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Abstract: Cross-docking is a relatively new logistic strategy which seeks to make economies in transportation, decrease lead time and reduce inventory. The main principle is to unload, sort, consolidate and transfer delivered packages from inbound trucks to outbound trucks, with a minimum of storage or treatment in between. Two key issues associated to this field are the truck scheduling and the shop-floor operation scheduling. We propose a mixed integer linear programming model to schedule truck arrivals, shop-floor activities and truck departures. The cross-dock configuration we study is based on an industrial case on the automotive industry. In particular, a repack operation and two temporary storage zones are considered. The objective is to minimize internal operation cost (penalty related to extra capacity needs) and outbound transportation cost (number of trucks). The model is implemented and tested in CPLEX with small size instances, based on industrial data. The proposed model could be easily adapted to a variety of cross-dock configurations, in terms of internal capacity and cost distribution.

Keywords: Cross-docking, Integer Linear Programming, International logistics, Operation Scheduling, Truck scheduling problem (TRSP).

1. INTRODUCTION

Nowadays supply chain performance is crucial to maintain competitiveness in a more and more globalized industrial environment (Dolgui and Proth, 2010). In order to respond to customer's demand in terms of timing, quality and cost, companies implement new logistic strategies. One of them is cross-docking.

A cross-dock platform is an intermediate point in the supply chain, in which incoming deliveries are transferred to outgoing vehicles, with almost no internal treatment or storage. Its main purpose is to enable economies in transportation, thanks to product consolidation (Boysen and Fliedner, 2010), but a reduction of lead time and a decrease (or even elimination) of stock levels are also expected benefits of cross-docking (Saddle Creek Report, 2011). In a cross-dock centre products are unloaded from incoming trucks, moved across the platform, sorted by outbound destination and finally loaded onto outgoing trucks.

In the context of global sourcing and internationalisation strategies, several carmakers have set up cross-docking facilities to optimize transportation costs. Renault Group share of sales outside Europe has doubled in the last decade, reaching 46% in 2014. The company relies on a worldwide network of cross-dock centres, called ILN (International Logistic Network). These centres mainly link overseas assembly plants with inland suppliers. Figure 1 shows the logistic network of an ILN and situates the problem treated in this research work. For more details on the functioning mode of ILN platforms, see Serrano et al. (2015). They propose a distribution and operation planning model to minimize transportation costs (inbound and outbound) and internal costs (storage and resources). Their research treats tactical decisions, since they seek to plan the weekly activity at the logistic platform. Our paper complements the cited work, by proposing an operational decision model, to deal with daily decisions at a cross-dock centre.

Some characteristics of the overseas outbound transportation that takes place in Renault ILN platforms are considered in this research work. The first one is related to a repack activity needed for some products, in order to adapt their packages to the specific conditions of maritime transportation. This fact must be taken into account during the scheduling of shop-floor activities. The second feature is that every outbound truck is routed to the harbour, where products wait for their corresponding vessel departure. The latter simplifies the decisions on the outbound segment of the cross-dock. In particular, there is neither a vehicle routing problem (all must go to the harbour) nor hard constraints on departure time of trucks (the only constraint is that all products must be shipped *before* the end of the planning horizon).

This research work treats the operation scheduling problem at a cross-dock platform, based on a case of study on the automotive industry. It is assumed that all inbound trucks are available at the beginning of the planning horizon. In the shop-floor, we include a repack activity (needed for some products) and two temporary storage (or staging) zones. Finally, outbound trucks must be departed before the end of the planning horizon and the customer demand must be completely fulfilled at this point as well. To our knowledge, no previous work has treated together the aforementioned cross-dock configuration. An industrial case is studied to support the assumptions of the studied approach and test the proposed model. The paper is organised as follows: section 2 presents the current research on scheduling within cross-docking. The next section gives more details on the case study and the characteristics of the Renault cross-dock platforms that are considered in this research work. Afterwards, we define the problem we treat and accordingly, a mixed-integer linear programming model is proposed. Numerical experiments' conditions and results are presented next. Finally, we address both conclusion and perspectives.

