Why do slot booking systems still generate time-losses and is there a solution for it?

Unforeseen time-losses in truck scheduling: severity, causes and a conceptual solution

Abstract

Truck arrivals at distribution centers (DCs) follow two main working practices: either working on a first-come-first-served principle or, alternatively, using time slots. While the former results in time losses due to unanticipated waiting time, the latter is expected to generate fewer time losses to compensate for the time spent on beforehand scheduling. Yet, even when a schedule is made, ad-hoc changes still require that sometimes orders are served on a first-come-first-served basis, making the use of slots appear superfluous. This research investigates the reasons why using time slots does not always bring the expected benefits and collects data to measure the time spent on scheduling (planning and dispatching) procedures. To do so, time measurements are carried out to reflect both the duration of each planning procedure (with slots and without) and the operational delays if and when they happen. An in-depth analysis is carried out on data from three distribution centers and five trucking companies that call those DCs. This research shows that, although slot booking systems are in use, they do not always bring the expected time savings. This shortcoming happens due to the incompatibility of the multiple ICT systems in use for slot bookings at different DCs, intermittent unexpected external delays and the variety of rules that need to be met when rebooking slots across DCs. As a follow-up, this research proposes an overarching solution defined as a Dynamic Slot Booking System (DSBS) that can address these issues. The proposed conceptual design of a DSBS makes use of data and algorithms to anticipate ad-hoc changes. This DSBS closes the gap between fragmented information available at DCs for slot use, planning of trucking companies, real-time time delay databases and the operational planning needs. Initial research shows that average-size carriers, running on average 75 trucks, can save between 885 and 992 minutes per day. Moreover, for trucks that arrive later than the planned slots, DCs that handle 72 trucks a day can save daily around 50 minutes of (planning) labor.

1. Introduction

The effects of gate congestion at hinterland warehouses and distribution centers (DCs) are similar to the ones generated within port areas at maritime container terminals. The latter has been well documented by previous research (Torkjazi et al., 2018), through developing heuristic approaches (Huynn et al., 2004; Namboothiri & Erera, 2008), applying mathematical models (Guan & Liu, 2009; Zehendner & Feillet, 2014) for truck appointments allocation (Namboothiri & Erera, 2008; Schulte et al., 2017) and/or switching slot allocation (Huynh, 2009; Azab et al., 2017). Carriers and hinterland distribution centers claim that, despite advances in technology, the number of hours lost annually due to unforeseen traffic jams, changes in planning and waiting time at DCs are continuously rising. Irannezhad et al. (2020) claim that the cooperation between logistics agents in sharing data through centralized information systems can decrease the total traveled distances and total logistics costs, as well as improve vehicle utilization. Yet, this study is limited to this general conclusion and suggests that further quantification of these savings should still be done. Hence, there is limited knowledge regarding the scale of cost increase and no quantification is done to review the value of these losses.

The traditional loading/unloading operations of trucks at DCs are handled on a first-come-first-served rule. This working practice does not plan warehouse workers' availability nor docks' capacity since there is no information at the DC about the timing of the truck arrivals. The planning is done relatively fast on the spot and decisions regarding follow-up orders are taken ad-hoc. This working practice often results in congestion (especially during peak hours) and can create a long waiting time for trucks at the DC gates. Alternatively, during off-peak hours, DC workers are waiting idly. To flatten out the trucks' arrivals, DCs implement slot booking systems where a limit is set on the number of trucks that will be handled. This working practice implies that more time is set in planning operations with the goal of reducing later delays and idling time. In practice, it appears that trucks are not able to respect the slots booked and, although more time is set in planning operations, delays still occur. Moreover, extra time is spent on the follow-up of operations to adapt to the newly-created bottlenecks as well as in the DCs but also for the trucking companies.

Initial inquiries with warehouse managers and planners at road transport companies formed the basis of the research framework. Hence, this research expands on the general conclusions taken from the literature study and contributes further to the problem of why contemporary slot booking systems still (in some instances) do not perform as initially designed. More specifically, this research contributes to the existing literature by the following. Firstly, this research determines the time consumed by current working practices of scheduling, defined as planning and dispatching for truck deliveries and pickups at DCs, for slot-based as well as first-come-first-serve systems. To do so, in-depth interviews are conducted to identify the elements that need to be considered. Secondly, this research inventories the working practices and conducts a quantitative comparative analysis between these practices. The analysis runs through the process of data collection, processing and formulating conclusions. Thirdly, this research provides concrete guidelines on the technical architecture and functionalities of a DSBS. Finally, the use of two case studies provides initial estimations regarding the time savings potential to be brought by a DSBS.

To investigate this topic in-depth, this paper starts from the following research questions (RQ):

- RQ1: What is the time spent by carriers and DCs for planning and dispatching activities for a transport order? How do these durations differ when a slot booking system is in use?
- RQ2: What are the functionalities of an overarching DSBS and how can it be connected to contemporary planning tools?
- RQ3: Which time savings are achieved when an overarching DSBS anticipates on early or late arrival of trucks?

This research is new from two viewpoints: first, it focuses on truck scheduling at DCs; and second, it provides a comparison of the operational implications for planning and dispatching activity when slots are not respected and/or DCs do not work with a slot booking system.

The structure of the paper is as follows. The outcomes of the literature review on research addressing the topic of truck appointments systems or truck slot booking systems are presented in section 2. Section 3 details the research framework. The findings of the qualitative research and the results of the quantitative inquiry are illustrated in sections 4 and 5, respectively. Section 6 builds on the results of the previous two sections, showing the conceptual necessity and structure of a DSBS. The same section elaborates a discussion and presents the time saving that is generated when a DSBS would be in use. Section 7 presents general conclusions and recommendations for future research.

The following section presents the literature review and the gap found in the literature by analyzing academic studies addressing the truck planning topic.

2. Literature review

An exhaustive literature review is carried out to shed light on working practices addressed by academia when studying truck appointment or slot booking systems. The goal of this overview is to outline common working practices, define the gap in the literature regarding this topic and then use this knowledge as a basis for the subsequent empirical analysis. Peer-reviewed articles covering the period 2004-2019 are screened and selected using recognized academic database search engines (*Scopus, Science Direct* and *Web of Science*). The following keywords are used as search terms: "truck appointment system", "truck slot booking" and "truck slot change". Content, relevance and quality are the three criteria used for screening the articles.

A meticulous reading focusing on the purpose, methodology and conclusions of these studies resulted in the retention of 36 relevant publications. This research adds to the collection of publications and type of parameters investigated in the research of Huynh et al. (2016). Table 1 below centralizes the key outcomes and indicates the type of change that is referred to in each of the described case studies. The changes that are studied are either related to introducing: a free, a fee-based or negotiation/collaboration slot booking system for changing slots (planning of slots considering negotiation of pick-up/delivery's parameters such as time, operational equipment used trucks, cranes or other assets etc.); or, according to the type of slot changing, allowing changes to be processed manually or automatically. The table is divided in two sections: the first section centralizes research that develops a case study for terminal operators at port or airports, while the second shows research that referred to a case study applied in (hinter)land warehouses/DCs. Moreover, a line is added to this overview table to highlight the differences of the current research compared with the already work carried out on the topic of truck slot booking applications.

Slot or appointment system characteristics	Pricing incentive			Slot changes operation		Time changes considered		
Authors (year)	Free of charge	Fee based	Collaboration/ Direct negotiation	Manually	Automatically	Planning (operators' activity)	Dispatching operators' activity)	Dispatching (trucks'/other assets activity)
Research that develops a case study(ies) for ports/airport terminal operators								
Huynn et al. (2004)				X				X
Lim et al. (2005)					X			X
Giuliano and O'Brien (2007)		X		X			X	X
Namboothiri and Erera (2008)	X			X				X
Huynh and Walton (2008)				X	X			X
Guan and Liu (2009)	X				X			X
Huynh (2009)	X			X				X
Guan and Liu (2009)	X				X			X
Huynh and Walton (2011)					X		X	X
Van Asperen et al. (2013)	X			X		X		X
Chen et al. (2013)					X			X
Fleming et al. (2013)					X			X
Anagnostopoulou et al. (2013)	X			X				X
Zehendner and Feillet (2014)	X				X			X

Ku (2014)				X	X			X
Phan and Kim (2015)			X	X		X		X
Schulte et al. (2015)					X			X
Phan and Kim (2016)			X		X			X
Azab and Eltawil (2016)				X				X
Huynh et al. (2016)	X	X	X	X	X			X
Ambrosino and Peirano (2016)				X				X
Schulte et al. (2017)			X		X	X		X
Gracia et al. (2017)				X				X
Azab et al. (2017)			X		X			X
Ramírez-Nafarrate et al. (2017)				X				X
Li et al. (2018)				X				X
Riaventin and Kim (2018)		X		X				X
Caballini et al. (2018)				X				X
Yang et al. (2018)					X			X
Belaqziz et al. (2018)				X				X
Torkjazi et al. (2018)				X				X
Zhang et al. (2019)				X		X		X
Yi et al. (2019)			X		X			X
Azab et al. (2020)	X				X			X
Caballini et al. (2020)	X				X			X
Li et al. (2020)	X				X			X
Mar-Ortiz et al. (2020)	X				X			X
Research that develops a case study(ies) for hinterland warehouses								
Zouhaier et al. (2016)					X			X
Zouhaier and Ben Said (2017)			X		X			X
Zouhaier and Said (2017)				X				X
Current research	X		X	X	X	X	X	X

Table 1. Literature review outcomes regarding the changes referred to in slot booking applications.

The screening of these studies in Table 1 leads to the following key conclusions:

- Theoretical models for assessing truck appointment or slot booking systems have been developed and tested by academia. Most publications discuss the implementation of functionalities with regard to: free of charge slot booking and manual reschedule (Guan & Liu, 2009; Zehendner & Feillet, 2014), free-of-charge slot booking with robust possibilities for changes (Namboothiri & Erera, 2008), fee-based slot booking when changes occur (Phan & Kim, 2016; Huynh et al. 2016), fee-based slot booking based on the peak period in the day (Giuliano & O'Brien, 2007) are scarce and experimental initiatives that involve direct negotiation (starting from Phan & Kim, 2015) are also discussed.
- The models identified in the literature focus mostly only on asset use optimization: reducing waiting time (Chen et al., 2013; Ramírez-Nafarrate et al., 2017; Li et al., 2018; Riaventin & Kim, 2018; Azab et al., 2020), reducing queues (Fleming et al., 2013; Mar-Ortiz et al., 2020), truck distribution over a longer period of time (Torkjazi et al., 2018) or minimizing external costs (Schulte et al., 2017; Zhang et al., 2019).
- Most applications presented in the literature are centered on data from terminal operators and road transport of containers (Giuliano & O'Brien, 2007; Huynh, 2009; Van Asperen et al., 2013; Zehendner & Feillet, 2014; Schulte et al., 2017; Caballini et al., 2020).

