Operational Plan for Intelligent Warehouse

Mathematical Optimisation Project 2022-2023

Candidate Number: 56023

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MA424 Modeling in Operations Research

1 Executive Summary

1.1 Objective

This document is written for Hollyboba, an e-commerce business company, in order to develop an optimal dispatching system for their intelligent warehouses. The intelligent warehouses contains racks storing different types of SKUs and some AGVs to transfer them to the workstations.

1.2 Findings

According to the given conditions, the AGV dispatching model will reach 4305.3 as the optimal value and 62.60% orders can be fulfilled. Furthermore, the AGV and integrated order dispatching model has a 3481.5 optimal value and will fulfill 89.01% orders due to current situation. By using the integrated order dispatching system, the cost of the warehouse falls 19.3%. It can be noticed that there are no idle AGVs in both optimal solutions. The specific AGV dispatching plan and the AGV and integrated order dispatching plan is given in the manage report. The models for generating the optimal dispatching plans are provided in technical appendices. Additionally, the costs may reduce even more if AGVs can deliver racks in multiple rounds, which will be shown in discussion sections.

1.3 Conclusion

Intelligent warehouses would save money from the solution calculated in the summary and management report. In order to reach the minimum cost, the AGV dispatching plan is highly recommended to follow, and the current legacy order-dispatching system should be replaced by newly developed integrated order dispatching system.

2 Manage Report

2.1 Introduction

This report will discuss the findings of an optimal dispatching system developed for intelligent warehouses of Hollyboba. It contains 2 models, an optimal AGV dispatching model and an optimal order and AGV dispatching model.

The intelligent warehouse of Hollyboba is a 50m×50m square with 20 AGVs and 80 racks. Four workstations are located at each corner of the warehouse and each workstation has a fixed number of berths for the AGVs. Each rack stores exact 10 different types of SKUs. There are 40 types of SKUs in total. A rack must be transported by an AGV and an moving rack must be arranged to an workstation. The aim of the optimal dispatching system is to minimize the cost, which contains the moving distance of AGVs and racks, and the penalty of unfulfilled units of SKUs. All coordinates of racks, AGVs and workstations are given.

2.2 Optimal AGV dispatching

The optimal AGV dispatching plan is shown in table 1. The first row of the table contains the sequential numbers of the AGVs and the second and third row are the assigned racks and workstations, respectively. The cost of this optimal dispatching plan is 4305.3 and this is considered as the minimum cost.

Table 1: Optimal AGV dispatching plan

AGV	1	2	3	4	5	6	7	8	9	10	AGV
rack	36	11	25	8	5	24	13	26	21	65	rack
workstation	W3	W1	W3	W1	W3	W1	W3	W2	W1	W4	workstation

AGV	11	12	13	14	15	16	17	18	19	20	AGV
rack	59	51	50	66	60	57	63	48	74	73	rack
workstation	W4	W4	W2	W2	W2	W3	W3	W4	W2	W4	workstation

Since there are limited AGVs in the warehouse and berths in the workstations, some orders are unfulfilled in the optimal dispatching plan. Table 2 shows the quantities of unfulfilled orders in each workstation and each column stands for one type of SKU.

Table 2: Unfulfilled orders in each workstation

SKU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
W1	0	0	25	0	0	12	0	0	0	6	0	0	7	4	18	16	28	34	0	0
W2	21	0	8	0	0	4	8	1	1	14	2	0	26	6	2	3	0	52	21	3
W3	5	0	9	0	0	5	3	0	0	19	8	0	12	0	11	3	15	3	32	0
W4	20	0	11	0	0	21	13	0	4	29	8	0	12	0	11	0	2	0	40	5

SKU	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
W1	0	21	0	0	9	0	0	11	0	25	17	3	6	0	0	60	21	3	22	3
W2	8	0	0	0	0	0	0	0	15	6	8	0	0	0	0	1	13	1	0	0
W3	0	0	0	0	3	0	0	9	34	0	9	0	0	0	0	7	12	0	0	0
W4	0	14	3	0	11	0	0	1	3	0	0	0	0	0	0	3	13	3	7	0

Under current legacy order dispatching system and the optimal AGV dispatching system, the unfulfilled units of SKUs in warehouse W1, W2, W3, W4 are respectively 351, 224, 185, 234, which makes the total number of unfulfilled orders 994. Since there are 2658 orders in total, 1664 orders are fulfilled. It can be shown that 62.60% orders can be fulfilled under current system.

