed.

This study is concerned with investigating how can the operations in an air cargo terminal be improved considering a systems-wide perspective, in contrast with an actor-oriented perspective. Owing to the complexities and characteristics of the problem, this system was modelled using discrete-event simulation, whereas some dynamic policies of shipment consolidation and resource sharing were considered to improve the performance of the system, since a static-deterministic optimization approach was deemed inapplicable to solve such a dynamic and stochastic environment.

The remainder of the paper is organized as follows. In Section 2 a description of the problem in hand is developed. Section 3 presents a short review of the literature related to this study. The methodological approach of the study is explained in Section 4. Section 5 shows the results of the simulation study, while Section 6 presents the discussion and conclusions of the paper.

2. Problem description

Outbound Shipment

It is a shipment arriving to the terminal by land and leaving by air. An outbound shipment could arrive to the air cargo terminal through two main channels.

- The first one is via a logistics operator with no physical presence within the airport – external logistics operator (ELO). These shipments arrive in a truck directly to the ground handlers’ terminals where they wait for documentation revision and unloading dock assignment. After the dock is assigned, the truck is parked in the dock and the shipment is unloaded and stored in the GH’s warehouse until the sorting of shipments for the airside takes place.
- The second channel is via a logistics operator with warehousing facilities inside the airport – internal logistics operator (ILO). When a shipment comes through an ILO, it first arrives to the warehouse of the ILO for further consolidation. ILOs need this final step of consolidation because they deliver shipments to different locations (depending on the number of GH) in some airports and, thus, the final route for different shipments can vary, depending on the needed time of delivery (related to flight departure time) and the final delivery point. Therefore, whenever the shipment is ready for delivery, an ILO-operated truck is dispatched to the corresponding GH for delivery, where it must wait for documentation revision and unloading dock assignment, after which the truck is parked and then unloads the shipment.

Inbound Shipment

It is a shipment coming to the terminal by air and then departing by land. For these types of shipping, also the previous two channels operate.

- In the case of inbound shipments using an ILO, the trip is inverse: after the shipment is ready to be picked-up from the GH warehouse, it waits for an ILO-operated truck to be picked-up. An ILO-operated truck will be dispatched to pick-up a shipment, depending on the urgency of the shipment or on an already programmed visit to that specific GH location. Then, the ILO-operated truck will wait to be assigned a loading dock, park in the dock and load the shipment, after which the shipment will travel to the ILO warehouse to be stored, sorted and further consolidated for its next destination outside the airport.
- In the case of an ELO shipment, it will only be picked-up by a truck and then leave the airport for a long-haul trip, with the corresponding visit (and waiting) to the GH’s loading docks.

Following this description, the problem of the landside operations of an air cargo terminal can be described by the dual problem of the planning of the ILO routes for picking-up and delivering shipments while also managing the workload in the GH’s docks. It is like this since very frequent routes between ILO and GH warehouses, i.e. minimal consolidation, could result in a higher workload for the docks and more travelling costs due to multiple visits; whereas a reduced dock workload and transportation costs could result from more infrequent routes, i.e. more consolidation, but with the trade-off of higher throughput times and possible late deliveries.

Adding complexity to the problem, inbound and outbound arrivals both from ELO and ILO shipments arrive to the system in a dynamic and stochastic manner as some of the shipments arrive unannounced and some others, despite a previous announcement from the logistic operators, arrive at different times and weights than previously announced. Thus, the management of the landside operations of an air cargo terminal is comprised as three interconnected decisions:

i. The frequency of the routes moving cargo between ILO and GH warehouses depending on a trade-off between consolidation efforts and throughput times: the shipment consolidation problem at one node (Satır et al., 2018).
ii. A decision of the actual routes travelled by the truck fleet to pick-up and deliver the shipments: the dynamic vehicle routing problem with pick-ups and deliveries (Berbeglia et al., 2010).
iii. The management and modeling of workload in the ground handlers' loading/unloading docks (see Selinka et al., 2016), considering docks as capacity-constrained resources.

