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# Assessing the reduction of empty backhauls using transshipment points

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**ABSTRACT:** *Further reducing empty running by trucks is clearly an important source of efficiency for transportation companies, as well as a valuable way to decrease their carbon footprint. The Pickup and Delivery Problem (PDP) aims at selecting routes such that the distance travelled empty is as short as possible, given a set of transportation requests. In this context, the driving time constraint may be a key factor since it restricts the number of possible routes for each vehicle. To overcome this time constraint, an opportunity is for vehicles to drop or swap their trailer at intermediary transshipment points. In this paper, we evaluate the benefits of using transshipment points in the PDP to reduce the length of the empty backhauls, and we study how the driving time constraint affects those benefits. For this, we apply a MIP model for the PDP integrating transshipment points, and conduct computational experiments comparing the results with a classical PDP. We find that indeed, when driving time is constraining, enabling transshipment points seems to be of interest (up to 25% more reduction in the distance travelled empty).*

**KEYWORDS:** *Pickup and Delivery Problem, Transshipment Points, Empty Backhauls, Driving Time.*

## 1 INTRODUCTION

In today's globalized and ever-changing market, companies have to find solutions to meet the demand of their customers while ensuring low transportation costs (Mason and Harris, 2019). Logistic providers have to move smaller volume on larger distances, more frequently (Belenguer et al., 2016). Moreover, the transportation sector has to consider societal challenges, in particular related to sustainability, as this sector is responsible for around a quarter of the EU-28 greenhouse gas emissions (European Environment Agency, 2015). To help them face these challenges, companies can count on improved technologies (i.e. energy efficiency and electrification of vehicles) but they also need to improve the efficiency of the logistics system as a whole (Creemers et al., 2017).

The reduction of empty hauls is an important source of improvement, as they represented 27.3% of the national road freight kilometers in 2010 (European Commission, 2011). This reduction can be achieved by optimizing the planning and the route selection, but also by more profound changes in the routing and return trip policies. Figure 1.a illustrates the simplistic case where full trucks ship products from a supplier to a customer and come back directly and empty, leading to half of the trips travelled empty. In-

stead, as illustrated in Figure 1.b, empty backhauling can be reduced by making a tour with more stages, where delivery at a customer is followed by loading at a, hopefully close, supplier. The ensuing problem, known in the literature as the Pickup and Delivery Problem (PDP), consists in designing routes that meet transportation requests in such way that the empty distance travelled is as short as possible (Savelsbergh and Sol, 1995).

In such configuration, the driving time limit may be an important constraint since it restricts the length of the tour that can be travelled by a single truck, and the number of possible combinations that can be used in order to decrease empty travelled distances. For instance, given a driving time limit, the tour depicted in Figure 1.b may be too long for a single truck. In this case, the transportation company would have to revert to two trucks, two return trips and longer empty backhauls (Figure 1.a). To circumvent the constraint set by the driving time limit, an option is to integrate intermediary transshipment points, where trucks may drop or swap trailers. This case is illustrated in Figure 1.c, where vehicle T4 collects the load at the supplier  $i1$ , drops it at the customer  $j1$  and directly loads the shipment destined to customer  $j2$  (that was brought from  $i2$  by truck T5), before visiting customer  $j2$  and coming back to its starting

