Flexibility in Home Delivery by Enabling Time Window Changes

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Abstract: To enhance the perceived quality of home delivery services more and more flexibility is offered to the receivers. Enabling same-day delivery, communicating predefined narrow time windows, choosing the time windows and alternative address delivery add to the receiver's experience, making the delivery company an interesting partner for parcel-shipping companies. A new flexibility is the possibility to change the chosen or communicated time window by the receiver during the day of delivery. In this paper we investigate the effect on delivery costs of this flexibility. Receivers are allowed to change their time window until the start of the old or new (the earliest) time window. In this paper two situations are investigated: one situation where communicated time window is a result of the planning process (Time Indication) and one situation where the original time window was already chosen by the receiver (Time choice). We show that the costs rises quickly in the Time Indication case when the percentage of time window changes grow. The Time Choice case is more costly at the start, but time window changes can be handled without (too much) extra costs. However, here a higher percentage of parcels is delivered outside the time windows.

1 INTRODUCTION

Last-mile delivery has become increasingly important with the rise of e-commerce (Joerss et al., 2016). In this last-mile delivery, the carrier transports the goods sent by the shipper to the receiver. Here the shipper is the carrier's customer and the receiver is the shipper's customer. To avoid ambiguities, we use the terms carrier, shipper and receiver. The problems regarding an optimal last-mile delivery fall in the area of Vehicle Routing Problems (VRP). Solving the VRP might result in minimal costs for the carrier or the shipper, but does not guarantee the (perceived) quality of the shipment. Also, several issues arise from home delivery activities for fulfilling those internet shopping orders, e.g., increased operating costs for handing failed home deliveries, and deteriorated traffic conditions due to frequent delivery trips (Song et al., 2016). An important factor for the (perceived) quality of the delivery service is the variety of delivery options a receiver can choose from (Yao et al., 2019; Rincon-Garcia et al., 2018; Gawor and Hoberg, 2019). Examples of delivery options are next-day delivery, same-day delivery, alternative address delivery or predefined time window delivery. Here, time windows offer the benefit of potentially serving as a communication tool towards the receiver, allowing companies to increase the success rate of their deliveries. Naturally, a decrease in the number of delivery failures will increase the receiver's satisfaction level. Nonetheless, as the implementation of time windows reduces the efficiency of the routing, a trade-off has to be made between receiver's satisfaction and delivery costs (Köhler et al., 2020). The possibilities to improve the efficiency of home delivery are investigated by (Van Duin et al., 2016). They conclude that contact with the receiver can significantly increase the efficiency. In addition, a process called address intelligence seems to hold great potential by using historical data as a way of predicting future deliveries. Other promising options that apply to home delivery are the possibility to use sliding time windows (Shao et al., 2019) or to deliver at a different location, within a predefined time window or change the delivery time. There is much work done on selection of time windows sizes, e.g., (Köhler et al., 2020; Côté et al., 2019; Mackert, 2019; Klein et al., 2019; Hernandez et al., 2017). The work of (Agatz et al., 2011) tackles the problem of selecting time windows to offer in different regions. In other words, receivers in certain regions are provided with specific choices to accommodate the ability to construct cost efficient routes. The results emphasise the trade-off between delivery effi-

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ciency and receiver's satisfaction since offering narrow time windows is convenient for the receiver but greatly reduces the efficiency of the routes.
To improve the perceived quality and receiver's satisfaction even more, more flexibility can be offered to the receivers, for example the possibility to change the delivery time window or place during the day of delivery. Again this reduces the efficiency of the routing. In this paper we study the effect of offering the flexibility to change the time window of delivery during the day of delivery and give insight in the cost of this flexibility in terms of driving time and vehicle kilometres. Where there are papers on incident handling and disruption management, we will however simply execute re-planning before every new time window. A general overview of papers that look at disruption management in VRPs can be found in (Eglese and Zambirinis, 2018). Yang et al. (Yang et al., 2017) provide a incident handling method in case of time window changes. We want to allow these changes and are interested in the effect these changes have on the operational costs. We are not aware of other papers that are doing this and this option is not taken into account in large literature overviews like (Boysen et al., 2020) and (Savelsbergh and Van Woensel, 2016).

In this paper we investigate the effect of offering the flexibility to change the delivery time window by the receiver. In Section 2 we start with the description of the case we consider, explain the assumptions we make and elaborate on the simulation approach we use. The results of this simulation approach are presented in Section 3. Finally, in Section 4 we discuss the results, draw some conclusions and suggest topics for further research.

