The one container drayage problem with soft time windows

Abstract

Intermodal freight transport consists of using different modes of transport without changing the load unit. This results in a significant reduction in the time that goods spend at intermodal terminals, where transshipment takes place. Drayage refers to the transport of freight on trucks among intermodal terminals, depots, customers and suppliers. In spite of the fact that drayage only represents between 5 and 10 percent of total distance, it may amount up to more than 30 percent of the total costs. The aim of this work is to study drayage operations. First, an extensive literature review is undertaken. Since the intermodal transport chain can become more efficient by means of a proper organisation of the drayage movements, the optimization of the daily drayage problem has been identified as one of the main ways of reducing the drayage cost and improving intermodal operations. On this problem, the lack of a common benchmark has hindered reaching further conclusions from all the research carried out. Therefore, this paper proposes a common framework and presents a generalized formulation of the problem, which allows modeling most drayage policies, with the limitation of only considering one-container problems. Results show that flexible tasks in the repositioning of empty containers as well as soft time windows can reduce the operating costs and facilitate the management of drayage companies. This work may help consider adequate policies regarding drayage operations in intermodal terminals.

Keywords:
Drayage, Intermodality, Benchmark, Soft Time Windows, Flexible Tasks

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1. Introduction

Nowadays, long chains of transport are responsible for connecting customers around the world, eliminating geographic barriers between production and consumption. This has fostered globalization, which requires efficient transport management.

Among the modes of transport, maritime transport is the most common option for long-distance journeys. However, being lacking in flexibility, it is necessary to synchronize maritime shipments, port-to-port, with other means of transport, such as rail and road transport. This concept is known as multimodal transport.

Among the different methods of good transportation, the largest growth occurs in intermodal transport, a type of multimodality. It consists of using different means of transport to carry a load unit, usually containers. This feature allows for a reduction of the time that goods must spend in intermodal terminals because operations of loading and unloading of goods from one container to another are replaced by operations of collecting and delivering containers between different means of transport.

Preprint submitted to Elsevier *May 27, 2020*

With all this, this paper focuses on drayage operations. These operations usually take place at the beginning and the end of the intermodal transport chain and include the collection and delivery of empty and loaded containers in depots, terminals and customers facilities. These containers are carried among different locations in the area of an intermodal terminal by road.

Even though drayage operations only represent a small percentage of the total distance in the intermodal chain, these amount to a high percentage of the total cost (Spasovic and Morlok, 1993; Escudero-Santana, 2013). The optimization of drayage operations represents an effective way to foster intermodal transport. Moreover, given that drayage movements usually take place near urban areas, adequate planning of drayage operations results in an indirect improvement of the environmental conditions and other external costs (Chen et al., 2013; Demir et al., 2015).

There are several types of drayage movements. The main movements are the freight importation and exportation orders, where the load unit (usually a container) is moved between the terminal and the customer or vice versa. In these instances, the container could be either full or empty, but the origin and destination of the movement are known (well-defined orders). Another possible type of drayage order is the repositioning of empty containers. This is necessary for the logistic activities of different customers. In this case, the movement could be carried out directly from or to the depot, known as direct-depot movement. In addition, empty containers that need to be withdrawn from a customer can be transferred directly to another customer in need for them. This is referred to as turn-street movement. Thus, there exist different possibilities for fulfilling the requirements, and some aspects of the orders are therefore flexible.

These orders are carried out by trucks, which are composed of tractors, trailers chassis and containers. Trucks perform two fundamental operations, collection and delivery of containers. A basic order usually involves a collection operation, a displacement, and a delivery operation.

Additionally, more complex orders are possible. As seen above, the need to have containers available at different points at certain times makes the transport of empty containers essential. Thus, sometimes it is necessary to alternate tasks of delivery and collection of containers at a given point. This may be caused by the client lacking sufficient space to store containers or a lack of additional containers to make other shipments. Two solutions are feasible: the driver stands by the container while it is unloaded, which is referred to as stay-with policy, or the driver leaves after the delivery of the container, known as drop and pick policy. In this case, an unloaded truck (not necessarily the vehicle that delivered the goods) will be required once the container is empty.

The daily drayage problem (DDP) has been the most studied problem of this area of research. This problem can be stated as follows (Jula et al., 2005): a set of containers needs to be moved in the area of an intermodal terminal by a trucking company. A set of trucks, initially located at the company depot, is deployed to move these containers among the depot, customers and terminals. Associated with each container there are time windows imposed by the customer and the terminal. The DDPTW is a relaxation of the vehicle routing problem with time windows (VRPTW). However, the procedures developed for the VRPTW are not well suited for the relaxation of the problem (Dumas et al., 1995).

Many authors have contributed to this area in order to address the necessity for specific methods. After an extensive literature review on drayage operation optimization using mathematical methods, we have found out that most of the works presented focus on the efficiency of their approaches. Besides, there exists a lack of a common framework or benchmark to develop these studies, which makes it hard to draw general conclusions.

Therefore, it is necessary to create a common benchmark to study the effect of different policies regarding the management of drayage operations. This work undertakes that goal and proposes a generalized formulation and benchmark for the comparison of different policies.

In addition to the proposed common framework, this paper provides an extensive review and analysis of how certain policies can influence the performance of haulage operations. Two policies have been studied: the effect of flexible tasks in the repositioning of empty containers and the effect of allowing soft time windows (a research angle neglected so far). The study presents several simplifications. Noticeably, that a truck can only carry one container at a time.

The rest of the paper is structured as follows. Section 2 identifies the methodology used in the review process. Section 3 provides a review of related works, identifying the contribution of each paper. Section 4 presents a deep formulation and description of the problem. Section 5 analyses the experiments conducted in previous studies and establishes the proposed benchmark. Section 6 discusses the experimental results. Finally, section 7 concludes the paper.

2. Review methodology

The following sections focus on the literature relating to drayage operation optimization using mathematical approaches. Qualitative studies are not covered in this study. The search was conducted on several library databases (Web of Science, Scopus and IEEE Xplore) through the insertion of some related keywords: drayage, VRP full load, intermodal hinterland, truck intermodal, container truck, and haulage. Selected papers from the searches were analysed and classified. The references of each paper were examined to find new related works.

This search method allowed us to cover a great variety of journal and conference papers. Some conference papers were improved by their author and subsequently published in a journal; in these cases, the review was limited to the most recent paper.

In total, 77 works have been examined, coming from journals such as Transportation Research (A, B, C, D, E), Transportation Research Record, European Journal of Operational Research, International Transactions in Operational Research, Operations Research Letters, OR Spectrum, IIE Transactions, Advanced Engineering Informatics, Computers and Industrial Engineering, and International Journal of Production Economics. Figure 1 shows the number of papers published in each journal. In section 3, these studies are classified and summarized according to their main line of action to improve the drayage. As we can observe in Figure 2, the tendency of number of publications per year is increasing.

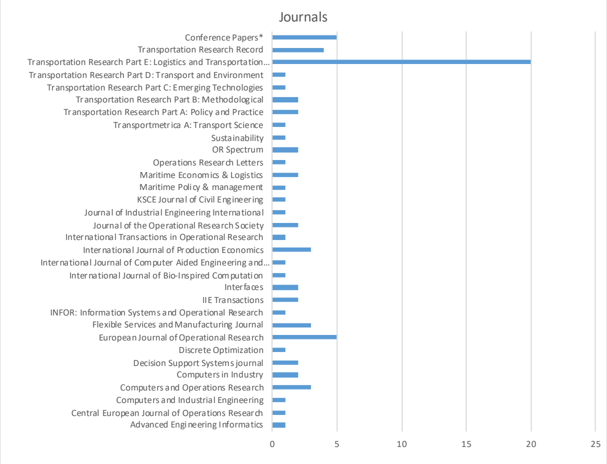
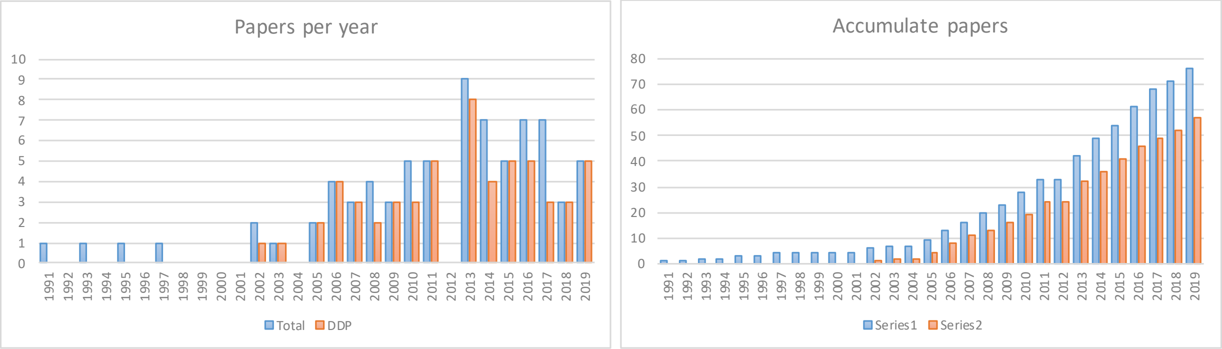


Figure 1: Number of papers published in each journal

Because most of the papers present an operational perspective and focus on the optimization of routes (usually referred to as the daily drayage problem, DDP), these works were studied more extensively. These papers are classified according to several characteristics of the problem (consideration of empty containers, consideration of time windows, possibility of flexible or complex tasks, dynamism or uncertainty consideration) and some characteristics of the solution methodology (formulation, method, etc.).



(a) Per year

(b) Accumulated

Figure 2: Number of papers per year

Other relevant information is the classification of the different instances or benchmarks used to validate these works. Because no common benchmark exists, an important aspect is to know if the studies are reproducible. Thus, we have identified the works whose instances are published or are at least reproducible. These are located in section 5.

There also exist some studies covering issues similar to the daily drayage problem. We have considered conducting a brief review of these works, since some of their conclusions could be useful for future works related to drayage. The search terms for these works are truck trailer and swap body.

3. Extensive literature review

As mentioned above, even though the drayage operations only represent a small percentage of the total distance of the intermodal chain, the optimization of these operations is a very important issue due to the fact that these operations represent a high percentage of the total cost.

The first studies regarding drayage operations dealt with the issue from a strategic perspective. They focused on the effect of different measures, decisions or regulations on the performance of the total supply chain and its potential market; the main items studied have been marked below in bold. Subsequent studies delved into operational aspects of drayage management, establishing approaches of planning daily operations that would allow to achieve the lines of action of previous studies.

Fowkes et al. (1991) was the first study to underline the implication of drayage operations in the total intermodal chain. It examined the relative **position of both origin and destination regarding intermodal terminal**, developing a cost model, and proved that it has implications over the profitability of the global transport. The combination of this cost model with a stated preference experiment determine the market share respect to road transport. In this line of research, Nierat (1997) studied the market area of a rail-truck terminal. The result of this study concluded the notable effect that the relative localization of the customer respect to terminal has over market area. Since an operational perspective, Taylor et al. (2002) studied two approaches of terminal selection, whose objective is to increase the efficiency and profitability of intermodal transport.

Morlok and Spasovic (1995) studied which factors influence drayage operation costs and established strategies to reduce the costs. These strategies, destined for both public and private sectors, are based on several measures: centralized management of drayage, the use of new technologies, adequate marketing and price selection, increase in terminal capacity, improvement in the access to it, and adequate land use policies.

Based on a previous study (Spasovic and Morlok, 1993), they considered that **centralized management of drayage operations**, among different carriers, can reduce the necessary time to perform the drayage tasks and yield substantial cost savings in the range of 30% to 45%. More recently, Sterzik et al. (2015) demonstrated the benefit of the cooperative use of empty containers. In addition to cost savings, adequate planning of drayage tasks can increase the area of influence of a terminal. The **increase in the occupation factor of the trucks or in the number of daily tasks per driver** is regarded by Nierat (1997) as responsible for a growth of this area. The advantage of an efficient management of the drayage operations is the main topic of the majority of the mathematical studies related to drayage. This topic will be the central issue of this paper, so this will be studied in a separate epigraph.

As noted by Morlok and Spasovic (1995), some **regulation measures** could influence the final drayage cost. A particular case is studied by Cheung et al. (2008), who analysed various historical regulations imposed by the Hong Kong government on drayage operation within China. They studied the 4up-4down policy versus other more flexible policies, such as 2up-2down or a free policy. Under the 4up-4down policy, when a quadruple of driver+tractor+trailer+container goes from Hong Kong to China, the exact same quadruple must return to Hong Kong together. In the 2up-2down policy, only the driver and tractor are inseparable. They conclude that there are losses of benefits due to this restriction and suggest a relaxation of these measures. In this line, Shiri and Huynh (2017) developed a new model of a free policy to assess the effectiveness of different chassis supply models currently in use in the U.S. on productivity and air emissions.

New technology investments help to reduce drayage costs. These technologies could focus on providing improved information (Huynh and Zumerchik, 2010) or facilitating the movement of loads (such as the work of Shintani et al. (2010), who studied the impact of foldable containers on container fleet management costs).