2.3 Optimal AGV and integrated order dispatching

After integrated the order dispatching to AGV dispatching system, the cost of the optimal dispatching plan falls to 3481.5. Table 3 shows the AGV dispatching plan when considering both AGV and order dispatching. The first row of the table is the number of the AGVs and the second and third row are the assigned rack and workstation, respectively. It can be noticed that because of the order dispatching plan has changed, the assignments of AGVs are not exactly the same as in table 1.

Table 3: Optimal AGV dispatching plan with order dispatching system

AGV	1	2	3	4	5	6	7	8	9	10	AGV
rack	36	19	25	11	15	5	13	24	26	65	rack
workstation	W1	W2	W3	W2	W2	W1	W3	W1	W1	W2	workstation

AGV	11	12	13	14	15	16	17	18	19	20	AGV
rack	57	60	41	66	51	61	80	48	71	74	rack
workstation	W4	W4	W3	W2	W3	W3	W4	W4	W3	W4	workstation

The order dispatching plan is shown in following Table 4. The first row of the table represents the types of SKUs. The second to the fifth row shows the units of each type of SKU in W1, W2, W3, W4 respectively. The sixth row gives the numbers of unfulfilled orders.

Table 4: Optimal integrated order dispatching plan

SKU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
W1	18	9	19	13	3	10	5	4	13	17	0	0	0	0	0
W2	0	0	0	0	0	0	0	0	0	0	31	38	27	44	18
W3	11	17	17	8	15	0	0	0	0	0	30	16	23	24	23
W4	13	19	9	20	14	0	0	0	0	0	13	7	18	18	6
unfulfilled	59	0	58	0	0	49	41	0	0	88	0	0	40	2	15

SKU	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
W1	0	0	0	0	0	35	33	15	12	14	31	19	20	37	32
W2	24	31	48	31	40	36	29	25	24	19	0	0	0	0	0
W3	37	12	29	31	15	24	21	13	18	17	53	50	29	16	36
W4	8	26	16	33	15	0	0	0	0	0	35	35	48	45	48
unfulfilled	0	28	68	79	0	2	2	0	0	34	0	0	48	61	0

SKU	31	32	33	34	35	36	37	38	39	40
W1	10	13	16	16	16	20	10	20	13	13
W2	25	25	23	22	17	0	0	0	0	0
W3	14	4	19	20	9	20	8	4	18	4
W4	0	0	0	0	0	22	35	24	23	18
unfulfilled	30	0	0	0	0	46	43	0	7	0

Therefore, when dispatching orders, the numbers of orders that should be dispatched to the workstations should follow the numbers in table 4. The unfulfilled orders can be arranged to any workstation in any distribution since they will not be satisfied under optimal dispatching solution.

By improving the order dispatching system, only 292 orders are unfulfilled. Meanwhile, 2366 units of SKU are fulfilled and the fulfill rate is 89.01%. Compared to the legacy order dispatching system, 702 orders can be fulfilled using the integrated order dispatching system and the fulfilled rate will seen a 42.19% increase. By applying the update, the total cost will decrease 823.8 (19.13%). Based on the data, the application of the newly developed integrated order dispatching system is highly recommended.

2.4 Discussion

Under current condition, the AGVs will stop after they took the selected racks to the workstation. However, since intelligent warehouses are usually using real-time systems, time dimension could be take into consideration. When assuming after an AGV took its rack to the specific workstation, it can move another round to another rack and deliver it to a workstation with available berths, the dispatching plan will reach a lower cost.

If AGVs can move in multiple rounds, the model will be more complex and the cost of the function will be lower. In fact, when AGVs can move at most 3 rounds, which means an AGV can deliver at most 3 racks sequentially, the optimal cost for the AGV dispatching system will be 3998.7 and the the optimal cost for the AGV and integrated orders dispatching system will be 2822.4.

Compared to the one round model, the costs of multiple rounds models are lower for the following reasons. On the one hand, at most 20 racks can be delivered to workstations since there are only 20 AGVs and each AGV can only take 1 rack in total. As a result, only at most 20 out of 25 berths in total can be used to fulfill the orders. In optimal multiple rounds AGV dispatching plan, 24 berths out of 25 are used. In optimal multiple rounds AGV and integrated orders dispatching plan, all 25 berths are used. On the other hand, the start positions of idle AGVs are far away from workstation W2 and W4. After an AGV delivered a rack to W2 or W4, using it again to move a rack around W2 and W4 would have a lower cost than arranging an idle one.