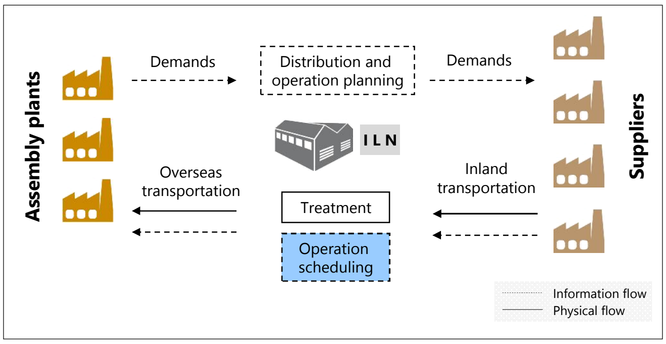

Fig. 1. Renault ILN supply chain network

2. RELATED WORK

Current research work related to cross-docking can be classified by decisional level (Van Belle et al., 2012). Main strategic issues are related to geographical location and shop-floor layout. On the tactical level, papers are focused on network flows, distribution planning and vehicle routing. Finally, operational decisions mainly concern dock door assignment, truck scheduling and shop-floor activity. Our interest is focused on the last two subjects.

In the last decade, cross-docking operation scheduling has received considerable attention. In Li et al. (2004) the shop-floor operation scheduling is modelled as the well-known machine scheduling problem. Two main operations are defined: breakdown incoming containers and build-up outgoing containers. They consider containers as jobs that must be treated by parallel machines (shop-floor teams). Intermediate storage is necessary if all machines are busy. The objective is to minimize holding cost and penalty cost associated to earliness and tardiness.

An exact method and two heuristics are developed and tested. They generate a set of 16 instances of various sizes. The exact method finds the optimal solution for 5 out of 16. Heuristics offer good solutions both in terms of cost and computing time. Yu and Egbelu (2008) consider a cross-dock platform with a temporary storage zone and conveyor belts to transport products. They propose a model that seeks to allocate products to outbound trucks and to determine truck sequence at inbound and outbound docks. They consider moving times in the shop-floor and the objective is to minimize makespan. A transhipment problem within a cross-docking network is studied by Miao et al. (2009). They consider time window constraints for both inbound and outbound trucks. Penalty costs are associated to tardiness on the outbound schedule. Cargos can be delayed in cross-dock for consolidation under a holding cost. Transportation costs are also included and are related to the distance travelled by trucks. The objective is to minimize total cost and a genetic algorithm is developed and tested with 8 set of instances. Boysen (2010) studies the truck scheduling problem (TRSP) at a cross-dock centre in the food industry. A zero inventory policy is adopted and therefore a completely synchronised inbound and outbound truck schedule is mandatory. An exact method model based on dynamic programming and a simulated annealing heuristics are presented.

Three different minimization objectives are considered: total flow time, outbound trucks' processing time and tardiness (based on customer due dates). It is shown that the heuristic method is suitable for real-world instances. Vahdani and Zandieh (2010) propose 5 meta-heuristics to schedule inbound and outbound trucks at a cross-dock, considering a temporary storage zone and which objective is to minimize total operation time.

The meta-heuristics are compared to a mixed integer linear model presented in a previous research work. Tests are run over 25 large-scale problems and meta-heuristics show, in overall, a better performance than the MILP model. A simultaneous scheduling of truck arrivals, truck departures and shop-floor pallet handling is studied by Ladier and Alpan. (2013). Earliness and tardiness are considered for both inbound and outbound trucks and a temporary storage of products is allowed. They present and integer program and a heuristics that seek to minimize the storage cost and the penalty costs associated to earliness and tardiness.