So, all in all, this specific problem could be defined as a dynamic vehicle routing problem with stochastic demands (D-VRPSD – Pillac et al., 2012) with pick-ups and deliveries (PDP), capacitated nodes (number of docks is finite and service times need to be considered) and consolidation decisions.

3. Related literature

As previously mentioned, landside air cargo terminal operations are a set of interconnected, separate problems. However, since no study has considered these problems conjointly, this section will review some of the papers that have tackled each one of the pertaining problems individually in order to better understand the nature and complexity of the problem and summarize previous findings.

The most traditional approach for solving problem (i), has been to use a decision policy for a non-capacitated vehicle dispatching based on three shipment-consolidation policies: quantity, time and time-quantity (Higginson and Bookbinder, 1994). In a quantity-based shipment consolidation policy, the decision of whether to dispatch a vehicle is taken based on the amount of weight or units, e.g., boxes that have been accumulated to be transported until the decision point. It is highly related to the economic order quantity. On the contrary, a time-based policy depends on the time that has passed since the decision period began, e.g., since the beginning of the day or since the last vehicle dispatch; therefore, a vehicle is only dispatched when a specific period has been reached. Vehicles are dispatched with the available consolidated shipments depending on which of the two thresholds, i.e. quantity or time, is reached first.

Most of the literature that has studied these shipment-consolidation policies (Bookbinder and Higginson, 2002; Çetinkaya et al., 2006; Çetinkaya and Bookbinder, 2003; Higginson and Bookbinder, 1994; Mutlu et al., 2010) agree that the quantity-based policy is superior in terms of cost minimization than the time-based policy in most instances (even when considering two classes of customers with different priorities – Satır et al., 2018) as this policy finds a good trade-off between inventory holding costs and transportation costs (caused by the number of dispatches). However, some studies have suggested that a time-quantity combined policy could have a better performance in terms of maximum waiting times and average order delay (Çetinkaya et al., 2014) than the quantity-based policy, as it has been found to have a subpar performance in terms of customer satisfaction due to late and long delivery times.

Using Battarra et al.'s (2014) classification, most of the studies concerned with problem (i) have focused on 1-1 problems, where only one product and commodity needs to be transported from one origin to one destination, although, in general, the actual trip to the destination is not modelled and only the decision in the origin point is taken into account. A notable extension to this simple problem can be found in Cook and Lodree (2017), where they suggest some simple rules-of-thumb for a 1-1 shipment consolidation problem with a capacitated vehicle:

- Dispatching the vehicle to the origin node when it is at the destination node is always optimal.
- Clearly, if the vehicle is already full at the origin point, it is optimal to dispatch it; whereas if no inventory has accumulated at the origin, there is no advantage on dispatching it.
- Whenever average supply (at the origin node) is greater than demand (at the destination node), a continuous dispatching policy is optimal, i.e. no vehicle idle times.

- Whenever average supply is sufficiently greater than demand or vehicle capacity is small enough to be insufficient to transport all the supply, a full-truck load policy is optimal, i.e. when a full-truck load policy is equivalent to a continuous dispatch policy.

Problem (ii), on the other hand, has been generally studied with an optimization approach by building routes for delivering and picking-up products in a set of nodes using one or many vehicles in order to optimize an objective function, commonly associated with minimizing transportation costs, i.e. distance travelled. While most of the research has focused on a deterministic and static problem (Braekers et al., 2016), stochastic and dynamic VRP are more relevant for the current practice and for this current study as transport requests arrive dynamically to a variety of logistic systems and the actual demand to be transported from point to point and the nodes to be served are random variables.