Because of the high volume of drayage trucks arriving at container terminals, the trucks often experience significant **delays at the terminal gates** or inside them. The effects of new technologies to reduce these delays are another important aspect to consider. Huynh and Zumerchik (2010) researched how automated transfer management systems (ATMS) can be combined with intelligent transport system (ITS) technologies and e-business environments of the terminals to reduce the dwell time of trucks in the terminal. This paper specifically investigates the effect of priority rules for stacking containers into the ATMS to improve port drayage operations. Namboothiri and Erera (2008) and Zehendner and Feillet (2014) studied the impact of appointment-based access control systems on the productivity of drayage firms. Minh and Huynh (2014) modelled the terminal gates by means of queuing theory to determine the most effective layout for marine container terminals. Finally, Huynh et al. (2016) and Zhang and Zhang (2017) examined the state of the art and the state of practice for truck appointment systems. Zhao and Goodchild (2011) underlined the importance of the **reliability of travel time** and developed a method to predict it. Marković et al. (2014) described a probabilistic subproblem of the drayage operation in a real environment where there is uncertainty. Their study attempted to recommend a departure time for a truck, with that being the objective of the minimization of the operating cost. They searched for this time through a local search and a hybrid genetic algorithm. The work developed by Chen and Yang (2010) solved the previous problem of determination of the time windows. Chen et al. (2013) developed a queuing-based bi-objective model for optimizing the truck arrival pattern and reducing truck emissions at container terminals. Escudero et al. (2009), Escudero et al. (2011b), Escudero et al. (2011a), Escudero et al. (2013), You et al. (2016) and You and Ritchie (2017) demonstrated the usefulness of GPS technology in analysing drayage truck tours and thus **improving the information available** to the solver. Wasesa et al. (2017) developed a seaport service rate prediction system that could help drayage operators improve their predictions of the duration of the pick-up/delivery operations at a seaport.

3.1. daily drayage problem

Morlok and Spasovic (1995) established centralized management of drayage as a critical aspect for the profitability of intermodal transport. Several years elapsed between that publication and the study of Wang and Regan (2002), which could be considered the first work from an operational perspective and focused on the daily drayage problem (DDP). A considerable number of studies now focus on the daily drayage problem, sometimes referred to by other names, as a full-load vehicle scheduling problem or container drayage problem. The increase in the number of publications coincides with the importance that intermodal transport has achieved in political institutions. A brief overview of the main contributions of every work is presented below.

Within the PDD, we can find works focused on different aspects of the problem. There are works that consider a single terminal, while others consider several; studies where the size of the containers is unique and others where different sizes are considered; and works that only consider well-defined orders and others where the tasks can be flexible, especially in the case of empty containers. At this point, we have grouped the works reviewed based on these criteria.

3.1.1. Well-defined orders of loaded or empty containers

The daily drayage problem with well-defined orders was the first problem studied. Wang and Regan (2002) adapted the pickup and delivery problem to the specific operations in rail or maritime intermodal terminals. They model the daily drayage problem as a multiple travelling salesman problem with time window constraints (am-TSPTW) and present an iterative solution approach where two versions of the problem (over-constrained and under-constrained) are solved by a specific time window partitioning approach. The over-constrained method provides a feasible solution, while the gap between the two solutions allows for a decision regarding the stop criterion. Cheung and Hang (2003) developed a deterministic model with time windows that is then solved by means of the discretization of time. They incorporated the concept of fictitious tasks, which is used to simulate restrictions of the vehicles. Jula et al. (2005) solved a problem with time windows at the origin and the destination by using three solution approaches: (a) an exact method based on dynamic programming, (b) a hybrid methodology consisting of dynamic programming to generate feasible solutions in conjunction with genetic algorithms, and (c) a heuristic insertion method. They model every possible well-defined single movement of a container in a metropolitan area. Caris and Janssens (2009) proposed a two-phase insertion heuristic to construct an initial solution that is then improved with a local search heuristic. Following this work, Caris and Janssens (2010) included a deterministic annealing algorithm. In Escudero-Santana et al. (2015), a metaheuristic based on viral systems was applied. Imai et al. (2007) developed a subgradient heuristic based on a Lagrangian relaxation. In this line, Di Francesco et al. (2019) present theoretical formulations and probe that its continuous relaxation admits integer optimal solutions.

The movement of empty containers is another issue of great interest. Jula et al. (2006) studied the movement of empty container in the Los Angeles and Long Beach (LA/LB) port area and developed a two-phase optimization technique. This paper, which could be considered the first work focused on the drayage of only empty containers, uses several case studies based on current and projected demand to evaluate two different policies: street-turn and depot-direct. Chang et al. (2008) followed the previous paper and proposed a heuristic method. Deidda et al. (2008) and Furió et al. (2013) analysed the effects of the street-turn policy in real environments.

3.1.2. Integration of both loaded container movement and empty containers repositioning

Special attention has been paid to integrate the allocation of empty containers and the routing in drayage operations. Ileri et al. (2006) considered several task types, both simple and combined, and studied the costs involved in drayage operations. In combined tasks, two operation modes are considered: drop-and-hook, where the driver drops one container and hooks to another, and live, where the driver must wait while the container is being loaded or unloaded. They solved the problem via a column generation method. Even though there exist empty containers movements, these are well-defined tasks. A related problem was solved by Xue et al. (2014) and Xue et al. (2015). They examined a drayage problem in which a tractor can be detached from its companion trailer and assigned to a new task. A tabu search algorithm and an ant colony optimization method were proposed, respectively. Song et al. (2017) also studied a drayage problem under a resource-separation mode; in addition, they considered the case in which some empty containers should return to the depot for maintenance. A branch-and-price-and-cut algorithm was proposed to solve it. Caballini et al. (2016) proposed an optimization model for the cooperative planning of multiple truck carrier operations to maximize the total profit derived from their cooperation. A compensation mechanism is introduced to motivate carriers to share their trips.

Some studies add the possibility of flexible tasks, since the origins and destinations of some movements can be chosen from a set of possible nodes. This feature is particularly interesting since it allows flexibility in the origin or destination of empty containers. In this line, Smilowitz (2006) studied the problem as an am-TSPTW with flexible tasks, which let him model a free policy of container repositioning. Therefore, turn-street and depot-direct movements can be considered for every empty container requirement. The possible executions of each flexible task are limited by the distance between nodes. Thus, turn-street movements are only carried out within a feasible geographical region. The solution approach developed to solve this problem includes column generation embedded in a branch-and-bound process. This work was improved by Francis et al. (2007), who introduced a variable radius method to define possible executions of flexible tasks. Zhang et al. (2011a) extended these previous works and added dynamic requests of tasks throughout the day. They embedded a branch and price in a rolling horizon method. Coslovich et al. (2006) described a fleet management problem focused on the minimization of the present and future operation costs. They formulated an integer programming model and proposed a Lagrangian relaxation, decomposing the problem into three subproblems: task pairing, resource assignment and container repositioning.

3.1.3. Multi-depot and multi-terminal

Reinhardt et al. (2016) presented a generalized formulation of the DDP in which flexible tasks and multiple depots are considered. They established a novel constraint to balance the empty container depot levels. By exploring the fact that the number of possible routes in the considered case is quite limited, they demonstrated that the model can be solved within a minute by use of an exact method based on column enumeration. Zhang et al. (2009) formulated the problem as an am-TSPTW with multiple depots and a single terminal and used a reactive tabu search to solve it. This problem was expanded by Zhang et al. (2010), who used a window-partition-based method inspired by Wang and Regan (2002). The problem defined in Zhang et al. (2010) was solved by Sterzik et al. (2015) using a cost-saving heuristic and a tabu search; their objective was to demonstrate the benefits of cooperative use of an empty container. Zhang et al. (2011b) limited the number of empty containers in the depot (even though this problem only considers a depot and a terminal, it is computationally more complex). A similar problem is solved in Zhang et al. (2020), which propose a large neighborhood search algorithm. Nossack and Pesch (2013) presented a new formulation for the truck scheduling problem based on a full-truckload pickup and the delivery problem with time windows and propose a two-stage heuristic approach. The results of computational experiments indicated that their 2-stage heuristic outperforms the method applied by Zhang et al. (2010) in terms of computational efficiency.

Following their previous line of work, Braekers et al. (2013) formulated an am-TSPTW to solve the DDPTW and empty container repositioning and proposed two methods: a sequential method, where empty container allocations are determined before vehicle routes are created, and an integrated method. Both methods are based on simulated annealing. They concluded that the integrated approach clearly outperforms the sequential one. Braekers et al. (2014) extended the previous work from a bi-objective perspective, and three solution algorithms were proposed: an iterative method, a two-phase deterministic annealing algorithm, and a two-phase hybrid deterministic annealing and tabu search algorithm. Their comparison determined that the best results are obtained by the last one.

Sun et al. (2014) described a solution method using a set-partitioning formulation and column-generation heuristic and reported on a large-scale implementation. They focused on real-world implementation details, including: (1) fast solution times to support near-real-time re-solving in the face of constantly changing data, (2) adjustments to account for traffic congestion and other operational considerations, and (3) integration with a commercial transportation management system to provide real-time data to the optimizer and to send solution recommendations to a driver-assignment process. This was used in large metropolitan hub areas, such as Chicago and Los Angeles.

Some works focus on the necessity of transfers among terminals. This is what occurs when intermodal containers need to be transferred from one terminal to another to continue the shipment. Chung et al. (2007) presented heuristic algorithms to solve a real-world example, the data set for which was collected from a container trucking company in Korea. Pazour and Neubert (2013) also developed a heuristic solution approach. They illustrated how this problem has special characteristics that require a novel methodology. Sterzik and Kopfer (2013) developed a tabu search to solve a problem that also considers empty container repositioning and several container sizes. All of these methods try to cover the maximum number of loads with the minimum empty moves. Bai et al. (2015) resolved a specific definition of the drayage problem where several labour shifts are considered. A set-covering model is formulated to solve the problem.

3.1.4. Multi-size container load

In addition to Sterzik and Kopfer (2013), other works have also considered different container sizes. Lai et al. (2013) addressed a problem in which trucks can carry one or two containers. They determined an initial solution by a variant of the Clarke-and-Wright algorithm and improved it by a sequence of local search phases. Zhang et al. (2015) and Funke and Kopfer (2016) formulated an extension of their previous works, modelling different types of containers. In Zhang et al. (2015), three tree search procedures and an improved reactive tabu search algorithm were designed to solve the problem with time windows not considered. In Funke and Kopfer (2016), a mixed-integer linear program was presented using two alternative objective functions: minimization of the total travel distance and minimization of the total operation time of the trucks. In Vidović et al. (2016), a multisize container drayage problem with time windows was modelled as a multiple matching problem and formulated as a mixed integer linear program model. To solve larger-sized problems, they proposed a variable neighbourhood search. Ritzinger et al. (2017) developed a variable neighbourhood search to solve a problem that considers the compatibility between container types and trailer types. Daham et al. (2017) presented a drayage problem that considers different sizes of containers, containers with multiple customer locations as its receivers, and weight constraints. They solved the problem by means of an exact method. Ghezelsoflu et al. (2018) propose a set-covering formulation for a drayage problem with single and double container loads. Real data of a carrier are used in the experimentation.

Since technologies of foldable container have almost matured, some studies are considering this containers into drayage service scheduling. Zhang et al. (2018) solve the foldable container drayage problem by means of a reactive tabu search. The results appoint to a saving of approximately 10% on transportation compared to the use of standard containers.

3.1.5. Terminal appointment and long-haul integration

Some works study the integrated scheduling of drayage operation and long-haul transportation. Using the data set generated by Zhang et al. (2009), Wang and Yun (2013) introduced the possibility of rail transportation and developed a hybrid tabu search to solve a mixed-integer programming model. Pérez Rivera and Mes (2019) design a simulation-based approach to integrate a MILP model for scheduling drayage operations and a Markov Decision Process model for scheduling long-haul transport in the context of synchromodal transport.Heggen et al. (2019) develop a large neighbourhood search heuristic to solve the integrated problem. Fan et al. (InPress) present an genetic algorithm.

Shiri and Huynh (2016) addressed the challenge posed to drayage firms of having to make appointments at terminals in advance. In this emerging practice, drayage firms need to make scheduling decisions while complying with the terminal-specified truck appointment system. They modelled the empty container allocation problem, vehicle routing problem and appointment booking problem in an integrated manner using a mixed-integer programming model. The integrated optimization model was solved by a reactive tabu search algorithm combined with a greedy algorithm. Torkjazi et al. (2018) present an approach for designing a Truck Appointment System (TAS) intended to serve both the maritime container terminal operator and drayage operators.

3.1.6. Stochastic

Other studies have also considered stochastic characteristics of the problem. These considerations appeared in the second part of the work of Cheung and Hang (2003), who solved it with a rolling window heuristic (being the first work with stochastic considerations). Cheung et al. (2005) considered the same problem and solved it by means of a labelling method. In both studies, randomness only affected the duration of the tasks, not the displacement time among different tasks. Escudero et al. (2009) and Escudero et al. (2011b) presented evolutionary algorithms to solve a problem with stochastic transit time. These studies were improved in Escudero et al. (2011a) and Escudero et al. (2013), where heuristic (based on Caris and Janssens (2009)) and genetic algorithms were implemented to solve a dynamic formulation of the problem. Uncertainty in both service time and arrival time was considered in Máhr et al. (2010). They developed a comparison between an on-line method and an agent-based method to solve a problem. Zhang et al. (2014) developed a window-partitioning method to solve a problem with flexible orders where logistic information could be updated during one time horizon. Shiri et al. (2019) present a work with stochastic packing and unpacking times.

3.1.7. Summary and similar problems

A summary of the different operational studies listed above is shown in Table 1. This table synthesizes information regarding the characteristic problem that the authors solve and the methodology of their solution.

Some interesting works have presented problems that are similar to the DDP, so their methods and some of their conclusions could be applied to the DDP. Ball et al. (1983) could be considered the first of these studies. They transformed the problem of the allocation of trailers for a chemical company into a vehicle routing problem (VRP). Origin and destination of a movement are considered as a single node that represents the entire movement with all the characteristics of the movement (duration, origin, destination and time windows).

A close problem is the vehicle routing problem with full truck loads. In this problem, there are a fleet of trucks, each located at one of several depots, which must serve a given number of shipments of full truckloads between specified pairs of points. Its objective is to determine minimum-cost truck routes. Its difference from the DDP is the absence of terminals as principal nodes of generation and attraction of flow. Some outstanding studies are presented below.