2 ASSUMPTIONS AND APPROACH

We consider a regional depot from which parcels are distributed over a certain area. Parcels arrive at night and are assigned to vehicles. This problem can be modelled as a VRP. We assume that this VRP was solved for this certain depot and that, at the beginning of the morning, the vehicles are loaded for their route. Next, receivers are informed about a delivery time window or time slot. For the way this is organised, we consider two cases:

- The VRP is solved and thus the routes of the vehicles are optimised without giving the receivers the possibility to choose a time slot. The indication the receiver obtain is a result of the optimisation. We will call this *Time Indication*. The VRP is an NP-hard problem (Lenstra and Rinnooy Kan, 1981).
- The VRP is solved with time windows (VRPTW) and thus the routes of the vehicles are optimised based on the preference of the receivers. The indication the receivers obtain is a result of the optimisation under the constraint of these preferences. We will call this *Time Choice*. The VRP-TW is also an NP-hard problem (Dror, 1994).

Both cases will be considered using two different time window lengths: 1 hour (not overlapping) and 3 hours (1 hour overlapping). So the first category consists of the time windows 9-10, 10-11, etc., the second category consists of the time windows 9-12, 11-14, 13-16 etc.

We now introduce the possibility for the receivers to change their time windows. The only restriction they have, is that they have to communicate this change before the start of their current time window *and* before the start of their newly chosen time window. This means, in the case of the 3-hour time windows, that when the receiver got assigned the time window 11-14h and he wants to change this to 13-16h, this has to be communicated before 11h. In the case that the receiver got assigned the time window 15-18h and he wants to change this to 13-16h, this has to be communicated before 13h.

We will restrict the case to a single vehicle. This vehicle delivers the parcels to the receivers. The size of the areas we consider is based on real data and the number of parcels that is considered is based on the number of parcels that can be delivered in that area within a working day of (around) eight hours. This assumption resulted in two areas, one with a size of 6 km^2 and 120 parcels to deliver, the other area has a size of 54 km^2 km and 90 parcels to deliver. We use real (fixed) deliver areas from practice, however, within this are we generate address data randomly for 50 days and a delivery time window for each address. Now we calculate for each day the optimal route in two ways:

1. The optimal route without time windows.
2. The (approximate) optimal route with time windows.

The first route is used as benchmark. From this first route the *Time Indication* case is derived. The resulting times from this optimal route are communicated to the receivers. From the huge number of optimisation techniques, as shown in (Psaraftis et al., 2016), for the second route we have chosen to use a simulated annealing approach (using the implementation of yarpiz.com). The parameters, the number of iterations, the initial temperature and the temperature damping rate, are chosen such that (without the time window constraints) it gives the same results as the first route. With this parameters the route with time window constraints, the *Time Choice* case, is calculated and communicated (confirmed) to the receivers.

Now for each day, the course of the day is simulated. Over all the receivers a percentage p is selected that is assigned a new delivery window. Of course, this assignment simulates the flexibility the receiver has in real life to change the delivery window himself. We assume this information gets available at the latest moment possible, compliant to the restriction the receiver has in changing the delivery time. During the simulation, at the start of each delivery window, a new (approximate) optimal plan is recalculated, using the latest delivery window information. This plan is executed until the beginning of the next delivery window. Note that a continuous updating scheme, or at least updating at each moment new information is revealed, and the availability of this information earlier that the latest moment possible, will increase the performance of this approach. This means that the extra costs of introducing this flexibility is lower than presented in this paper, which can be considered as a worst case.

3 RESULTS

As indicated, we did this simulation for the two areas, for the two time slot lengths, for five percentages ($p = 5\%, 15\%, 25\%, 35\%$ and 45%) and for the cases *Time-Indication* and *Time-Choice*. Each simulation was repeated 50 times to get a (statistically) reliable answer.

In Figures 1-3 the results are presented for the 6 km^2 area. We present the results relative to the general *Time Indication* solution. In the actual results, approximately 50 kilometre is already taken by going to and from the depot. In analysing the relative differences we will exclude this 50 kilometres. Then, as expected, the optimal route with *Time Indication* is the route with the lowest travel distance. If we introduce time interventions (both with 1h and 3h time windows) to this route, from 5 to 45% of the receivers, we see an increase in distance travelled in Figure 1. The more receivers ask for a change in delivery window, the higher the costs in kilometres, going up by 86% (from 30 to 55 kilometres, subtracting the 50 kilometres) in the case of the 1 hour time window and by 122% in case of the 3 hour time window at the point of 45% of the receivers realising time interventions. Note that the two time windows start at the same value, caused by the fact that there is no difference in starting solution. The only difference is the length of the delivery window they get communicated. However, in the case of time interventions the costs in kilometres rises more quickly for the 1-hour case.