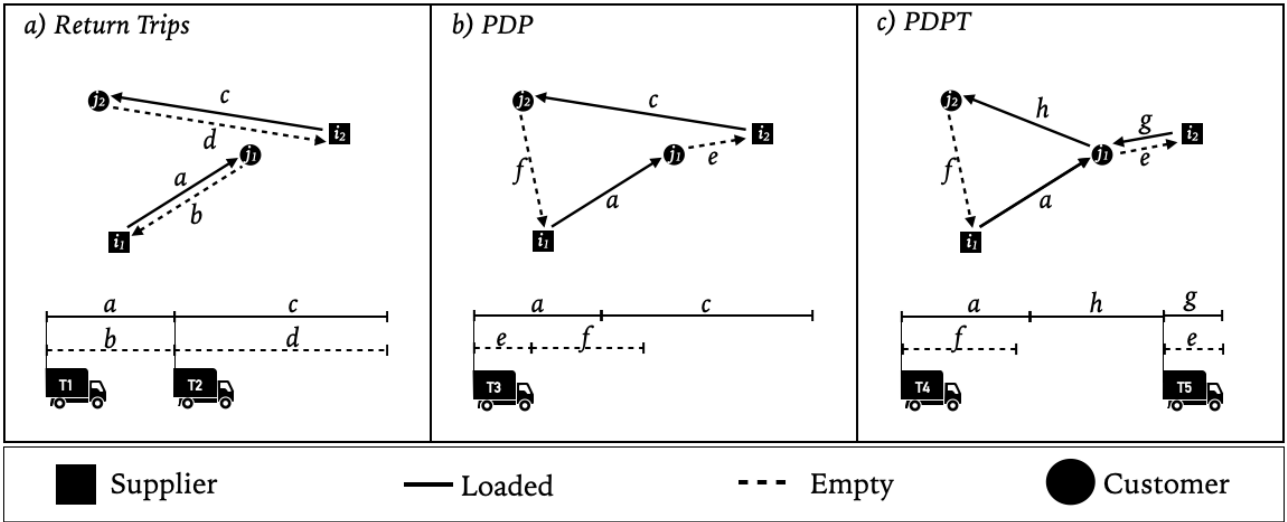


Figure 1 – Illustration of three transportation policies and their impact on travelled distances: (a) direct return trips; (b) pickup and delivery without transshipment; (c) pickup and delivery with transshipment.

point. In this case, the driving time limit is respected and the empty travelling distances are still reduced, using the location of customer  $j1$  (or close by) as a transshipment point. Also note that the full truckload distance is slightly lengthened, to allow for the trucks to meet at the transshipment point and eventually to reduce empty distances. This configuration naturally leads to an extension of the PDP, called the Pickup and Delivery Problem with Transshipment (PDPT).

In this paper, our goal is to assess the reduction in distances travelled empty when transshipment points are included in the network, and how this reduction is impacted by the tightness of the driving time limit. For this, we compare the results of two MIP models, for the PDP without and with transshipment, and vary the driving time limit. Those comparisons are performed on instances derived from real data of a Belgian transportation company (protected by a non-disclosure agreement), offering mainly long-distance full truckload transportation in Europe.

The remainder of the paper is structured as follows. Section 2 presents the PDPT literature. In Section 3, we present the problem and both PDP models, without and with transshipment points. The reduction in empty distances, the impact of the driving time limit and managerial insights are discussed in Section 4. Finally, Section 5 concludes our paper.

## 2 LITERATURE

The literature on the pickup and delivery problem (PDP) is vast as many variants have been studied and various solutions methods applied (see for example, Ropke and Pisinger, 2006; Montoya-Torres et al., 2015; Schiffer et al., 2019). Berbeglia et al. (2007) propose a classification of pickup and deliv-

ery problems, including the PDP with transshipment (PDPT). Compared to the PDP, the PDPT is less explored in the literature (Danloup et al., 2018), but it has attracted increased attention from the research community in the last few years for its ability to design an agile and intelligent distribution network that helps reducing travelled distances. The PDPT, which is studied in this paper, considers a fleet of vehicles which can exchange trailers or customer requests at special locations, called transshipment points. These locations can be specific facilities like depots of carriers or cross-docking centres, when a specific equipment is required to operate the transshipment, or more simply, public places like parking areas or motorway service areas when the goods or complete trailers can be moved between vehicles without specific equipment (Vornhusen et al., 2014).

In addition to two metaheuristics to solve the PDPT (a large neighbourhood search and a genetic algorithm), Danloup et al. (2018) present an extensive literature review on the PDPT, distinguishing exact and heuristic methods. In the following, we present the contributions that are most related to our research. Mitrović-Minić and Laporte (2006) propose a two-phase heuristic to solve a PDPT with time windows. The construction phase provides several solutions using various random initial orderings of the requests and the improvement phase modifies the best solution found by successively removing and reinserting the requests. The authors then use their heuristic to assess the impact of four transshipment points in the transportation networks, considering uncapacitated vehicles delivering up to 100 transport requests to several cities. The total route length is reduced in comparison with the model without transshipment, with different magnitudes depending on the instances (from 2% to 40%). The benefits increase with the