De Meulemeester et al. (1997) and Bodin et al. (2000) applied the transformation of Ball et al. (1983) but without the consideration of time windows. Arunapuram et al. (2003) developed a branch-and-bound algorithm, based on column-generation, to solve an integer-programming formulation of this problem. They also took into consideration the time-window constraints and waiting costs. Currie and Salhi (2003) and Currie and Salhi (2004) solved the full-load, multi-terminal, vehicle scheduling problem with backhauling and time windows using exact and heuristics methods and a tabu search. Gronalt et al. (2003) developed four heuristics based on cost savings to solve a full-load pick-up and delivery problem with time windows. Mes et al. (2007) and Mes et al. (2010) used multiagent systems to solve the problem (as in Máhr et al.

Table 1: Summary of the studies of the daily drayage problem

Paper	Problem						Method				
	Objective	TW	Empty Container	Size Container	Terminals	Uncertain	Model	Exact	Heuristic	Meta-Heuristic	
Wang and Regan (2002)	min. Dist.	y	n	1	1	no	am-TSPTW	x*	x		
Cheung and Hang (2003)	min. Cost	y	n	1	1	Service times	MIP	x+			
Cheung et al. (2005)	min. Cost	y	n	1	1	Service times	MIP	x+			
Jula et al. (2005)	min. Cost	y	n	1	1	no	am-TSPTW	x*	x	x	Genetic algorithm
Coslovich et al. (2006)	min. Cost	y	y	1	1	no	IP	x*			
Ileri et al. (2006)	min. Cost	y	y	1	1	no	IP	x			
Jula et al. (2006)	min. Cost	n	y	1	1	no	IP	x			
Smilowitz (2006)	min. Cost	y	y	1	1	no	IP	x			
Chung et al. (2007)	min. Cost and min. Fleet	y	n	2	m	no	am-TSPTW		x		
Francis et al. (2007)	min. Cost	y	y	1	1	no	IP	x			
Imai et al. (2007)	min. Cost	n	n	1	1	no	FLPDPTW	x*			
Caris and Janssens (2009)	min. Cost	y	n	1	1	no	FLPDPTW		x		
Escudero et al. (2009)	min. Cost	y	y	1	1	Transit Time	am-TSPTW			x	Dynamic evolutionary algorithm
Zhang et al. (2009)	min. Time	y	y	1	1	no	am-TSPTW			x	Tabu search
Caris and Janssens (2010)	min. Cost	y	n	1	1	no	FLPDPTW			x	Simulated annealing
Mahr et al. (2010)	min. Time	y	y	1	m	Service times	MIP			x	Multi agent systems
Zhang et al. (2010	min. Time and min. Fleet	y	y	1	3	no	am-TSPTW	x*	x		
Escudero et al. (2011a)	min. Cost	y	n	1	1	Transit Time	am-TSPTW		x		
Escudero et al. (2011b)	min. Cost	y	n	1	1	Transit Time	am-TSPTW			x	Genetic algorithm
Zhang et al. (2011)	min. Time and min. Fleet	y	y	1	1	no	am-TSPTW				Tabu Search
Zhang et al. (2011a)	min. Cost	y	y	1	1	Online Tasks	IP	x+			
Braekers et al. (2013)	min. Cost	y	y	1	1,3	no	am-TSPTW			x	Simulated annealing
Escudero et al. (2013)	min. Cost	y	n	1	1	Transit Time	am-TSPTW		x	x	Genetic algorithm
Lai et al. (2013)	min. Cost	n	y	2	1	no	MIP		x		
Nossack and Pesch (2013)	min. Time	y	y	1	m	no	FLPDPTW		x		
Pazour and Neubert (2013)	min. Dist.	n	n	1	n.i.	no	n.i.		x		
Sterzik and Kopfer (2013)	min. Time	y	y	1	m	no	MIP			x	Tabu Search
Wang and Yun (2013)	min. Cost	y	y	1	2	no	MIP			x	Tabu Search
Braekers et al. (2014)	min. Cost and min. Fleet	y	y	1	1,3	no	am-TSPTW		x	x	Simulated annealing Tabu Search
Sun et al. (2014)	min. Cost	y	y	1	2	no	MIP	x			
Xue et al. (2014)	min. Cost	n	y	1	1	no	MIP			x	Tabu Search
Zhang et al. (2014)	min. Time	y	y	1	m	Online tasks	MIP	x*			Window partition
Bai et al. (2015)	min. Dist.	y	n	1	m	no	MIP	x*			
Escudero et al. (2015)	min. Cost	y	n	1	1	no	am-TSPTW			x	Viral system
Sterzik et al. (2015)	min. Time	y	y	1	m	no	IP		x	x	Tabu Search
Xue et al. (2015)	min. Cost	n	y	1	1	no	MIP			x	Ant Colony
Zhang et al. (2015)	min. Time	n	y	2	1	no	MIP			x	Tabu Search
Caballini et al. (2016)	max. Profit	y	y	1	1	no	IP	x			
Funke and Kopfer (2016)	min. Dist. and min. Time	y	y	2	m	no	MIP	x			
Reinhant et al. (2016)	min. Cost and min. Fleet	y	y	2	m	no	IP	x			
Shiri and Huynh (2016)	min. Time	y	y	1	1	no	MIP			x	Tabu Search
Song et al. (2016)	min. Time	y	y	1	1	no	MIP			x	Tabu Search
Vidovic et al. (2016)	min. Cost	y	y	2	1	no	MIP	x		x	Variable Neighbour Search
Daham et al. (2017)	min. Cost	y	y	2	1	no	MIP	x			
Ritzinger et al. (2017)	min. Cost and max. Orders	y	y	1	1	no	MIP			x	Variable Neighbour Search
Zhang et al. (2018)	min. Time	y	y	F	1	no	am-TSPTW			x	Tabu Search
Torkjazi et al. (2018)	min. Cost	y	n	1	1	no	MINLP	x			
Ghezelsoflu et al. (2018)	min. Cost	y	y	2	1	no	MIP	x			
Di Francesco et al. (2019)	min. Cost	n	n	1	1	no	IP				
Shiri et al. (2019)	min. Time	y	y	1	1	Service times	MIP	x		x	Tabu Search
Heggen et al. (2019)	min. Cost	y	y	>1	m	no	am-TSP			x	Large neighbourhood search heuristic
Pérez-Rivera and Mes (2019)	min. Cost	n	y	1	1	no	MIP	x	x		
Fan et al. (In Press)	min. Cost	n	n	1	m	no	IP			x	Genetic Algorithm
Zhang et al. (2020)	min. Time and min. Fleet	y	y	1	1	no	MIP			x	Large neighbourhood search heuristic
(F) Foldable								(*) Problem relaxation (+) Rolling horizont			

(2010)).

One variation of the previously mentioned problem is the truck and trailer routing problem (TTRP). In the TTRP, a fleet of trucks (considering a truck as only the tractor) and trailers serves a set of customers. Some customers with accessibility constraints must be served just by truck, while others can be served either by truck or by a complete vehicle. The aim is to minimize the total distance travelled to cover all tasks or to minimize the use of resources. Li et al. (2016) and Neves-Moreira et al. (2016) presented review papers. Some interesting articles are: Chao (2002) and Scheuerer (2006), which proposed algorithms based on tabu search; Villegas et al. (2013), which proposed a two-phase matheuristic (that uses a hybrid GRASP with iterative local search (ILS) in a set-partitioning formulation of the problem); Lin et al. (2009), which solved the problem by means of simulated annealing; and Regnier-Coudert et al. (2016), which developed a constructive heuristic to solve the problem on a real industry scenario.

4. Problem definition and formulation

Drayage tasks contemplate every container movement around a terminal by using a truck. Because drayage is usually the beginning and the end of the intermodal transport chain, the main drayage orders are the movements of load containers between a terminal and customers. The movement of a container from a terminal to a consignee is referred to as an importation order, while the movement of a container from a consignor to a terminal is referred to as an exportation order. These orders consider the collection of the container in the origin, the transportation of this from the origin to the destination, and the delivery of the container to the destination. Thus, two fundamental operations can be defined: requests for collection and requests for delivery. For orders of importation and exportation, the operation of collection and delivery are paired, and thus the origin and destination of the order are known in advance. These orders are referred to as well-defined orders.

While these orders to load a container require having an empty container in a particular facility, complementary orders are necessary to have empty containers available at a specific time and place. In these orders, only the destination of the empty container is specified because the consignor requests an empty container, regardless of its origin. Likewise, when the containers are unloaded, the receipts sometimes require the withdrawal of the container. Again, the destination of these empty containers does not matter on many occasions. These orders of request and removal of empty containers are named flexible orders since only either the origin or the destination is known in advance.

The movement of an empty container is not always associated with flexible orders, with the ability to impose a specific origin and destination. In many cases, this depends on the properties of the containers and the necessities of the container depot for balancing of the companies. Anyway, the movement of empty containers must be reduced as much as possible with the objective of maximizing the transport load factor.

In summary, four types of orders have been defined: exportation (E), importation (I), request for an empty container (IE) and removal of an empty container (OE). Other authors present more complex tasks, where several of these basic orders are grouped. For example, Ileri et al. (2006) presented several combined tasks and distinguished between stay-with and drop-and-pick complex orders. The formulation that will be presented can contemplate these combined tasks. However, without limiting the generality of the foregoing, we only consider the four basic orders, since (a) every complex task can be divided into basic orders and (b) the imposition of stay-with policies usually supposes suboptimal solutions.

All of these orders (I, E, OE, IE) must usually be performed with consideration of some temporal constraints. Thus, time windows can be imposed at the origin and destination of each tasks. Depending on the type of order, the temporal constraints are different.

In exportation orders, these constraints are more severe, as a delay in delivery of a container at the terminal can mean missing the link with the main transport (train or vessel). Thus, the container has to wait at the terminal until the next means of transport that can be used for the shipment. It could take hours or days and may result in additional storage costs. In importation orders, there is an early time before which the shipment cannot start since the container is not available.

In addition to these constraints, which are derived directly from the schedule of the main transportation at the terminal, there are other restrictions arising from terminal storage policies. Commonly, the terminal provides time windows within which it is possible to pick up or deliver a container without any additional cost. In export operations, delivering the goods before the time window carries a cost storage imposed by the terminal managers, since the container should wait at the terminal before being loaded into the vessel or train. Collection of a container outside the time window in import tasks assumes a similar cost for the same reasons.

In the customers facilities, time-window constraints could be contemplated as well. For example, if an empty container needs to be loaded and then sent to the terminal, this empty container must be in the facility before a required time. In the case of removing an empty container, a temporal limitation can be imposed due to the necessity of space.

This peculiarity allows the problem to be solved to be defined as a DDPTW, where there are several orders or tasks that should be covered with a combination of vehicles within certain time windows. The problem is to assign each task to a vehicle so that the generated costs are minimized.

Between the different costs that must be minimized, the first distinction appears between fixed costs and variable costs. Fixed costs mainly include the salaries of drivers and the depreciation of vehicles. Among the variable costs are those that depend on the distance travelled, such as fuel costs. There are also other costs in drayage problems, which are the costs of penalization, which are supported when the truck violates any restrictions involving compensation.

4.1. Modelling of the problem

Let $i \in \mathcal{O}$ be an order. Each order is associated with several parameters that define it.

- The origin where the order begins to develop, o_i.

- The destination where the order concludes, d_i.

- The service times in the origin and destination, s_i^o and s_i^d, which are the times for loading and unloading the container.

- Times windows in origin and destination, $[E_i^o, L_i^o]$ and $[E_i^d, L_i^d]$, which are the intervals of time in which the order should begin at the origin or at the destination to avoid extra costs.

Because four basic orders exist, the set $\mathcal{O}$ has been divided into four subsets: importation orders $\mathcal{O}^I$, exportation orders $\mathcal{O}^E$, inbound empty containers $\mathcal{O}^{IE}$ and outbound empty containers $\mathcal{O}^{OE}$. Subsets $\mathcal{O}^I$ and $\mathcal{O}^E$ are well-defined orders, so all their parameters are known in advance. In importation orders, the origin is located at the terminal, $\dot{T}$, while in the exportation orders, the terminal is the destination. Subsets $\mathcal{O}^{IE}$ and $\mathcal{O}^{OE}$ are flexible orders, which represent requests and removals of empty containers. In these orders, only some parameters are known in advance. For example, the origin of a container in a request for an empty container order could be the depot, $\dot{D}$, or the container removal from an outbound empty container order.

Because the problem under study allows soft time windows, some penalization costs have assumed if the orders are not performed within the time window associated:

- An exportation order cannot begin before the container is ready in the origin (see Figure 3.a). In the destination, the terminal, breaking the time window due to delays means missing the train or ship responsible for the main transportation. Thus, a high penalty cost is generated by missing the main transport, C_i^m. Moreover, dropping the container off early can result in extra storage costs, C_i^s . This is shown in Figure 3.b.

- In importation orders, the container cannot be retired before this arrives. Moreover, as shown in Figure 3.c, breaching the time windows in the origin due to delays means extra storage costs due to the waiting time, C_i^s. The penalization of the destination could be modelled with the origin time windows. Thus, no extra constraints are added (see Figure 3.d).

- In inbound empty container orders (see Figure 3.b), there exist two penalization costs, one relative to early deliveries and another relative to delayed deliveries.

- In outbound empty containers, as shown in Figure 3.c, a cost relative to removal delays exists.

A fleet of vehicles exists to perform all orders. C_v is the cost of using a new vehicle. Each vehicle has been modelled by means of two dummy orders; thus, different origins, destinations and working times can be considered. One dummy order represents the beginning of the working day, and another represents the end. These orders are included in the sets $\mathcal{O}^{VI}$ and $\mathcal{O}^{VE}$. The workday is framed in a time window; before the end of the day, all trucks have to return to the vehicle depot, $\dot{V}$, in the case of noncompliance there exist an extra cost. The penalty will be a cost per unit of time of delay, C_i^d.