Then we go to the result of the case Time Choice without time interventions. Receivers can choose their own delivery window from the start. Now, see Figure 2 the travel distance already goes up by 113% for the 3 hour case and even with 225% for the 1 hour case. In fact, instead of one tour in the delivery area, the vehicles drives a number of tours equal to the number of time-windows. Introducing the possibility to change the time window here hardly has an effect, as can be seen in Figure 3. In the 3 hour time window case there is enough slack and possibilities to change the routes without effecting the number of kilometres driven. In the 1 hour time windows it comes with a small cost. However, in both cases the number of kilometres is independent of the percentage of changes. The solution is already disturbed enough that it can handle any number of change. The (small) rise of costs is caused by the less efficient routing from and to the depot.

In figure 4 all the results are presented for the 54 km^2 area. We see largely the same results, where the gaps between the cases with and without time-interventions for the *Time Choice* cases are a bit larger, due to the larger distances. We also see that the 1h and 3h time windows for the *Time Indication* have almost the same course.

The results for the *Time Indication* case with time interventions are equal. However, what is not depicted in the costs is the number of deliveries outside the communicated time windows. For the *Time Indication* case with the 3 hour (overlapping) time windows, all the receivers can be delivered within their time windows for all percentages of time interventions. For the 1 hour time window this is not the case. On average 4% up to 8% of the deliveries are outside the time window. For the *Time Choice* case this is much worse. Here introducing the time interventions for the 3 hour time windows give 26% late deliveries and in the 1 hour time windows case even 40-60%. This means that introducing time interventions in a big(ger) area with tight time windows might not incur (that much) extra distance, it dramatically deteriorates the quality of the delivery service.

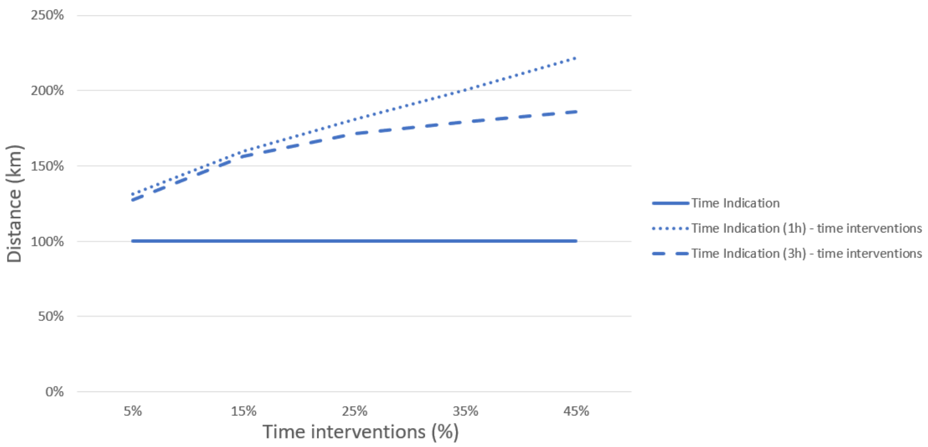

Figure 1: Result of introducing time interventions to the *Time Indication* case. The distance is given relative to the general *Time Indication* case. A 1 hour time indication with time interventions leads to the highest costs and costs rise more quickly if more interventions are made.

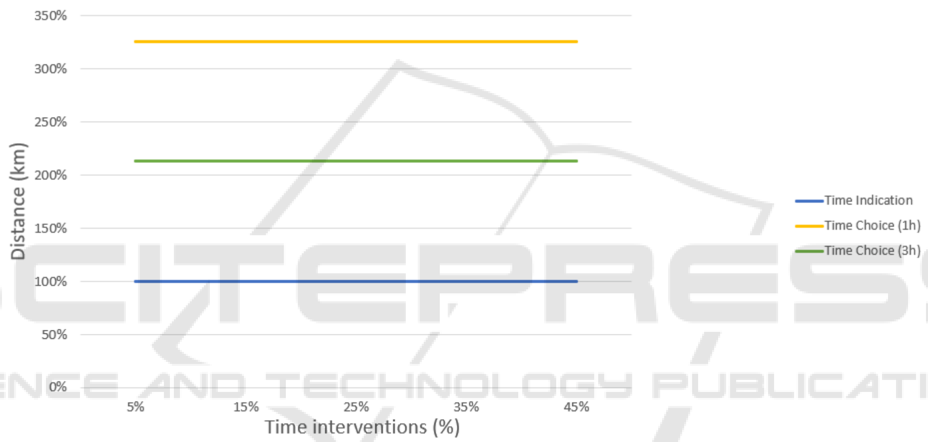

Figure 2: Result of giving receivers the possibility to choose a 1-hour or 3-hour delivery window. The distance is given relative to the general *Time Indication* case. Choice for a 1-hour time window increases costs by 225% compared to a scenario where receivers are given a time indication.

