


31

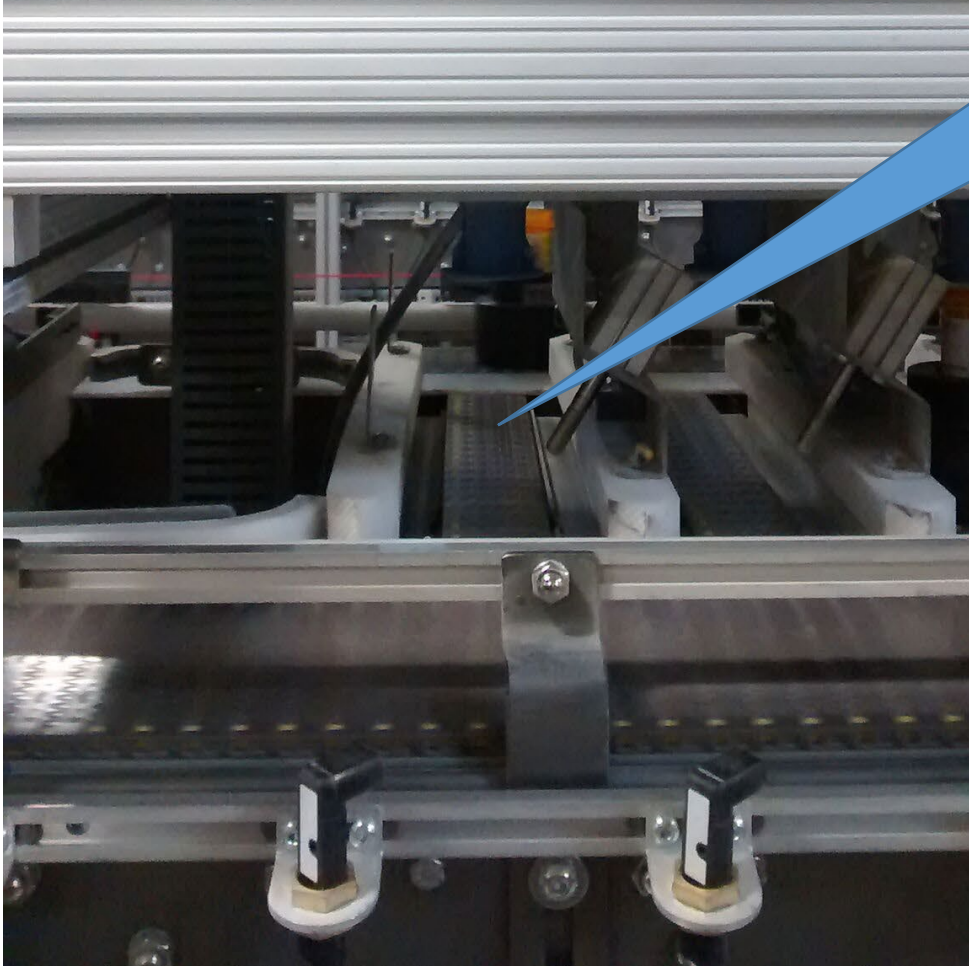
Minimizing the Variance of Fulfillment Cycle Time in a Central Fill Pharmacy: Why and How

Mohamed El Tonbari and Leon McGinnis
Keck Virtual Factory Lab, Georgia Tech






6 canisters each dispensing a single NDC, can fill ~360/hr




"Lane" for the puck to position under the feeder




Vials in pucks on puck conveyor

>2000 drugs (NDCs); top 10 account for 30% of order lines

Very high speed filling; each canister has short queue, with extremely small cycle time at the filler.