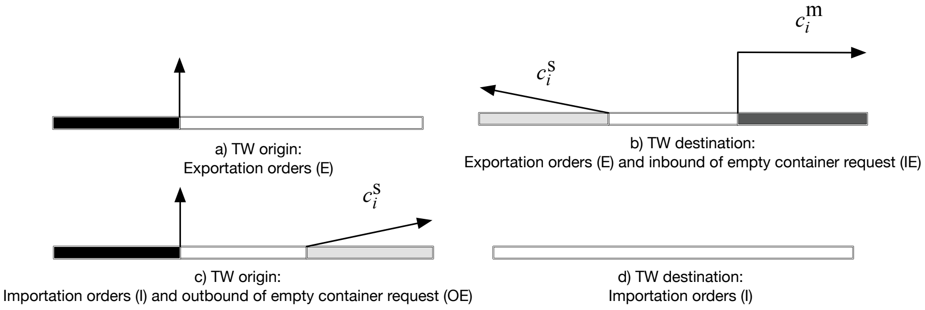


Figure 3: Time windows

The inclusion of these dummy orders and the soft time windows where some delays are allowed (although with penalty costs) allows the model to be adapted to dynamic and probabilistic problems in which there could exist delays in the services and displacement times. Moreover, this lets us use the model in methods as the rolling horizon. In these cases, it is necessary to know which vehicles have been previously used. This information is in the parameter U_i (1 if $i \in \mathcal{O}^{VI}$ was used, else 0).

The variables of the model are:

- x_{ij}, binary variable. 1 if orders i and j are served consecutively, else 0.
- n_i, binary variable. 1 if new vehicle i is used, else 0 (in dynamic problems).
- t_i^o start time of the order i in the origin (load).
- t_i^d: start time of the order i in the destination (unload)
- w_i^o Delay time on the later expected beginning time in order i, extra storage cost.
- w_i^d Advance time at the earliest planned start time in order i, extra storage cost.
- $w_i^{\dot{V}}$ Delay time of the vehicle i in the latest expected hour of arrival at the depot of vehicles ($\dot{V}$).
- l_i^d binary variable. 1 if order i break its destination time window, else 0.

To facilitate the modelling, three auxiliary parameters are defined:

- T_i, which represents the time of loading the container in the origin of order i and the displacement to the destination of i.
- T_{ij}, which represents the time of unloading the container in the destination of order i and the displacement to the origin of order j.
- C_{ij}, which represents the distance of displacement of order i plus the distance between destination of i and origin of j.

The values of these parameters depend on the sequence in which the orders are performed. Supposing a unique terminal ($\dot{T}$), depot ($\dot{D}$) of containers and depot of vehicles ($\dot{V}$), the values of these parameter are as shown in Table 2. The model can be easily extrapolated to problems with several terminals or depots. δ_{AB} represents the distance between two geographical localization, A and B, and τ_{AB} is the expected travel time between those points. For example: $\tau_{\dot{V}o_j}$ is the expected travel time between the vehicle depot and the origin of the order j and $\delta_{o_i d_i}$ represent the distance between origin and destination of the order i.

Table 2: Transition time and costs

ij	$\mathcal{O}^{I}$	$\mathcal{O}^{E}$	$\mathcal{O}^{IE}$	$\mathcal{O}^{OE}$	$\mathcal{O}^{VE}$
$\mathcal{O}^{VI}$	$T_i = 0$ $T_{ij} = \tau_{\dot{V}\dot{T}}$ $C_{ij} = \delta_{\dot{V}\dot{T}}$	$T_i = 0$ $T_{ij} = \tau_{\dot{V}o_j}$ $C_{ij} = \delta_{\dot{V}o_j}$	$T_i = 0$ $T_{ij} = \tau_{\dot{V}\dot{D}} + s_{\dot{D}} + \tau_{\dot{D}d_j}$ $C_{ij} = \delta_{\dot{V}\dot{D}} + \delta_{\dot{D}d_j}$	$T_i = 0$ $T_{ij} = \tau_{\dot{V}o_j}$ $C_{ij} = \delta_{\dot{V}o_j}$	$T_i = 0$ $T_{ij} = 0$ $C_{ij} = 0$
$\mathcal{O}^{I}$	$T_i = s_i^o + \tau_{\dot{T}d_i}$ $T_{ij} = s_i^d + \tau_{d_i\dot{T}}$ $C_{ij} = \delta_{\dot{T}d_i} + \delta_{d_i\dot{T}}$	$T_i = s_i^o + \tau_{\dot{T}d_i}$ $T_{ij} = s_i^d + \tau_{d_i o_j}$ $C_{ij} = \delta_{\dot{T}d_i} + \delta_{d_i o_j}$	$T_i = s_i^o + \tau_{\dot{T}d_i}$ $T_{ij} = s_i^d + \tau_{d_i\dot{D}} + s_{\dot{D}} + \tau_{\dot{D}d_j}$ $C_{ij} = \delta_{\dot{T}d_i} + \delta_{d_i\dot{D}} + \delta_{\dot{D}d_j}$	$T_i = s_i^o + \tau_{\dot{T}d_i}$ $T_{ij} = s_i^d + \tau_{d_i o_j}$ $C_{ij} = \delta_{\dot{T}d_i} + \delta_{d_i oj}$	$T_i = s_i^o + \tau_{\dot{T}d_i}$ $T_{ij} = s_i^d + \tau_{d_i\dot{V}}$ $C_{ij} = \delta_{\dot{T}d_i} + \delta_{d_i\dot{V}}$
$\mathcal{O}^{E}$	$T_i = s_i^o + \tau_{o_i\dot{T}}$ $T_{ij} = s_i^d$ $C_{ij} = \delta_{o_i\dot{T}}$	$T_i = s_i^o + \tau_{o_i\dot{T}}$ $T_{ij} = s_i^d + \tau_{\dot{T}o_j}$ $C_{ij} = \delta_{o_i\dot{T}} + \delta_{\dot{T}o_j}$	$T_i = s_i^o + \tau_{o_i\dot{T}}$ $T_{ij} = s_i^d + \tau_{\dot{T}\dot{D}} + s_{\dot{D}} + \tau_{\dot{D}d_j}$ $C_{ij} = \delta_{o_i\dot{T}} + \delta_{\dot{T}\dot{D}} + \delta_{\dot{D}d_j}$	$T_i = s_i^o + \tau_{o_i\dot{T}}$ $T_{ij} = s_i^d + \tau_{\dot{T}o_j}$ $C_{ij} = \tau_{o_i\dot{T}} + \delta_{\dot{T}o_j}$	$T_i = s_i^o + \tau_{o_i\dot{T}}$ $T_{ij} = s_i^d + \tau_{\dot{T}\dot{V}}$ $C_{ij} = \tau_{o_i\dot{T}}\tau_{\dot{T}\dot{V}}$
$\mathcal{O}^{IE}$	$T_i = 0$ $T_{ij} = s_i^d + \tau_{d_i\dot{T}}$ $C_{ij} = \delta_{d_i\dot{T}}$	$T_i = 0$ $T_{ij} = s_i^d + \tau_{d_i o_j}$ $C_{ij} = \delta_{d_i o_j}$	$T_i = 0$ $T_{ij} = s_i^d + \tau_{d_i\dot{D}} + s_{\dot{D}} + \tau_{\dot{D}d_j}$ $C_{ij} = \delta_{d_i\dot{D}} + \delta_{\dot{D}d_j}$	$T_i = 0$ $T_{ij} = s_i^d + \tau_{d_i o_j}$ $C_{ij} = \delta_{d_i o_j}$	$T_i = 0$ $T_{ij} = s_i^d + \tau_{d_i\dot{V}}$ $C_{ij} = \delta_{d_i\dot{V}}$
$\mathcal{O}^{OE}$	$T_i = s_i^o + \tau_{o_i\dot{D}}$ $T_{ij} = s_{\dot{D}} + \tau_{\dot{D}\dot{T}}$ $C_{ij} = \delta_{o_i\dot{D}} + \delta_{\dot{D}\dot{T}}$	$T_i = s_i^o + \tau_{o_i\dot{D}}$ $T_{ij} = s_{\dot{D}} + \tau_{\dot{D}o_j}$ $C_{ij} = \delta_{o_i\dot{D}} + \delta_{\dot{D}o_j}$	$T_i = s_i^o$ $T_{ij} = \tau_{d_i o_j}$ $C_{ij} = \delta_{d_i o_j}$	$T_i = s_i^o + \tau_{o_i\dot{D}}$ $T_{ij} = s_{\dot{D}} + \tau_{\dot{D}o_j}$ $C_{ij} = \delta_{o_i\dot{D}} + \delta_{\dot{D}o_j}$	$T_i = s_i^o + \tau_{o_i\dot{D}}$ $T_{ij} = s_{\dot{D}} + \tau_{\dot{D}\dot{V}}$ $C_{ij} = \tau_{o_i\dot{D}} + \tau_{\dot{D}\dot{V}}$

Of the information shown in Table 2, it is important to highlight that, in the flexible orders, subsets IE and OE, the containers have the depot ($\dot{D}$) as origin and destination. However, when an IE order is executed after an OE order, the container is transferred directly (see Figure 4).

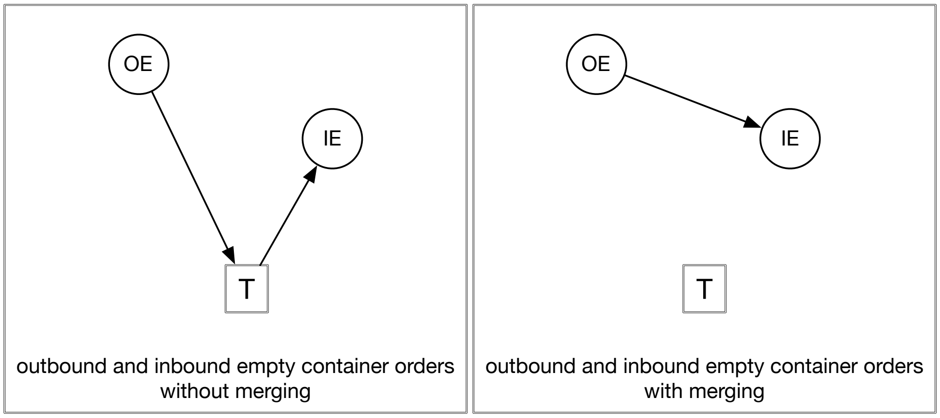


Figure 4: Savings for merging flexible empty container orders

With the above notation, the DDPTW problem is formulated as shown:

$$\begin{aligned} OF: \min \Bigg(& \sum_{i \in \mathcal{O}^{VI} \cup \mathcal{O}} \sum_{j \in \mathcal{O} \cup \mathcal{O}^{VE}} C_{ij} x_{ij} + \sum_{i \in \mathcal{O}^{VI}} C_v n_i + \sum_{i \in \mathcal{O}^{E} \cup \mathcal{O}^{IE}} C_i^s w_i^d \\ & + \sum_{i \in \mathcal{O}^{I} \cup \mathcal{O}^{OE}} C_i^s w_i^o + \sum_{j \in \mathcal{O}^{E} \cup \mathcal{O}^{IE}} C_j^m l_j^d + \sum_{i \in \mathcal{O}^{VE}} C_i^d w_i^{\dot{V}} \Bigg) \end{aligned} \tag{1}$$

suject to:

$$\sum_{i \in \mathcal{O}^{VI} \cup \mathcal{O}} x_{ij} = 1 \qquad \forall j \in \mathcal{O} \cup \mathcal{O}^{VE}, \tag{2}$$

$$\sum_{j \in \mathcal{O} \cup \mathcal{O}^{VE}} x_{ij} = 1 \qquad \forall i \in \mathcal{O}^{VI}, \tag{3}$$

$$\sum_{i \in \mathcal{O}^{VI} \cup \mathcal{O}} x_{ij} - \sum_{i \in \mathcal{O} \cup \mathcal{O}^{VE}} x_{ji} = 0 \qquad \forall j \in \mathcal{O}, \tag{4}$$

$$t_i^o \geq E_i^o \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{E} \cup \mathcal{O}^{OE} \cup \mathcal{O}^{V}, \tag{5}$$

$$t_i^d \geq E_i^d \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{V}, \tag{6}$$

$$E_i^d - t_i^d \geq w_i^d \qquad \forall i \in \mathcal{O}^{E} \cup \mathcal{O}^{IE}, \tag{7}$$

$$t_i^d \geq t_i^o + T_i \qquad \forall i \in \mathcal{O} \cup \mathcal{O}^{V}, \tag{8}$$

$$t_i^d + T_{ij} - t_j^o \leq M \cdot (1 - x_{ij}) \qquad \forall i \in \mathcal{O} \cup \mathcal{O}^{VI}, \forall j \in \mathcal{O} \cup \mathcal{O}^{VE}, \tag{9}$$

$$t_i^o - L_i^o \leq M \cdot w_i^o \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{OE}, \tag{10}$$

$$t_j^d - L_j^d \leq M \cdot l_j^d \qquad \forall j \in \mathcal{O}^{E} \cup \mathcal{O}^{IE}, \tag{11}$$

$$t_i^o - L_i^o \leq M \cdot w_i^{\dot{V}} \qquad \forall i \in \mathcal{O}^{VE}, \tag{12}$$

$$\left(\sum_{j \in \mathcal{O}} x_{ij} \right) - U_i \leq n_i \qquad \forall i \in \mathcal{O}^{VI}, \tag{13}$$

$$t_i^o \geq 0 \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{E} \cup \mathcal{O}^{OE} \cup \mathcal{O}^{V}, \tag{14}$$

$$t_i^d \geq 0 \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{E} \cup \mathcal{O}^{IE} \cup \mathcal{O}^{V}, \tag{15}$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in \mathcal{O}^{VI} \cup \mathcal{O}, j \in \mathcal{O} \cup \mathcal{O}^{VE}, \tag{16}$$

$$n_i \in \{0,1\} \qquad \forall i \in \mathcal{O}^{VI}, \tag{17}$$

$$w_i^o \geq 0 \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{OE} \cup \mathcal{O}^{V}, \tag{18}$$

$$w_i^d \geq 0 \qquad \forall i \in \mathcal{O}^{I} \cup \mathcal{O}^{E} \cup \mathcal{O}^{IE} \cup \mathcal{O}^{V}, \tag{19}$$

$$l_j^d \in \{0,1\} \qquad \forall j \in \mathcal{O}^{E} \cup \mathcal{O}^{IE}, \tag{20}$$

$$w_i^{\dot{V}} \in \{0,1\} \qquad \forall i \in \mathcal{O}^{VE}, \tag{21}$$

The objective function of the model aims to minimize the total amount of costs associated with a solution to the problem: (a) costs associated with the total distance travelled, (b) the fixed costs associated with the number of vehicles required, and (c) the costs generated by the breaches of the time windows.