The optimal multiple rounds dispatching plans are omitted since this project requires specific single round model only. Further modelling details are provided in the multiple rounds models section in appendices.

Technical Appendices

AGV dispatching model

The AGV dispatching model is an linear model and is as following. Note that all variables that contain capital letters in their names are parameters given in the data file, and variables whose names contains only lowercase letters are variables that need to be calculated.

$$
\begin{aligned}
min \quad & \alpha_1 \cdot (\sum_{a=1}^{A}\sum_{r=1}^{R} DAR_{a,r} \cdot y_{a,r}) + \alpha_2 \cdot (\sum_{w=1}^{W}\sum_{r=1}^{R} DWR_{w,r} \cdot x_{w,r}) + \alpha_3 \cdot (\sum_{w=1}^{W}\sum_{s=1}^{S} unf_{w,s}) \\
s.t. \quad & unf_{w,s} \geq DEM_{w,s} - sup_{w,s}, \ w = 1,2,...,W, \ s = 1,2,...,S && (1) \\
& sup_{w,s} = \sum_{r=1}^{R} INV_{r,s} \cdot x_{w.r}, \ w = 1,2,...,W, \ s = 1,2,...,S && (2) \\
& \sum_{w=1}^{W} x_{w,r} \leq 1, \ r = 1,2,...,R && (3) \\
& \sum_{r=1}^{R} x_{w,r} \leq BER_w, \ w = 1,2,...,W && (4) \\
& \sum_{r=1}^{R} y_{a,r} \leq 1, \ a = 1,2,...,A && (5) \\
& \sum_{a=1}^{A} y_{a,r} = \sum_{w=1}^{W} x_{w,r}, \ r = 1,2,...,R && (6) \\
& \sum_{w=1}^{W} x_{w,MVR_m} = 1, \ m = 1,2,...,M && (7) \\
& y_{MVA_m,MVR_m} = 1, \ m = 1,2,...,M && (8) \\
& x_{w,r} \in \{0,1\}, \ w = 1,2,...,W, \ r = 1,2,...,R && (9) \\
& y_{a,r} \in \{0,1\}, \ a = 1,2,...,A, \ r = 1,2,...,R && (10) \\
& unf_{w,s} \geq 0, \ unf_{w,s} \in Z, \ w = 1,2,...,W, \ s = 1,2,...,S && (11) \\
& sup_{w,s} \geq 0, \ sup_{w,s} \in Z, \ w = 1,2,...,W, \ s = 1,2,...,S && (12) \\
& DAR_{a,r} = |LOCAX_a - LOCRX_r| + |LOCAY_a - LOCRY_r|, \ a = 1,2,...,A, \ r = 1,2,...,R && (13) \\
& DWR_{w,r} = |LOCWX_w - LOCRX_r| + |LOCWY_w - LOCRY_r|, \ w = 1,2,...,W, \ r = 1,2,...,R && (14)
\end{aligned}
$$

Here are the explanations for the parameters.

A = # of AGVs in this warehouse. It is shown as "N_AGV" in the code. In this problem, $A = 20$.

S = # of types of SKUs. It is shown as "N_SKU" in the code. In this problem, $S = 40$.

R = # of racks in this warehouse. It is shown as "N_racks" in the code. In this problem, $R = 80$.

W = # of workstations in this warehouse. It is shown as "N_workstation" in the code. In this problem, $W = 4$.

MV = # of AGVs currently moving carrying a rack. It is shown as "N_moving" in the code. In this problem, $MV = 6$.

$\alpha_1, \alpha_2, \alpha_3$ = coefficient for the three parts of costs respectively. They are shown as "alpha1", "alpha2", "alpha3" in the data file. here, $\alpha_1 = 1,\ \alpha_2 = 1.3,\ \alpha_3 = 3$.

BER_w = # of open berths for the w-th workstation. The array is shown as "Berths" in the data file.

$DEM_{w,s}$ = # of orders of the s-th type of SKU to be dispatched to the w-th workstation. This matrix is shown as "demand" in the data file.

$INV_{r,s}$ = the stock level of the s-th type SKU in the r-th rack. This matrix is shown as "inventory" in the data file.

