Warehouse Layout Problem

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Problem Description

- A warehouse contains bins of products spread over ten aisles
- Each aisle has about 1000 stacks - there are approximately 50 000 bins in the warehouse
- Aisles are stacked five levels high - levels 4 and 5 can only be reached with a ladder
- Orders listing products and quantities are received
- Orders have to be collected in a short time (1-4 hours)
- There are 12-30 pickers who collect orders from the bins
- There is a collation point at the front of the warehouse where pickers receive their order lists and deliver completed orders
- The only existing layout strategy is placing high-frequency items on ground level for easy access

Problem Description

Objective: To optimize the picking process by minimising order completion times (this includes minimizing time delays and maximizing route efficiency)

The main question that we are considering is: Where does one locate various products in the warehouse?

Optimally positioning products will minimize the time spent on the floor collecting orders (shorter routes, less congestion, smaller picking time). In simple terms the problem narrows down to having to consider the *congestion* and *distance travelled* in the warehouse.

Congestion

- Pickers use a trolley to collect orders.
- Only two trolleys can fit side-by-side in one aisle, a third one cannot pass
- When a picker stops to collect an order, they block the space in front of that shelf.
- If a picker uses a ladder, this blocks access to two bins
- Only one picker can access a bin at once and queues can build up at frequently-picked bins
- The spaces in front of frequently-picked bins or bins with time-consuming orders are more likely to be blocked

Distance

Distance travelled depends mainly on picker route strategies.

- Pickers decide what route they will follow.
- Pickers can pick multiple orders at the same time
- If there are multiple bins of a product, pickers are sent to the bin with the soonest expiry date (FEFO)

Sub-problems

Congestion and distance can be addressed in the following ways:

- Optimising product layout within the warehouse
- Optimising picking routes and strategies
- Optimising order list specifications

Simplifying assumptions

In order to simplify the problem, initial solutions will assume:

- All bins are the same size
- The number of bins of a product is proportional to demand
- Pick-time per unit is constant across all products and takes the same time as one step (i.e. all products are the same size)
- Picker completes one order at a time
- Pickers are aware of the layout of the warehouse
- Picker takes the shortest path to the item closest to him
- Trolleys have capacity to fit an entire order
- Multiple bin levels are not considered
- The warehouse never runs out of stock
- FEFO applies

Initial Hypotheses

- Frequently-picked products should not be placed too close together in order to avoid blockages
- Placing frequent products far away from each other increases the distance that pickers must walk
- Frequent products at the beginning/end of aisles may block access to the middle of the aisle
- Frequent products in the middle of aisles increase the distance that pickers must walk

Analysis of Data

In order to assign products to optimal locations, each product must be analysed and classified. The frequency of orders and order size must be considered (Other factors include: size (units per bin), time to pick, weight, seasonality)

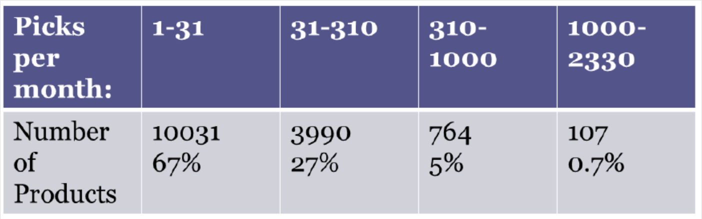
Analysis of Data

Product profiles were built from real data from the warehouse for 31 days of orders:

Total orders: 110 515
Orders per day: 3 565
Total picks: 1 048 576
Total Products: 14 892

Frequency

The vast majority of products are picked only a few times a month:



Picks per month:	1-31	31-310	310-1000	1000-2330
Number of Products	10031 67%	3990 27%	764 5%	107 0.7%

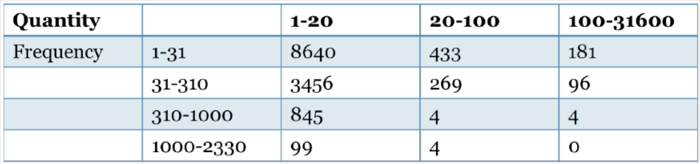
Quantity

The vast majority of products have very small average quantities:

Picks per month:	1-20	20-100	100-31600
Number of Products	12930 93%	710 5%	281 2%

Product Priority

There are very few high frequency products
There are very few high-frequency high-quantity products
The location of these products will be given priority as they contribute most to congestion/picker route times.