Agustina et al. (2014) present a model to treat simultaneously the vehicle routing and the truck scheduling problems, taking into account the consolidation at a cross-dock centre and customer time windows. The mixed integer program they propose seeks to minimize earliness and tardiness penalty costs, the holding and outbound transportation costs. Tested in CPLEX, the first model seems suitable only for small scale problems. In order to treat medium-size real-life instances, an alternative version that simplifies the vehicle routing problem, based on the adoption of customer zones and hard time windows constraints is proposed.

3. PROBLEM DESCRIPTION AND MODELING

3.1. Problem definition

We propose an operation scheduling model at a cross-dock platform to determine the inbound trucks' arrival time, the internal flows between the different stages at shop-floor (temporary staging zones, repacking zone and departure) and, finally, an approximation of the number of outbound trucks needed to fulfil customers' demand. Since the problem treats operational-related decisions, we consider a platform that is already functioning and the following parameters are given as input data:

- The number of inbound and outbound doors. Both are modelled as hard constraints.
- The shop-floor capacity is limited. It concerns the storage capacity (temporary staging zones), the package moving capacity and the repack zone capacity. The first two are modelled as soft constraints and the latter as

hard constraint. If the cross-dock centre serves several companies, extra storage capacity could be acquired by renting space allocated to another company. Package moving capacity could be obtained by hiring temporary employees.

Other important assumptions are:

- Since there is a relatively high diversity on the size of packages, all capacities related to shop-floor activities are given in m^3.
- Time space is discretised in periods of a fixed length, which are considered long enough to transport packages between zones and to carry the repack activity (periods of one or two hours).
- The previous assumption implies that distances between different shop-floor zones are not considered.

The model seeks to minimize internal operation cost and outbound transportation cost. The first one represents the penalty costs associated to the extra capacity needs on shop-floor (temporary storage area and package moving activity). The outbound transportation cost is related to the number of trucks used to fulfil customer demand.

3.2. Characterization of the proposed cross-dock centre

Based on the cross-dock settings studied by Ladier and Alpan (2015) and taking into account the industrial situation described above, we characterize the platform modelled in this paper. Main parameters are presented below (*in italics*).

First of all, on the strategic level, we assume the *shape* (physical layout) is not relevant, since the distance between doors is not taken into account in the model. The *number of doors* is known and we consider *internal transportation* as manual (workers and forklifts).

Secondly, main characteristics on the tactical level are: an exclusive *service mode*, since each door is solely dedicated either to inbound trucks or outbound trucks. *Pre-emption* is not allowed, which means that the loading or unloading of a truck cannot be interrupted. Finally, the *temporary storage capacity* and the *internal resource capacity* are limited.

Third and last, on the operational level the cross-dock is characterized as follows: the *arrival time*s of inbound trucks must be established and we assume that all trucks are available at the beginning of the planning horizon.

Outbound trucks content must be defined by the model and their *departure time* deadline corresponds to the final period of the horizon. *Product interchangeability* is allowed and for each destination a given demand must be fulfilled (products can be loaded indistinctly in the outbound trucks).

3.3. Input parameters and decision variables

The described framework uses the following notation:

Sets

i in I	Products.
j in J	Inbound trucks.
k in K	Customers.
t in T	Time periods.

Parameters

Products

v_i	Volume of product i (m^3).
rt_i	1 if product i must be repacked, 0 otherwise.

Inbound

ind	Number of inbound doors.
$itr_{i,j}$	Quantity of product i transported in truck j.

Internal

ct	Total package moving capacity of shop-floor (m^3 per period).
crz	Total capacity of repacking zone (m^3 per period).
cs	Total capacity of staging zones (m^3 per period).
pcs	Penalty cost of extra storage (m^3 per period).
pct	Penalty cost of extra package moving capacity (m^3 per period).

Outbound

oud	Number of outbound doors.
$icu_{i,k}$	Quantity of product i demanded by customer k.
cfc_k	Fixed cost of outbound trucks for customer k.
vc	Capacity of outbound trucks (m^3).