$MVA_m,\ MVR_m$ are two arrays that stores the m-th moving AGV and the rack it is carrying respectively. They are storing in array "moving" in the data file, using "r" and "a" as the labels of the racks and AGVs respectively. The data in these arrays are used as subscripts of the variables x and y.

$LOCAX_a,\ LOCAY_a$ stores the x and y coordinate of the a-th AGV respectively, stored in array "loc_AGV" in the code. $LOCRX_r,\ LOCRY_r$ stores the x and y coordinate of the r-th rack respectively, stored in array "loc_rack" in the code. $LOCWX_w,\ LOCWY_w$ stores the x and y coordinate of the w-th workstation respectively, stored in array "loc_work" in the code.

$DAR_{a,r}$ = the Manhattan distance from the a-th AGV to the r-th rack, shown as "distar" in the code. $DWR_{w,r}$ = the Manhattan distance from the w-th workstation to the r-th rack, shown as "distwr" in the code. They are parameters since they can be calculated directly from the coordinates of AGVs, racks, and workstations and their value will never change when solving the problem.

Here are the explanations for the variables.

Elements in both matrices x and y are binary variables. In dispatching plans, $x_{w,r} = 1$ means the r-th rack should be delivered to the w-th workstation. Otherwise it means the r-th rack will not be delivered to the w-th workstation. $y_{a,r} = 1$ means the r-th rack is assigned to the a-th AGV. Otherwise it means the r-th rack is not assigned to the a-th AGV.

$sup_{w,s} = \#$ of the units the s-th type of SKU can be satisfied to the w-th workstation, shown as "supply" in the code. It is not totally necessary to be introduced in the model, but by displaying it, the orders that can be fulfilled are clearer. This variable must be positive integer according to what the report says.

$unf_{w,s} = \#$ of the units the s-th type of SKU which are unfulfilled to be delivered to the w-th workstation, shown as "unfulfilled" in the code. This variable must be positive integer according to what the report says.

Here are the explanations for the constraints. There are 14 lines in total in the model except the target function. But equation (13) and (14) are not actual constraint since all variables in which are constants and they are written to calculate the distances from given coordinates.

Constraints (1), (2), (11) and (12) calculate sup and unf from the optimal dispatching plan. Constraint (1) ensures that if the supply is less or equal than the demand, the unfulfilled orders will be the demand orders minus the supplied orders. Constraint (11) ensures that if the supply is greater or equal than the demand, the unfulfilled orders will be 0. Constraints (2) calculate the units of SKUs supplied to the workstations. If a rack is delivered to a workstation, every SKU in its inventory should be added to the supply.

Constraint (3) means for each rack, there is at most only one workstation it can go. If it does not go to any workstation, the left hand side of this constraint will be 0. Constraint (4) means for each workstation, the racks it receives cannot be more than the available berths it have. Constraint (5) means for each AGV, it can only deliver at most one rack. In fact, in the optimal solution, all AGVs are used. The right hand side of constraint (6) is exactly same as the left hand side of constraint (3), meaning that for each rack, if it is selected to a workstation, it must be delivered by exactly one AGV. If it is not going to any workstation, both sides of this constraint will be 0 and no AGV should be assigned to this rack. Constraints (9) and (10) restrict that every variable in x and y must be binary.

Constraints (7) and (8) restricted the usage of moving racks and AGVs. Constraint (7) means that every moving racked must go to a workstation eventually according to what the report says. Constraint (8) means confirms the assignment for every moving AGV to the rack it is carrying.

The objective function is the cost in total containing three parts: the distance AGVs reaching their racks, the distance AGVs heading to workstations carrying the racks, and the penalty for unfulfilled orders.

Taking only constraints (3) and (4) into consideration, it seems like this problem is similar to a knapsack problem. The 4 workstations can be regarded as 4 knapsacks and the racks can be regarded as items that required to be put into the the knapsacks. Taking the locations into consideration will make this problem more complex than an original knapsack problem.