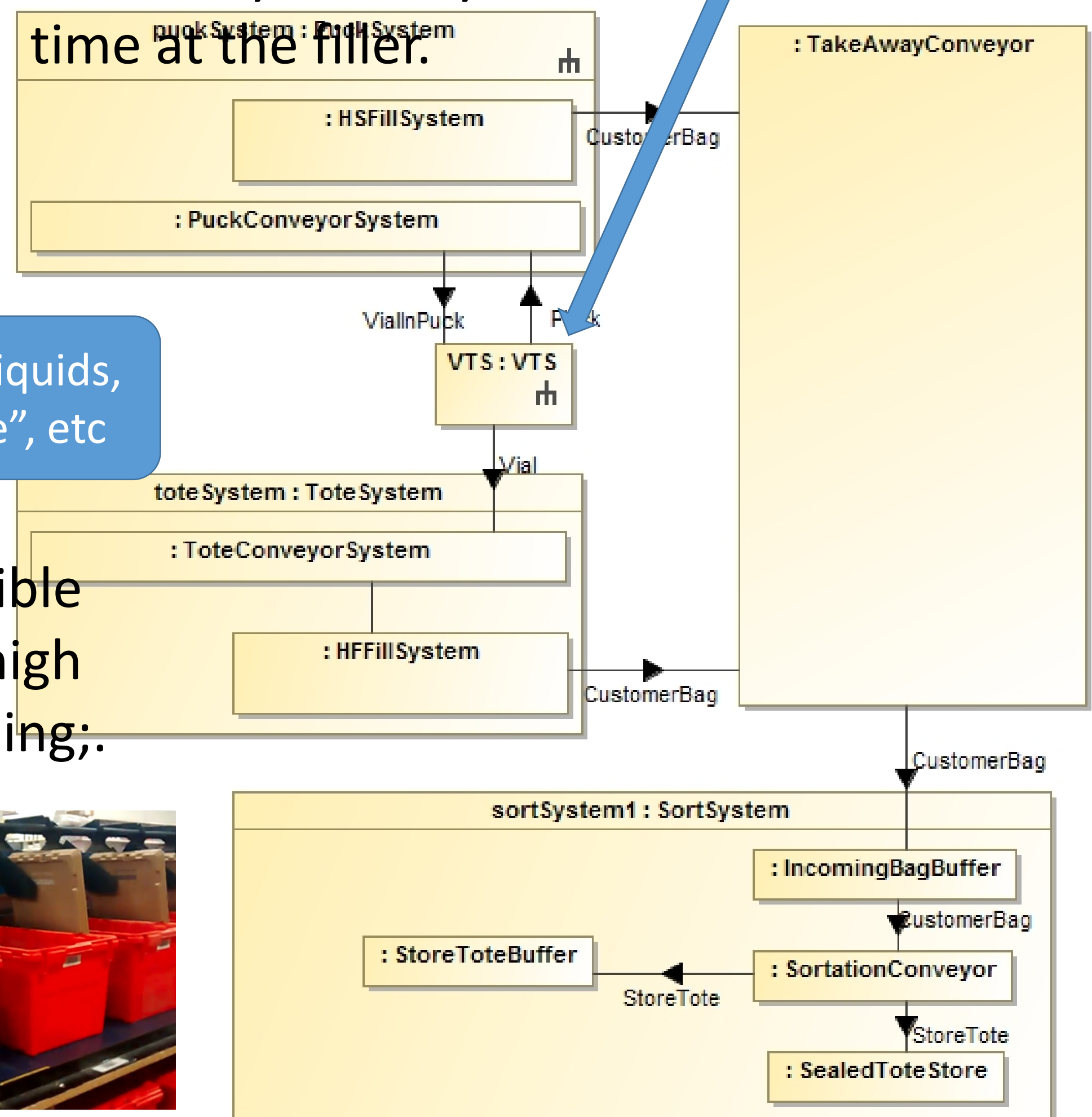


Robot back here accesses the 160 canisters; can fill ~90/hour



Manual, liquids, "A-Frame", etc

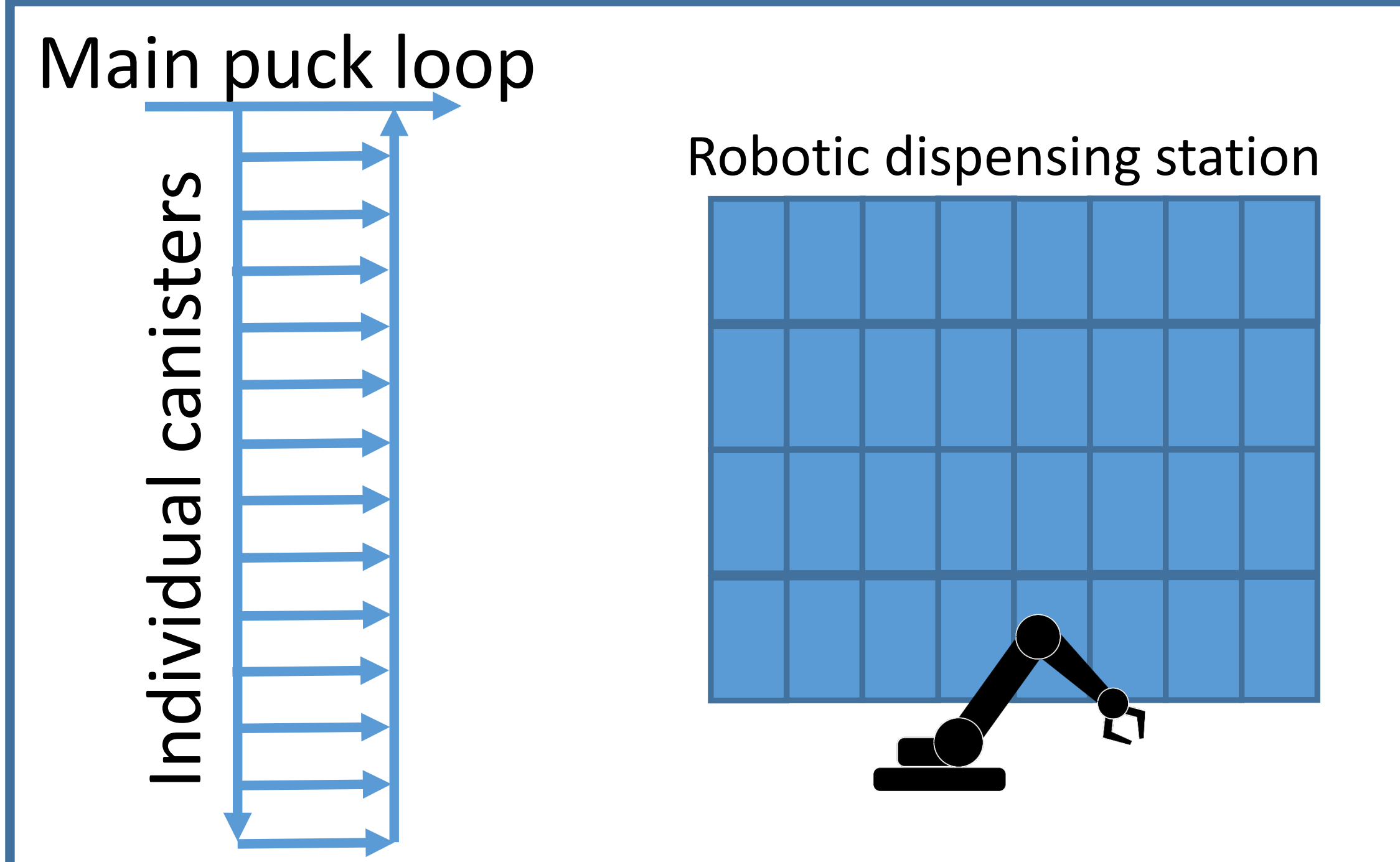
Very flexible but not high speed filling;



The problem: number of pharmacies served is much larger than the number of lanes in the sortation system, AND, orders arrive continuously through the day. => wave picking

The problem: While there may be distinct boundaries between waves at release, the variability of fulfillment cycle time causes "wave overlap"

The proposal: assign NDC to dispense channel to minimize the variance of fulfillment cycle time.



Variable component of fulfillment cycle time is travel time on the high speed filler and robotic arm travel

A companion effort has almost completed the development of a simulation testbed where we can evaluate the actual impact of the proposal, in terms of minimizing the "wave overlap".

In an "ideal" system (constant travel time between cells with "adjacent" travel times, we can prove that an "organ pipe arrangement" (OPA) minimizes the variance of travel time. The proof is tedious and boring.