Decision variables

Inbound

$IT_{j,t}$	1 if inbound truck arrives in period t, 0 otherwise.

Internal

$AD_{i,t}$	Quantity of product i going from arrival zone to departure zone, on period t.
$AS^r_{i,t}$	Quantity of product i going from arrival zone to repack staging zone, on period t.
$AR_{i,t}$	Quantity of product i going from arrival zone to repack zone, on period t.
$AS^o_{i,t}$	Quantity of product i going from arrival zone to outbound staging zone, on period t.
$S^rR_{i,t}$	Quantity of product i going from repack staging zone to repack zone, on period t.
$RS^o_{i,t}$	Quantity of product i going from repack zone to outbound staging zone, on period t.
$RD_{i,t}$	Quantity of product i going from repack zone to departure zone, on period t.
$S^oD_{i,t}$	Quantity of product i going from outbound staging zone to departure zone, on period t.
$S^r_{i,t}$	Quantity of product i stored at repack staging zone, on period t.
$S^o_{i,t}$	Quantity of product i stored at outbound staging zone, on period t.
$R_{i,t}$	Quantity of product i repacked on period t.
SE_t	Extra storage capacity needed on period t (in m3).

TE_t Extra package moving capacity needed on period t (in m3).

Outbound

$Y_{i,k,t}$ Quantity of product i, affected to customer k and departing on period t.

$OT_{k,t}$ Approximation (based on package volume, m^3) on the number of outbound trucks for customer k, departing on period t.

Figure 2 summarizes the proposed model.

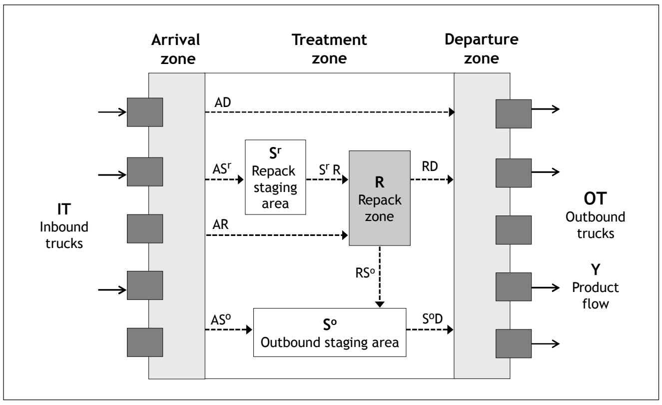

Fig. 2. Proposed model schema

3.4. Mathematical formulation

The mixed integer linear programming model is defined as follows:

$$Min\ Z = SP\_cost + PMP\_cost + OUT\_cost \quad (1)$$

Where:

$$SP\_cost = \sum_t (SE_t * pcs) \quad (2)$$

$$PMP\_cost = \sum_t (TE_t * pct) \quad (3)$$

$$OUT\_cost = \sum_{k,t} (OT_{k,t} * cfc_k) \quad (4)$$

Subject to:

Inbound

$$\sum_j IT_{j,t} <= ind \quad \forall t \quad (5)$$

$$\sum_t IT_{j,t} = 1 \quad \forall j \quad (6)$$

$$\sum_j (itr_{i,j} * IT_{j,t}) = rt_i * (AR_{i,t} + AS^r_{i,t}) + (1-rt_i) * (AD_{i,t} + AS^o_{i,t}) \quad \forall i,t \quad (7)$$