number of requests and when time windows are less restrictive. Rais et al. (2013) also show that transshipment points may bring benefits, presenting mixed integer programming models with and without time windows. The objective of their model is to find a set of minimum-cost vehicle routes for meeting all customer requests. They consider a fleet of capacitated vehicles which are able to exchange part of their customer requests at transshipment points. The authors demonstrate that the routes including transshipment points are shorter in five of the ten 10-node instances, and eight of the ten 14-node instances. Vornhusen et al. (2014) assess the benefits of transshipment in a collaborative context, using a mixed-integer programming model. In their model, a single customer request can be split among different vehicles while the schedules of the deliveries must be synchronized. The authors analyse 10 instances with two carriers (one vehicle per carrier), nine requests and one transshipment point. The cost reductions coming from the collaboration and the request exchanges are of around 19% and the use of one transshipment point brings additional benefits ranging from 2% to 4%.

In our paper, we consider the PDPT faced by a long-distance full truckload transportation company. We analyse instances built from real data including a large number of transshipment points (around 40 possible locations) and assess the benefits on around 20 requests. Moreover, we study the impact of the driving time limit, which is a determining factor to choose between a classical PDP and a PDPT (i.e. to know when the additional operational costs due to transshipment are valuable).

### 3 MODELS PRESENTATION

#### 3.1 Pickup and delivery

The pickup and delivery problem we study is the classical problem faced by long-distance full truckload transportation companies. Given a set of commodities, i.e. shipments to deliver from suppliers to customers, the goal is to select the shortest combination of routes, minimizing the empty travelled distance (as full truckload distance is fixed). Importantly, each truck has to respect a certain driving time limit (e.g. for legal reasons). We assume that the fleet of vehicles is homogeneous and that the number of vehicles/drivers (potentially contractors) available is sufficient and geographically spread, i.e. that the number of vehicles is not limiting. In the following, we formulate a simple MIP model for this PDP without transshipment, which will serve as a comparison point in our numerical experiments. We will include transshipment points in the next subsection. Table 1 lists the notations that will be used throughout the paper.

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#### Sets and indices:

$i, j \in S_L$	Locations.
$k \in S_K$	Commodities.
$v \in S_V$	Vehicles.

#### Parameters:

$Dist_{ij}$	Distance between nodes $i$ and $j$ , in <i>km</i> .
$T_{ij}$	Driving time between $i$ and $j$ , in <i>hours</i> .
$R_k$	Number of shipments for commodity $k$ .
$O_k$	Origin location of commodity $k$ .
$D_k$	Destination location of commodity $k$ .
$Th$	Handling time at a location, in <i>hours</i> .
$Tmax$	Driving time limit, in <i>hours</i> .

#### Decision variables:

$x_{ij}^v$	Number of loaded trips from $i$ to $j$ by $v$ .
$y_{ij}^v$	Number of empty trips from $i$ to $j$ by $v$ .
$f_{ij}^k$	The flow of commodity $k$ on arc $(i, j)$ .

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Table 1 – Overview of the mathematical notations.

$$\min \sum_{i,j,v} Dist_{ij}(x_{ij}^v + y_{ij}^v) \quad (1)$$

$$\text{s.t.} \quad \sum_v x_{ij}^v = R_k \quad \forall k, i = O_k, j = D_k \quad (2)$$

$$\sum_{i,v} x_{ij}^v + y_{ij}^v = \sum_{i,v} x_{ji}^v + y_{ji}^v \quad \forall j \quad (3)$$

$$\sum_{i,j} (x_{ij}^v + y_{ij}^v) \cdot (T_{ij} + Th) \leq Tmax \quad \forall v \quad (4)$$

$$x_{ij}^v, y_{ij}^v \in \mathbb{Z}^+ \quad \forall i, j, v \quad (5)$$

The objective (1) is to minimize the total distance, made of loaded and empty trips. Constraints (2) stipulate that the demand for a commodity  $k$  should be satisfied, directly from its origin location to its destination location. The only potential for improvement is thus in the empty backhauling trips. The vehicle flow conservation constraints (3) ensure that each vehicle arriving at a node  $j$  also leaves it. Constraints (4) prevent a vehicle/driver to work more than the driving time limit. Note that the time limit includes the driving time (mostly) but also the handling time spent for loading/unloading the trailer whenever entering into a node. Finally, constraints (5) enforce the integer nature of the decision variables.