According to Pillac et al. (2013), dynamic problems have been solved with different solution approaches. Considering a dynamic but deterministic scenario, previous work has used both periodic and continuous re-optimization strategies to cope with the dynamism of the problem. While periodic re-optimization uses a static approach to generate routes at decision intervals, continuous re-optimization generates routes every time the state of the system changes, e.g., a new order arrives. Thus, as continuous re-optimization constantly updates the routes of each vehicle with the latest information, this approach could be difficult to implement in some environments, as the vehicle only knows the next route whenever they have finished their current request.

When considering a dynamic and stochastic VRP, Pillac et al. (2013) conclude that authors have focused on three main strategies. The first strategy is stochastic modelling using Markov Decision Processes which consider preprocessed decision policies (Ritzinger et al., 2016) based on the stochastic and dynamic characteristics of the problem. The second strategy is based on sampling of possible future scenarios, where routes are planned based on the probability of the realization of future demand in some pre-defined nodes. In this way, the route is planned based on the actual demand but incorporating a route that is better optimized to (possibly) insert a new visit in case it is needed. The third strategy is based on operational rules which can be easily implemented as rules-of-thumb in real life, much like the rules suggested by Cook and Lodree (2017). For instance, deciding under which conditions should a vehicle wait in a node, e.g., a strategic location, before moving to the next request in order to service a possible future demand realization or deciding whether to relocate the vehicle to a different critical location (see, e.g., Bélanger et al., 2016).

Whereas research focused on both shipment-consolidation problems and VRP has mainly studied the problem considering a single firm, e.g., third-party logistic companies (Tyan et al., 2003), another stream of research has tried to understand the impact of logistic operators collaboration to increase firm-wise and system-wise performance. As it is based on the concept of resource pooling (Cattani and Schmidt, 2005), multiple research has found advantages in inter-firm collaboration (Ankersmit et al., 2014; Montoya-Torres et al., 2016; Nadarajah and Bookbinder, 2013; Serrano-Hernandez et al., 2017; Yilmaz and Savasaneril, 2012) in terms of transportation (and environmental) costs, vehicle utilization and even travelling times. Despite this operational performance advantages, inter-firm collaboration is still difficult to implement as the degree of collaboration, and allocation of costs and risks per firm are complex problems to manage (Gansterer and Hartl, 2018).

This short revision of solution approaches to problem (ii) show that, despite the fact that this problem has been extensively studied considering realistic characteristics such as dynamism, stochasticity, inventory routing with pick-up and deliveries (see Archetti et al., 2018), capacitated vehicles and even many loading constraints (see Pollaris et al., 2015), previous efforts have not considered that loading and unloading tasks are resource-constrained and that it might take some time, depending on the amount of weight/pieces (Cook and Lodree, 2017), to carry out a pick-up or delivery task.

Thus, to the best of our knowledge, no study has considered problem (iii) in the context of a shipment consolidation and pick-up and delivery problem. The only exception to this assumption comes from the work by Zhang et al. (2018, 2014) where they studied the dynamic orienteering with stochastic servicing times dependent on the corresponding network queues. In this problem, Zhang et al. (2018, 2014) consider a travelling agent that needs to visit different nodes in the network to collect rewards, but it has a time limit to reach all the nodes to collect those rewards, so it must decide which nodes to visit (or balk) depending on the length of the queue or the length of stay at a node. In 2014, Zhang et al. modelled the average stay times dependent on queue length based on the results of off-line simulation experiments; whereas in 2018 they modelled the average stay times using discrete-time Markov Chains.

Overall, it can be concluded that the problem at hand, i.e. the operations in an air cargo terminal, has not been studied considering all the interconnected and interdependent processes relevant for a good performance of the cargo terminal. Therefore, it is felt that developing a modelling framework in which this problem can be studied can deliver a good starting point for investigating the relevance of different operational policies to increase the competitive advantage of air cargo terminals.