Internal

$$S^r_{i,t} + S^o_{i,t} + R_{i,t} = S^r_{i,t-1} + S^o_{i,t-1} + R_{i,t-1} + \sum_j (itr_{i,j} * IT_{j,t}) - \sum_k Y_{i,k,t} \quad \forall i, t_{>1} \quad (8)$$

$$S^r_{i,t} + S^o_{i,t} + R_{i,t} = \sum_j (itr_{i,j} * IT_{j,t}) - \sum_k Y_{i,k,t} \quad \forall i, t_{=1} \quad (9)$$

$$S^r_{i,t} = S^r_{i,t-1} + AS^r_{i,t} - S^rR_{i,t} \quad \forall i, t_{>1} \quad (10)$$

$$S^r_{i,t} = AS^r_{i,t} - S^rR_{i,t} \quad \forall i, t_{=1} \quad (11)$$

$$S^o_{i,t} = S^o_{i,t-1} + AS^o_{i,t} + RS^o_{i,t} - S^oD_{i,t} \quad \forall i, t_{>1} \quad (12)$$

$$S^o_{i,t} = AS^o_{i,t} + RS^o_{i,t} - S^oD_{i,t} \quad \forall i, t_{=1} \quad (13)$$

$$R_{i,t} = AR_{i,t} + S^rR_{i,t} \quad \forall i,t \quad (14)$$

$$\sum_t R_{i,t} = rt_i * \sum_j itr_{i,j} \quad \forall i \quad (15)$$

$$\sum_i R_{i,t} * v_i <= crz \quad \forall t \quad (16)$$

$$\sum_i (S^r_{i,j} + S^o_{i,j}) * v_i <= cs + SE_t \quad \forall t \quad (17)$$

$$\sum_i (AD_{i,t} + AS^r_{i,t} + AR_{i,t} + AS^o_{i,t} + S^rR_{i,t} + RS^o_{i,t} + RD_{i,t} + S^oD_{i,t}) * v_i <= ct + TE_t \quad \forall t \quad (18)$$

Outbound

$$\sum_k OT_{k,t} <= oud \quad \forall t \quad (19)$$

$$\sum_k Y_{i,k,t} = RD_{i,t} + S^oD_{i,t} + AD_{i,t} \quad \forall i,t \quad (20)$$

$$\sum_t Y_{i,k,t} = icu_{i,k} \quad \forall i,k \quad (21)$$

$$\sum_i (Y_{i,k,t} * v_i) <= OT_{k,t} * vc \quad \forall k,t \quad (22)$$

The objective function in (1) seeks to minimize internal operation cost (storage and package moving) and outbound transportation cost. Equations (2) and (3) characterize internal costs and it refers, respectively, to the extra needs on storage capacity and package moving activity. Equation (4) characterizes outbound cost, based on the approximation on the number of trucks needed. Constraint (5) guarantees the respect of the number of inbound doors available at the cross-dock. Equation (6) assures the arrival of all inbound trucks. Arrival flot conservation is represented in (7). Constraints (8) and (9) are related to global flot conservation. Equations (10) to (13) describe the flot of temporary staging zones (repack and outbound). Repack zone is characterized from (14) to (16): flot conservation, assure all concerned products are repacked and respect of total capacity, respectively. Constraints (17) and (18) link available and extra capacity of temporary staging zones and shop-floor package moving capacity. Equation (19) assures the respect of the number of outbound doors available. Constraints (20) and (21) are, respectively, related to departure flot and total demand. Finally, (22) represents the outbound trucks capacity.

4. NUMERICAL EXPERIMENTS

In this chapter we present the instance generation method as well as the related numerical results. We used CPLEX on a 4GB RAM Intel Celeron P4600 @ 2.00GHz CPU.

4.1. Instance generation

The following input data is collected from our case of study:

- An aggregated list of products going through the cross-dock platform. For each product, the following associated data is available: v_i (volume, m^3), rt_i (repacking information, approximately 30% of products) and the corresponding supplier and customer. The latter information permits to deduce K (total number of customers) and to calculate $icu_{i,k}$ (total product demand per customer).
- An estimated outbound trucks costs and capacity: cfc_k and vc, respectively.