The initial literature review leads to the identification of several gaps. Firstly, research on slot booking systems focusing on warehouses or DCs is scarce. Secondly, a limited number of studies investigate the total duration of scheduling operations and delay when slots are introduced, as compared with following the first-come-first-served rule. For the latter, no studies distinguish among the time effects of planning and dispatching on scheduling activities and truck delay when slots are not respected or when implementing systems where slots can be changed under certain conditions only. Hence, there is a major research gap in the research looking into the duration of scheduling (planning and dispatching operations) and delay and waiting time caused for trucks. Moreover, no research mentions the implementation of an overarching slot booking or appointment system that integrates data from several terminals/warehouses/DC's.

The present research contributes thus to literature by filling the identified major gaps. The focus of the current research consists thus of an investigation on slot booking practices that have the following characteristics: truck slot booking process does not require booking fees, yet it allows for collaboration to switch slots, the process of rebooking slots can be carried out either manually or automatically, the time necessary to process planning changes is considered from three perspectives: namely planning activity, dispatching activity and assets' activity, and the application scope is set on hinterland-warehouses.

The next section presents the in-depths of the research methodology used to withdraw the conclusions of the current research.

3. Research framework

This section presents the methodology applied in this research. Three key steps are detailed in the following paragraphs. These steps are carried out within a research framework titled Optiplan[1]. The initial step is carrying out in-depth interviews with industry representatives to map truck-scheduling processes. The second step bundles these results and consists of further field observations at DCs and trucking companies measuring the duration of the different (sub-)processes. The last step builds on the observed data, makes an in-depth analysis, presents and discusses a potential solution, and frames general conclusions. This research design is presented in figure 1.

As shown in figure 1, an initial literature review presents the main conclusions of the research of truck appointment systems and the potential use of slots. This review reveals that a gap exists in the literature regarding the lack of focus of these studies on specific operational changes. This leads to the conclusion that a framework is needed to monitor, measure and analyze the activities necessary taken for truck and DC time slot scheduling.

Step 1 of the empirical research consists of qualitative research based on parallel interviews carried out with managers involved in the planning and dispatching (follow-up) of slots for road transport (both from the point of view of road carriers and DCs) and provides details about contemporary working practices. The interviews are semi-structured discussions to elicit information on the processes used by different organizations when planning and following up transport orders. The length of interviews varies between one to two hours. The interview design enquires about the following elements: company information (type and number of quays, unloading/loading infrastructure, trucks, drivers, trailers, capacity and availability), the current planning process

[1] This research is executed for the Flemish Institute for Logistics (VIL) by the Artesis Plantijn University College of Applied Sciences Antwerp and covers the research objective and scope (framed by the logistics enterprises participating in this project). https://vil.be/en/project/optiplan/

(loading/unloading planning and route planning), the truck planning and dispatching execution, operational cooperation and communication aspects between shippers and carriers. The result of this step is defining and mapping the set of activities for which time measurements are subsequently needed.

Following this qualitative investigation, the necessary time measurements are carried out at eight organizations: three DCs and five trucking companies. The time measurements are disaggregated at the individual transport order level. The data collected through this research step refers to orders (deliveries) of full truck loads and is the foundation of the analysis.

The last step of this research proposes a technical solution for time savings and presents a discussion on how they can be achieved. This step draws conclusions from the qualitative and quantitative data. The technical solution avoids the nonconformities found in present operating procedures. Moreover, two use cases are developed to make initial estimations regarding the benefits brought by the proposed technical solution.

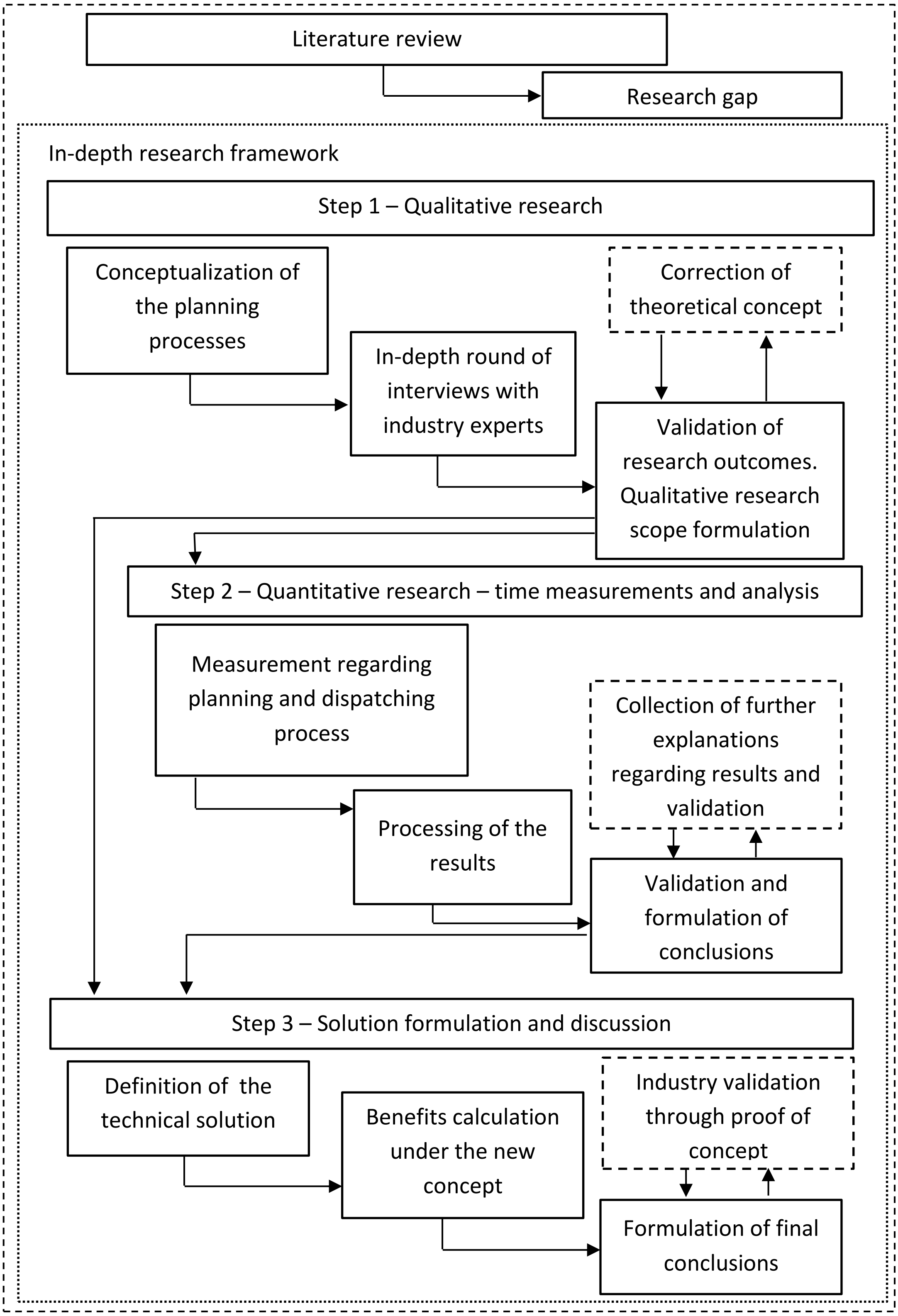

Figure 1. Research framework scheme.

The following section builds further on these findings and discusses the research findings derived from inquiries with the planning and dispatching departments at carriers and DCs.

4. Qualitative research findings

This section presents the details of the data collected through the qualitative phase of the research. The following issues are identified concerning the planning and dispatching at carriers and DCs. Stakeholders claim that different working practices implemented independently at the different actors, combined with relatively long communication loops, slow down the communication of delays and the reaction to these changes. These impediments sometimes create an unresponsive and time-consuming process. The interviewees claim that significant labor is necessary both for planning and ad-hoc changes (dispatching), and there are still operational delays regardless of the working practice used at DCs. The following sub-sections present in detail these results and use them to set the framework for the subsequent quantitative research. Two main work practices are identified: 'working with slots' and 'working without slots'. DCs choose unilaterally one of the options or a combination of both. Each DC defines the parameters and conditions as well as how the procedures should function in practice (e.g., the timing upon a booking can be made, the length of the slot, the rescheduling rules etc.). Carriers that serve several DCs in one day have difficulties in making a consistent schedule for their trucks and need to comply with different practices for different DCs. From a scheduling perspective, a distinction needs to be made between two phases: planning and dispatching. Planning is defined as the activity of scheduling personnel, equipment or infrastructure (e.g., loading or unloading dock) to serve specific transport orders. Dispatching is defined as the follow-up of the planned transport orders during their execution with interventions and re-planning whenever the schedule cannot be kept. Based on the qualitative research in the first phase and in line with the working practices, specific time elements are defined, describing recurring and punctual actions that employees take to measure the durations of these actions. The research dimensions, time elements and analysis approach are presented next in the following sub-sections.

4.1. Research dimensions

The qualitative research identified the following dimensions to be considered in the empirical analysis. The two scheduling procedures that generate the relevant labor activity at both DCs and carriers are planning and dispatching.

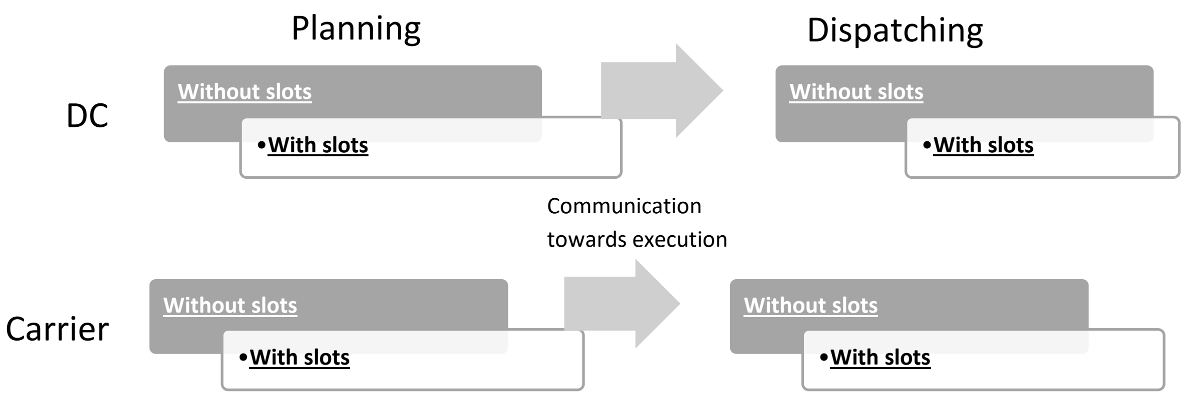

Figure 2. Dimensions for which empirical measurements (field research) are carried.