4. Methodological approach

Because of the complexity and dependency of the various landside processes in an air cargo terminal, this overall problem is very difficult to model with an analytical approach. There are multiple shipments arriving to various locations that need to be delivered to different destinations arriving dynamically and stochastically, in terms of quantity (weight) and origin-destination pairs. Furthermore, nodes are capacity-constrained as the number of docks is finite and loading and unloading times depend on the type of container where cargo is carried and on the quantity of cargo that is being handled. Similarly, vehicles have a capacity constraint that cannot be exceeded. Owing to this complexity, it was deemed that discrete-event simulation was the best modelling paradigm to represent this complex system as it can model capacity-constrained resources and represent stochastic and dynamic events. Furthermore, as a base case example to assess our model and solution proposals, we consider here the cargo terminal of Schiphol Airport in Amsterdam.

Next, we describe the characteristics of the model as well as the tactical approaches used to dynamically manage this complex system.

4.1. Model description

The landside of the cargo terminal of Schiphol Airport has five different ground handlers operating in the facilities of the airport (Air Cargo Netherlands, 2018). Thus, both ILO and ELO pick-up and deliver goods at those five different locations take place. Furthermore, more than 100 logistic operators work with airlines departing and arriving to Schiphol while several individual trucking companies service those logistic operators. Because of the difficulty to manage and control all these firms to improve operations, it was decided to divide shipment arrivals into two stream categories depending on the degree of operational control that can be implemented into the firms: ILO shipment arrivals and ELO truck arrivals. ILO shipment arrivals are shipments that arrive at the airport via the most important ILOs operating within the surroundings of Schiphol airport, based on the total number of inbound and outbound Air-Way Bills (AWB).

ILO shipment arrivals were modeled in this study as individual AWBs arriving to ILO’s warehouses to be further consolidated and transported to the corresponding GH destination (and vice-versa). Thus, five ILOs were selected to be modeled in this category as they represented 16% of total cargo flow. Based on historical data, it was calculated that outbound AWBs pertaining to one of these five ILOs arrive every 6.44 minutes, on average, to the terminal while inbound AWBs arrive to the terminal every 2.34 minutes. Both outbound and inbound inter-arrival times were modelled as random arrivals with exponential probability distribution. Each ILO AWB was also randomly assigned an arrival node and a destination node, depending on historical information of the flow between ILOs and GHs and vice-versa. Furthermore, as most of the times actual weights are not reported before arrival to the air cargo terminal, the weight of an AWB was also modelled as a random exponential variable, with a mean of 272 kg. for outbound shipments and a mean of 684 kg. for inbound shipments.

All other inbound/outbound cargo was modeled as ELO cargo, represented in the model as truck arrivals with random arrival times and random percentage of load. Truck arrivals occur with a time-varying Poisson mean arrival rate (Green et al., 2007) that depends on both the weekday and the hour of the day (see, Selinka et al., 2016; Yan et al., 2008) due to work shifts by both trucking and handling companies as well as flight schedules. Data from Schiphol showed that the average number of trucks arriving per day to deliver shipments to the air cargo terminal (including the five GHs) was 465, excluding the trucks that brought ILO AWBs; whereas the average number of trucks arriving to pick-up shipments was 384, also excluding trucks with ILO-managed AWBs. Truck arrivals were then modeled following the time-varying pattern dependent on hour and day but taking into account the average number of trucks arriving per day. Moreover, ELO truckloads (weight of all the shipments) were modeled as triangular random variates with a mode of 5 tons, a minimum parameter of 0 tons, and a maximum parameter of 10 tons, due to the maximum practical weight normally transported in this cargo terminal.

