भारतीय प्रौद्योगिकी संस्थान मुंबई

Indian Institute of Technology Bombay

SOM 624

Warehouse Operations

Warehouse Optimization

Group 4

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This report is written in three parts, where it answers three different questions based on the given situation. The data and calculation part is given in an excel sheet (the link is attached at the end of the report).

Part 1

In part 1 of this report we answer the following questions:
Design a forward-reserve configuration with a forward pick area size with 10 slots (5 storage slots along the picking aisle and 2 storage slots along the height). Data regarding coordinates of these slots and their travel time is provided in the supplementary file. The average one-way travel times between the aisle entrance and different storage slots in the reserve area to carry out putaway or pick operation is found to be 12.02 seconds. Select the products based on the two heuristics (H1 and H2) discussed in the case for the above forward-reserve configuration. Benchmark the performance of this forward reserve-configuration for both the heuristics against the current random storage policy in terms of storage space requirement and total travel time. It has been mentioned in the case that for the random storage policy, the average one-way travel time between the entrance to the picking aisle and reserve area is 11.54 seconds and space required per rack is 154 storage slots.

Random Storage policy :

Number of putaway, D = 914
Number of total picks, P = 4360
Average time for one way operation, t^{Random} = 11.54

Total time required for the random storage policy = $2^* t^{Random} *D + 4^*t^{Random} *P$
= 11.54*2*914 + 11.54*2*2*4360

$\mathbf{T_{Random}}$ **= 222353 Seconds**

Assumption : One product is kept in only one slot of the forward stock area, hence a total of 10 products in the forward reserve area.

Heuristic 1 :

In this the products which have higher number of pick up are placed in the premium locations, so that we can quickly pick the required products. This intuitively reduces the travel time required for the S/R. The top products are ranked according to the number of picks.

The top 10 products according to the number of picks are

⇒ 5, 46, 36, 8, 44, 48, 56, 1, 20, 3.

These products will be assigned slots in the forward pick area, and these will be having shorter picking time.

Putaway time ⇒ $\mathbf{T_{Putaway}} = 2\ x\ t^{Reserve}\ x\ D$

$= 2*11.54*914 = \mathbf{21095.12}$

Picking Time :

Forward pick time ⇒ $\mathbf{T_F} = sum_j(\ 4\ x\ t_f^{Forward}\ x\ P_j\ )$

$= \mathbf{17450.52}$

Reserve area picking time ⇒ $\mathbf{T_R} = 4\ x\ t^{Reserve}\ x\ P_R$

$= 4*12.02*\ \mathbf{sum_j(}P_{R\,j})$

$= \mathbf{126306.2}$

Internal replenishment time ⇒ $\mathbf{T_{Replanishment}} = sum_j\ (c_j^{Replanishment}\ x\ d_j)$

$= \mathbf{31950.21}$

Total time taken by **heuristic 1** is given by ⇒ $\mathbf{T_{H1}} = \mathbf{T_{Putaway}} + \mathbf{T_F} + \mathbf{T_R} + \mathbf{T_{Replanishment}}$

$\mathbf{T_{H1}} = 21095.12 + 17450.52 + 126306.2 + 31950.2$

$\mathbf{T_{H1}}$ **= 196802.01 seconds**

Heuristic 2 :

In this type of configuration the premium slots are assigned to the products having higher ratio of number of pick to the load. The products are arranged in the descending orders and the top products are assigned to the premium locations in order to reduce the time required to travel.

The top 10 products according to the ratio of number of picks to load are

⇒ 46, 20, 54, 32, 51, 40, 42, 35, 11, 44

These products will be assigned slots in the forward pick area, and these will be having shorter picking time, according to heuristic 2.

Putaway time ⇒ $\mathbf{T_{Putaway}} = 2\ x\ t^{Reserve}\ x\ D$

$= 2*11.54*914 = \mathbf{21095.12}$

Picking Time :

Forward pick time ⇒ $\mathbf{T_F} = \text{sum}_j(4 \text{ x } t_f^{Forward} \text{ x } P_j)$

$= \mathbf{10276.96}$

Reserve area picking time ⇒ $\mathbf{T_R} = 4 \text{ x } t^{Reserve} \text{ x } P_R$

$= 4*12.02* \mathbf{sum_j}(P_{R\,j})$

$= \mathbf{158952.5}$

Internal replenishment time ⇒ $\mathbf{T_{Replanishment}} = \text{sum}_j\ (c_j^{Replanishment} \text{ x } d_j)$

$= \mathbf{599.4}$

Total time taken by **heuristic 2** is given by ⇒ $\mathbf{T_{H2}} = \mathbf{T_{Putaway} + T_F + T_R + T_{Replanishment}}$

$\mathbf{T_{H2}} = 21095.12 + 10276.96 + 158952.5 + 599.4$

$\mathbf{T_{H2} = 190923.96}$ **seconds**

Random Storage policy	Heuristic 1	Heuristic 2
222353 secs	196802.2 secs	190923.96 secs

Note: Please refer the excel sheet for calculation

Part 2

In part 2 of this report we deal with the following situation :
There is room for improvement in design by using an optimization model for the selection of products as well as the allocation of storage slots to products instead of the heuristic methods proposed to be used in question 1. Demonstrate this by developing and solving an optimization model for the forward-reserve configuration described in question 1. Compare the solution obtained using the optimization model with those obtained in question 1.
Tip: Any commercial solver can be used to obtain a solution to the developed optimization model. However, if MS Excel Solver is used and if any limitation on the number of variables is faced when using the in-built Solver of MS Excel, then one can use OpenSolver plugin for MS Excel to overcome such a problem (available for download free of charge at https://opensolver.org/).

