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A Data-Driven Storage Assignment Strategy for Automated Pharmacy

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Abstract—Automated pharmacy (AP) with random storage location assignment (RSLA) strategy has been widely applied in large hospitals and retail pharmacies. In this paper, an integrated optimization problem of storage location assignment (SLA) and robot arm path planning (RAPP) is considered. For the trade-offs, a Hungarian method (HM)-based storage location assignment (HMSLA) method is proposed for further improving the operation efficiency of AP. Two phases are involved in the proposed method. At phase one, AP is divided into four areas based on BP neural network, and then medicine storage area and specific location are determined through data mining of drug delivery frequency and common combinations. At phase two, HM is applied for optimal scheduling of dispensing multiple medicines. Numerical studies show the proposed method outperforms significantly the traditional RSLA strategy.

Keywords—Data mining, Drug storage and distribution, Robot arm path planning, Hungarian method

I. INTRODUCTION

In traditional pharmacies, medicines are orderly placed at medicine racks for the convenience of manual management. To manage medicines more efficiently and accurately, automated pharmacy (AP) as a mature technology has been widely applied to hospitals and retail pharmacies in many developed countries [1]. A practical storage location assignment (SLA) process may face great uncertainty owing to various unpredictable factors such as the specifications and types of medicines [2]. The simplest storage method is the random storage location assignment (RSLA) strategy which randomly assigns incoming medicines to available storage locations and randomly conducts dispensing path planning, however, RSLA leads to less efficiency despite high space utilization. For further improving efficiency and storage resource utilization, storage location assignment (SLA) and robot arm path planning (RAPP) in AP are considered simultaneously in this paper.

Storage location assignment (SLA) as a generalization of classic assignment problem is widely concerned in previous research, particularly in an automated warehouse [3]. One common method is the full-turnover storage policy which first determines the turnover of the items, and then assigns the most popular items to storage locations closest to the warehouse [4, 5]. Some researchers have found that assigning correlated items to each other works better than considering only individual item attributes [6, 7].

In an automated warehouse with SLA, path planning is a subproblem which is a special case of travelling salesman problem (TSP) and can be solved in polynomial time [8, 9]. Robotic path planning mainly solves the following three problems: (i) Mobile robot can reach the ending task point from the starting task point; (ii) Mobile robot can accurately avoid obstacles, and (iii) Optimize the selected path as much as possible. Commonly used path planning methods include graph-search, Dijkstra's shortest path algorithm, artificial neural network, genetic algorithm, etc. [10-13]. By comparison, RAPP in AP is not complex. In this paper, we employ the Hungarian method for an exact solution of RAPP.

Multicriteria decision-making problems are typically encountered in complex system design [14]. Most studies just made the storage assignment decisions according to turnover or correlation extracted from historical orders based on big data, without considering the trade-offs between SLA and path planning. To this end, a Hungarian method (HM)-based storage location assignment (HMSLA) strategy including two phases is presented.

The remainder of this paper is organized as follows. Problem descriptions including the proposed AP system and its working mode, some rules of SLA, and shortest time algorithm-based RAPP, are given in Section 2; followed by the two-phase HMSLA strategy is presented in Section 3. Numerical studies are conducted and the results are discussed in Section 4. Finally, Section 5 concludes the paper.

II. PROBLEM DESCRIPTIONS

A. The system description of AP

With the continuous deepening and omnidirectional development of automation technology in the medical field, the technical innovation of pharmacy automation will be its new development direction. As the core equipment of AP, automatic storage and distribution system (ASDS which is shown as Fig.1) determines the popularity and speed of hospital pharmaceutical automation equipment. ASDS is a kind of automatic storage equipment for AP to realize automatic replenishment, intensive warehousing and automatic dispensing. It has complex and diverse storage locations and a large amount of storage space, so it is a kind of intensive storage device. Compared with traditional pharmacies, AP greatly improves the dispensing efficiency of pharmacists and saves storage space to a great extent. However, in the face of complex and diverse drugs, the RSLA strategy is still adopted and the types and specifications of drugs are not distinguished., which will greatly reduce the transmission efficiency of drugs and cause unnecessary waste of storage space. At the same time, with the accumulation of drug

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use data and prescriptions in hospitals, data resources will be wasted and idle. How to improve the drug delivery rate of AP, how to improve the space utilization of ASDS, and how to improve the utilization rate of idle resources such as prescription data have become the technical core issues to further optimize AP [15].