AGV and integrated order dispatching model

The AGV and integrated order dispatching model is an linear model and shown below. This model is the same as the AGV model except for the objective function and constraints (1) and (11). As a result, constraints (2) to (10), (12) to (14) are omitted because they are exactly same as the AGV model.

$$
\begin{aligned}
min \quad & \alpha_1 \cdot (\sum_{a=1}^{A}\sum_{r=1}^{R} DAR_{a,r} \cdot y_{a,r}) + \alpha_2 \cdot (\sum_{w=1}^{W}\sum_{r=1}^{R} DWR_{w,r} \cdot x_{w,r}) + \alpha_3 \cdot (\sum_{s=1}^{S} totunf_s) \\
s.t. \quad & totunf_s \geq TOTDEM_{w,s} - \sum_{w=1}^{W} sup_{w,s}, \ s = 1, 2, ..., S & (1) \\
& ...... \\
& totunf_s \geq 0, \ totunf_s \in Z, \ s = 1, 2, ..., S & (11) \\
& ......
\end{aligned}
$$

(Please check the AGV model to see constraints (2) to (10) and (12) to (14))

Here are the explanations for the newly appeared parameter, variable and constraints.

$TOTDEM_{w,s}$ = # of demanded orders of the s-th type of SKU in total. This array is given in the document and shown as “total_demand” in the data file.

$totunf_s$ = # of the units the s-th type of SKU which are unfulfilled in all 4 workstations, shown as “total_unfulfilled” in the code.

Constraints (1) and (11) are changed to calculate $totunf$ in the integrated optimal dispatching plan. Constraints (1) ensures that if the total supply from all 4 workstations is less or equal than the demand, the total unfulfilled orders will be the total demand orders minus the total supplied orders. Constraint (11) ensures that if the total supply is greater or equal than the total demand, the total unfulfilled orders will be 0. The other constraints remain same since the only difference is that the way that unfulfilled orders are calculated.

Multiple rounds models (Discussion)

This multiple rounds model is developed in the first time and was simplified to the previous two dispatching models because it is not concise enough. Actually, when the maximum of rounds (The MI parameter below) is set to 1, it is exactly the same as the previous AGV dispatching model.

$$
\begin{aligned}
min \quad & \alpha_1 \cdot (\sum_{a=1}^{A}\sum_{r=1}^{R} DAR_{a,r} \cdot y_{a,r,1}) + \alpha_1 \cdot (\sum_{a=1}^{A}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{i=1}^{MI-1} DWR_{w,r} \cdot yz_{a,w,r,i}) + \\
& \alpha_2 \cdot (\sum_{w=1}^{W}\sum_{r=1}^{R} DWR_{w,r} \cdot x_{w,r}) + \alpha_3 \cdot (\sum_{w=1}^{W}\sum_{s=1}^{S} unf_{w,s}) \\
s.t. \quad & unf_{w,s} \geq DEM_{w,s} - sup_{w,s}, \ w = 1,2,...,W, \ s = 1,2,...,S && (1) \\
& sup_{w,s} = \sum_{r=1}^{R} INV_{r,s} \cdot x_{w.r}, \ w = 1,2,...,W, \ s = 1,2,...,S && (2) \\
& \sum_{w=1}^{W} x_{w,r} \leq 1, \ r = 1,2,...,R && (3) \\
& \sum_{r=1}^{R} x_{w,r} \leq BER_w, \ w = 1,2,...,W && (4) \\
& \sum_{r=1}^{R} y_{a,r,i} \leq 1, \ a = 1,2,...,A, \ i = 1,2,...,MI && (5) \\
& \sum_{a=1}^{A}\sum_{i=1}^{MI} y_{a,r,i} = \sum_{w=1}^{W} x_{w,r}, \ r = 1,2,...,R && (6) \\
& \sum_{w=1}^{W} x_{w,MVR_m} = 1, \ m = 1,2,...,M && (7) \\
& y_{MVA_m,MVR_m,1} = 1, \ m = 1,2,...,M && (8) \\
& x_{w,r} \in \{0,1\}, \ w = 1,2,...,W, \ r = 1,2,...,R && (9) \\
& y_{a,r,i} \in \{0,1\}, \ a = 1,2,...,A, \ r = 1,2,...,R, \ i = 1,...,MI && (10) \\
& unf_{w,s} \geq 0, \ unf_{w,s} \in Z, \ w = 1,2,...,W, \ s = 1,2,...,S && (11) \\
& sup_{w,s} \geq 0, \ sup_{w,s} \in Z, \ w = 1,2,...,W, \ s = 1,2,...,S && (12)
\end{aligned}
$$

$$DAR_{a,r} = |LOCAX_a - LOCRX_r| + |LOCAY_a - LOCRY_r|,\ a = 1,2,...,A,\ r = 1,2,...,R \tag{13}$$