Figure 2 presents the dimensions that frame the comparative quantitative analysis hereafter. There are two working practices of delivering and/or receiving orders at DCs. The traditional way is applying the rules of first-come-first-served, meaning there is no slot booking system in place. The other, more advanced practice is working with slots. These two practices have obvious implications for both types of actors involved in this chain: DCs and carriers. Besides the working practices and stakeholder types, this research defines two scheduling phases that are impacted by the possible use of slots: the planning and the subsequent dispatching (or follow-up). The planning is defined as the time elapsed from the moment that an order is placed at a carrier until the moment the planning is frozen, meaning that the vehicle, the driver, the trailer and the timing of arrival and departure at the DC has been defined and communicated. The dispatching is the process starting from the moment the planning is frozen (and communicated on to the drivers and truck drivers to be executed) until the moment the goods (linked to an order) are un-/loaded in a truck and the truck leaves the DC. The following sub-section presents the time elements measured in each scheduling phase at the participating operators.

4.2. Measured time elements

The quantitative analysis starts with gathering data about the actions taken at DCs and carriers during the planning and dispatching phases. Table 2 sets the time elements for which durations are determined during on-site observations.

<table>
<tr><th rowspan="2">Site of observation</th><th colspan="2">Time element duration of the action for one order</th></tr>
<tr><th>Planning</th><th>Dispatching</th></tr>
<tr><td rowspan="2">DC</td><td rowspan="2">• Plan a transport order (contact the carrier or transport company)
• Plan in-house employees and loading/unloading operations
• Turnaround time</td><td>Operators activity:
• Follow-up a transport order
• Change a slot
• Ad-hoc plan
• Time lost at DC
• Re-plan other orders
• Delay to other orders</td></tr>
<tr><td>On-site truck movement:
• Check-in process at the gate
• From the gate to the loading/unloading dock
• Loading-unloading process
• Check-out process</td></tr>
<tr><td>Carrier</td><td>• Plan a transport order
• Buffer time
• Turnaround time</td><td>• Follow-up a transport order
• Change a slot
• Time lost arriving too early (waiting time)
• Turnaround time
• Time lost due to missing the initial slot
• Plan an extra truck
• Time delay to other orders</td></tr>
</table>

Table 2. Time elements for which field measurements are carried out

The above table indicates the operations for which time measurements are taken. Each of the time elements investigated is further defined in the Annex. Time measurements at DCs are taken for two categories of time elements. The first category refers to the duration of activities carried out by the DC dispatchers and the second one refers to the duration of activities carried out by the truck driver during the turnaround time (i.e., on-site truck movement from gate-in to gate-out). At carriers, measurements are taken for the duration of scheduling activities (planning and dispatching). The method used to aggregate the data regarding these time measurements is presented in the next sub-section.

4.3. Data processing and analysis approach

Time measurements are carried out registering the activity of planners, dispatchers or truck drivers. These measurements generate disaggregate data at the level of one order. Hence, a set of time measurements is generated for each of the blocks (see Table 2) presented above. Data related to orders are then aggregated according to these blocks to be further analyzed. For the above blocks, the notations are defined as follows:

- *s* – indicates the stakeholders for which the time measurement is carried out - it can be either 'DC' or 'C' as value: 'DC' – order data recorded at a DC; 'C' – order data recorded at a carrier.
- *w* – indicates the working practice - it can take either 'withoutSB' or 'withSB' as a value: 'withoutSB' – without time slot; 'withSB' – with time slot
- *i* – indicates the operation for which the time measurement is done - it can be either 'planning' or 'dispatching' as value: 'planning' – order data measured during the planning activity; 'dispatching' – order data measured during the dispatching activity

A time element is then identified with indications of 'DC' or 'C', 'withoutSB' or 'withSB', and 'planning' or 'dispatching'. For example, the *buffer time* duration is identified as a time element for which individual measurements have been carried out. Therefore, the buffer duration taken during the planning at a DC, which does not work with a slot booking system (withoutSB), is identified as $t_{buffer\ time}^{DC,\ withoutSB,\ planning}$.

Next, the subsequent data processing sub-step consists of calculating averages for each of the time elements defined. These averages are calculated for each of the time measured elements using Eq. 1:

$$\overline{t_x^{\,s,w,i}} = \frac{\sum_{j=1}^{k} t_x^{\,s,w,i}{}_j}{k} \qquad (1)$$

Where:

$t_x^{s,w,i}$ – time element for which the time measurement is carried out; x – can be either of the time elements presented in Table 2;
k – the number of measurements in the series of data.

The calculation of averages for each block of data is needed to compare and analyze the duration of planning and dispatching operations when working with and without slots. To eliminate outlier values, the lowest and highest 5% of measured values are separated. These outlier values are then used to calculate local averages and then these results are addressed as 'minimum average' and 'maximum average', respectively. This eliminates extreme values from the core data set and still retains information about those data categories. The rest of the 90% of the measured values (after eliminating the outlier values) are used to calculate time averages. The following section presents the details of the data sets and the results of the analysis.

5. Empirical analysis results

This section builds on the framework presented above. It presents the data collected and shows the results of the empirical analysis. A first sub-section discusses the data from the perspective of orders as the number of individual measurements/entries (observations) and the statistical significance of these measurements. The second sub-section presents how the data is aggregated and processed. A third sub-section presents the overarching results of the time measurements and their interpretation.

5.1. Data collected

This section details the data that has been collected and used in the later analysis. Within the studied companies, there are three DCs and five carriers. Observations regarding the duration of the planning and dispatching processes are made for four consecutive days at each of those companies. The number of observed orders for which data has been collected from the point of the type of stakeholders participating in the study (carrier or DC), the number of orders making use of slots or not at DC's and the number of orders making use of slots or not at carriers are presented in figure 3.

Figure 3. Total number of orders for which data is collected.

As shown in figure 3, data related to a total of 386 orders are collected. Observing the planning and dispatching actions at carriers resulted in data related to 235 transport orders. From this total, 105 entries hold data for planning operations and 130 for dispatching. In parallel, a total of 151 orders at DCs are followed up, from which 67 during the planning and 84 during the dispatching operations. These data sets are the foundation on which all subsequent analysis of scheduling operations is made. This data collected from the perspective of each type of actor is further discussed.

As shown in figure 3, 16 of the observed orders are planned at DCs without time slots, while 135 orders take place at DCs using time slots (for both planning and dispatching operations). These 151 orders, for which detailed time measurements are taken, are chosen randomly from a total sample of 534 (carried out in total during observations), so the analyzed sample covers thus 28,2% of the total activity. There are relatively few entries that carry data for planning operations at DCs without time slots because when there are no time slots, little time is spent for the planning of arrivals at DCs. Moreover, the qualitative interviews show that the planning process at DCs is the same regardless of whether slots are used or not. This process is done in one bulk step, by attributing orders to road transport operators. The rest of the truck arrival planning is done automatically, being generated from the slot booking done by the carriers. Hence, for the planning operation, this research formulates conclusions (by averaging the duration of the planning process) regardless of whether they use slots or not.

Figure 3 shows as well the number of orders observed at carriers. There is a relatively equal amount of orders representing each category. There is a total number of 116 orders planned at carriers for which no time slots are used. From these orders, 49 orders provide input related to the planning and 67 orders related to dispatching operations. In the group of orders planned by carriers using time slots, 56 entries provide time measurements for planning activities and 63 for dispatching. Therefore there is a total number of 235 used for this study for each measurement have been done at carriers. These orders are randomly distilled from a total daily activity of 682 processed orders, resulting in the fact that 34.4% of orders were included in the study. These data sets are used to compare differences in time spent in handling orders which have been planned at DCs based on both practices, with and without time slots. The results obtained by analyzing the entries from the time measurements are given in the next section.

5.2. Empirical results from time measurements

The goal of these time measurements is to offer an overview of the durations of the actions related to planning: planning time, buffer planned and planned turnaround, and to dispatching: follow-up time, re-planning, realized turnaround, waiting and delay thus answering RQ1.

The following sub-sections follow the same structure. They present the results of time measurements carried out at DCs and carriers. For each type of stakeholder, the practice of working without slots and the results of time measurements are shown first. Similarly, the work practice followed when working with slots and the results of the time measurement are then presented. Finally, the conclusions which discuss the differences between the two are put forward. The latter are used as a key input for the follow-up section of this paper that details two practical case studies.

The results of the empirical research for DCs and trucking companies are summarised in the following figures and tables. The figures plot, for each time element measured, the following elements: the average value calculated excluding the 5% lowest and highest measurements, the lowest and the highest values of this interval, and the average of the outlying values kept out of the calculation. While the first value shows the standard duration of the planning and dispatching activities, the latter two show possible extreme variations. The summarizing tables show in the first column the time element for which the measurements are carried out. The second column presents the averages of the measurements (calculated excluding the 5% lowest and highest measurements from the series as this technique is used to eliminate outliers from the data series). The last, third column presents observations concerning these time measurements.

5.2.1. Planning process durations of orders received with and without slots at DCs

Figure 6 and Table 3 show the results regarding planning durations at DCs, by analyzing the data collected for 67 orders. Observations and explanations are given in the following paragraph.

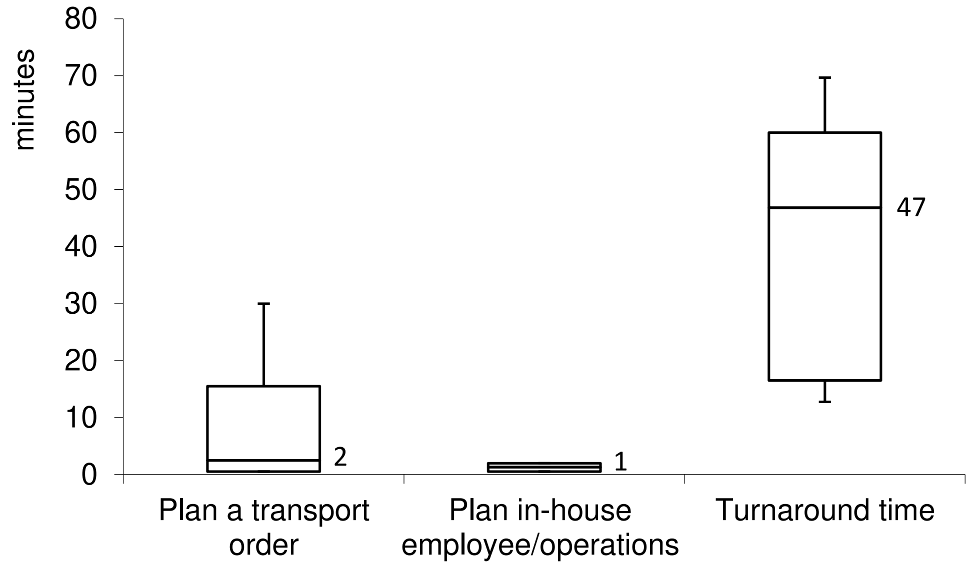

Figure 4. Results concerning planning durations at DC for orders with and without slots.

Measured time elements	Observations
Plan a transport order	Planning is done in 'blocks' (working in parallel with several orders)
Plan in-house employee/operations	Quick actions taken by the planner: Confirms the planning with the carrier; Checks the employee available; and Checks whether there is equipment available.
Turnaround time	The turnaround time is calculated automatically; The standard turnaround time for loading or unloading a full truck is one hour.

Table 3. Duration of planning operations at DCs.