Note that this model does not include subtour elimination constraints. As the number of available vehicles is supposed to be sufficient, two subtours could simply be run by two different vehicles (and the driving time would still be complied with). Subtour elimination could be included in the same way as proposed by Rais et al. (2014) who first propose a model without subtour elimination and then an extension including variables  $z_{ij}^v$  and constraints to model precedence.

In our numerical experiments, both models, for the PDP and the PDPT, do not include subtour elimination to be comparable, and this of course reduces the computational complexity significantly.

### 3.2 Pickup and delivery with transshipment

As discussed in the introduction, and illustrated in Figure 1, transshipment points may help complying with the driving time limit and reducing the empty travelled distance. In this subsection, we include the possibility of transshipment points in the PDP model presented earlier, building on network design modelling ideas. At a transshipment point, a vehicle may drop, pickup or swap its trailer. In this model, we suppose that the transshipment locations are those of customers and suppliers (or in the same city). Note that this assumption is not limiting, as any location could easily be added as a *virtual* customer with no demand (no commodity attached to it). We assume that the timing and synchronization of the vehicles routes is decided after they have been designed using the PDPT model. A time ( $Th$ ) for handling the operations related to dropping, picking or swapping a trailer at a transshipment is included in the model. In the following, we formulate the PDPT model, including transshipment.

$$\min \sum_{i,j,v} Dist_{ij}(x_{ij}^v + y_{ij}^v) \quad (6)$$

$$\text{s.t.} \quad \sum_j f_{ij}^k - \sum_j f_{ji}^k = R_k \quad \forall k, i = O_k \quad (7)$$

$$\sum_j f_{ij}^k - \sum_j f_{ji}^k = -R_k \quad \forall k, i = D_k \quad (8)$$

$$\sum_j f_{ij}^k = \sum_j f_{ji}^k \quad \forall k, i \neq O_k, i \neq D_k \quad (9)$$

$$\sum_v x_{ij}^v = \sum_k f_{ij}^k \quad \forall i, j \quad (10)$$

$$\sum_{i,v} x_{ij}^v + y_{ij}^v = \sum_{i,v} x_{ji}^v + y_{ji}^v \quad \forall j \quad (11)$$

$$\sum_{i,j} (x_{ij}^v + y_{ij}^v) \cdot (T_{ij} + Th) \leq T_{max} \quad \forall v \quad (12)$$

$$x_{ij}^v, y_{ij}^v \in \mathbb{Z}^+ \quad \forall i, j, v \quad (13)$$

$$f_{ij}^k \geq 0 \quad \forall i, j, k \quad (14)$$

As in the PDP model, the objective 6 is to minimize the total distance. Constraints (11-13) are also conserved from the PDP model, to represent the vehicle flow conservation at each location and the driving time limit. Constraints (7-9) are the network flow conservation constraints (at a commodity's origin, destination or transshipment point). They ensure that each commodity is shipped from its origin to its destination, whether with a direct delivery or using transshipment. They allow for commodities to

go through one or more transshipment points. It also means that, unlike for the PDP, loaded trips are no longer predefined but are also a decision of the model. Constraints (10) relate the commodity flows and the vehicle flows. They guarantee that every flow/arc of commodity built in the network is covered by a vehicle. A commodity may thus be served by several vehicles. Finally, constraints (14) enforce the positive nature of decision variables  $f_{ij}^k$  (the integer nature of  $f_{ij}^k$  does not need to be enforced).

## 4 COMPUTATIONAL EXPERIMENTS

### 4.1 Experimental setting

The instances used in our experiments are based on data from a Belgian long-distance transportation company (due to strict confidentiality reasons, we are not allowed to give more information on this collaboration). From the weekly transportation requests of the company, we build 8 different commodity matrices (instances), each with around 20 transportation requests (22.4 on average) spread across around 40 locations (43.4 on average, which are also possible locations for transshipment points). Distances between locations are computed using the haversine formula (distance as the crow flies) and multiplied by a factor of 1.34 to estimate the actual road distance (Héran, 2009). The average distance from a commodity's origin to its destination is 581km, and the average distance between two locations is 705km (as seen in Figure 2, locations are spread all over Europe). To compute the driving time, we assume an average speed of 70km/h. A handling time  $Th$  of half an hour is supposed, identical at all locations, whether it is to unload, load or exchange a trailer (Vornhusen et al., 2014). To illustrate, Figure 2 shows the routes computed for a specific instance. Tours with multiple commodities appear when the PDP model is applied (Figure 2.b). Transshipment points are used when the PDPT model is applied, for example to reach a remote location in the North-East (Figure 2.c).