Restrictions are divided into several groups. (2-4) indicate that each task should be covered once. (5-12) represent the restrictions of time windows. As can be observed, this work contemplates soft time windows. M represent a great number. (13) indicate if a new vehicle is used, since the model is adapted to dynamic resolution, U_i indicates if a vehicle $i \in \mathcal{O}^{VI}$ has been previously used. (14-20) define variables in a range, whether as binary (decision variables) or positive (those that record time).

The commercial software Gurobi v7.5 was used to solve the formulation shown previously. The default setting of tolerance was modified to make the method more restrictive: the parameter *FeasibilityTol*, which establishes the tolerance of the constraints, was set to 10^{-9}. The MIP solver of Gurobi terminate, considering optimal result, when the gap between the lower and upper objective bound is less than *MIPGap* times the absolute value of the upper bound; so this parameter was set to 0. The maximum time expended was fixed in 3600 seconds.

5. Experimental design

Despite the number of studies focused on different variants of DDP, it is impossible to develop a clear comparison among them. This is because the different experiments and tests do not follow a common framework. The clusters of researchers have independently developed their own tests, and sometimes these are not published; consequently, these experiments are not replicable.

A summary of the different tests and their characteristics is shown in Table 3. This table contains information regarding the origin of the data (artificial or based on a realistic environment), the possibility of replicating the test (y: yes, n: no, m: the experiment could be replicated but the results are not directly comparable), the maximum number of orders, and the characteristics of the time windows. This table also shows which works were developed by the same cluster of researchers.

This paper aims to establish a common framework for DDP studies. With this objective, two different batteries of tests are proposed. These batteries are designed to discover the performances of the approach in several environments.

The first battery (B1) only has importation and exportation orders, it is to say, the battery only contains well-defined orders. The second battery (B2) also considers movements of empty containers, so both, well-defined and flexible orders are taken into account. This benchmark provides an extensive variety of cases, with several time windows and positions of the customers (See Table 4). The customers can be randomly distributed (R), clustered (C) or a mixed model (RC). There are tests in which all the orders have time windows, while for other tests, only a percentage have this restriction. Moreover, the lengths of the time windows can vary from very narrow windows to much wider windows.

Both batteries are developed with different numbers of orders. In B1 28 different tests were completed with 4 problem sizes (10 orders, 25 orders, 50 orders and 100 orders). Since B2 is an extension of some tests of the first one, again four different numbers of orders are tested (20, 50, 100 and 200) for 21 different test. So, a total of 196 tests were studied.

Table 3: Summary of test batteries in the drayage literature

Cluster	Paper	Artificial	Base Real	Replicable	n. orders	TW characteristic (min)
	Wang and Regan (2002)	x		n	Up to 150	30, 90, 240
A	Cheung and Hang (2003)	x		n	Up to 50	U[120,360]
A	Cheung et al. (2005)	x		n	Up to 200	U[120,360]
	Ileri et al. (2006)		x	n	Up to 60	n.i.
B	Jula et al. (2005)	x	x	n	Up to 100	30, 60, 120, 180 min
B	Coslovich et al. (2006)	x	x	n	Up to 359	n.i.
B	Jula et al. (2006)		x	n	Up to 4208	--
C	Smilowitz (2006)	x	x	n	Up to 621	n.i.
C	Francis et al. (2007)	x		n	Up to 100	n.i.
C	Zhang et al. (2011a)	x		n	Up to 75	120 -720
	Imai et al. (2007)	x		n	Up to 200	--
	Chung et al. (2007)		x	y	700 aprox.	--
D	Caris and Janssens (2009)	x		m	Up to 200	U[60,120] or U[90,240]
D	Caris and Janssens (2010)			m	Up to 200	U[60,120]
D	Braekers et al. (2013)	x		m	Up to 200	U[60,120] or U[120,240]
D	Braekers et al. (2014)	x		m	Up to 200	U[60,120] or U[120,240]
E	Escudero et al. (2009)	x		m	Up to 100	U[30,240]
E	Escudero et al. (2011a)	x		m	Up to 100	U[60,120] or U[90,240]
E	Escudero et al. (2011b)	x		y	Up to 100	(*)
E	Escudero et al. (2013)	x		y	Up to 100	(*)
E	Escudero et al. (2015)	x		y	Up to 100	(*)
F	Zhang et al. (2009)	x		n	Up to 200	U[0,180]
F	Zhang et al. (2010)	x		n	Up to 75	60, 120, 180, 240
F	Zhang et al. (2011b)	x		n	Up to 75	U[0,240] in O U[0,300] in D
F	Sterzik and Kopfer (2013)	x		n	Up to 75	(*)(+)
F	Wang and Yun (2013)	x		n	Up to 40	U[0,180]
F	Zhang et al. (2014)	x		n	Up to 66	0 - 120
F	Sterzik et al. (2015)	x		n	Up to 75	(+)
F	Zhang et al. (2015)	x		n	Up to 75	--
F	Funke and Kopfer (2016)	x		n	(#)	(#)
	Mahr et al. (2010)		x	n	Up to 65	120
	Lai et al. (2013)	x	x	n	Up to 250	--
	Nossack and Pesch (2013)	x		n	Up to 75	(+) or 600, 660, 720
	Pazour and Neubert (2013)		x	n	n.i.	--
	Sun et al. (2014)	x	x	n	Up to 450	n.i.
G	Xue et al. (2014)		x	n	Up to 200	U[180,300]
G	Xue et al. (2015)		x	n	Up to 200	U[180,300]
	Bai et al. (2015)	x	x	y	Up to 2000	60 - 4320 min
	Caballini et al. (2016)		x	n	Up to 220	600 or 900 min
	Reinhant et al. (2016)	x	x	n	Up to 308	n.i.
	Shiri and Huynh (2016)	x		n	Up to 200	240
	Song et al. (2016)	x		n	Up to 35	240
	Vidovic et al. (2016)	x		y	Up to 100	(*)
	Daham et al. (2017	x		n	Up to 350	n.i.
	Ritzinger et al. (2017)	x		n	Up to 50	30

NOTES: In Chung et al. (2007) Bai et al. (2015) the orders are performed among terminals (max. 10 nodes)
(*) Based on Solomon (1987)   (+) Based on Zhang et al. (2010)   (#) Based on Sterzik and Kopfer (2013)

Table 4: Characteristics of the tests in batteries

Battery	Class	Test	Orders	Customers	TW	Length TW	Problem Sizes
B1	B1_R	1	I, E	Random (R)	100%	60	10, 25, 50, 100
B1	B1_R	2	I, E	Random (R)	75%	60	10, 25, 50, 100
B1	B1_R	3	I, E	Random (R)	50%	60	10, 25, 50, 100
B1	B1_R	4	I, E	Random (R)	25%	60	10, 25, 50, 100
B1	B1_R	5	I, E	Random (R)	100%	90	10, 25, 50, 100
B1	B1_R	6	I, E	Random (R)	100%	120	10, 25, 50, 100
B1	B1_R	7	I, E	Random (R)	100%	240	10, 25, 50, 100
B1	B1_R	8	I, E	Random (R)	100%	120*	10, 25, 50, 100
B1	B1_R	9	I, E	Random (R)	100%	240*	10, 25, 50, 100
B1	B1_R	10	I, E	Random (R)	100%	30	10, 25, 50, 100
B1	B1_C	1	I, E	Cluster (C)	100%	60	10, 25, 50, 100
B1	B1_C	2	I, E	Cluster (C)	75%	60	10, 25, 50, 100
B1	B1_C	3	I, E	Cluster (C)	50%	60	10, 25, 50, 100
B1	B1_C	4	I, E	Cluster (C)	25%	60	10, 25, 50, 100
B1	B1_C	5	I, E	Cluster (C)	100%	90	10, 25, 50, 100
B1	B1_C	6	I, E	Cluster (C)	100%	120	10, 25, 50, 100
B1	B1_C	7	I, E	Cluster (C)	100%	240	10, 25, 50, 100
B1	B1_C	8	I, E	Cluster (C)	100%	120*	10, 25, 50, 100
B1	B1_C	9	I, E	Cluster (C)	100%	240*	10, 25, 50, 100
B1	B1_RC	1	I, E	RC	100%	60	10, 25, 50, 100
B1	B1_RC	2	I, E	RC	75%	60	10, 25, 50, 100
B1	B1_RC	3	I, E	RC	50%	60	10, 25, 50, 100
B1	B1_RC	4	I, E	RC	25%	60	10, 25, 50, 100
B1	B1_RC	5	I, E	RC	100%	90	10, 25, 50, 100
B1	B1_RC	6	I, E	RC	100%	120	10, 25, 50, 100
B1	B1_RC	7	I, E	RC	100%	240	10, 25, 50, 100
B1	B1_RC	8	I, E	RC	100%	120*	10, 25, 50, 100
B1	B1_RC	9	I, E	RC	100%	240*	10, 25, 50, 100
B2	B2_R	1	I, E, IE, OE	Random (R)	100%	30	20, 50, 100, 200
B2	B2_R	2	I, E, IE, OE	Random (R)	100%	60	20, 50, 100, 200
B2	B2_R	3	I, E, IE, OE	Random (R)	100%	90	20, 50, 100, 200
B2	B2_R	4	I, E, IE, OE	Random (R)	100%	120	20, 50, 100, 200
B2	B2_R	5	I, E, IE, OE	Random (R)	100%	240	20, 50, 100, 200
B2	B2_R	6	I, E, IE, OE	Random (R)	100%	120*	20, 50, 100, 200
B2	B2_R	7	I, E, IE, OE	Random (R)	100%	240*	20, 50, 100, 200
B2	B2_C	1	I, E, IE, OE	Cluster (C)	100%	30	20, 50, 100, 200
B2	B2_C	2	I, E, IE, OE	Cluster (C)	100%	60	20, 50, 100, 200
B2	B2_C	3	I, E, IE, OE	Cluster (C)	100%	90	20, 50, 100, 200
B2	B2_C	4	I, E, IE, OE	Cluster (C)	100%	120	20, 50, 100, 200
B2	B2_C	5	I, E, IE, OE	Cluster (C)	100%	240	20, 50, 100, 200
B2	B2_C	6	I, E, IE, OE	Cluster (C)	100%	120*	20, 50, 100, 200
B2	B2_C	7	I, E, IE, OE	Cluster (C)	100%	240*	20, 50, 100, 200
B2	B2_RC	1	I, E, IE, OE	RC	100%	30	20, 50, 100, 200
B2	B2_RC	2	I, E, IE, OE	RC	100%	60	20, 50, 100, 200
B2	B2_RC	3	I, E, IE, OE	RC	100%	90	20, 50, 100, 200
B2	B2_RC	4	I, E, IE, OE	RC	100%	120	20, 50, 100, 200
B2	B2_RC	5	I, E, IE, OE	RC	100%	240	20, 50, 100, 200
B2	B2_RC	6	I, E, IE, OE	RC	100%	120*	20, 50, 100, 200
B2	B2_RC	7	I, E, IE, OE	RC	100%	240*	20, 50, 100, 200

(120*) There exist fixed slot a long the day [[0-120][120-240][240-360][360-480][480-600][600-720]]

(240*) There exist fixed slot a long the day [[0-240][240-480][480-720]]

This wide variety allows the different stakeholders to learn the impact of their decisions on adequate planning of the movements. For example, in the case of route planners, this common benchmark would let them determine which method of resolution is most appropriate depending on the characteristics of the terminal in which they are developed. In the case of terminal managers, it will allow them to discover the effects of different policies, for example, by imposing very limited access appointments.

The designed benchmark is published at a provided URL. Without loss of generality, the terminal localization, the vehicle depot and the container depot have the same localization. Other parameters of the benchmarks are not fixed in the URL. However, in most of the experiments, these parameters are equal. The mean speed is 60 km/h, the time of loading and unloading is 15 min, the cost per kilometre is 1, the waiting cost is 10 per hour, and the cost of failing to complete a task is 1000. The fixed cost per vehicle is 10 or 100.

6. Results

Using the proposed benchmark, different studies were developed. First, we tested the performance of the method considering hard time windows, so we run both batteries. Tables show the achieved results, including the minimum cost found, the distance and number of vehicles of the solution, the gap between the lower bound and the solution, and the execution time. Since convergence of exact methods is not guaranteed within a reasonable time, the execution of each problem was limited to one hour.