Table 1. Problem sets characteristics

	Problem size						Cross-dock shop-floor configuration			
Problem set	Volume (m^3)	Time periods *T*	Type of products *I*	Inbound trucks *J*	Customers *K*	Total number of products	Doors *ind / oud*	Package moving capacity *ct*	Staging zones capacity *cs*	Repack zone capacity *crz*
1	200	6	5	7	3	171	3 / 3	For all: 1,1 * *ct_sm*	For all: 0,2 * *ct*	For all: 1,5 * *crz_sm*
2	200	8	5	7	3	171	3 / 3			
3	350	6	5	12	3	300	4 / 3			
4	350	8	5	12	3	300	4 / 3			
5	500	6	5	16	3	433	4 / 4			
6	500	8	5	16	3	433	4 / 4			

ct_sm and *crz_sm* represent the average workload per time period

- Inbound transportation data. A given supplier can be affected to dedicated trucks or a milk-run.

The rest of parameters are generated based on the following protocol:

- Set the total volume (m^3) that will be treated.
- Fix the number of inbound (*ind*) and outbound (*oud*) and the time periods (*T*).
- Allocate products to inbound trucks, based on supplier and inbound transportation data. We obtain $itr_{i,j}$ and by extension *J*. The filling rate of inbound trucks is randomly generated within a pre-defined range. Inbound trucks are generated until the total volume (m^3) set in 1 is attained. By extension we obtain *I* and *K*.
- Calculate the average workload per period, for each stage at the shop-floor: staging zones, repack operation and package moving activity. Based on these values we determine *cs*, *crz*, *ct*.

4.2. Experiments and results

The last parameters to be set concern the cost distribution for which two different scenarios are proposed, which are based on our industrial experience. For both scenarios we consider that the outbound cost is highly superior to penalty costs. This seems logical if we consider the overseas transportation between a Renault ILN and its customers. Concerning penalty costs, the first cost distribution represents a cross-dock platform in which the storage cost is greater than the package moving activity cost. We could imagine a platform with very limited space, but with flexible manpower with a relatively low cost. The second scenario envisages the opposite. One might think of a cross-dock centre situated in a country with a high manpower cost, serving several companies for which the storage space is allocated upon request.

The six problem sets described on Table 1 are run for each cost distribution scenario, resulting on 12 different tests. We consider 5 type of products (2 of which must be repacked), demanded by 3 different customers. Fixing previous parameters, we tested different levels of volume in this way: total number of products varies from 171 to 433. The inbound and outbound doors are between 3 and 4. In terms of number of trucks, they go from 7 inbound trucks and 5 outbound trucks for the smallest one, to 16 and 9, respectively, for the major one.

Table 2 summarize tests' results. Other than the instance size, computational time seems to be related to the cost distribution. In terms of outbound performance, we notice the same result for the two cost distribution scenarios. The difference lies on shop-floor operation. To better asses this impact, we calculate the average load per time period and the standard deviation for the storage level and the package moving activity. Cost distribution #1 shows a highly variable workload on package moving activity, with an average storage level lower than the available capacity (for 5 out of 6 sets). This can be explained because since the storage cost is higher than the packing moving cost.

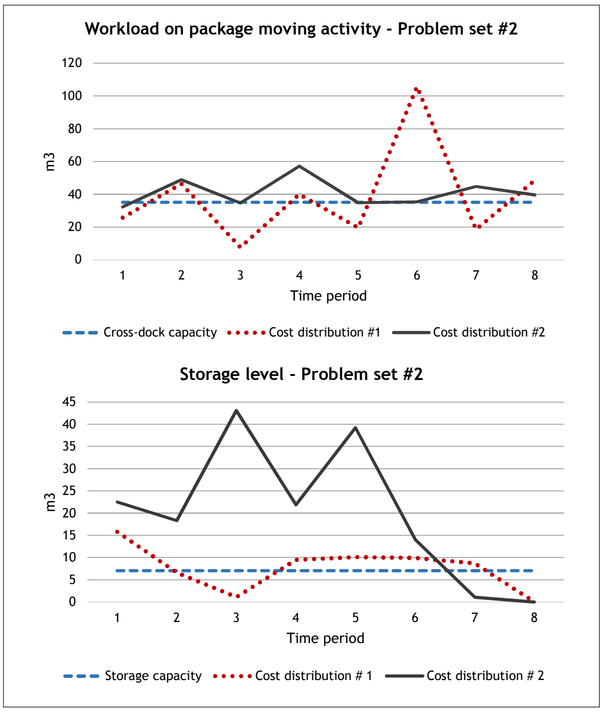

Fig. 3. Results' comparison between the two cost distributions, for problem set #2