As shown in Table 3, the average time needed for planning one order is around 2 minutes. Within this time, the DC planner checks the order information and searches for a suitable carrier to execute the order. The planning can take up to 30 minutes in exceptional cases when finding a suitable service provider is difficult. These exceptional cases occur in the peak period when additional carriers and/or loading/unloading equipment need to be booked. Next, the planning of in-house employees and/or operations is also done relatively fast, around 1 minute. This task is completed prior to the planning so that during the planning process, only one extra check is needed. The third measurement shows that the planned turnaround time of a truck per delivery takes an average of 47 minutes. This turnaround time is calculated in function of the order size (i.e., the pallets that need to be loaded, unloaded or both).

5.2.2. Dispatching durations for orders received with and without slots at DCs

Figure 7, Figure 8 and Table 4 summarize the results after processing the time measurements for dispatching activities at DCs. These results are obtained by analyzing the data about 14 orders that work without slots and 70 orders that work with slots. The interpretation of these results is presented in the following paragraph.

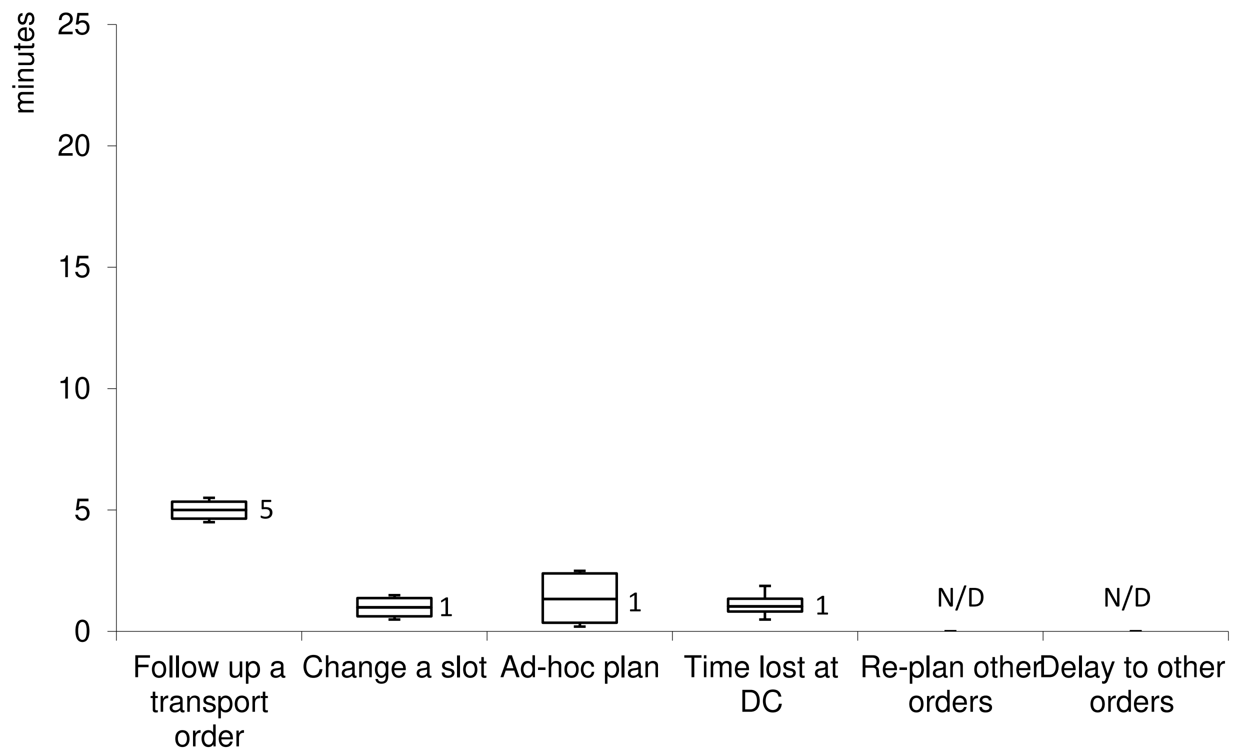

Figure 5. Results concerning dispatching durations at DCs for orders with slots.

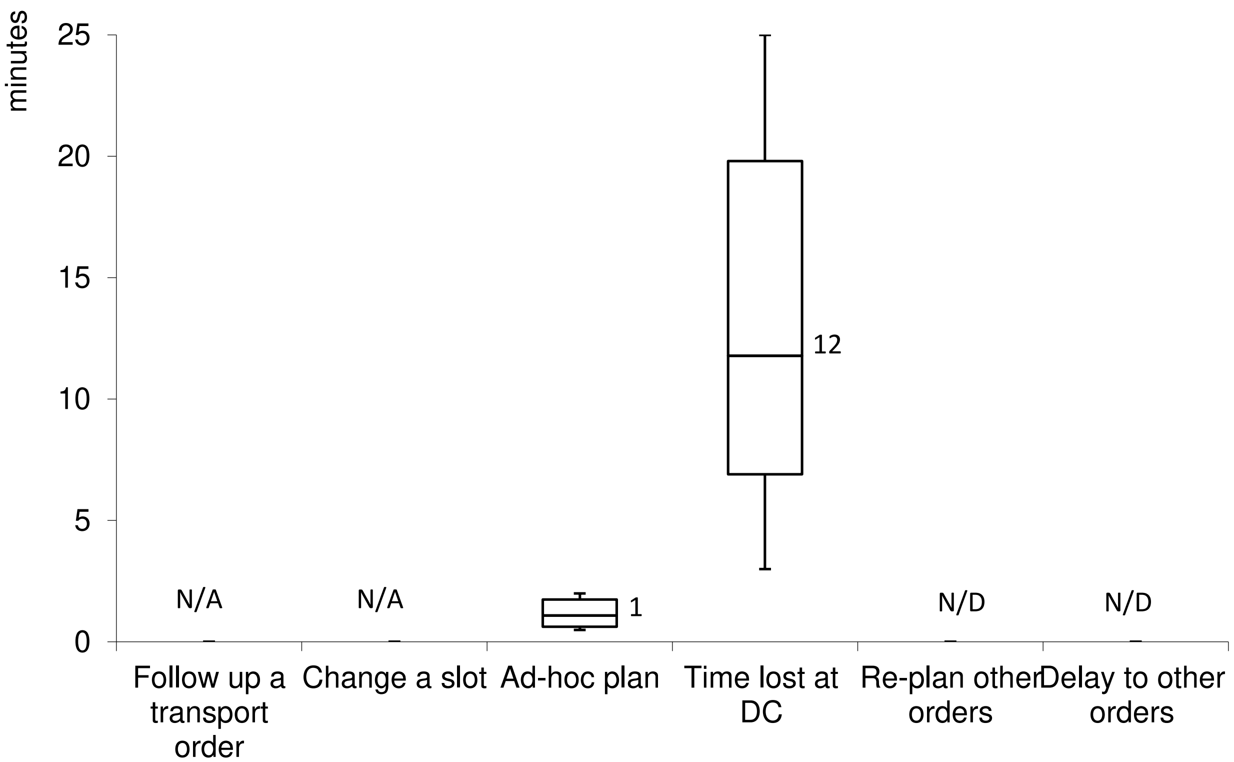

Figure 6. Results regarding dispatching durations at DC for orders without slots.

Measured time elements	Observations at orders with slots	Observations at orders without slots
Follow-up on a transport order	Rare occurrence of actions to be taken by the planner (4% of orders were registered as too late)	Did not occur during the observations (not applicable)
Change a slot	It happens automatically or with the help of the planner or customer service (by phone or email)	
Ad-hoc plan	The planner decides when and at which dock the truck is attributed (rare occurrence 2%)	The planning employee decides when and at which dock the truck is attributed
Time lost at DC	Time is foreseen to prepare the loading/unloading operation	
Re-plan other orders	Did not occur during the observation	
Delay to other orders		

Table 4. Duration of dispatching activities at DC.

Table 4 presents the data for the dispatching activity at DCs. This table shows a comparison between working with and without slots. From this table, it is concluded that working with slots generates follow-up activity at DCs. This type of follow-up is needed for trucks that do not make their booked slot in time and for which updates are needed. Although rare, this type of activity takes around 5 minutes. This type of follow-up is not needed for orders that do not work with slots. Yet, the change of slots is done relatively fast, taking an average of 1 minute. This and other types of ad-hoc planning are not different between orders that work with or without slots. Ad-hoc planning refers to the time spent to attribute a dock to an order. However, there is a significant difference in time lost on the work floor at DCs that do not work with slots in comparison to the ones that have a slot booking system. The former, on average, shows a loss in a productive time of around 12 minutes in comparison to 1 minute for the latter ones. This time is spent on preparing the loading/unloading operations and for the personnel to take over the new order. During the observation period, there are no delay occurrences found to other orders, caused by orders being re-planned, for neither of the used practices.

These observations show that the planning activity at DCs is not impacted by any of the used practices: working with or without slots. They show no considerable differences in duration. However, for the dispatching activity, working with slots reduces the time necessary to handle an order at DCs by 11 minutes. The following sections show the results of time measurements carried at transport companies (carriers).

5.2.3. Planning durations of orders delivered with and without slots by carriers

This section summarizes the results after processing the time measurements of the planning activities at the carriers. These results are obtained after analyzing data about 49 orders that are handled without slots and 56 orders with slots. Figure 9, Figure 10 and Table 5 present these results.

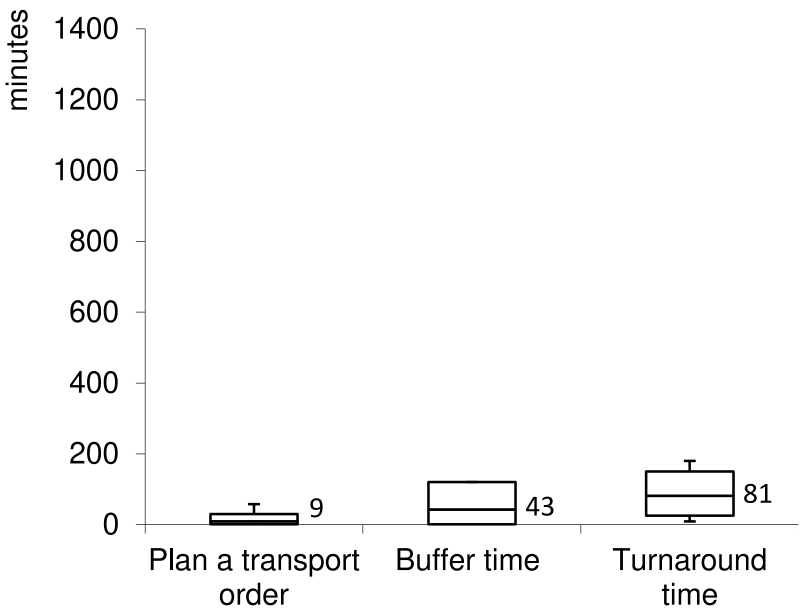

Figure 7. Results concerning planning operations durations at carriers for orders with time slots.

