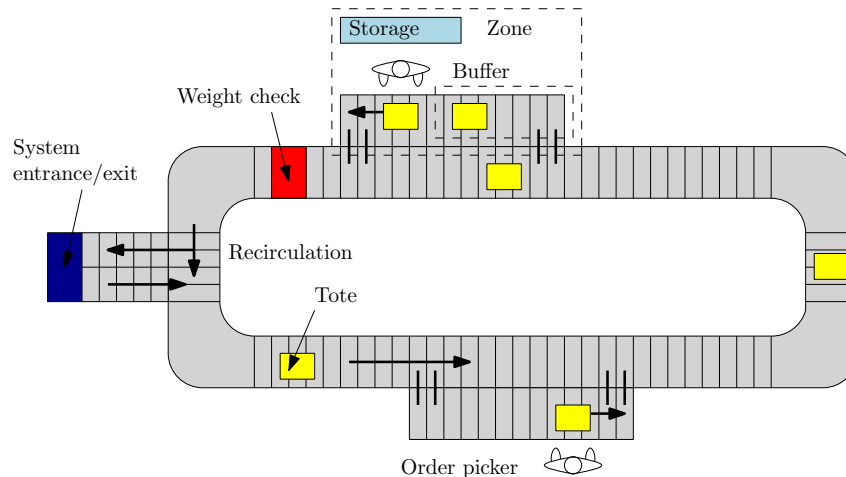


Assignment Facility Logistics Management, March 31, 2021

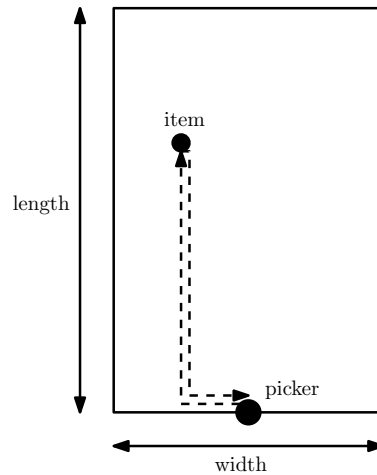
In a zone picking system with single-segment routing, three different elements can be distinguished: the entrance/exit of the system, the conveyor, and the zones. These elements of a single-segment zone picking system with two zones are shown in the figure below, where we can distinguish one entrance/exit, two zones, labeled zone 1 and 2, and three conveyor segments (connecting the entrance/exit and the zones).



At the entrance of the system, a customer order is assigned to a new order tote. The tote is released into the system as soon as it is allowed by the workload control mechanism. This mechanism keeps the number of totes in the system constant over time (say K totes) and only releases a new tote when a tote with all required order lines leaves the system. This workload control mechanism prevents the conveyor to become the bottleneck of the system. After release, a tote moves to the buffer of a requested zone (which is assumed to have ample space). When the picking process has finished in a zone, the picker pushes the tote back on the conveyor. The waiting time for a sufficiently large space on the conveyor belt is considered to be negligible. The conveyor then transports the tote to the next zone to be visited (if any). A weight check at the end of the conveyor loop ensures that the tote contains all the required order lines. When the tote has visited all the required zones, it leaves the system at the exit and a new order tote is immediately released into the system. We assume new totes are released one-by-one at an exponential rate μ_e . A fraction p_1 of the new totes only has to visit zone 1, a fraction p_2 only needs to visit zone 2, and the rest needs to visit both zones. The service times at zone i are exponential with rate μ_i . Each zone has a single order-picker. The travel time on a conveyor segment is $1/\mu_c$ seconds. We will assume that $1/\mu_e = 5$ seconds, $1/\mu_c = 100$ seconds, $1/\mu_i = 18$ seconds, and the release probabilities are $p_1 = \frac{1}{2}$, $p_2 = \frac{1}{4}$.

1. **(2 pts)** Model this single segment as a closed queueing network (i.e., introduce stations, service times, routing, and so on).
2. **(1 pts)** What is the bottleneck station in the network?
3. **(1 pts)** What is the throughput as K tends to infinity?
4. **(2 pts)** Formulate a mean value algorithm to compute the throughput, mean flow time, mean buffer contents at the zones, and the utilization of the order pickers in each zone, for workload threshold $K = 10, 50, 100$.
5. **(2 pts)** By re-allocating the items to the zones, it may be possible to obtain more load balance between the two zones. Investigate the effect of load balancing on the performance of the system (such as throughput, mean buffer content, and so on).

6. (1 pts) The assumption of exponential picking times is a rough approximation. We now formulate a more accurate model for the picking times. The zone or storage area for a picker is shown in the figure below. The width of the storage area is 24 meter, the length is 36 meter, and the walking speed of the picker is 3 meter per second. Order totes are waiting in the buffer, located at the starting point of the picker. Assume (as an approximation) that the item to be picked is randomly located in the storage area. The time to pick the item is 2 seconds.



Argue that the total picking time P (walking time plus time to pick the item) can be expressed as

$$P = 2 + \frac{2}{3}(X + Y)$$

where X and Y are the walking distance in horizontal and vertical direction, respectively, X and Y are independent, X is uniform on $(0, 12)$ meter, and Y is uniform on $(0, 36)$ meter.

7. (2 pts) Plot the density of P and compute its mean and standard deviation (does it resemble the exponential density?).
8. (2 pts) Based on the above picking time model, adapt the mean value algorithm, compute again the performance and compare it to the exponential model.
9. (2 pts) Suppose the storage area can be re-designed. While keeping the area of square meters the same, what are the optimal dimensions (in view of the system performance) and why? Evaluate the performance benefits of re-design.