Since the most common type of truck used to move cargo is the semi-trailer with dimensions 13.6 x 2.48 x 2.80 m., it was considered as the single type of truck to move cargo within the model. Based on experts' feedback regarding the typical density of the goods transported in Schiphol air cargo terminal, it was deemed that the maximum weight load used with combined cargo was 10 tons (the actual maximum load was limited by the volume of the goods, not the weight). ILO AWBs were always assumed to be packaged as combined cargo while ELO shipments were assumed to be either transported as ULDs, standard Pallets or combined packaging. Thus, the truck loading and unloading times depended on the type of container used to transport the goods and on the weight of the shipment/AWB that is being (un)loaded. Table 1 shows the rules used to calculate the (un)loading times depending on the type of shipment and container. ELO maximum (un)loading times were modeled following experts' advise while ILO maximum times were taken from the work of Burdzik et al. (2014). Despite the fact that it has been shown that truck loading takes more time than unloading (Burdzik et al., 2014), for this exercise it was assumed that loading and unloading required the same effort.

Table 1. Loading/unloading times per type of container

Type of shipment	Type of container	Loading/unloading times
ILO	Combined	Weight/MaxWeight x 30 min
ELO	ULD	Weight/MaxWeight x 15 min
ELO	Pallet	Weight/MaxWeight x 60 min
ELO	Combined	Weight/MaxWeight x 120 min

Finally, the number of docks per GH was also modeled to represent the capacity-constrained reality of the air cargo terminal. The number of docks per GH is shown in Table 2. The number of loading/unloading docks was equal to five for all ILOs.

Table 2. Number of loading/unloading docks per GH

GH	Number of Docks Outbound	Number of Docks Inbound
1	23	23
2	43	43
3	22	
4	11	
5	7	10

4.2. Tactical approaches

The conjoint management of three interconnected and interdependent problems presented in Section 2 could be an unfeasible task if each problem is solved individually by the traditional approaches shown in Section 3. Therefore, this study selected a more practical approach to solve this problem based on a simple mechanism taking into account that control for ILO-operated shipments is easier to implement than ELO-operated goods as collaboration. One of the key components for improving the operations of an air cargo terminal, can be implemented with a small set of actors working within the facilities of the air cargo terminal, instead of the whole set of firms involved in these operations.

Following the ideas of shipment-consolidation policies, the economic shipment weight (ESW) notion (Higginson and Bookbinder, 1994) was used to decide whether to ship a specific set of consolidated shipments at specific nodes considering full collaboration between the five main ILOs. The ESW is a notion that is equivalent to the Economic Order Quantity in inventory management that tries to find a balance between holding costs and transportation costs (the cost of sending a shipment). ESW is calculated in the following manner:

$$ESW = \sqrt{(2DSW/h)} \tag{1}$$

Being that
D – average shipment demand rate in the period
S – transportation (shipping) costs
W – mean weight per shipment/AWB
h – inventory holding costs (including costs of high throughput times)

For this particular exercise, S was considered to be 50 times higher than h. The mean weight per shipment was dependent on whether the AWB was outbound (272 kg.) or inbound (684 kg.). The demand factor, on the other hand, was calculated based on three different consolidation policies while considering full collaboration, in terms of both information and vehicle sharing, between GHs and ILOs: GH-based, ILO-based and node-to-node. A GH-based consolidation policy takes into account all the shipments that are waiting to be picked-up at a single GH location (for inbound) to be transported to multiple ILO nodes or that are waiting to be delivered at a single GH location from (possibly) different ILO locations (for outbound). For instance, throughout any given day, outbound AWBs destined to be delivered to GH1 will start accumulating at the warehouses of the five ILOs until the ESW is reached, considering a typical demand of all outbound AWBs passing through GH1. At that moment, an instruction to all ILOs will be sent to prepare all their available shipments that need to go to GH1 and a truck will be dispatched (if available) to visit all ILOs' warehouses to pick-up the shipments and then deliver them to GH1. The management of inbound shipments for this policy is easier as each GH only needs to control the total accumulated weight at their warehouse and send a truck to the different ILO locations every time the ESW is exceeded.