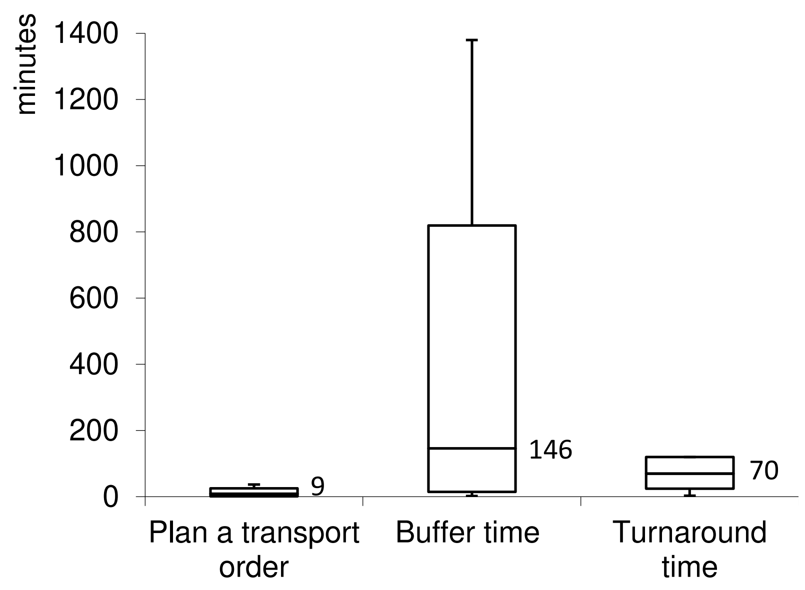

Figure 8. Results concerning operations durations at carriers for orders without time slots.

Measured time elements	Observations at orders with slots	Observations at orders without slots
Plan a transport order	No special remarks were made during the observations	
Buffer time	30% of orders have a buffer	25% of the orders have a buffer The average time buffer excludes orders with buffer higher than 9 h (5% of orders). This rule applies also to trips where 1 or 2-day buffer (for distances higher than 600km) is taken (long-distance pharma transport)
Turnaround time	No special remarks were made during the observations	

Table 5. Duration of the planning activities at carriers

Table 5 shows the aggregated results of the time measurements carried out for the planning activity at the carriers. From this table, it is obvious that working with slots does not influence the planning time for an order. Although planners need to take extra conditions into account, like slot availability or the variable length of slots at different DCs, they use the same amount of time for this task. Yet, a key difference is observed for the buffer time taken. While for orders with slot booking systems, the planners consider an average buffer time of 43 minutes, the orders that are delivered to DCs without slot booking systems are given a buffer time of 146 minutes. This difference comes from the knowledge that, having a slot booked at a DC, the realized waiting and turnaround times are shorter; therefore, a shorter buffer is taken. In contrast, at DCs without slot booking systems, the planners expect that a relatively higher waiting time is probably going to occur, so extra time is foreseen as a buffer. The latter is unproductive time that leads to unproductive periods for the trucks. For the planned turnaround time, there are no noticeable differences between the two used practices. The turnaround time allocated to orders booked at DCs with slot booking systems is only 10% higher. This practice is explained through more accurate time allocation for loading/unloading operations.

5.2.4. Dispatching durations for orders delivered with and without slots by carriers

Figure 11, Figure 12 and Table 6 show the results of the time measurements carried out for the dispatching activities at carriers. A comparison is made between the duration of activities and issues that appeared at the handling of orders that require slots (63 orders) and the ones that did not (67 orders).

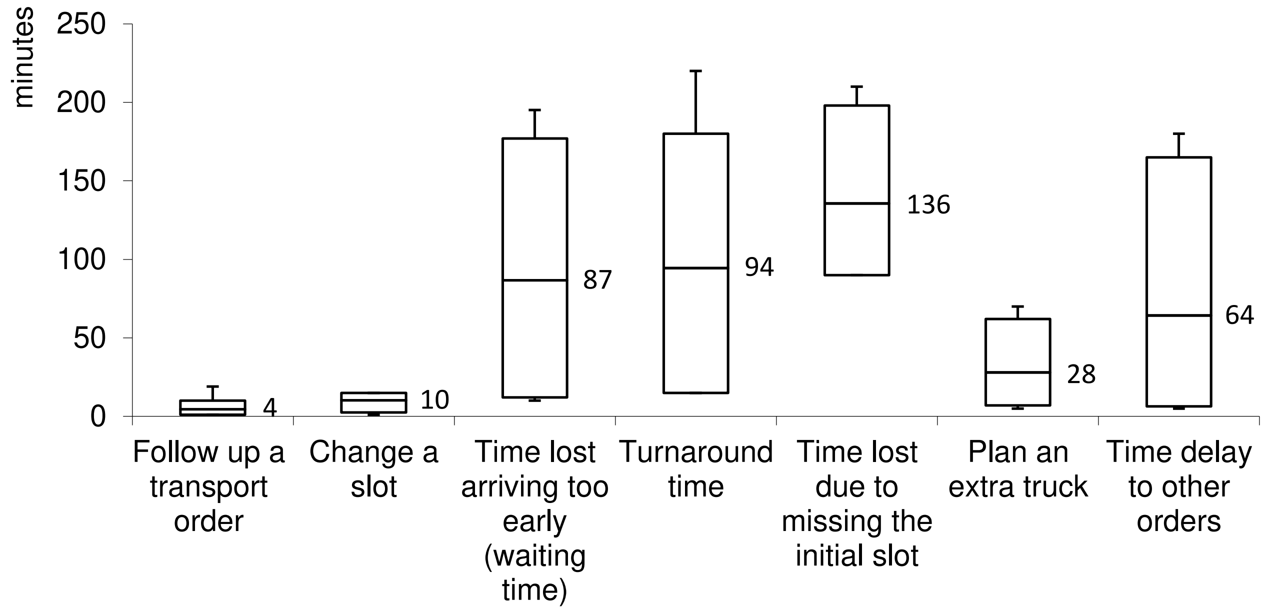

Figure 9. Results concerning dispatching durations at the carrier's side for orders with time slots.

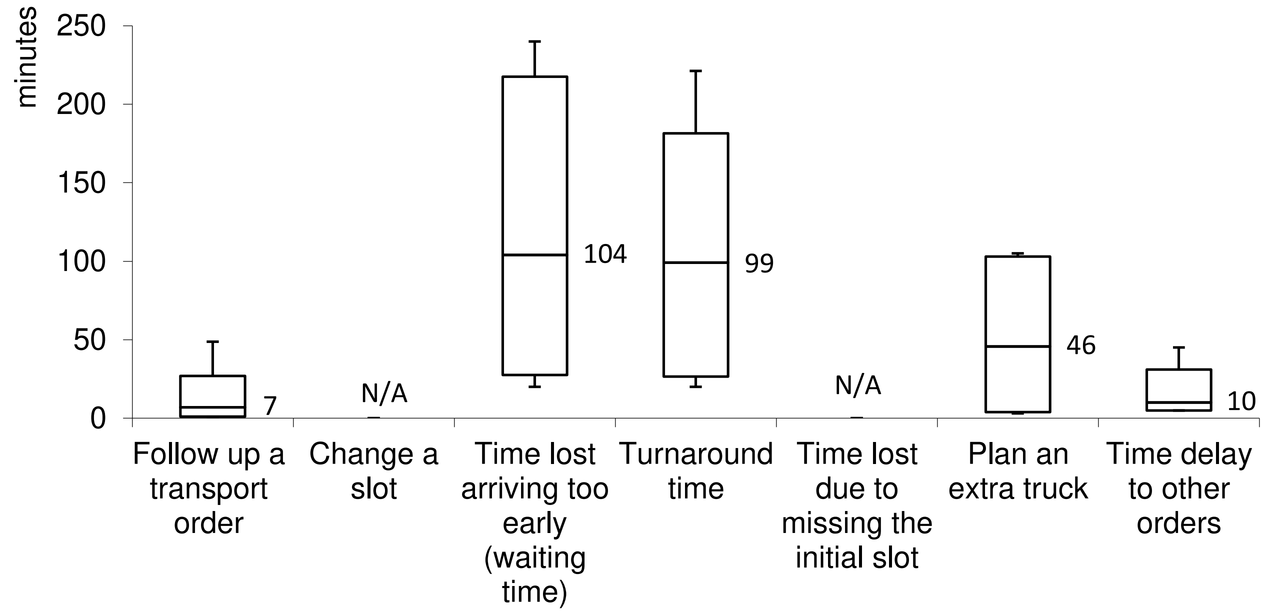

Figure 10. Results concerning planning durations at the carrier's side for orders without time slots.

Measured time elements	Observations at orders with slots	Observations at orders without slots
Follow-up a transport order	11% of orders needed follow-up	67% of the orders needed to be followed up (interaction between planner and the truck driver and/or track and trace)
Change a slot	13% of orders needed to change the initial slot	Did not occur during the observation
Time lost arriving too early (waiting time)	35 % of orders have had waiting time One special case with 1-day arrival too early (pharma)	21% orders > 30 min waiting time
Turnaround time	No special remarks were made during the observations	
Time lost due to missing the initial slot	13% of orders needed rebooking	Did not occur during the observation
Plan an extra truck	6% of orders needed to plan an extra truck	In 10% of the cases it is needed to re-plan an extra truck
Time delay to other orders	10% of orders caused a delay to other orders	12% of orders caused a delay to other orders.

Table 6. Duration of the dispatching activities at carriers.

As shown in Table 6, the time spent on the follow-up of the planning differs for orders that are booked at DCs with slots from the ones booked without slots. In the former case, a follow-up time occurs for 11% of the orders and it takes around 4 minutes. In the latter, planners need to follow up their planning more intensively, for 67% of the orders, and they spend on average 7 minutes interacting with the driver and/or track and trace tools. This is explained by the fact that the schedules of orders with no slot booking systems are unpredictable and drivers require much more attention to receive complementary tasks. Another observation refers to the fact that 13% of orders need a slot rebooking and this activity takes around 10 minutes per order (as, in some cases, it involves contacting the customer service of the DC). The measurements of the waiting time show that relatively longer waiting times are generated by orders planned at DCs without using a slot booking system. The same conclusion applies to the realized turnaround times. Table 6 shows that the change of an initial slot for a certain order generates an extra delay of 136 minutes, on average, per truck. When working with slots, the time necessary to plan an extra truck is around 28 minutes and occurs for 6% of the orders. For orders which have been delivered without slots, this type of activity (re-planning) occurs for 10% of orders and takes 46 minutes. Finally, it is observed that working with slots generates more time delay to other orders. This is explained by the tighter buffer time and the necessity of finding new time slots in the DCs' planning.