The achieved results on B1, test battery with only exportation and importation orders, are presented in Table 5. Two cases of fixed cost per vehicle are studied: 10 and 100. These two cases let us analyze two different sceneries: companies with wide fleets of vehicles (and with permanent resources to execute the orders) and companies that need to subcontract drivers or even the complete execution of some orders. The comparison of the two cases shows that an increase in fixed cost per vehicle usually leads to a reduction in the fleet required, but an increase in the total distance travelled. In other words, reduced fleets will lead to an increase in the distance travelled when trying to make profitable use of existing resources. As it has been widely studied in this field, this study confirms that collaboration and cooperation among companies significantly reduces the distance travelled, which would also lead to environmental benefits.

Moreover, since this battery contains tests with the same orders but different lengths of time windows we can explore the influence of time windows restriction over the cost of the solution. By analysing the results of these tests, we can state that the increase in time windows represents savings of operating costs (sea Figure 5). In realistic environments, with a number of orders to be carried out between 25 and 100, doubling the duration of the time window implies reductions in transport costs of around 6-7%. Besides, we can achieve identical conclusion when not all the orders have time window restriction (See Figure 6). Analyzing this image, some significant results can be observed. Allowing some customers total flexibility in their port access results in cost savings. When this flexibility affects 25% of the orders, a cost saving of around 10% is achieved. This saving increases as the number of orders involved increases, although the increase is not so significant. In scenarios with 75% truck without port access restrictions the saving is around 15%.

Table 5: Result of the problem class B1 (hard time windows)

				Vehicle Cost = 10					Vehicle Cost = 100						
N. Orders	CLASS	TEST	TW	N. Vehicles	Distance	Cost	GAP	Time	N. Vehicles	Distance	Cost	GAP	Time	Δ Veh.	Δ Dist.
10	B1_R	1	30	3	388,15	418,15	0,00%	0,01	2	420,58	620,58	0,00%	0,00	-1,00	32,43
	B1_R	2	60	3	388,15	418,15	0,00%	0,04	2	399,02	599,02	0,00%	0,07	-1,00	10,87
	B1_R	3	60	2	369,95	389,95	0,00%	0,02	2	369,95	569,95	0,00%	0,02	0,00	0,00
	B1_R	4	60	2	357,42	377,42	0,00%	0,01	2	357,42	557,42	0,00%	0,04	0,00	0,00
	B1_R	5	60	1	335,09	345,09	0,00%	0,16	1	335,09	435,09	0,00%	0,05	0,00	0,00
	B1_R	6	90	2	388,15	408,15	0,00%	0,01	2	388,15	588,15	0,00%	0,00	0,00	0,00
	B1_R	7	120	2	388,15	408,15	0,00%	0,02	2	388,15	588,15	0,00%	0,07	0,00	0,00
	B1_R	8	240	2	357,42	377,42	0,00%	0,05	1	370,35	470,35	0,00%	0,07	-1,00	12,93
	B1_R	9	120*	2	402,21	422,21	0,00%	0,01	2	402,21	602,21	0,00%	0,01	0,00	0,00
	B1_R	10	240*	1	379,78	389,78	0,00%	0,01	1	379,78	479,78	0,00%	0,05	0,00	0,00
	B1_C	1	60	3	260,97	290,97	0,00%	0,05	2	290,90	490,90	0,00%	0,00	-1,00	29,93
	B1_C	2	60	2	228,87	248,87	0,00%	0,10	2	228,87	428,87	0,00%	0,06	0,00	0,00
	B1_C	3	60	2	197,95	217,95	0,00%	0,06	2	197,95	397,95	0,00%	0,06	0,00	0,00
	B1_C	4	60	1	197,95	207,95	0,00%	0,05	1	197,95	297,95	0,00%	0,02	0,00	0,00
	B1_C	5	90	2	260,97	280,97	0,00%	0,00	2	260,97	460,97	0,00%	0,01	0,00	0,00
	B1_C	6	120	1	265,55	275,55	0,00%	0,01	1	265,55	365,55	0,00%	0,01	0,00	0,00
	B1_C	7	240	1	198,58	208,58	0,00%	0,04	1	198,58	298,58	0,00%	0,09	0,00	0,00
	B1_C	8	120*	2	293,19	313,19	0,00%	0,00	2	293,19	493,19	0,00%	0,00	0,00	0,00
	B1_C	9	240*	1	291,34	301,34	0,00%	0,09	1	291,34	391,34	0,00%	0,08	0,00	0,00
	B1_RC	1	60	3	517,44	547,44	0,00%	0,06	3	517,44	817,44	0,00%	0,06	0,00	0,00
	B1_RC	2	60	3	448,79	478,79	0,00%	0,05	2	496,70	696,70	0,00%	0,14	-1,00	47,90
	B1_RC	3	60	2	439,59	459,59	0,00%	0,04	2	439,59	639,59	0,00%	0,05	0,00	0,00
	B1_RC	4	60	2	439,59	459,59	0,00%	0,03	2	439,59	639,59	0,00%	0,04	0,00	0,00
	B1_RC	5	90	3	517,44	547,44	0,00%	0,01	2	577,60	777,60	0,00%	0,01	-1,00	60,16
	B1_RC	6	120	2	517,44	537,44	0,00%	0,01	2	517,44	717,44	0,00%	0,01	0,00	0,00
	B1_RC	7	240	2	511,30	531,30	0,00%	0,07	2	511,30	711,30	0,00%	0,40	0,00	0,00
	B1_RC	8	120*	2	654,80	674,80	0,00%	0,01	2	654,80	854,80	0,00%	0,00	0,00	0,00
	B1_RC	9	240*	2	584,69	604,69	0,00%	0,03	2	584,69	784,69	0,00%	0,05	0,00	0,00
25	B1_R	1	30	7	1013,22	1083,22	0,00%	0,02	6	1036,18	1636,18	0,00%	0,02	-1,00	22,96
	B1_R	2	60	4	1029,03	1069,03	0,00%	0,05	4	1029,03	1429,03	0,00%	0,19	0,00	0,00
	B1_R	3	60	4	898,77	938,77	0,00%	0,78	3	922,07	1222,07	0,00%	41,27	-1,00	23,30
	B1_R	4	60	3	871,69	901,69	0,00%	10,04	3	871,69	1171,69	6,90%	3600,02	0,00	0,00
	B1_R	5	60	3	823,09	853,09	1,77%	3600,02	3	823,09	1123,09	17,77%	3600,02	0,00	0,00
	B1_R	6	90	4	961,22	1001,22	0,00%	0,07	3	977,91	1277,91	0,00%	0,19	-1,00	16,68
	B1_R	7	120	4	940,74	980,74	0,00%	0,10	3	970,92	1270,92	0,00%	1,20	-1,00	30,18
	B1_R	8	240	3	851,80	881,80	0,00%	1,93	3	851,80	1151,80	5,49%	3600,01	0,00	0,00
	B1_R	9	120*	4	917,07	957,07	0,00%	0,19	3	949,56	1249,56	0,00%	0,95	-1,00	32,49
	B1_R	10	240*	4	855,72	895,72	0,00%	3,96	3	870,65	1170,65	0,00%	2023,56	-1,00	14,93
	B1_C	1	60	4	751,02	791,02	0,00%	0,05	4	751,02	1151,02	0,00%	0,15	0,00	0,00
	B1_C	2	60	4	681,96	721,96	0,00%	0,83	3	711,16	1011,16	0,00%	122,56	-1,00	29,21
	B1_C	3	60	3	644,54	674,54	0,00%	27,65	3	644,54	944,54	9,40%	3600,01	0,00	0,00
	B1_C	4	60	2	629,02	649,02	1,36%	3600,01	2	629,02	829,02	12,06%	3600,01	0,00	0,00
	B1_C	5	90	4	731,02	771,02	0,00%	0,17	3	746,16	1046,16	0,00%	0,36	-1,00	15,14
	B1_C	6	120	3	715,24	745,24	0,00%	0,29	3	715,24	1015,24	0,00%	6,41	0,00	0,00
	B1_C	7	240	3	634,82	664,82	0,00%	3,61	3	634,82	934,82	14,06%	3600,02	0,00	0,00
	B1_C	8	120*	3	739,81	769,81	0,00%	0,17	3	739,81	1039,81	0,00%	2,44	0,00	0,00
	B1_C	9	240*	3	708,77	738,77	0,00%	1899,95	3	708,77	1008,77	16,26%	3600,01	0,00	0,00
	B1_RC	1	60	4	1364,54	1404,54	0,00%	0,03	4	1364,54	1764,54	0,00%	0,07	0,00	0,00
	B1_RC	2	60	4	1150,56	1190,56	0,00%	0,40	4	1150,56	1550,56	0,00%	10,88	0,00	0,00
	B1_RC	3	60	3	1143,70	1173,70	0,00%	11,60	3	1143,70	1443,70	0,00%	102,78	0,00	0,00
	B1_RC	4	60	3	1138,48	1168,48	0,83%	3600,01	3	1138,48	1438,48	6,95%	3600,02	0,00	0,00
	B1_RC	5	90	4	1340,92	1380,92	0,00%	0,03	4	1340,92	1740,92	0,00%	0,30	0,00	0,00
	B1_RC	6	120	4	1240,89	1280,89	0,00%	0,11	4	1240,89	1640,89	0,00%	1,24	0,00	0,00
	B1_RC	7	240	3	1223,47	1253,47	0,00%	14,33	3	1223,47	1523,47	0,00%	251,83	0,00	0,00
	B1_RC	8	120*	4	1407,48	1447,48	0,00%	0,15	4	1407,48	1807,48	0,00%	0,92	0,00	0,00
	B1_RC	9	240*	4	1301,77	1341,77	0,00%	157,96	3	1333,96	1633,96	1,87%	3600,01	-1,00	32,20
50	B1_R	1	30	11	1973,38	2083,38	0,00%	0,12	9	2004,99	2904,99	0,00%	0,10	-2,00	31,61
	B1_R	2	60	9	1949,14	2039,14	0,00%	0,56	7	2003,75	2703,75	0,00%	1,15	-2,00	54,61
	B1_R	3	60	7	1824,99	1894,99	0,00%	37,48	6	1877,69	2477,69	10,85%	3600,01	-1,00	52,69
	B1_R	4	60	5	1776,30	1826,30	0,47%	3600,02	5	1789,99	2289,99	8,17%	3600,01	0,00	13,69
	B1_R	5	60	5	1703,98	1753,98	1,71%	3600,01	5	1703,98	2203,98	16,99%	3600,01	0,00	0,00
	B1_R	6	90	7	1931,55	2001,55	0,00%	1,54	6	1974,49	2574,49	0,00%	25,30	-1,00	42,94
	B1_R	7	120	6	1843,86	1903,86	0,00%	4,34	6	1843,86	2443,86	3,87%	3600,02	0,00	0,00
	B1_R	8	240	5	1722,40	1772,40	1,59%	3600,01	5	1725,24	2225,24	21,42%	3600,02	0,00	2,84
	B1_R	9	120*	7	1837,63	1907,63	0,00%	0,39	5	1893,55	2393,55	1,00%	3600,03	-2,00	55,92
	B1_R	10	240*	6	1758,18	1818,18	1,07%	3600,01	6	1758,18	2358,18	19,18%	3600,01	0,00	0,00
	B1_C	1	60	9	1553,61	1643,61	0,00%	0,20	7	1602,19	2302,19	0,00%	1,93	-2,00	48,58
	B1_C	2	60	7	1433,12	1503,12	0,00%	33,30	6	1449,01	2049,01	8,14%	3600,02	-1,00	15,88
	B1_C	3	60	5	1371,06	1421,06	0,00%	137,86	5	1371,06	1871,06	4,99%	3600,01	0,00	0,00
	B1_C	4	60	5	1366,50	1416,50	2,12%	3600,01	5	1366,50	1866,50	16,07%	3600,03	0,00	0,00
	B1_C	5	90	7	1505,26	1575,26	0,00%	0,78	6	1541,26	2141,26	0,00%	122,78	-1,00	35,99
	B1_C	6	120	6	1490,08	1550,08	0,00%	4,99	5	1570,41	2070,41	6,93%	3600,03	-1,00	80,33
	B1_C	7	240	5	1389,35	1439,35	1,39%	3600,01	5	1389,35	1889,35	24,12%	3600,01	0,00	0,00
	B1_C	8	120*	6	1509,58	1569,58	0,00%	0,53	5	1534,62	2034,62	0,00%	1189,95	-1,00	25,04
	B1_C	9	240*	5	1466,54	1516,54	0,34%	3600,02	5	1466,54	1966,54	14,23%	3600,02	0,00	0,00
	B1_RC	1	60	9	2833,03	2923,03	0,00%	0,40	9	2833,03	3733,03	0,00%	1,21	0,00	0,00
	B1_RC	2	60	8	2565,72	2645,72	0,00%	3,09	8	2565,72	3365,72	0,00%	1730,79	0,00	0,00
	B1_RC	3	60	7	2523,52	2593,52	0,36%	3600,01	7	2523,52	3223,52	5,24%	3600,03	0,00	0,00
	B1_RC	4	60	6	2433,13	2493,13	0,80%	3600,01	6	2433,13	3033,13	9,83%	3600,02	0,00	0,00
	B1_RC	5	90	8	2793,44	2873,44	0,00%	0,62	8	2793,44	3593,44	0,00%	4,56	0,00	0,00
	B1_RC	6	120	8	2629,44	2709,44	0,00%	2,51	7	2653,60	3353,60	0,00%	27,52	-1,00	24,16
	B1_RC	7	240	6	2474,97	2534,97	1,01%	3600,02	6	2537,29	3137,29	13,53%	3600,01	0,00	62,32
	B1_RC	8	120*	8	2801,67	2881,67	0,00%	0,41	8	2801,67	3601,67	0,00%	90,22	0,00	0,00
	B1_RC	9	240*	9	2477,08	2567,08	1,99%	3600,01	7	2537,17	3237,17	15,04%	3600,02	-2,00	60,09
100	B1_R	1	30	15	3712,14	3862,14	0,00%	0,82	15	3712,14	5212,14	0,00%	0,70	0,00	0,00
	B1_R	2	60	13	3635,47	3765,47	0,00%	6,87	11	3695,17	4795,17	0,00%	439,33	-2,00	59,70
	B1_R	3	60	12	3375,62	3495,62	1,19%	3600,19	11	3423,71	4523,71	13,64%	3600,09	-1,00	48,09
	B1_R	4	60	11	3308,52	3418,52	1,46%	3600,11	11	3308,52	4408,52	12,98%	3600,04	0,00	0,00
	B1_R	5	60	10	3256,54	3356,54	2,09%	3600,04	10	3258,12	4258,12	18,21%	3600,08	0,00	1,57
	B1_R	6	90	11	3578,62	3688,62	0,12%	3600,05	11	3581,04	4681,04	5,67%	3600,02	0,00	2,42
	B1_R	7	120	11	3443,02	3553,02	0,90%	3600,02	11	3482,78	4582,78	14,60%	3600,03	0,00	39,76
	B1_R	8	240	10	3262,40	3362,40	3,02%	3600,02	11	3258,83	4358,83	25,21%	3600,05	1,00	-3,57
	B1_R	9	120*	11	3423,32	3533,32	0,01%	3600,04	10	3460,10	4460,10	5,54%	3600,07	-1,00	36,78
	B1_R	10	240*	10	3255,26	3355,26	1,21%	3600,05	10	3328,27	4328,27	21,51%	3600,02	0,00	73,01
	B1_C	1	60	13	3926,97	4056,97	0,00%	3,75	12	3939,41	5139,41	0,56%	3600,04	-1,00	12,45
	B1_C	2	60	12	3442,24	3562,24	0,56%	3600,03	11	3490,78	4590,78	11,18%	3600,05	-1,00	48,54
	B1_C	3	60	11	3304,21	3414,21	1,40%	3600,06	11	3304,21	4404,21	11,32%	3600,33	0,00	0,00
	B1_C	4	60	10	3213,33	3313,33	2,11%	3600,29	10	3213,33	4213,33	16,61%	3600,06	0,00	0,00
	B1_C	5	90	11	3805,75	3915,75	0,00%	52,32	11	3838,30	4938,30	3,68%	3600,04	0,00	32,55
	B1_C	6	120	11	3752,07	3862,07	0,55%	3600,03	11	3801,09	4901,09	11,54%	3600,02	0,00	49,03
	B1_C	7	240	11	3439,26	3549,26	3,00%	3600,01	11	3501,88	4601,88	25,24%	3600,02	0,00	62,62
	B1_C	8	120*	11	3828,33	3938,33	0,00%	168,60	11	3835,51	4935,51	4,82%	3600,02	0,00	7,18
	B1_C	9	240*	10	3521,13	3621,13	1,38%	3600,04	11	3574,88	4674,88	20,21%	3600,03	1,00	53,76
	B1_RC	1	60	14	4602,59	4742,59	0,00%	31,22	13	4614,58	5914,58	0,00%	132,25	-1,00	11,99
	B1_RC	2	60	13	4078,75	4208,75	0,92%	3600,22	12	4082,36	5282,36	13,87%	3600,02	-1,00	3,61
	B1_RC	3	60	11	3999,59	4109,59	0,97%	3600,08	11	3999,59	5099,59	9,47%	3600,09	0,00	0,00
	B1_RC	4	60	12	3914,35	4034,35	1,98%	3600,09	11	3927,94	5027,94	14,19%	3600,03	-1,00	13,58
	B1_RC	5	90	12	4452,39	4572,39	0,00%	60,42	12	4466,72	5666,72	2,27%	3600,01	0,00	14,33
	B1_RC	6	120	13	4282,62	4412,62	0,45%	3600,02	12	4299,24	5499,24	8,85%	3600,03	-1,00	16,62
	B1_RC	7	240	11	4026,73	4136,73	2,56%	3600,03	11	4076,04	5176,04	22,16%	3600,03	0,00	49,31
	B1_RC	8	120*	12	4513,55	4633,55	0,00%	92,00	12	4517,93	5717,93	3,16%	3600,04	0,00	4,38
	B1_RC	9	240*	13	4046,63	4176,63	2,12%	3600,02	13	4091,61	5391,61	22,25%	6182,65	0,00	44,98