In a first set of experiments (see Section 4.2), we solve our 8 instances with both models, PDP and PDPT, considering a driving time limit of 35 hours, corresponding to a workweek. In a second set of experiments, to study the impact of the driving time limit (see Section 4.3), we solve 4 instances (for computational time's sake) with both models, PDP and PDPT, varying the driving time from 30h to 80h. This leads to a total of 96 experiments. Note that when the driving time does not allow to satisfy a transportation request even with a direct return trip (e.g. a request longer than 1225km when supposing 35h driving time), we suppose that it is performed with a return trip, extending the driving time of the vehicle as little as possible. This only happens with

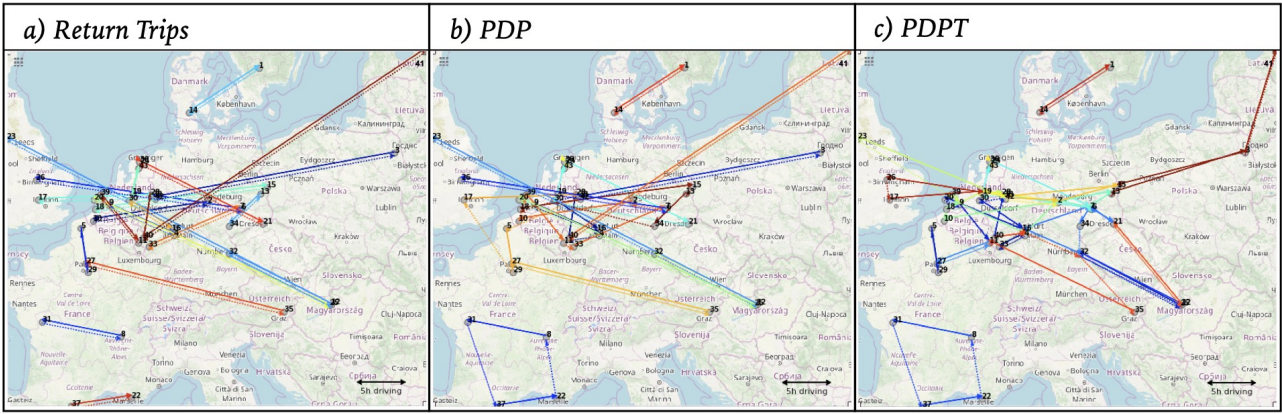


Figure 2 – Routes computed for a specific instance, supposing return trips (a), applying the PDP model (b), and including transshipment (c). Loaded trips are in solid lines and empty trips are in dashed lines.

the PDP, and not with the PDPT as transshipment point allow to reduce the length of a tour. In fact, this may be seen as an advantage of transshipment points: allowing to always comply with the driving time limit.

Both models, the PDP and the PDPT, have been implemented in Mosel using the MILP solver of Xpress IVE. All computations are conducted on an Intel Core processor running at 3.2 GHz with 8 GB of RAM. The computational time per instance is limited to two hours and the computations stop when an optimality gap of 0.5% is reached. The resulting average optimality gap in our 96 experiments equals 2.5%.

#### 4.2 Potential benefits of transshipment

In this subsection, we discuss the results of our first set of experiments, solving our 8 instances with a driving time limit of 35 hours. Table 2 gives the average results, comparing to direct return trips. The PDP allows to reduce the total distance by 13% and adding transshipment allows to further reduce it by a substantial 10.8%. Unsurprisingly, this reduction comes from the reduction of empty trips, which are reduced by 50% with the PDPT, compared to direct

return trips. The important difference in results comparing PDP and PDPT comes from the fact that indeed transshipment points are extensively used, 12.6 times per instance on average, i.e. for more than half of the transportation requests (56.2%). Using transshipment points leads to detours, which justify the slight increase in loaded distance (2.3%), while, using PDP, loaded trips are of course unchanged compared to direct return trips.