Working with and without slot practices brings advantages and disadvantages. The time observations lead to the following conclusions. At carriers, working with slots does not generate changes in the planning time. However, the main difference is found in the buffer time that is planned. This buffer time has been used as waiting time at DCs in case of delivering orders without a slot or for re-planning flexibility in case of delivering orders with a slot. When working with slots, the lower buffer time generates lower slack and thus increases the risk for chain delay. This is confirmed by the data as the delays caused by slot changes are longer. The planner compensates for these delays by comparing the risk of taking a shorter buffer time (considering that it is not going to be used) with the risk of having chain delays. Therefore, when a change occurs, significantly higher waiting times and delays occur. For this type of order, the planner cannot anticipate these waiting times and delays. The data shows that buffer time is used to mitigate the potential chain delay (delay to other orders), but it works only in limited situations. Next, further investigations are carried out to check the time spent on activities during the turnaround process at DCs. The following sections detail more on this topic.

5.3. Detailed analysis of the turnaround time (relative to arrival)

An in-depth look at the data collected raises further questions for the differences in the turnaround time recorded as planned and realized. While DCs plan a turnaround time of 40 minutes, the carriers plan a turnaround time between 70 min and 81 min. Qualitative data explains this difference as follows.

The DCs count as turnaround time for the effective loading and/or unloading operation: this duration is the most relevant as it is the time that the dock and employees are dedicated to that specific order. However, for the carrier, the turnaround time refers to the gate-in–gate-out cycle. Yet, other differences have been identified. Comparing the planned turnaround time, the realized turnaround for carriers is 94 minutes and 99 minutes respectively for orders delivered with slots and without slots. Therefore, a difference of approximately an additional 24 and 17 minutes, as compared to the planned turnaround time, is observed. This difference is absorbed by the overestimated buffer time. However, follow-up research is needed to identify the detailed actions taken by truck drivers during the turnaround and how long these take. In addition, results in Table 7 show the realized turnaround time of trucks that arrive too early, on time or too late.

The definition of an on-time arrival of a truck is as follows. The qualitative data show that the average slot length is two hours. Hence, trucks that arrive within one hour before and one hour after their booked slot (the slot being an exact moment in time, not a time period) are considered to be on time. Thus, trucks are referred to as arriving ‘too early’ if they arrive more than one hour before their slot and ‘too late’ if they build up a delay that makes them arrive later than one hour after their slot. Data regarding 70 orders are further analyzed. This data is collected at DCs that work with time slots. Table 7 shows the percentage of trucks arriving too early, on time and too late. Equally, the average duration of the turnaround process for these categories of trucks is also given.

	Average duration		
	Too early	**On time**	Too late
Percentage of trucks	9%	**81%**	10%
Average time divergence from the planned slot	147 min	**-**	118 min
Measured turnaround time elements			
Check-in process at the gate	5 min	**4 min**	5 min
From the gate to the loading dock	10 min	**33 min**	24 min
Loading/unloading process	32 min	**39 min**	25 min
Check-out process	8 min	**9 min**	5 min
Total	55 min	**85 min**	59 min

Table 7. Duration of the turnaround process

Table 7 breaks down the turnaround time. The first time element refers to the time spent at the gate during the check-in operation and shows no significant variations linked to any of the displayed types of truck arrivals (on time or not). The next time element is the duration of the route from the gate to the loading dock, as some trucks encounter on-site waiting time. The duration of this activity is around 33 minutes on average for trucks that arrive on time. This duration is significantly lower (10 minutes) for trucks that arrive too early. Trucks that arrive earlier than planned are allowed to enter the DCs' site only when there is enough capacity and they drive directly to the loading dock. Trucks that arrive on time or later than the initial slot are allowed to enter the site but are directed to an internal parking location to wait temporarily. During this period, the truck expects to be called to the respective dock. Next, the time spent for the loading/unloading activity is 39 min. This result is in line with the turnaround time initially planned by the DCs. The final step is the check-out process when document administration formalities are handled. This step takes around 9 minutes for trucks that are on time. From the above, it is confirmed that the average realized turnaround time for trucks adds up to 85 minutes. However, while working with slots should normally eliminate the need for waiting when the truck arrives on time, there is still an average of 33 minutes of waiting time before check-in. The latter is not anticipated in the initial planning phase and the oversized buffer time is used to compensate for this delay. When a truck is unloaded and/or loaded, final administrative check-out operations take 9 minutes. This activity could be carried out during the loading/unloading operations. Those two time-elements (unplanned waiting and check-out) could be eliminated by improving the procedures of working with slots as follows. The waiting time could be eliminated by anticipating the on time arrival of trucks by assigning a dock right away and finalizing the check-out documents during the loading/-unloading operations, thus reducing the turnaround time by an average of 42 minutes per order.

The above-presented issues are the result of the current working practice of using slots. The present practice of using slots is caused by data fragmentation. Key data like location of trucks, ETA and DC free slot capacity come from separate, unconnected systems. This research shows that there is considerable manual processing of data and information in the planning and dispatching (follow-up) process. Both carriers and DCs rely on people to plan and process changes when it comes to the booking of slots. Although there are specialized systems on the market to process order data and track and trace, there are problems synchronizing the DC side with the arrival of trucks. These problems are caused by the fact that, although the orders' data (volume, time, etc.) are determined centrally and the information is sent digitally to the carriers, the carriers follow the activity of their trucks manually. Added to this, there are still unexpected events that generate changes to the planning for which the current communication loop takes too long; planners, dispatchers and customer service centers that handle the data are all working in different, unconnected systems. The planners make decisions based on their own assumptions and experience. Later, when changes need to be made to the booked slots, planners must deal with inflexible systems and need to contact DC employees or customer centers, individually and personally. This approach consumes time and is not reliable for road haulers. In addition, the implementation of different slot booking systems and procedures at DCs is often counterproductive and causes an additional delay for both parties.

This type of issue can be improved by implementing an overarching Dynamic Slot Booking System (DSBS) that could monitor these data on an aggregate level. The above results are used to build the conceptual design of a DSBS.

6. Overarching Dynamic Slot Booking System

In the contemporary working environment, there is a relatively high amount of data and diversity in communication systems used in planning and dispatching. This creates difficulties in communication when manual actions are carried. This paper presents a proposal for an overarching system that can be used to integrate data (for track and trace, forecast of delay, planning changes etc.), provide extra functionalities to users and deploy an integrated framework for planning and dispatching operations.

Within this section, the conceptual design of a DSBS is defined. The goal of a DSBS is to retrieve real-time data, consider conditions imposed by supply chain stakeholders, achieve an optimal global solution and coordinate at operational and strategic levels the aforementioned traffic flows generated by logistics operations to and from DCs.

6.1. Conceptual architecture of a DSBS

Based on the principle described by Hill and Böse (2017), a first set up of an advanced DSBS is created. The functionalities and the architecture of a DSBS consist of three main blocks: a backend, an information system where users can get the applicable data, and interfaces between the DSBS and the third-party systems (Tanenbaum & Wetherall, 1996; Tanenbaum & Van Steen, 2007; Hill & Böse, 2017).

The design of IoT-based systems is the topic of several research publications (Papert & Pflaum, 2017; Tu, 2018; Carlan et al., 2019; Pan et al., 2019). Pan et al. (2019) contribute to the research and discuss the opportunities of a smart Product-Service System (PSS) in intelligent interoperable logistics. They describe a conceptual framework and discuss the essential architecture from the perspective of three main components: the stakeholders, smart connected products and intelligent systems. Their conclusion is that the stakeholders are the providers of the ecosystems where the intelligent systems need to run. Smart connected products are the results of the interaction between the stakeholders through systems (services). Following this principle, this paper builds the conceptual design of the DSBS.

Figure 13 puts forward the architecture of a proposed DSBS. This architecture considers both the principle of a backend system combined with the necessary functionalities of contemporary IoT technicalities and answers RQ2: *What are the functionalities of an overarching DSBS and how can it be connected to contemporary planning tools?* The figure visualizes the stakeholders involved, DC and carriers (C) respectively, and the informational links that need to be foreseen in the context of a DSBS.

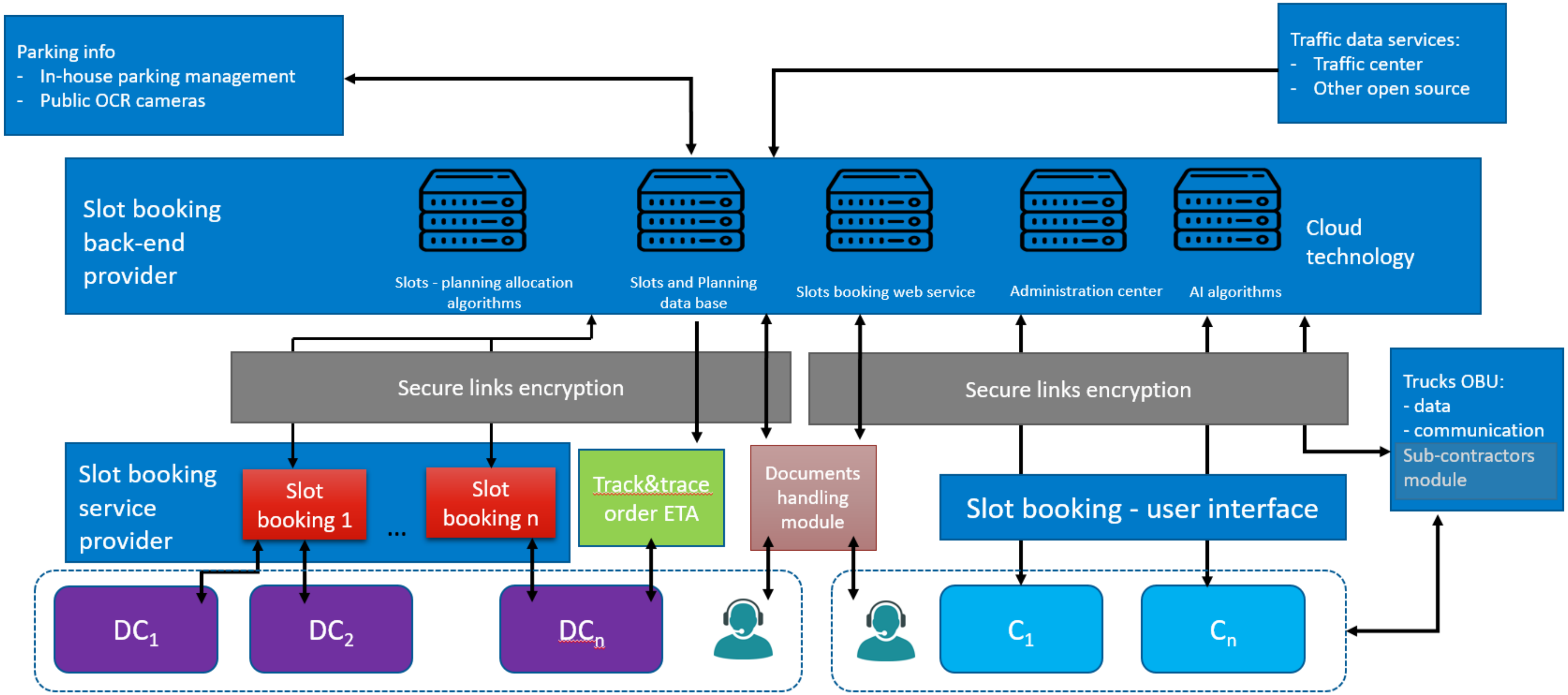

Figure 13. Dynamic Slot booking System – conceptual design

Figure 13 shows how the communication between operators at DCs and carriers concerning changing time slots is substituted by a slot booking backend provider. The backend services offered are the following: providing a library for slot booking algorithms, storing data with regard to time slots and planning in a database, running artificial intelligence (AI) algorithms for the decision making process, keeping the service running through web services and providing the backbone for administrative needs. The long term and full information of orders and active fleet (i.e., the demand for transport and the supply of equipment to carry out this service) are stored in the database as anonymous information, which is used by the AI algorithm to refine the decision process. The data stored in this database is updated from the systems of both the shippers and DCs, and also the carriers.