Quantity		**1-20**	**20-100**	**100-31600**
Frequency	1-31	8640	433	181
	31-310	3456	269	96
	310-1000	845	4	4
	1000-2330	99	4	0

Solution

- Simulation
- Optimization

Simulation

The primary focus of the simulation was to realistically describe the behaviours of the pickers as a set of rules. We assumed that each picker would pick the product on their list that was closest to their current location and would handle congestion by overtaking where possible and waiting when confronted with a blockage.

The simulation works like the internet...
Basically, its a miracle!

Simulation

Two problems were found when coding the simulation:

- Time complexity
- Storage

Both of the above items make it computationally expensive to simulate the picking process. As a result, only a short list of orders was used to run the simulation.

Optimisation Problem

The following variables were defined:

- $X_{i,m,n} = 1$ if the product i is in bin(m,n) , $i = 1, 2, ...J$
- Q, the number of pickers
- $m, m = 1, 2, ...M$, the number of aisles (rows)
- $n, n = 1, 2, ...N$ is the number of shelves (columns) per aisle
- $\Gamma_{k,j}$ = number of product j in order k (a KxJ order matrix)
- $c_i, i = 1, 2, ...J$ is the number of units of product i per bin
- $R_i, i = 1, 2, ...J$ is the number of bins required to store product i
- $O_{m,n}$ is the order of product in bin (m,n)
- $P_{m,n}$ is the product in bin (m,n)
- $T(s)_{m,n}$ is the initial time for picking a product in bin (m,n)
- $T(f)_{m,n}$ is the final time for picking a product in bin (m,n)

Optimisation Problem

$$X_{i,m,n} = \begin{cases} 1 & \text{if product i is in bin } (m,n) \\ 0 & \text{otherwise} \end{cases}$$

$$\phi(x) = \begin{cases} x, & x > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$R_i = \left\lceil \tfrac{1}{c_i} \textstyle\sum_{k=1}^{K} \Gamma_{k,j} \right\rceil$$
$$T(s)_{m,n} = (O_{m,n} - 1) * \frac{3600}{R_{P_{m,n}}}$$
$$T(f)_{m,n} = O_{m,n} * \frac{3600}{R_{P_{m,n}}}$$

Optimisation Problem

With the aid of the results of our simulation and data analysis, the following objective function was formulated:

$$\text{minimize } \alpha \sum_{m=1}^{\lceil \frac{m}{2} \rceil} \sum_{n=1}^{N} \sum_{k=max\{N-1,1\}}^{min\{N,n+1\}} \sum_{i,j} X_{i,2m-1,n} X_{j,2m,k} * \phi(min\{T(f)_{2m-1,k}, T(f)_{2m,k}\} - max\{T(s)_{2m-1,k}, T(s)_{2m,k}\})$$

Optimisation Problem

subject to:

$$\sum_{m.n} X_{i,m,n} = R_i$$
$$\sum_{i} X_{i,m,n} \leq 1$$

Conclusion

Some practical conclusions:

- FEFO is probably the cause of a lot of congestion - it may be beneficial to work with three bins of all frequently-used products instead of just one
- It may be useful to reserve spaces on only one side of each aisle for frequent products to encourage better traffic flow

Achievements so far:

- A 2-D simulation that calculates the total time taken to pick a set list of orders with a given floor plan
- A congestion function, coded in Matlab, that optimises the floor plan by minimising congestion at each bin in the warehouse

Future work

Possible future work on this problem:

- Include stacked levels
- Optimisation with a genetic algorithm
- Rosmo's equation