#### 4.3 Impact of the driving time limit

With the second set of experiments, our goal is to assess the impact of the driving time limit, as it is one of the main motivations to include transshipment. Figure 3 shows that the driving time limit is indeed a determining factor. With transshipment, the distance reduction is stable, mostly independent of the driving

	PDP	PDPT
<b>Loaded</b>	0%	+2.3%
<b>Empty</b>	-25.9%	-50.0%
<b>Total</b>	-13.0%	-23.8%
<b>Transshipments</b>	0	12.6

Table 2 – Average change compared to return trips in loaded, empty and total distances, for the PDP and for the PDPT, and average number of transshipments per instance, when assuming 35h driving time (8 instances).

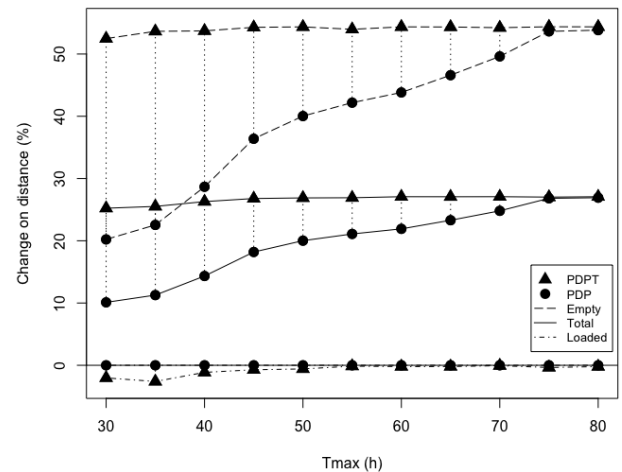


Figure 3 – Average change compared to return trips in loaded, empty and total distances, for the PDP and for the PDPT, with varying driving time limits (4 instances).

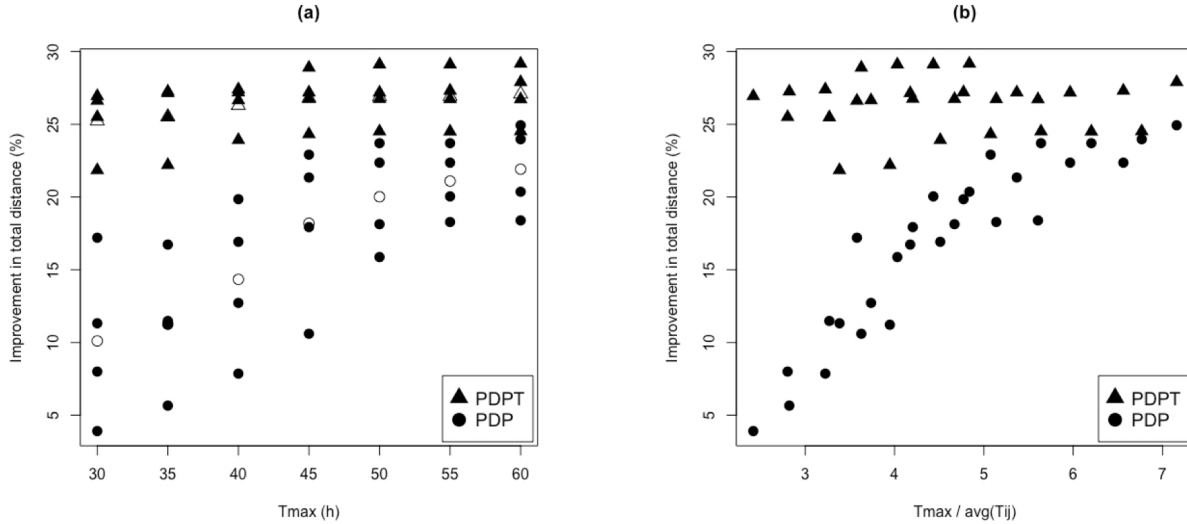


Figure 4 – Improvement in total distance, compared to return trips, for the PDP and for the PDPT, for the 4 instances, with driving time limits from 30h to 60h.

time limit, around 25% in total distance and around 50% in empty distance. On the opposite, the distance reduction when transshipment points are not considered (PDP) is clearly a function of the driving time. When the driving time limit is tight, allowing for transshipment makes a substantial difference (from 10.1% to 25.2% on average total distance with 30h driving time). The benefit of transshipment points decreases regularly as the driving time increases, up to a point where transshipment does not bring any value and the PDP should be solved rather than the PDPT for simplicity sake.