The further optimization of AP mainly depends on the optimization of storage space allocation strategy and the decision-making optimization of the path of tonic and dispensing manipulator. Among them, the path optimization problem is often transformed into the minimum time problem, and the minimum time algorithm is a concept in logistics. Logistics is a process processing science that combines technical engineering with management engineering to transfer the goods entity from the supply place to the acceptance place. At present, logistics technology has made great achievements in our country, such as JD.com, Cainiao Smart Logistics Network Limited and so on. The reasonable application of logistics principles to the actual demand can not only effectively improve its efficiency, but also increase time and space benefits. In this paper, the optimization process of ASDS in AP is divided into three parts, including decision-making of the initial storage location of all kinds of drugs, replenishment sequence and path decision of automatic robot arm, dispensing sequence and path decision of automatic robot arm.

On the one hand, with the in-depth development of hospital management information, a large number of hospital drug administration and drug use data based on pathology have been accumulated. It reflects the patients' condition, the doctors' medication habits, the type and quantity of prescription drugs and the relationship between drugs in the form of prescription. How to make full use of these historical data through data mining technology to find out the internal relationship between drugs, the frequency of drug use and the change of drug turnover rate is an important basis for the decision-making of drug initial storage location. On the other hand, each replenishment process and each dispensing process of the automatic mechanical arm is a function of the distance from the origin of the robot arm and the hoist to their target point, so the closer the distance is, the shorter the time of replenishment and dispensing is. The more frequently used drugs are stored in the storage space closer to the conveyor belt, the overall consumption time will be greatly shortened. Similarly, in a complete process of tonic (dispensing), the closer the relative distance of all drugs that need to be replenished (distributed), the time consumed will be greatly reduced. The combination of the two aspects will greatly improve the refill and dispensing efficiency of AP, while massively saving storage space and reducing cost consumption.

The automated pharmacy studied in this paper is mainly composed of rapid drug delivery system (RDDS), batch drug delivery system (BDDS), intelligent drug delivery system (IDDS) and intelligent power distribution system (IPDS). The storage device of AP is composed of multiple rows of storage units, and each storage device is provided with a conveyor belt and an automatic robot arm, where the drug delivery belt and the incoming conveyor belt are alternately arranged between every two rows of storage boxes, and an automatic robot arm is arranged between the conveyor belts. The HMSLA strategy proposed by combining the above two aspects will greatly improve the work efficiency of AP and alleviate the problems of large numbers of patients in hospital pharmacies and low efficiency of pharmacy equipment.

Fig. 1. Automatic storage and distribution system

B. *The working mode of the proposed AP system*

Taking AP of Beijing Aerospace Center Hospital as an example, the pharmacy consists of one RDDS, one BDDS, two intelligent storage systems and four intelligent drug delivery systems. The RDDS can store up to 120000 boxes of drugs and distribute 6000-8000 boxes of drugs per day, accounting for about half of the total. The intelligent storage system and the intelligent drug delivery system are that the prescription information of the patients is transmitted to the data server, and after the drug fee is paid, the medicine will be dispensed quickly through the IDDS. After dispensing, the bar code is printed to the pre-dispensing box, and the patients' name and language prompt are displayed on the display screen to remind the patients to take the medicine. The specific system flow is shown in Fig.2.

Traditional pharmacy medicines are stored on metal shelves, and pharmacists are often required to move between multiple shelves after the pharmacist gets the prescription. This traditional way of dispensing tonic takes up a lot of space, the path of dispensing/tonic is long, the operation is complex, and the efficiency is very low. As can be seen from the flow chart of AP, AP are designed to solve automatic replenishment and intensive distributed storage. With the explosive growth of the type and quantity of drugs, the current RSLA strategy has been unable to meet the needs of this dense and distributed storage, so it is necessary to further improve and perfect the storage allocation strategy of AP [16, 17].