An ILO-based policy, on the other hand, tracks all the shipments that are waiting to be transported from a single ILO location to (possibly) multiple GHs (for outbound) or that are waiting to be picked-up at multiple GH nodes and be delivered to one single ILO location. For example, the total weight of inbound shipments destined to depart from the air terminal through ILO1 will be monitored in the warehouses of the five GHs and when the ESW, considering the expected flow of inbound AWBs per hour through ILO1, is surpassed, then GHs will receive an instruction to prepare all the shipments that need to be delivered to ILO1 and a truck will be dispatched to visit the corresponding GHs and deliver the shipments to ILO1.

Finally, a node-to-node consolidation policy considers only the demand between one single GH node and one single ILO node and vice-versa. Thus, every time a node-to-node based ESW is reached, a shipment will be prepared and wait to be picked up. A truck will be dispatched to pick-up a set of either inbound (from GH) or outbound (from ILO) shipments whenever a truck can be fully loaded. This policy was modeled to represent the equivalent of traditional pick-up and delivery solutions where pick-ups and deliveries are made irrespective of the relation between origin and destination nodes. To complete the set of policies, a full-truckload (FTL) node-to-node consolidation policy was also considered where shipments will only be prepared when a full-truck can be loaded with a single trip from one pick-up location to one delivery location. Clearly, this last FTL policy will have the best overall performance in terms of total distance travelled because it will complete fewer trips than all the other policies.

Considering truck dispatching, trucks will service shipment calls following a FIFO discipline and the order of visit of pick-up and delivery nodes will depend on the shortest distance first discipline. Furthermore, this study considers full collaboration between the agents by the sharing of complete AWB information and warehouse status and by the sharing of five semi-trailers, which are the total number of trucks currently used by all the ILOs combined, i.e. one truck per ILO. It is worth noting that while only five shared semi-trailers move cargo between GHs and ILOs, this model also considers all the other flow of trucks coming from ELO. So, most of the workload in the GH docks is due to ELO-operated trucks.

4.3. Experimental setting

The Simio 64 bits simulation software (Kelton et al., 2014), version 10.165, was used to build this model. Results from the steady-state of this system were of interest for this study, so transient results from the simulation runs were discarded, considering that 10 days of warm-up period (Welch, 1983) represented the initial transient state. Results were then collected for simulation runs of length 30 days. Each simulation run was replicated 5 times to build confidence intervals for the results. Four consolidation policies were considered as experimental factors: node-to-node full-trucks, GH-based consolidation, ILO-based consolidation and node-to-node consolidation. Finally, six responses were measured:

- Total distance travelled: the sum of the distances travelled by all the shared trucks moving cargo between GHs and ILOs and vice-versa.
- Throughput time of outbound ELO-operated shipments (TT_OUT_ELO): The total time of stay of a shipment in the landside air cargo terminal between the moment an ELO-operated shipment arrived at the vicinities of the airport and the time it was unloaded into the GH's warehouse.
- Throughput time of outbound ILO-operated shipments (TT_OUT_ILO): The total time of stay of a shipment in the landside air cargo terminal between the moment it arrived at the ILO's warehouse and the time it was unloaded into the GH's warehouse.
- Throughput time of inbound ELO-operated shipments (TT_IN_ELO): The total time of stay of a shipment in the landside air cargo terminal between the moment an ELO-operated shipment arrived at the GH's warehouse and the time it left the vicinities of the airport in a truck.
- Throughput time of inbound ILO-operated shipments (TT_IN_ILO): The total time of stay of a shipment in the landside air cargo terminal between the moment an ILO-operated shipment arrived at the GH's warehouse and the time it was unloaded into the ILO's warehouse.
- Waiting time for an outbound shipment to be consolidated in an ILO's warehouse (Wait_ILO): The time between the arrival of an ILO-operated shipment to the ILO's warehouse and the time it was ready to be picked-up for transport to its final GH destination.
- Waiting time for an inbound shipment to be consolidated in a GH's warehouse (Wait_GH): The time between the arrival of an ILO-operated shipment to the GH's warehouse and the time it was ready to be picked-up for transport to its final ILO destination.

It is worth noting that shipment preparation and sorting times in both GH and ILO warehouses were considered as zero in this study.