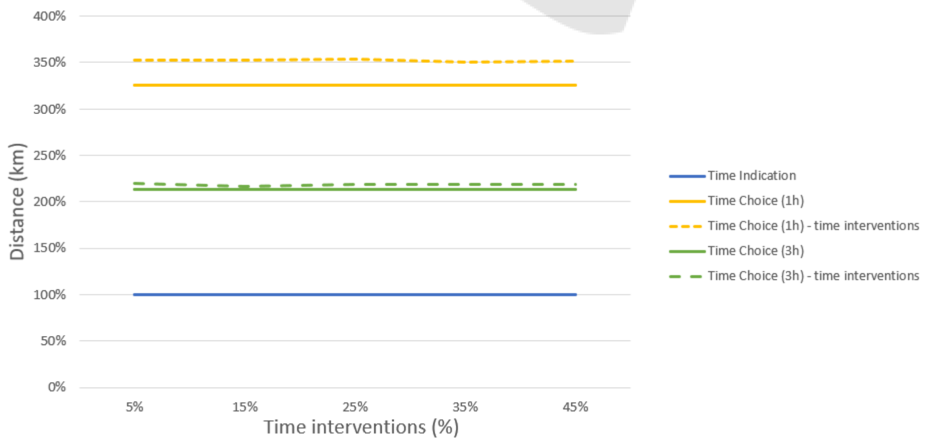

Figure 3: Result of introducing time interventions to the *Time Choice* case. The distance is given relative to the general *Time Indication* case. Introducing the possibility to change a chosen time-window has a marginal effect on the costs for both the 1 hour and 3 hour time windows.

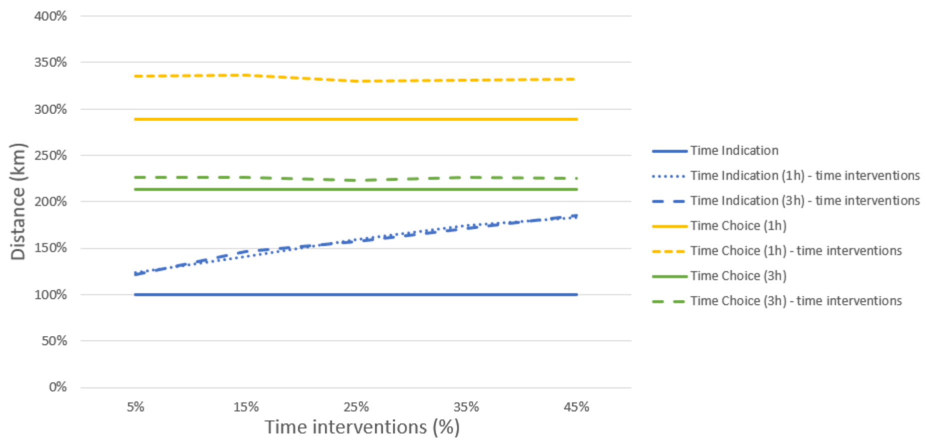

Figure 4: Results for the 54 km^2 area. Largely the same results as earlier. Note that the gaps for the *Time Choise* cases are bigger.

4 DISCUSSION AND CONCLUSIONS

In the previous section we saw how much the travel distance increases when enabling the end-customers to change the communicated or chosen time windows. In the case of *Time Indication*, where the end-users cannot choose their initial time window but are only informed about their time window, this increase is dependent on the percentage of receivers that uses this possibility. In the case of *Time Choice*, where the receivers have chosen the time window, which already provides an increase of travel distance, the system is robust enough to absorb these disturbances.

Note that we started with the assumption 'the number of parcels that is considered is based on the number of parcels that can be delivered in that area within a working day of (around) eight hours'. That means that all solution other than the *Time Indication* starting point without time interventions will take more than eight hours and will not be feasible within one shift. For the small area, the 6 km^2 area, the *Time Choice* base case with 3 hour time windows takes around 11 hours, the 1 hour time windows case with time interventions takes even around 16 hours. This means that these routes actually will cost much more that the distances shown in Figures 1-4. It will come with the costs of an extra driver, an extra vehicle and extra kilometres from the depot to the distribution area for this vehicle.

What we also see is how much flexibility can be offered in the *Time Indication* case before it is (almost) as costly to introduce *Time Choice* as an alternative, apart from the implementation costs of a *Time Choice* system. Most carriers do not have direct contact with the receivers, so this has to be organised together with their customers, the shippers.

As possibility for further research we see the following topics. First, we could validate in practice what the preferences of receivers are. This impacts the strategic decisions to be made by the carrier. Second, as said earlier, we could take into account the total costs of the time-interventions by only accepting plans (after time-interventions) that can be executed within the limitations of working hours.

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