On the opposite, results on cost distribution #2 reveal a smooth workload, close to the available capacity, with a higher occupation of storage space. The latter analysis is illustrated on Figure 3, for the problem set #2. Further tests and analysis with other configurations are needed to better assess the performance of the proposed model. Based on our industrial experience, the cost distribution between inbound, internal and outbound segment can be considerably different from one cross-dock to another and its impact on shop-floor

Table 2. Results of numerical experiments.

	Cost distribution #1: storage cost > package moving cost							Cost distribution #2: storage cost < package moving cost						
				Storage		Package moving					Storage		Package moving	
Problem set	CPU (s)	Outbound trucks	Total cost*	Capacity (m3 / t)	Average (m3 / t)	Capacity (m3 / t)	Average (m3 / t)	CPU (s)	Outbound trucks	Total cost*	Capacity (m3 / t)	Average (m3 / t)	Capacity (m3 / t)	Average (m3 / t)
1	3,5	5	10499	9,4	7,7 ± 5	46,9	50,0 ± 16	3,3	5	10749	9,4	17,8 ± 15	46,9	49,6 ± 5
2	67,7	5	10752	7,0	8,8 ± 5	35,2	40,9 ± 35	108,6	5	11400	7,0	26,4 ± 12	35,2	40,6 ± 10
3	9,4	8	16512	16,7	7,0 ± 4	83,3	81,0 ± 6	11,8	8	16512	16,7	7,8 ± 6	83,3	80,1 ± 7
4	59,7	8	16515	12,5	8,0 ± 5	62,47	62,8 ± 2	237,5	8	16545	12,5	9,8 ± 4	62,0	62,0 ± 1
5	24,9	9	18921	23,8	11,6 ± 9	119,0	116,1 ± 7	228,1	9	18934	23,8	13,8 ± 10	119,0	117,9 ± 2
6	32,54	9	23096	21,4	9,5 ± 7	107,2	100,4 ± 7	23,6	9	23094	21,4	17,4 ± 9	107,2	106,4 ± 1

operation scheduling must be assessed. The proposed approach should be use for this purpose.

5. CONCLUSIONS

Nowadays companies of all industries are implementing cross-dock platforms to accelerate logistic flows, to optimize storage and to reduce transportation costs. Truck scheduling and shop-floor operation scheduling are crucial activities to ensure a high performance at a cross-dock platform. We propose a mixed integer linear programming model to plan truck arrivals, shop-floor operation and truck departures to minimize total associated costs. A case study in the automotive industry is presented and some particular characteristics are included in this research work. In particular, we consider two temporary staging zones and a repack zone at the shop-floor, as well as an outbound trucks' constraint consisting on a departure time before the end of the planning horizon.

The mathematical model is implemented and tested in CPLEX. Small size instances are generated based on real-data sets. We consider two different cost distribution scenarios, which might represent industrial cross-dock platforms. 12 different tests were run and results showed similar performance on total cost, but with different shop-floor operation, impacting the variability of workload on package moving activity and available storage utilisation.

The presented model is intended to serve as a managerial decision-aid tool at a cross-dock platform. Even though we include specific characteristics of an industrial situation, it can be adapted to other configurations both in terms of shop-floor characteristics (no repack and/or storage zones) and in terms of cost distribution. As perspectives, we address three main subjects. First, real-life size instances must be tested in order to better assess the model performance. Second, inbound segment constraints could be considered, such us delivery time windows. Finally, it would be interesting to include uncertainties such us truck content and transportation delays.

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