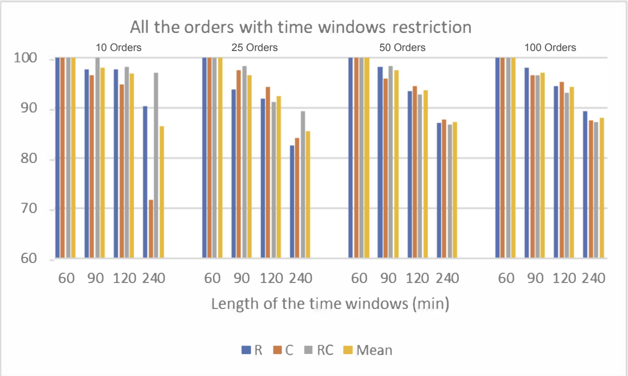


Figure 5: Effect of the increase the time windows.

Figure 6: Effect of reducing orders with time window restriction

Another important analyses is to know the effect of allowing flexible orders in the performance of inbound and outbound empty container orders. Table 6 shows the results of the B2 considering a fixed cost per vehicle equal to 10. Two cases are considered regarding the empty container movements: (a) well-defined orders, so the reposition of empty container must be done by means of the depot, and (b) flexible orders. By analysing the results of the B2, it is clear that this flexibility involves cost savings for the operations.

All the policy studies seen above, which have been numerically justified, are in line with the logical assumption that more flexibility enables more cost-effective solutions. In the case of flexibility in the repositioning of empty containers, this flexibility means an overall benefit for all actors: cost reduction, possibility of attending to a greater number of tasks, reduction in the number of operations needed in the depot, etc. This would reduce traffic congestion in a high-traffic area. If the depot were located near the terminal, this benefit would be even more significant.

Flexibility in time windows, considering it either the absence of restriction or a sufficiently large time window, would help reduce the costs of the haulage operations, but it would make the management of the port operations more difficult. It is becoming increasingly common for ports to try to impose a series of temporary slots for the transit of trucks in and out of the port. This way, both unnecessary congestion events at the gates and trucks waiting to be handled are avoided. In essence, knowing in advance the arrival time of the trucks let the terminal improve its management and size its resources properly.

Therefore, there are conflicting interests between two actors in the intermodal chain: the terminal managers and the haulage operators. This work studies the effect of flexible time windows, where those transporters who adapt to the agreed window are rewarded, but a certain flexibility is provided to cover the regular incidents and uncertainties in this type of operation.

Finally, the effects of soft time windows versus strict time windows were studied. In the case of DDP, we only consider soft time windows when the missing the main transport in the terminal is not considered. In Table 7, the results of the method in both cases are compared. We can observe the savings that the flexibility in the completion of the orders suppose due to the soft time windows. In Figure 7 the costs of the operative with strict time windows (120 and 240 minutes) are compared to the costs of the operative with soft time windows (30, 60 and 90 minutes), different waiting cost per hour are analysed. Below a certain waiting cost, it is possible to achieve costs in the operation with narrow time windows at the level of those with wider time windows.

Such a policy would help plan operations within terminals more efficiently by greatly reducing the uncertainty in arrivals without prejudicing the costs involved for the transport company.

7. Conclusion

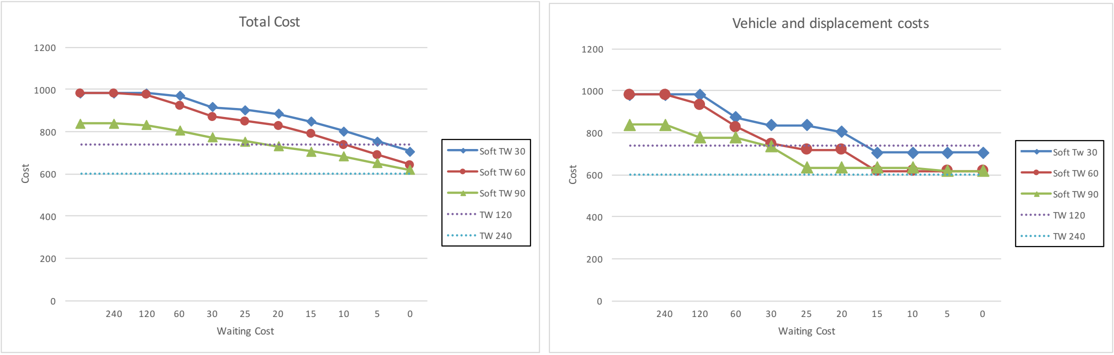
This paper intends to achieve three objectives. First, we have carried out a thorough bibliographic study of the works presented to date in relation to drayage operations, especially those that present quantitative models. The number of papers published in this field has increased in recent years. This is undoubtedly due

Table 6: Result of the problem class B2 (hard time windows)

