Picking Multi-item Orders in the Warehouse of a Large Online Retailer: Data, Models, and Simulations

**Background and motivation.** This paper describes data-driven work in collaboration with a large online retailer that operates multiple warehouses. We study a setting in which a warehouse has to fulfill a sequence of orders, each including multiple items. All orders have to be processed by picking all the corresponding items in the order and packaging them together before they are shipped from the warehouse to the desired destination. The picking is done by pickers who are periodically assigned a batch of items from multiple different orders. The pickers pick the assigned items on a first-come, first-served basis using picking totes. When a picker fills her tote she returns it to a conveyor which sends it to the sorting area (also called the wall), where the items picked are sorted into their respective orders. Specifically, each order is allocated a slot on the wall once its first item arrives to the sorting area. Once all the items of the order have arrived at the wall, the order is sent to the packing area and the slot on the wall is freed up for other orders. Note that the items in one order could be picked by multiple pickers.

The setting described above gives rise to a fundamental tradeoff regarding the balance between optimizing picking efficiency and sorting efficiency. Picking efficiency is measured by the number of picked items per unit time. Optimizing the picking efficiency entails a well-designed assignment of items to the pickers that dynamically takes into account the location of the pickers as they pick throughout the warehouse and the potential locations of item inventory in the warehouse. On the other hand, the efficiency of the sorting area is dictated by the physical space or the number of physical slots on the wall. Higher utilization of the wall and shorter cycle times (how long each order takes up a slot on the wall) lead to shorter mean order completion time. The risk of running the wall in high utilization is that if it becomes full, then any arriving item that opens a new order has nowhere to go (‘gridlock’), creating a major disruption or even a stop in the warehouse operations (Gallien and Weber 2010). As a result, the current practice of the retailer with whom
we collaborate is to optimize the efficiency of the pickers while trying to keep the utilization of
the wall below a specified threshold. Our work suggests that this approach leads to suboptimal
mean order completion time, and that policies that balance these two objectives differently could
accomplish higher sorting efficiency with similar picking efficiency.

**Contributions.** Our contributions are as follows.

1. We propose a novel variant of the Traveling Salesman Problem (TSP) exploring a tradeoff
   that has not previously been studied. We show that, under certain conditions, a routing
   heuristic prioritizing items from open (partially picked) orders can reduce the mean cycle
time by a greater percentage than the increase in makespan compared to the nearest neighbor
   heuristic.

2. Based on our results, we propose a picking policy that outperforms the current policy in a
data-driven simulation, reducing wall utilization by 38% and order cycle time by 60%.

**Model and results.** In our model, we consider a single picker picking 2-item orders with
items evenly spaced on a line in a random permutation. The picker walks at constant speed and
requires an additional constant time to pick each item, and we are concerned with analyzing the
tradeoff between minimizing makespan and minimizing mean order cycle time. Previous work
on warehouse picking has mainly focused on modeling order picking as a TSP for some specific
topology and then deriving either exact solution methods (Ratliff and Rosenthal 1983) or heuristics
(Platzman and Bartholdi 1989) to minimize makespan. Although there have been variants of the
TSP optimizing criteria other than makespan, to the best of our knowledge order cycle times for
multi-item orders is not one of these criteria, so we are analyzing a tradeoff that has not previously
been investigated.

We propose a policy that skips over items from new orders to pick slightly further items from
open orders. Compared to the nearest neighbor policy (which is optimal for makespan), we char-
acterize a condition under which the expected percentage decrease in mean order cycle time is
larger than the expected percentage increase in makespan. Specifically, the condition is that the
constant picking time should be larger than a threshold. This demonstrates that for a small sacrifice in picking efficiency, we can attain a larger increase in sorting efficiency.

**Data and simulation.** Our industry partner provided us with picking data for more than 300,000 orders. By analyzing the mean time between consecutive items of orders as it varies with the number of unpicked items in the order, we conclude that the current method of assigning items to pickers is based primarily on picker efficiency without actively trying to complete orders. We next use this data to build a simulation. This simulation stochastically models the time it takes for items to reach the wall once they are assigned to a picker, and accurately replicates the distribution of times spent by orders on the wall. This allows us to test the effect of different pick assignment policies on order cycle times. In particular, we propose a policy that assigns a picker to the closest available item, but items from open orders are viewed as closer by some fixed distance. In this way, we prioritize items from open orders in a similar way to the policy considered in our model. Therefore, our proposed policy takes into account both sorting and picking efficiency. In our simulations, we are able to achieve a 38% decrease in average wall utilization, 60% decrease in median order cycle time, 54% decrease in mean order cycle time, and 4% increase in orders completed.

**References**