By using the pulp modeler which uses CBC (Coin OR Branch and cut) inside to solve the integer programming. The coding language used to solve the IP is PYTHON in the Google Colab.
The link for the colab is "WareHosuse for the IP.ipynb"

INDEX	1	2	3	4	5
2	20	54	50	14	3
1	46	8	48	44	56

This above is the representation of the product number in the forward area in dedicated slots.

Mathematical Model

Objective Function:

$$\text{Minimize } Z = \sum_k \sum_i \sum_j \frac{\mathrm{C}_f^{\mathrm{rep}}[j][i] \cdot x_{kij} \cdot d_k}{\mathrm{ratio}[k]}$$
$$+ \sum_k \sum_i \sum_j 4 \cdot t_f[j][i] \cdot x_{kij} \cdot p_k$$
$$+ \sum_k \sum_i \sum_j 4 \cdot 12.02 \cdot (1 - x_{kij}) \cdot p_k$$

Where:

- x_{kij} is a binary decision variable (0,1) indicating product k's placement at location (i, j),
- $\mathrm{C}_f^{\mathrm{rep}}[j][i]$ = Matrix of internal replenishment time,
- d_k is the volume of picks for product k,
- ratio$[k]$ is Picks per unit load k,
- $t_f[j][i]$ is the internal replenishment time for location (i, j),
- p_k is the weight or penalty for product k,
- $4 \cdot 12.02$ represents the penalty when $x_{kij} = 0$ for each product k.

Constraints:

1. Each product can be assigned to at most one location:

$$\sum_i \sum_j x_{kij} \leq 1 \quad \forall k$$

2. Each storage location must be assigned exactly one product:

$$\sum_k x_{kij} = 1 \quad \forall i, \forall j$$

Comparing the results for the Heuristic 1, Heuristic 2 and the exact method using a mathematical model. The calculations are the same as that for heuristic 1 and 2. We got the optimal product number to which is to be kept in different slots in the forward area.

Random Storage policy	Heuristic 1	Heuristic 2	Mathematical model (by solver)
222353 secs	196802.2 secs	190923.96 secs	180607.16 secs

Note: Please refer the excel sheet for calculation (link at the end of report)

Part 3

In this part we deal with the following situations and answer it:
Until this point, Ravi has focussed on understanding the utility of forward-reserve arrangement and the use of heuristics or an optimization model as an aid in the design of such a system. For this purpose, he has arbitrarily picked a design with 10 storage slots in the forward pick area (refer to Q1 and Q2). The dimensions of this forward pick area were 5x2 (i.e., five storage slots horizontally along the length of picking aisle and two storage slots vertically along the height). Ravi decides to explore alternate designs with five different sizes of the forward pick area (8, 12, 16, 20, and 24 storage slots) and all possible rectangular arrangements for each size. In line with questions 1 and 2, he used different approaches (Heuristic 1 (H1), Heuristic 2 (H2) and the optimization model) for selecting products for the forward pick area. The percentage improvement in the total travel time for each such design over the design under the prevailing random storage policy is shown in the figure below.

3a:

Based on the chart, here we can say about the two heuristics (H1 and H2) and the optimization model:

Heuristic 1 (H1) :
H1 does better than random storage but is generally worse than both H2 and the optimization model. However, when the forward pick area gets bigger, especially with more columns than rows, H1 starts to perform almost the same as H2. The optimization model still performs better though.

Heuristic 2 (H2) :
H2 is better than H1 in most cases. But like H1, when the forward pick area gets bigger with more columns, the difference between H1 and H2 becomes smaller, and both start to give similar results.

Optimization Model :
The optimization model is consistently better than both H1 and H2. As the forward pick area gets larger, the gap between the optimization model and H1 gets even bigger, showing that the optimization model is much more effective, especially in larger areas.

3b

As the forward pick area becomes larger:

Travel Time :
Increasing the size of the forward pick area helps reduce travel time. H2 and the optimization model benefit more from this, but for H1, the travel time improvement becomes smaller as the area grows to a certain limit.

Buffer Storage Capacity :
A larger forward pick area means less space for buffer storage, which is the space used to keep products for restocking. This could limit how much product can be stored and might cause issues if not managed properly. The optimization model can help find the right balance between reducing travel time and keeping enough storage space for smooth operations.

Data and Calculations:
ForStudent_Case_Data.xlsx