To further understand when transshipment is worth considering, and the PDPT worth solving, we first show in Figure 4.a the total distance reduction for each of the four instances, and on average (empty triangles and circles, corresponding to the solid lines in Figure 3). It appears clearly that the driving time alone is not sufficient to foresee the extent of the difference between PDP and PDPT results. With 30h driving time for example, the PDP distance reduction varies widely, from 3.9% to 17.2%. The driving time has to be balanced with the length of the arcs that the vehicle will have to travel during this time. When designing the routes, if many shipments can easily be included in one vehicle tour, the PDP will be efficient to combine those shipments and reduce empty distances. When the number of possible shipments in a tour decreases, the opportunities to combine shipments in order to reduce empty trips decreases as well. In this case, transshipment points are valuable as they help relax the tension of the driving time limit and increase the number of possible combinations (with not only complete shipments but also partial segments of shipments).

To reflect this, we propose to divide the total driving time limit by the average driving time between all pairs of locations in the instance, i.e.  $T_{max} / \text{avg}(T_{ij})$ . This «tension» measure roughly represents the number of nodes (or arcs) that we can hope to include in a vehicle tour, on average. Figure 4.b shows the total distance reduction for each of the four instances with various driving time limits as in Figure 4.a, but as a function of this «tension» measure. As anticipated, it appears to be a better predictor of the results of the PDP, as the results provided by the various instances with various driving time limits tend to be quite consistent. When only few nodes can be visited by a vehicle during its driving time (small  $T_{max} / \text{avg}(T_{ij})$ ), PDP is powerless to reduce empty backhauls and the distance reduction is mild.

Figure 4.b thus also allows to distinguish more clearly cases where applying the PDPT model and considering transshipment points is beneficial. If the «tension» measure,  $T_{max} / \text{avg}(T_{ij})$ , is around four or less, transshipment is clearly advised, as it may help further decreasing the total distance, by more than 10%. If this measure is in the vicinity of five, transshipment points may still be worth considering, depending of the organisational burden they represent. Finally, for values larger than six, transshipment is likely not worth considering. In short, transportation companies should consider including transshipment points in their operations if a tight driving time limits leads their vehicles to visit five or less locations per tour.

## 5 CONCLUSION

For transportation companies, a key issue for reducing their costs is the shortening of empty backhauling trips. To this end, the PDP aims at designing routes that meet transportation requests, while reducing the distance travelled empty. In such problems, the driving time limit appears to be decisive since it restricts the length of a tour that can be achieved by a single truck. To circumvent this limit, the PDPT includes intermediary transshipment points that can be used by vehicles to swap their trailers. In this paper, we aimed to assess the additional benefits in distance reduction brought by the introduction of transshipment points in the network, and to study the impact of the driving time limit on those benefits.

To achieve this, we applied MIP formulations for the PDP and the PDPT, and conducted 96 computational experiments based on real data from a Belgian long-distance transportation company. We found that, compared to the PDP, the PDPT makes a substantial difference, allowing for up to 25% more reduction in the distance travelled empty. However, the additional benefit brought by transshipment points decreases regularly as the driving time constraint is released. From our experiments, it appears that considering transshipment points is advisable as soon as the driving time limit prevents a vehicle from visiting more than five locations in one tour, on average. In other words, considering transshipment points is of clear interest when the driving time limit tightens or when the distances to be covered increases: two real challenges of today.

This research could be extended in several directions. A first potential improvement would be to consider the reduction in  $CO_2$  emissions, assuming that emissions depend on whether a vehicle is loaded or empty. Also, it would be interesting to account for the interoperability challenge by considering a heterogeneous fleet of vehicles. Finally, now that the potential savings regarding the use of transshipment points are assessed, the natural next step could be to integrate the problem of ensuring the good synchronization of the transshipment operations.

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