				Well-defined Orders					Flexible Orders					
N. Orders	CLASS	TEST	TW	N. Vehicles	Distance	Cost	GAP	Time	N. Vehicles	Distance	Cost	GAP	Time	Improve
20	B2_R	1	30	5	557,87	607,87	0,00%	0,09	5	540,85	590,85	0,00%	0,10	2,88%
	B2_R	2	60	5	557,87	607,87	0,00%	0,02	5	540,85	590,85	0,00%	0,02	2,88%
	B2_R	3	90	4	513,15	553,15	0,00%	0,05	4	496,13	536,13	0,00%	0,03	3,17%
	B2_R	4	120	3	477,15	507,15	0,00%	0,04	3	440,25	470,25	0,00%	0,05	7,85%
	B2_R	5	240	2	601,65	621,65	0,00%	0,55	2	403,08	423,08	0,00%	0,60	46,93%
	B2_R	6	120*	2	434,72	454,72	0,00%	0,03	2	402,21	422,21	0,00%	0,04	7,70%
	B2_R	7	240*	2	434,72	454,72	0,00%	0,16	2	379,78	399,78	0,00%	0,10	13,74%
	B2_C	1	30	6	399,02	459,02	0,00%	0,01	6	365,28	425,28	0,00%	0,10	7,93%
	B2_C	2	60	5	389,53	439,53	0,00%	0,02	5	355,79	405,79	0,00%	0,02	8,31%
	B2_C	3	90	4	357,28	397,28	0,00%	0,02	3	295,17	325,17	0,00%	0,04	22,17%
	B2_C	4	120	3	357,28	387,28	0,00%	0,02	3	295,17	325,17	0,00%	0,06	19,10%
	B2_C	5	240	2	357,28	377,28	0,00%	2,72	2	260,97	280,97	0,00%	0,47	34,28%
	B2_C	6	120*	2	357,28	377,28	0,00%	0,04	2	325,41	345,41	0,00%	0,09	9,22%
	B2_C	7	240*	2	357,28	377,28	0,00%	0,29	2	291,34	311,34	0,00%	0,43	21,18%
	B2_RC	1	30	7	863,49	933,49	0,00%	0,02	7	863,49	933,49	0,00%	0,02	0,00%
	B2_RC	2	60	6	776,57	836,57	0,00%	0,03	6	776,57	836,57	0,00%	0,02	0,00%
	B2_RC	3	90	5	776,57	826,57	0,00%	0,02	4	753,07	793,07	0,00%	0,02	4,22%
	B2_RC	4	120	3	728,96	758,96	0,00%	0,02	4	668,80	708,80	0,00%	0,03	7,08%
	B2_RC	5	240	2	714,96	734,96	0,00%	0,28	3	517,44	547,44	0,00%	0,08	34,26%
	B2_RC	6	120*	4	862,19	902,19	0,00%	0,02	4	744,24	784,24	0,00%	0,03	15,04%
	B2_RC	7	240*	3	714,96	744,96	0,00%	0,23	3	584,69	614,69	0,00%	0,34	21,19%
50	B2_R	1	30	9	1381,05	1471,05	0,00%	0,07	9	1244,59	1334,59	0,00%	0,07	10,22%
	B2_R	2	60	7	1381,05	1451,05	0,00%	0,10	7	1254,45	1324,45	0,00%	0,10	9,56%
	B2_R	3	90	5	1309,47	1359,47	0,00%	0,11	6	1173,01	1233,01	0,00%	0,13	10,26%
	B2_R	4	120	5	1288,59	1338,59	0,00%	0,60	6	1089,55	1149,55	0,00%	0,16	16,44%
	B2_R	5	240	5	1599,20	1649,20	0,00%	1711,19	5	951,30	1001,30	0,00%	3042,35	64,71%
	B2_R	6	120*	6	1246,16	1306,16	0,00%	1,11	6	1024,17	1084,17	0,00%	0,61	20,48%
	B2_R	7	240*	5	1246,16	1296,16	2,31%	3600,01	5	855,72	905,72	0,00%	3,44	43,11%
	B2_C	1	30	9	1173,94	1263,94	0,00%	0,07	9	964,94	1054,94	0,00%	0,20	19,81%
	B2_C	2	60	7	1164,45	1234,45	0,00%	0,09	7	955,45	1025,45	0,00%	0,32	20,38%
	B2_C	3	90	7	1132,20	1202,20	0,00%	0,09	6	889,01	949,01	0,00%	0,10	26,68%
	B2_C	4	120	5	1132,20	1182,20	0,00%	0,13	5	876,62	926,62	0,00%	0,23	27,58%
	B2_C	5	240	4	1132,20	1172,20	1,35%	3600,01	4	807,99	847,99	0,00%	4,31	38,23%
	B2_C	6	120*	6	1132,20	1192,20	0,00%	5,04	6	792,65	852,65	0,00%	21,51	39,82%
	B2_C	7	240*	5	1132,20	1182,20	2,54%	3600,01	4	714,89	754,89	0,00%	2374,46	56,60%
	B2_RC	1	30	11	2035,19	2145,19	0,00%	0,18	10	1802,75	1902,75	0,00%	0,16	12,74%
	B2_RC	2	60	10	1948,27	2048,27	0,00%	0,11	9	1715,83	1805,83	0,00%	0,08	13,43%
	B2_RC	3	90	7	1948,27	2018,27	0,00%	0,07	7	1692,33	1762,33	0,00%	0,07	14,52%
	B2_RC	4	120	7	1900,66	1970,66	0,00%	0,31	6	1638,26	1698,26	0,00%	0,15	16,04%
	B2_RC	5	240	5	1886,66	1936,66	0,52%	3600,03	5	1403,05	1453,05	0,00%	2,23	33,28%
	B2_RC	6	120*	7	2039,69	2109,69	0,00%	1,19	7	1563,04	1633,04	0,00%	1,99	29,19%
	B2_RC	7	240*	6	1886,66	1946,66	0,51%	3600,04	6	1303,40	1363,40	0,00%	101,24	42,78%
100	B2_R	1	30	18	2884,50	3064,50	0,00%	1,26	19	2527,57	2717,57	0,00%	1,38	12,77%
	B2_R	2	60	16	2769,64	2929,64	0,00%	0,38	16	2412,70	2572,70	0,00%	0,38	13,87%
	B2_R	3	90	12	2688,06	2808,06	0,00%	0,56	12	2262,39	2382,39	0,00%	0,46	17,87%
	B2_R	4	120	10	2651,46	2751,46	0,00%	1,86	11	2169,00	2279,00	0,00%	1,32	20,73%
	B2_R	5	240	11	2998,58	3108,58	3,21%	3600,04	10	1946,92	2046,92	7,98%	3600,03	51,87%
	B2_R	6	120*	10	2707,55	2807,55	0,00%	118,97	12	1967,26	2087,26	0,00%	8,91	34,51%
	B2_R	7	240*	10	2624,75	2724,75	3,11%	3600,04	10	1758,18	1858,18	2,54%	3600,09	46,64%
	B2_C	1	30	19	2538,14	2728,14	0,00%	0,32	19	2023,98	2213,98	0,00%	0,39	23,22%
	B2_C	2	60	16	2528,65	2688,65	0,00%	1,30	16	2014,49	2174,49	0,00%	1,49	23,65%
	B2_C	3	90	13	2487,62	2617,62	0,00%	1,45	12	1963,07	2083,07	0,00%	2,77	25,66%
	B2_C	4	120	10	2453,89	2553,89	0,00%	3,80	11	1888,66	1998,66	0,00%	1,06	27,78%
	B2_C	5	240	9	2411,46	2501,46	2,98%	3600,04	8	1590,92	1670,92	1,07%	3600,05	49,71%
	B2_C	6	120*	9	2482,31	2572,31	0,00%	1086,98	12	1646,78	1766,78	0,57%	3600,06	45,59%
	B2_C	7	240*	10	2411,46	2511,46	3,98%	3600,06	9	1466,54	1556,54	2,65%	3600,10	61,35%
	B2_RC	1	30	22	4472,16	4692,16	0,00%	1,02	21	3937,57	4147,57	0,00%	1,84	13,13%
	B2_RC	2	60	18	4275,30	4455,30	0,00%	0,65	18	3740,70	3920,70	0,00%	0,63	13,64%
	B2_RC	3	90	15	4275,30	4425,30	0,00%	3,33	15	3653,63	3803,63	0,00%	2,91	16,34%
	B2_RC	4	120	13	4077,84	4207,84	0,00%	9,27	13	3429,33	3559,33	0,00%	3,02	18,22%
	B2_RC	5	240	11	4059,84	4169,84	1,68%	3600,03	11	2958,61	3068,61	0,54%	3600,19	35,89%
	B2_RC	6	120*	13	4380,94	4510,94	0,00%	573,95	14	3206,66	3346,66	0,00%	1804,43	34,79%
	B2_RC	7	240*	12	4059,84	4179,84	2,41%	3600,05	12	2625,96	2745,96	5,86%	3600,05	52,22%
200	B2_R	1	30	29	5261,51	5551,51	0,00%	6,53	29	4493,55	4783,55	0,00%	6,49	16,05%
	B2_R	2	60	26	5124,31	5384,31	0,00%	3,67	26	4351,46	4611,46	0,00%	5,44	16,76%
	B2_R	3	90	22	5069,41	5289,41	0,00%	4,26	22	4231,25	4451,25	0,00%	4,49	18,83%
	B2_R	4	120	19	5048,93	5238,93	0,00%	2,67	18	4116,51	4296,51	0,00%	45,07	21,93%
	B2_R	5	240	19	5427,29	5617,29	3,50%	3600,08	19	4011,16	4201,16	17,43%	3600,10	33,71%
	B2_R	6	120*	18	5153,07	5333,07	1,45%	3600,05	21	3810,58	4020,58	3,56%	3600,13	32,64%
	B2_R	7	240*	17	4989,42	5159,42	3,29%	3600,06	18	3271,36	3451,36	3,67%	3600,28	49,49%
	B2_C	1	30	32	6120,45	6440,45	0,00%	2,69	32	5045,63	5365,63	0,00%	12,83	20,03%
	B2_C	2	60	28	5917,91	6197,91	0,00%	5,46	28	4843,09	5123,09	0,00%	6,03	20,98%
	B2_C	3	90	23	5847,12	6077,12	0,00%	12,81	23	4734,20	4964,20	0,00%	31,69	22,42%
	B2_C	4	120	18	5813,39	5993,39	0,00%	24,71	19	4611,39	4801,39	0,00%	67,05	24,83%
	B2_C	5	240	20	5770,96	5970,96	3,04%	3600,09	18	4402,39	4582,39	9,93%	3600,20	30,30%
	B2_C	6	120*	20	5988,85	6188,85	1,69%	3600,05	23	4272,59	4502,59	4,17%	3600,11	37,45%
	B2_C	7	240*	19	5770,96	5960,96	3,10%	3600,08	17	3706,18	3876,18	6,61%	3600,07	53,78%
	B2_RC	1	30	33	7048,88	7378,88	0,00%	9,31	32	5991,28	6311,28	0,00%	8,35	16,92%
	B2_RC	2	60	29	6872,30	7162,30	0,00%	2,03	29	5814,70	6104,70	0,00%	4,96	17,32%
	B2_RC	3	90	25	6880,78	7130,78	0,00%	194,86	25	5717,23	5967,23	0,00%	23,92	19,50%
	B2_RC	4	120	21	6631,54	6841,54	0,00%	15,85	21	5437,12	5647,12	0,00%	100,68	21,15%
	B2_RC	5	240	21	6617,54	6827,54	2,83%	3600,06	19	4785,18	4975,18	2,91%	3600,09	37,23%
	B2_RC	6	120*	21	6960,22	7170,22	1,16%	3600,03	23	5073,94	5303,94	3,88%	3600,07	35,19%
	B2_RC	7	240*	20	6617,54	6817,54	2,79%	3600,06	19	4540,61	4730,61	11,99%	3600,09	44,12%

Table 7: Effects of soft time windows

				Hard Time Windows					Soft Time Windows					
N. Orders	CLASS	TEST	TW	N. Vehicles	Distance	Cost	GAP	Time	N. Vehicles	Distance	Cost	GAP	Time	Improve
20	B2_R	1	30	4	582,65	982,65	0,00%	0,11	2	684,85	800,06	0,00%	2,49	22,82%
	B2_R	2	60	4	582,08	982,08	0,00%	0,12	2	597,71	738,34	0,00%	1,27	33,01%
	B2_R	3	90	3	539,23	839,23	0,00%	0,18	2	614,72	681,57	0,00%	2,01	23,13%
	B2_R	4	120	3	440,25	740,25	0,00%	0,47	2	577,83	614,69	0,00%	2,02	20,43%
	B2_R	5	240	2	403,08	603,08	0,00%	652,33	2	388,15	590,36	4,17%	3600,01	2,16%
	B2_C	1	30	3	475,42	775,42	0,00%	0,19	3	637,52	712,50	0,00%	0,69	8,83%
	B2_C	2	60	3	425,85	725,85	0,00%	0,10	2	509,54	568,44	0,00%	0,47	27,69%
	B2_C	3	90	2	350,00	550,00	0,00%	0,08	2	475,17	505,86	0,00%	0,40	8,73%
	B2_C	4	120	2	333,23	533,23	0,00%	0,38	2	475,17	498,05	0,00%	3,01	7,06%
	B2_C	5	240	2	260,97	460,97	0,00%	446,08	2	260,97	460,97	12,81%	3600,01	0,00%
	B2_RC	1	30	5	1007,20	1507,20	0,00%	0,10	2	966,57	1096,00	0,00%	2,52	37,52%
	B2_RC	2	60	5	857,78	1357,78	0,00%	0,02	2	966,57	1074,81	0,00%	1,62	26,33%
	B2_RC	3	90	4	753,07	1153,07	0,00%	0,06	2	871,46	984,21	0,00%	2,30	17,16%
	B2_RC	4	120	3	728,96	1028,96	0,00%	0,19	2	834,80	888,56	0,00%	1,39	15,80%
	B2_RC	5	240	2	541,85	741,85	0,00%	1,01	2	541,85	741,85	0,00%	14,74	0,00%
50	B2_R	1	30	7	1355,03	2055,03	0,00%	0,07	5	1656,71	1769,23	2,86%	3600,02	16,15%
	B2_R	2	60	6	1291,04	1891,04	0,00%	0,11	5	1569,56	1689,95	2,49%	3600,01	11,90%
	B2_R	3	90	5	1204,85	1704,85	0,00%	0,80	4	1479,56	1592,45	3,73%	3600,02	7,06%
	B2_R	4	120	5	1100,24	1600,24	0,00%	16,31	4	1414,48	1508,96	5,24%	3600,01	6,05%
	B2_R	5	240	4	996,92	1396,92	30,26%	3600,02	4	936,76	1368,13	31,66%	3600,02	2,10%
	B2_C	1	30	7	1074,87	1774,87	0,00%	0,33	5	1414,43	1575,29	7,82%	3600,01	12,67%
	B2_C	2	60	6	997,09	1597,09	0,00%	1,12	5	1373,20	1478,06	5,72%	3600,01	8,05%
	B2_C	3	90	5	931,79	1431,79	0,00%	1,67	4	1277,13	1384,09	7,56%	3600,02	3,45%
	B2_C	4	120	5	876,62	1376,62	0,00%	25,86	4	1243,39	1315,00	7,54%	3600,03	4,69%
	B2_C	5	240	4	807,99	1207,99	23,84%	3600,04	5	807,99	1207,99	31,41%	3600,02	0,00%
	B2_RC	1	30	8	1946,46	2746,46	0,00%	0,16	6	2255,83	2402,39	3,77%	3600,02	14,32%
	B2_RC	2	60	7	1887,15	2587,15	0,00%	0,17	5	2179,98	2356,87	2,06%	3600,01	9,77%
	B2_RC	3	90	7	1692,33	2392,33	0,00%	0,57	6	2170,72	2256,06	4,70%	3600,04	6,04%
	B2_RC	4	120	6	1638,26	2238,26	0,00%	0,64	5	2077,72	2160,33	5,39%	3600,01	3,61%
	B2_RC	5	240	5	1403,05	1903,05	6,97%	3600,02	5	1403,05	1903,05	22,44%	3600,03	0,00%



(a) (b)

Figure 7: Effect of the variation in waiting costs

to the importance that this part of the intermodal chain has for the viability of the entire chain. We consider that this increased attention from the scientific community requires a study to analyse the research trends in this field. To this end, in addition to the description of all the references analysed, a compilation of the works has been shown, presented via a table that summarizes the main characteristics of every paper.

The second objective addresses a gap detected in the literature: the lack of a benchmark to assess and compare the previous studies without having to repeat the experiments. To date, each group of collaborating researchers has followed its own path in this regard. Therefore, a series of tests are presented and made public. These can serve as benchmarks for future work so that the performances of different methods can be directly compared.

Third, a generalized formulation has been presented. This formulation allows for the modelling of most drayage operation policies. Only those cases in which vehicles can carry more than one container at the same time are excluded. The presented formulation considers locations of vehicles as dummy orders, which allows us to use this formulation in sliding window procedures or in re-optimization due to dynamic information. For this reason, we study the performance of the method in tests with different numbers of orders.

Based on this versatile formulation, the effects of policies such as flexible tasks, size of time windows and flexible time windows on the performance of the hauling operation have been analysed. As other studies have previously concluded, the flexibility in the development of orders for the provision and removal of empty containers leads to savings in operational costs.

Regarding the flexibility in complying with the time windows, it has been observed that relaxing this restriction, even including penalty costs, can reduce operating costs and facilitate the management of companies dedicated to haulage.

The size of the time window is another aspect that also influences the performance of drayage operations. Obviously, an increase in the length of time windows simplifies the management of drayage companies; however, it would hinder the operations at the terminals, as the influx of containers at their gates would not levelled. The experiments carried out show that, in the case of companies that manage a high number of daily orders, the improvement from very large time windows is less significant.

The two previous analyses may help consider mixed policies, where the terminal determines appointments with narrower windows which, however, may be breached incurring penalties. In this manner, access to the terminals would be decongested, but some haulage operators would not be restricted by potential circumstances. In other words, a policy of narrower windows, which benefits terminal management, but where there is some flexibility in its compliance, could be considered a management strategy that favours both terminals and drayage operators.

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