5. Results

A summary of the experimental simulation results is shown in Table 3. As expected, following a policy of FTL resulted in the best performance for total distance travelled but a significantly bad performance in terms of throughput time for ILO-operated shipments as well as shipment-consolidation waiting times. Interestingly, FTL resulted in the lowest TT_OUT_ELO, a result that could be caused by a reduced number of visits from shared trucks to GH docks caused by full consolidation of shipments.

Table 3. Average response results and their 95% confidence intervals (in parenthesis)

Response	FTL	GH-based	ILO-based	Node-to-node
Total Distance Travelled	22,655 (22,372, 22,938)	40,366 (40,024, 40,708)	41,107 (40,809, 41,405)	32,597 (32,281, 32,912)
TT_OUT_ELO	0.936 (0.929, 0.942)	0.942 (0.933, 0.950)	0.937 (0.929, 0.945)	0.939 (0.928, 0.950)
TT_OUT_ILO	38.816 (37.760, 39.871)	6.132 (5.706, 6.558)	6.584 (6.414, 6.755)	16.370 (16.062, 16.679)
TT_IN_ELO	1.133 (1.127, 1.138)	1.135 (1.128, 1.142)	1.134 (1.128, 1.140)	1.132 (1.126, 1.139)
TT_IN_ILO	6.943 (6.857, 7.028)	2.151 (2.139, 2.164)	2.254 (2.235, 2.273)	4.040 (3.996, 4.083)
Wait_ILO	40.648 (39.245, 42.051)	5.705 (5.234, 6.176)	6.073 (5.923, 6.222)	13.515 (13.172, 13.858)
Wait_GH	10.389 (10.090, 10.688)	2.049 (2.024, 2.073)	1.584 (1.555, 1.613)	4.317 (4.219, 4.415)

However, the GH-based consolidation policy had a good performance, overall, in terms of ILO-operated shipments, as TT_OUT_ILO, TT_IN_ILO and Wait_ILO were reduced with this consolidation policy. This result was attained because the GH-based policy considered an ESW based on single GH demand, which is aimed at finding a trade-off between holding and transport costs. Perhaps the main cause of the difference in throughput time performance between a GH-based policy and an ILO-based policy is the fact that visits to GH docks were reduced when applying a GH-based policy as only single visits with moderately loaded trucks were done in one trip to the GH docks instead of multiple stops to different GHs done by one truck when using the ILO-based policy. Furthermore, the GH-based consolidation policy was even more effective than the ILO-based policy in terms of total distance travelled.

The node-to-node consolidation policy seems to be a middle ground between FTL and both GH and ILO-based consolidation policies as its performance in terms of distance, throughput times and consolidation waiting times was between the FTL and the GH/ILO-based policies. This node-to-node policy results in less distance travelled than GH/ILO-based policies because it only dispatches a truck when a full truckload is filled with multiple node-to-node shipments. However, it performs worse in terms of TT_OUT/IN_ILO than GH/ILO-based policies because consolidation is reached quicker in GH/ILO-based policies due to the pooling of multiple node demand.

6. Conclusions

This preliminary study from Schiphol airport cargo terminal shows that shipment-consolidation policies based on the economic shipment weight policy can be used to influence the performance of the landside operations in an air cargo terminal when considering various realistic aspects of the system. In particular, the GH-based consolidation policy was found to have the best balance between travel distances (associated with transport costs and emissions) and throughput times (associated with holding costs), however as it was presented, different objectives are present and it is necessary to establish what factor(s) to be consider in order to have an overall balance.

More research is needed in this regard to more comprehensively assess the impact of these shipment-consolidation polices in interaction with various truck dispatching priority rules and compared with non-collaborative scenarios. Furthermore, a better mechanism to influence the workload in the GH docks needs to be investigated as the policies considered here did not have a significant influence in the throughput times of shipments handled by external logistic operators.

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