Can use the OPA even when the time between adjacent cells (in travel time order) is not constant to get a heuristic solution. Can use pairwise interchange, based on specific conditions, to try to improve the solution.

Lemma 1. If $p_1 \geq p_2$ and $t_1 \geq t_2$, then $p_1 \geq p_2$.

Proof of Lemma 1.

$$p_1 - p_2 = \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i + \sum_{i=1}^n p_i t_i$$

$$= \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i + \sum_{i=1}^n p_i t_i$$

$$= \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i - \sum_{i=1}^n p_i t_i + \sum_{i=1}^n p_i t_i$$

Since $(p_1 - p_2) \geq 0$ and $(t_1 - t_2) \geq 0$, $p_1 - p_2 \geq 0$ and $p_1 \geq p_2$.

Similarly, if $t_1 < t_2$, then $p_1 < p_2$.

Proof of Proposition 1. Assume the premise of the proposition: $p_1 \geq p_2$ and $(p_1 - t_1) \geq (p_2 - t_2)$.

We have:

$$p_1^2 - p_2^2 = (p_1 - p_2)(p_1 + p_2)$$

$$= (p_1 - p_2)(p_1 + p_2)$$

$$= (p_1 - p_2)(p_1 + p_2)$$

There are four possible cases. Since $p_1 \geq p_2$ in all cases, we focus on the second and the third of (1).

- $t_1 \geq t_2$. Then, $(p_1 - t_1) \geq (p_2 - t_2) \Rightarrow p_1 - t_1 \geq p_2 - t_2 \Rightarrow p_1 - p_2 \geq t_1 - t_2$.
- From Lemma 1, $p_1 \geq p_2$, and $p_1 - p_2 \geq (p_1 - t_1) - (p_2 - t_2) \geq 0$.
- where the last inequality follows from $p_1 - t_1 \geq 0$ and $t_1 - t_2 \geq 0$.
- We then have $(p_1 - t_1) - (p_2 - t_2) \geq 0$ and $t_1 - t_2 \geq 0$.
- Thus, $p_1^2 - p_2^2 \geq 0 \Rightarrow p_1 \geq p_2$.
- $t_1 < t_2$. Then, $(p_1 - t_1) \geq (p_2 - t_2) \Rightarrow p_1 - t_1 \geq p_2 - t_2 \Rightarrow p_1 - p_2 \geq t_1 - t_2$.
- From Lemma 1, $p_2 \geq p_1$, and $p_2 - p_1 \geq (p_2 - t_2) - (p_1 - t_1) \geq 0$.
- where the last inequality follows from $p_2 - t_2 \geq 0$ and $t_1 - t_2 \geq 0$.
- We then have $(p_2 - t_2) - (p_1 - t_1) \geq 0$ and $t_1 - t_2 \geq 0$.
- Thus, $p_2^2 - p_1^2 \geq 0 \Rightarrow p_2 \geq p_1$.

For a chosen λ , we perform 100 experiments for different randomly generated travel times and order rates. For each experiment, we compute the optimal variance V^* and the optimality gap resulting from the heuristic and the organ pipe arrangement. The optimality gap is computed as $\frac{V - V^*}{V^*}$, where V is the cycle time variance resulting from either the heuristic or the OP arrangement. We present the average and standard deviation of the optimal gaps over the 100 runs in table 1.

Table 1: Average and Standard Deviation of Optimality Gaps

| | Parameter λ | Inter-travel Time Variance | |
|----------------|---------------------|----------------------------|-----------|
| | | Organ Pipe | Heuristic |
| Optimality Gap | 3.5 | 0.0816 | 0.0755 |
| | 3 | 0.1111 | 0.0884 |
| | 2.5 | 0.1600 | 0.0844 |
| | 2 | 0.25 | 0.0823 |
| | 1.5 | 0.4444 | 0.0950 |
| SD | 3.5 | 0.0816 | 0.0755 |
| | 3 | 0.1111 | 0.0884 |
| | 2.5 | 0.1600 | 0.0844 |
| | 2 | 0.25 | 0.0823 |
| | 1.5 | 0.4444 | 0.0950 |