The information provided by a DSBS is the result of telematics services, combining both telecommunication and information technology. Data gathering of assets (e.g., containers, trucks, trailers) and slots availability is essential. This is made possible through the further links with the on-board units (OBU) of the trucks. Also, information about the scale and utilization of available trucking capacities will optimize the truck routes, DC capacity or adjacent services usage (e.g., cleaning, servicing, parking etc.). To this end, two secure encrypted links must be foreseen. Firstly, to the end user, the DSBS should present in a user-friendly way the information from the backend, including slot availability and updates when changes are required. This data can be presented via a web interface or an application on a smartphone/tablet. This type of service is standardly offered to a DC by specialized slot booking system providers, thus a connection with these providers suffices. Secondly, an interface for carriers that need to visualize the slots' availability for multiple DCs would be required. Extra informational links to pull data concerning parking availability (for both on-site and public areas) are needed, together with getting reliable real-time and structural traffic information from specialized providers.

This setting allows providing real-time accurate ETAs to DCs related to the trucks which are on the way to deliver or pickup orders. These ETAs are key essential information to provide the optimum solution in a dynamic and large-scale environment. To do so, it is necessary that DCs submit slot availability to the central service; similarly, road carriers who have signed up for DSBS, must submit each day the new planning and continuous changes to the central server via a webservice for planning for the rest of the day and the next day. The central server runs the optimization and matching algorithm and uses a webservice to retrieve the routes and transportation plans. The routes are enhanced with traffic data, structural delay and own calculation of driving durations based on OBU data. The latter could make use of AI to compile accurate driving times. These results are then used to check for potential deviations (at both DCs and carriers) from the initial planning and trigger planning algorithms to look up potential solutions.

Table 8 presents the stakeholders involved in the DSBS and the functionalities that each stakeholder expects, the challenges they would face and the data they require.

	Service provider	DC	Carrier
Functionalities	DSBS backend (integration between existing system: 3rd party providers, in-house IT etc.)	Orders' ETA (calculated based on track and trade data) Dynamic slot change	Universal slot booking Dynamic slot change
Challenges	Centralize and integrate requirements of each DC Visualize the slot availability for Carriers	Reliability (traffic delay, driving and resting hours, orders sequence time LTFs trucks)	Overview of DC slot booking Track and trace of orders pushed to subcontractors
Data	Planning data from the carriers Live truck location DC slot availability Traffic data – live delay Parking availability	Real accurate ETA (integrate traffic delay, driving and resting hours, intermediary stops)	Slot (capacity) availability Waiting time at DCs (before the gate and turnaround time)

Table 8. DSBS stakeholders, functionalities, challenges and data required.

As shown in Table 8, a new stakeholder, generically named 'service provider', is needed to manage and exploit the DSBS. This stakeholder needs to act as an integrator of existing systems and develop the functionalities of the DSBS. In this framework, DCs will be looking forward to receiving accurate ETAs and benefits from the dynamic slot change, while the carrier's goal is to become the users of a universal overarching slot booking system that also has the functionality of dynamically changing the slots, thus reducing their lost truck time and needed buffers.

Research has shown that digital information over each of these elements already exists, but there is little automatic coordination. This type of DSBS would make use of existing software pieces and acts as a coordinating party. Moreover, digitalization and technology are no longer barriers and a neutral party could pursue this level of integration. After integrating these sources of information, public APIs could be opened for the use of a wide range of application developers.

6.2. Estimations of potential time savings

This section makes early tentative calculations, based on the above, of the potential time saving should a DSBS be used in operations. To calculate the time savings at both carriers and DCs, the following time saving calculation model is used. It assumes that unplanned waiting times are eliminated from the dispatching process, also that unexpected issues are anticipated so that they do not generate extra delays. The calculation is reduced to determining the duration of the time saved from unexpected waiting, answering thus to RQ3: *Which time savings are achieved when an overarching DSBS anticipates on early or late arrival of trucks?*

The carrier's time savings achieved by structuring information and slot changes (for trucks arriving too early or too late) is calculated following Eq. 2:

$$t_C = o_{DC}^{C} * n_{DC} * \mu_{truck} * \tau_{truck} \tag{2}$$

Where:

t_c – time saved by a carrier by structuring information and changing slots
o^C_{DC} – number of orders scheduled to be delivered per day at a DC by the carrier
n_{DC} – number of DCs visited per day by the carrier

μ_{truck} – *percentage of trucks being delayed*
τ_{truck} – *the average duration of the delay*

The DC's time savings achieved by structuring information and slot changes (for trucks arriving too early or too late) is calculated following Eq. 3:

$$t_{DC} = o_{DC} * (\sigma_{truck_{DC}} * \tau_{truck_{DC}} + \rho_{truck\_ad-hoc\_DC} * \tau_{truck\_ad-hoc\_DC}) \quad (3)$$

Where:

t_{DC} – *time saved by a carrier by structuring information and changing slots*
o_{DC} – *number of orders scheduled to be delivered per day at a DC*
σ_{truck_DC} – *percentage of trucks being delayed*
τ_{truck_DC} – *the average duration of delay at DCs*
σ_{truck_DC} – *percentage of trucks ad-hoc followed-up*
τ_{truck_DC} – *the average duration of the follow-up*

The goal of a DSBS is to provide solutions to both DCs and carriers when truck drivers or DC employees need to change the planning. In this context, two scenarios are envisaged and studied. The first scenario describes the steps needed to identify and execute a changed slot in case a truck would arrive before its scheduled time, while the second discusses the potential delay of trucks that do not meet their initial slot.

6.2.1. Potential time savings gains by anticipating trucks that arrive too early

This sub-section discusses the issues that appear when a truck would arrive earlier at its appointment than initially planned. The DSBS intervenes during truck movements towards DC and when: (a) too much buffer time is anticipated in the planning, (b) structural delays did not occur or (c) a previous transport is finalized early. During the observations, it is noted that trucks that are too early must wait for their assigned slot (if the DC works with a slot booking system). When a slot booking system is not in use, the same procedure as with timely trucks is followed and the truck queues until it can be loaded/unloaded, causing waiting time as well. This waiting time can be theoretically avoided by using a DSBS. Table 9 puts forward the steps necessary to be taken for a truck that is arriving earlier than planned.

Action steps	Involved Stakeholder	Data
1. Calculate the ETA and detect it as 'earlier ETA'	Service provider	Truck OBU – location, etc Traffic data - delay
2. Check for available slots at DCs	Service provider on DC data	Slots available
3. Check for driving time (resting hours, turnaround time etc.)	Service provider on Carrier and DC data	OBU data Estimated turnaround time
4. Confirm the respective change with DC and Carrier	Service provider DC and Carrier	
5.a. Send updates to DC, Carrier and Shipper	Service provider	
5.b. Update slots database	Service provider	Slots database

Table 9. Steps taken by the DSBS algorithms when a truck's ETA is earlier than initially planned

As shown by Table 9, there are five main steps that are taken by a DSBS. The first three steps are carried out in the background: detecting the real ETA (including the driving and resting hours of the driver) of the truck, checking the best availability of a slot at the concerned DC and checking whether the legally allowed driving time remaining of the driver does not interfere with the turnaround time during the visit. These steps require OBU data from road carriers, the real-time planning of slots at DCs and external data (e.g., traffic data, structural delay etc.). Once a solution is found, this is brought to the front-end layer and presented to the operators at the DCs and carriers to validate it, as in step 4. A certain time limit for this validation can be set up, as agreed by the stakeholders (as other solutions/checks might depend on it). If the operators agree on the proposed planning change, the slot is assigned as suggested. Step 5 refers to updating the information for the involved stakeholders and making the changes in the slot database. This semi-automated process reduces the waiting time of trucks at DCs. Moreover, it spares human operators from manually tracking and tracing their fleet of vehicles and identifying planning conflicts. It also represents a first solution that works on integrating data from at least two types of stakeholders (carriers and DCs). Table 10 identifies the data used to calculate the potential time saving for the involved stakeholders.

Time calculation element	Variable range	Value used in the theoretical model
At carrier		
o^{C}_{DC}	1 to 200 (orders)	15
n_{DC}	1 to 25	5
μ_{truck}	0 to 100 %	9%*
τ_{truck}	0 to 24 hours	147 minutes*
At DC		
o_{DC}	0 to 200	72
σ_{truck_DC}	0 to 100 %	9%*
τ_{truck_DC}	0 to 24 hours	0 minutes
σ_{truck_DC}	0 to 15 %	0 %
τ_{truck_DC}	0 to 10 minutes	5 minutes
**see table 7*		

Table 10. Data used to calculate the DSBS impact.

The data in Table 10 provides the necessary input to calculate the time savings at both carriers and DCs who would use a DSBS that anticipates the early arrival of trucks. A mid-sized carrier owning 75 trucks that handle on average 15 orders at five different DCs could benefit from a time saving of around 992 minutes per day. This is based on the earlier observations that show that 9% of trucks arrive 147 minutes before their scheduled time. When trucks arrive too early, a DC has limited time losses. These trucks do not cause delay and/or do not generate extra follow-up activity for DCs.

The following sub-section applies a similar methodology to generate conclusions about trucks arriving too late.

6.2.2. Potential time savings gains by anticipating trucks that arrive too late

In parallel with the previous section, this sub-section discusses the issues appearing when a truck's ETA is detected as being later at its appointment than originally planned and what a DSBS could do to minimize the impact. The DSBS intervenes during truck movements towards DC and when: (a) the truck departure is delayed from a previous stop, (b) encounters on-route delays and/or (c) queues are formed at the DC gates. The observations show that multiple options are used when trucks arrive too late. The most common are: (a) it waits at the back of the line and it is served when its turn, (b) the truck is assigned a new slot at a later moment, (c) it waits until an off-peak moment comes or (d) it is appointed to a new slot the following day. Currently, these decisions are taken on the spot at the moment a truck arrives at the gate. The potential of a DSBS is to anticipate these situations and offer solutions, e.g., changing slots for both DCs and carriers, anticipating the late arrival and generating a minimum time loss. Table 11 puts forward the necessary steps when a truck will arrive later than initially planned.