$$DWR_{w,r} = |LOCWX_w - LOCRX_r| + |LOCWY_w - LOCRY_r|,\ w = 1,2,...,W,\ r = 1,2,...,R \tag{14}$$

$$\sum_{r=1}^{R} y_{a,r,i} \leq \sum_{r=1}^{R} y_{a,r,i-1},\ a = 1,2,...,A,\ i = 2,...,MI \tag{15}$$

$$z_{a,w,i} \geq y_{a,r,i} + x_{w,r} - 1,\ a = 1,2,...,A,\ w = 1,2,...,W,\ r = 1,2,...,R,\ i = 1,...,MI \tag{16}$$

$$\sum_{w=1}^{W} z_{a,w,i} = \sum_{r=1}^{R} y_{a,r,i},\ a = 1,2,...,A,\ i = 1,...,MI \tag{17}$$

$$yz_{a,w,r,i-1} \geq z_{a,w,i-1} + y_{a,r,i} - 1,\ a = 1,2,...,A,\ w = 1,2,...,W,\ r = 1,2,...,R,\ i = 2,...,MI \tag{18}$$

$$z_{a,w,i} \in \{0,1\},\ a = 1,2,...,A,\ w = 1,2,...,W,\ i = 1,...,MI \tag{19}$$

$$yz_{a,w,r,i} \in \{0,1\},\ a = 1,2,...,A,\ w = 1,2,...,W,\ r = 1,2,...,R,\ i = 1,...,MI \tag{20}$$

Here are the explanations for the newly appeared parameter, variables and constraints.

MI = # of the maximum rounds set manually. It is shown as "max_iter" in the code. It is set as 3 in provided code.

The definition y changes slightly and the third dimension of y identifies the number of the round. For instance, $y_{a,r,i} = 1$ means the r-th rack is assigned to the a-th AGV in the i-th round. In other word, the r-th rack is the i-th rack that the a-th AGV delivers. Array z gives the position of the AGVs after each round. More specifically, $z_{a,w,i} = 1$ means the a-th AGV stops at the w-th workstation after the i-th round. Array yz is introduced to avoid non-linear constraints.

Constraint (15) means that if an AGV does not move in this round, it cannot move in the next round. This ensures that an AGV cannot move once it stops and prevents model from large quantities of useless calculation. Constraints (16) and (19) are equivalent to $z_{a,w,i} = y_{a,r,i} \cdot x_{w,r}$. Similarly, constraints (18) and (20) are equivalent to $yz_{a,w,r,i-1} = z_{a,w,i-1} \cdot y_{a,r,i}$. They were written in this way to make sure the model is linear. Constraint (17) ensures that once an AGV moves in a round, it must stops in a workstation. The objective function changes its first part into 2 situations, depending on the rack is delivered in the first round or not.

The multiple round AGV and integrated order dispatching model is omitted because the differences between it and the multiple round AGV dispatching model is exactly the same as the differences between the single round models. The only changed constraints are (1) and (11). The code of this model is provided and will be described in the next section.

The manually set parameter maximum iteration MI is highly related to the time complexity of the model. Using Gurobi as the default solver to solve both multiple rounds models, maximum rounds from 1 to 4 have been tried to run. When $MI = 1$, it is exactly the same as the previous AGV dispatching model. When $MI = 2$, it also costs a few seconds to show the optimal solution. When $MI = 3$, which is also the default settings in the model document, it costs about 2 minutes to solve the model. When $MI = 4$, ampl will not solve the model in half an hour and after that it was shutdown manually when trying. All mentioned running times are given by a Macbook Pro.

Running the code

There are 9 ampl code document attached in total. The "project_data.dat" is the provided data in this project used in every model.

Four files ended with ".mod" are the models. The AGV dispatching model is in file "model.mod". The AGV and integrated order dispatching model is in file "model2.mod". The multiple rounds AGV dispatching model is in file "model1_multi.mod". The multiple rounds AGV and integrated order dispatching model is in file "model2_multi.mod".

There are four running files ending with ".run" are used to running the models. For example, to run the AGV dispatching model, enter "include model1.run;" in ampl and the optimal solution 4305.3 will show. To run the AGV and integrated order dispatching model, enter "include model2.run;" in ampl and the optimal solution 3481.5 will show.

The default solver is set to Gurobi. Both single round models, "model.mod" and "model2.mod", will be solved in seconds. The running time of multiple rounds models are discussed in the previous section.

All models and codes, along with this report are developed by myself individually.