Action steps	Stakeholder	Data
1. Validate late ETA	Service provider	Truck OBU – location etc. Traffic data - delay
2. Check for earlier available truck/order	Service provider of carrier data	Truck location
3. Check for driving time (rest hours and turnaround times.)	Service provider of carrier and DC data	OBU data Estimated turnaround time
4. Calculate handling times and new Slots	Service provider on DC data	Slots data
5. Confirm the respective change with DC and Carriers	Service provider DC, carrier 1 and carrier 2	
6.a. Send updates to DCs, Carriers and Shippers	Service provider	
6.b. Update slots database	Service provider	Slots database

Table 11. Steps taken by the DSBS algorithms when a truck ETA is later than initially planned

The DSBS could offer alternative solutions for late arrival of a truck through the six main steps provided in Table 11. The first four steps refer to establishing the real ETA (including driving and resting hours of the driver) of a truck, checking the availability of a later slot at the concerned DC and the driving time in relation to the forecasted handling (loading/unloading) time. These steps are carried out in the background and require data from carriers, DCs and external data providers (e.g., traffic data). Once a solution is found, this is brought to the front-end layer and presented to the operators at DCs and carriers for validation, as shown in step 5. Here too, a certain time limit can be set up to avoid that the proposed solution becomes obsolete due to other changes. In step 6, new updates are sent to the involved parties: carriers, DCs and shippers. The use of algorithms to monitor late truck arrivals saves employees time at carriers in dispatching, but also for DCs that are also using personnel to make ad-hoc changes to planning and dispatching (follow-up) as a result of late truck arrivals. The data needed to calculate the potential time saving at these stakeholders is presented in Table 12.

Time calculation element	Variable range	Value used in the theoretical model
At carrier		
o^{C}_{DC}	1 to 200 (orders)	15
n_{DC}	1 to 25	5
μ_{truck}	0 to 100 %	10%*
τ_{truck}	0 to 24 hours	118 minutes*
At DC		
o_{DC}	0 to 200	72
σ_{truck_DC}	0 to 100 %	10%*
τ_{truck_DC}	0 to 24 hours	5 minutes**
σ_{truck_DC}	0 to 15 %	4 %**
τ_{truck_DC}	0 to 10 minutes	5 minutes**

**see table 7*
***see table 4*

Table 12. Data used to calculate the DSBS impact.

The data provided in Table 12 results from the empirical observation carried out. Results of the time savings for carriers and DCs that use the functionalities of a DSBS and anticipate the late arrival of trucks are calculated. A mid-size carrier can save 885 minutes a day, according to the calculation results. DCs that handle around 72 orders per day also benefit from time saving of around 50 minutes a day. These results consider that 10% of the trucks arrive later than planned, so they require ad-hoc planning and 4% of these trucks need extra follow-up actions of DCs' planners. The following section presents the general conclusions of this research.

7. Conclusions

The past 10 years have been marked with pioneer studies resulting in the development of practices and algorithms for scheduling truck visits at depots. Yet, the overview of this research topic shows that some gaps remain still to be filled in regarding the duration of scheduling activities carried out around the planning and dispatching of trucks to DCs and how truck arrival delays can be solved.

The present research fills in this gap and looks at the contemporary practices used to plan and follow-up appointments of trucks at DCs. To close this gap, the present study firstly quantifies the waiting time generated by contemporary scheduling (planning and dispatching) instances. Results are given from the perspective of two common practices: using a slot booking system or not. Through this empirical research, waiting times and delays are measured that are regularly generated at distribution centers by incoming truck flows. Secondly, this research presents the set-up and regarding how an overarching DSBS can be connected to existing systems and make use of data. Equally, it visualizes its architecture through a functional diagram showing and explaining how the system should work. Finally, this research develops two applications to make first estimations regarding the potential time saving in two scenarios: (1) a truck that would arrive earlier than originally planned and (2) a truck that would arrive later than originally planned. The next paragraphs provide a succinct summary of the research approach and present general conclusions.

The type of integration proposed in this study requires an extensive amount of coordination and cooperation. Communication and integration actions are needed across businesses' boundaries.

Hence, the complexity of the adoption process and the associated coordination of costs create a potential for opportunistic behavior that can damage the adoption process. To avoid this, this study investigates the present planning processes as they are in use today, as well as the duration of the different planning steps with the goal of establishing the benefits that each stakeholder might have after adhering to a DSBS.

Traditionally, the trucks are loaded/unloaded at DCs in the order in which they arrive. Working with a slot booking system sometimes results in applying the same practice. Yet, due to significant uncertainty regarding the arrival time of trucks, there are difficulties in making an ad-hoc distribution of loading and unloading capacities at DCSs. These DCs run the risk of being over-or understaffed at times. From the point of view of a road carrier, operating without a slot booking system also has the advantage of relatively fast planning since it applies only its own constraints on the availability of drivers, trucks and order characteristics. However, unknown waiting time and unknown time duration of loading or unloading activities result in the necessity of a larger buffer duration that finally generates long unproductive periods for trucks and drivers. This also means that road haulers can only plan new trips after a truck has been unloaded and/or loaded. The implementation of slot booking systems implies more time spent on planning but, in theory, brings more certainty regarding the dispatching of orders. However, there are external factors that can cause this planning to be unfeasible, resulting, during the dispatching and execution, in more work to reschedule truck appointments. These external factors are linked to the following: (a) the existence of multiple independent track and trace solutions, (b) specific "slot change" rules at each DC, (c) non-structural delay in traffic and (d) short windows to realize deliveries. These factors cause extra work in both planning and dispatching (follow-up). This research shows that slot booking systems, as they are in use today, do not always bring the expected time savings.

In addition, this study indicates the functionalities that an overarching dynamic slot booking system should have. First, a connection needs to be made between different TMS, slot booking systems in use at DCs, and track and trace systems used by carriers. Secondly, data from different track and trace systems should be used to calculate real ETAs. The structural bottlenecks regarding turnaround durations at each DC could be centralized in a database. By doing so, the DSBS can automatically calculate the arrival time at subsequent customers/stops (in interaction with other systems). In addition, an automatic login system at the DCs could be installed. This system could feed a transparent time slot change algorithm with data, where the track and trace system of a truck is used to automatically indicate whether an order will arrive earlier or later than expected.

The application part of this research provides early tentative estimations regarding the time savings realized through automatic planning and dispatching. Time savings for a mid-size carrier, with 75 trucks, are estimated at around 992 minutes per day for trucks that arrive too early and 885 minutes for trucks that arrive later than the initially planned slot. For DCs, savings can be made of around 50 minutes a day by releasing employees from follow-up activities and ad-hoc changes to the planning. Additional time savings can be made if other available slots or time windows are identified.

One should be aware of the framework of this research and the data used to draw the conclusions presented. This study is carried out in Belgium on a sample of three DCs and five carriers. Moreover, only transport orders that imply full truck loads are analyzed. While this methodology can be replicated and expanded to other cases or geographical areas, yet further research can still be carried out to investigate whether similar conclusions are valid for other types of transport orders (on LTL, liquid bulk, exceptional cargo, or transport orders of goods that are not loaded on pallets). For the latter, other operational activities and time windows might be foreseen.

The results of this study are further relevant both for academia and industry. Academia benefits from a basis to build further research on calculating the costs, benefits and potential cost-effectiveness of implementing an overarching DSBS. Other research can be carried out to identify, based on the orders delivered, the return on investment for stakeholders that use the DSBS or how to gain sharing methods can be set in practice to cover the costs for IT implementation. Industry can benefit from this research as they have evidence of the duration of planning and dispatching (follow-up) activities when slot booking are or are not in use. Equally, stakeholders have access to the results, pointing to the time savings that a DSBS brings.

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Annex

Time elements measured for the empirical analysis

Time elements measured at Carriers	Definition
Planning	
Planning of a transport order	The amount of time spent planning an order (drivers, vehicles and slot booking). This measurement refers to the time needed to choose which order is attributed to which driver.
Buffer time	This measurement refers to the time set as a buffer. This can be determined by recording the difference in the time needed to complete the trip under normal conditions and the time that the planner takes into account in the planning.
Turnaround time	This measurement refers to the time considered by the planner as gate–in–gate–out time on the DCs.
Dispatching	
Following up the transport order	Time spent following the planning per trip. This measurement refers to the working time needed to track orders.
Changing a slot	Time spent changing a slot. This measurement complements the above and refers to the time spent by the dispatcher (or another department if applicable) contacting the sender, driver or DC to change and confirm new slots.
Time lost arriving too early (waiting time)	This measurement refers to the time lost by the carriers by arriving at the gate too early or too late. This can be measured by checking the planned time of arrival and the actual time of arrival at the DC or destination, if applicable.
Turnaround time	Realized turnaround time (gate-in – gate-out).
Time lost due to missing the initial slot	This measurement refers to the time lost by a truck when a slot is missed. It can consist of waiting time, extra driving time to another DC and extra loading and unloading operations.
Planning an extra truck	This measurement refers to the time it takes to re-plan a new truck. It can also refer to the time lost to schedule an extra truck to compensate for a missed slot.
Time delay to other orders	This measurement refers to the amount of delay in other orders caused by the delay of the controlled order(s).

Time elements measured at DC	Definition
Planning	
Planning a transport order	This measurement relates to the time planners need to choose (from a list of carriers) which carrier will transport which order. This type of planning activity is theoretically performed for both types of DCs (working with or without a slot booking system).
Plan in-house employees and loading/unloading operations	The time spent planning personnel (material) for loading/unloading goods, if applicable (this is not the time of the loading/unloading itself, that is the planned turnaround time, which comes below).
Turnaround time	This relates to the time allocated to each order to be loaded or unloaded, if applicable.
Dispatching	
Following up the transport order	This measurement refers to labor spent on tracking delayed orders, but not to the time needed to change slots, which follows later, not every delay has a slot change.
Change a slot duration	This measurement is complementary to the above and refers to the time spent by the dispatcher contacting the shipper or carrier to book and confirm new slots. (It is also interesting to see what percentage of orders require rebooking and how much time is spent on average).
Ad-hoc planning	This measurement is similar to the previous one and applies to orders (DCs) that do not work with a slot booking system. It takes into account the time needed to plan and receive a truck (for loading or unloading) upon arrival at the DCs, which has not booked a slot in advance.
Time lost at DC	Lost time in DCs/warehouses (inefficiencies on the floor) or time lost by employees due to orders that do not show up. This measurement refers to the time that employees who are scheduled to load and unload but who are on standby due to trucks not coming (or too late).
Re-planning other orders duration	Time taken by one dispatcher to reschedule other orders as a result of a delay of another order.
Delay to other orders	This measurement refers to the length of delay caused by other orders.

Turnaround time at DC

Time elements measured at DC	Definition
Turnaround	
Check-in process at the gate	Realized time of the check-in process (and is it still too early, too late, on time) from logging in at the gate to entering past the gate
From the gate to the loading dock	Realized time from the gate to the quay (and is it still too early, too late, on time), sometimes a truck is allowed inside, but there is no place on the quay yet, and he has to wait for an internal parking lot.
Loading-unloading process	Realized time for loading/unloading and back to gate.
Check-out process	Duration of the check-out process, time spend from the moment that the loading/unloading is finished until the truck leaves the DC terrain.