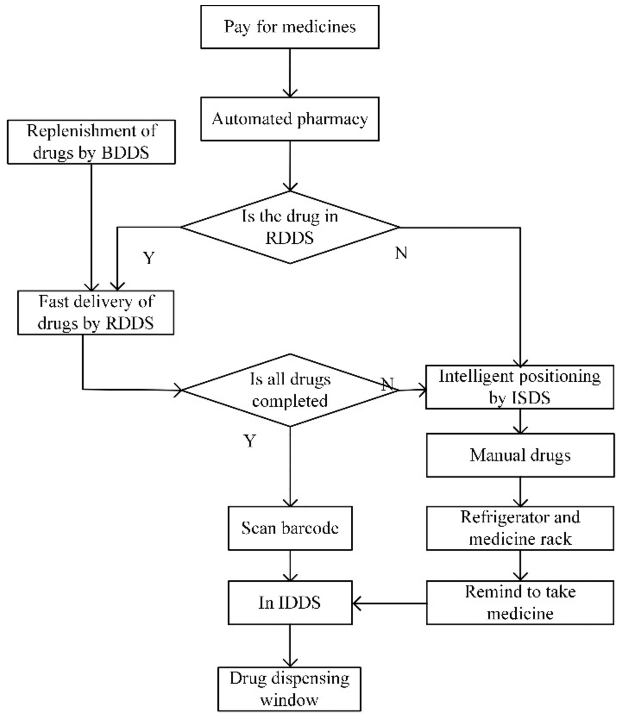

Fig. 2. Flow chart of Automatic storage and distribution system

The equipment structure of the drug storage in the AP is shown in Fig.3, which is composed of automatic tonic equipment, slope storage unit, automatic drug delivery equipment and automatic sorting equipment. The automatic sorting equipment is installed at the entrance where the incoming conveyor belt enters the drug storage equipment and at the exit where the outgoing conveyor belt sends out the medicine. The drug storage equipment adopts the gravity principle and the assistance of the automatic robot arm to accomplish the dispensing process of drug delivery. There are u-shaped slots of different specifications in each storage unit of the storage device, according to the drug specifications and the assistance of the automatic robot arm, the number of dispensing can be 4-8 boxes at a time, and the slope storage unit on the same line can deliver drugs at the same time. At the same time, there is a drug register at the exit of the output conveyor belt, which can assist in checking the number of medicines. The dispensing task is completed when it is correct to check the number of medicines [18].

Ensuring the rational distribution of storage units in AP and the optimal path of automatic robot arm dispensing and tonic will further improve the work efficiency of AP. Based on this, this paper proposes an HMSLA strategy.

C. Storage Decision Model Based On Data-Driven Region Division

The traditional storage strategy mainly includes location storage, random storage and classified storage. At present, most of the research on storage strategy aims to reduce the time cost of tonic and dispensing, but it is not enough to consider this in practical application. We should comprehensively consider the time cost of tonic and dispensing and the space utilization of storage equipment. At the same time, a large number of hospital dispensing data reflect the patients' condition, doctors' medication habits, the type and quantity of prescription drugs and the relationship between drugs in the form of prescriptions. Through mining the internal information of prescription data by clustering method, it is found that the frequency of different drugs used together, the proportion of dosage when different kinds of drugs are used together, the dynamic change law of the maximum turnover rate of all kinds of drugs, and so on. This is an important basis for the decision of the initial storage location of the drug. The HMSLA is a comprehensive optimizing strategy from two aspects of time efficiency and space utilization, and the AP is optimized as a whole through the data-driven method. Through the cluster analysis of prescription data, this paper mainly makes the initial location decision according to the following storage criteria [19, 20].

- The principle of the regional division of similar drugs. The height of the storage unit of the storage device on the same layer is the same, but the width can be different, and the height can be different at a different layer, so according to the types of drugs, packaging specifications and the characteristics of the storage unit, the storage device can be divided into different storage areas, and the drug packaging can be optimized according to the same type of drugs and high concomitant use rate of different types of drugs. Make the packaging of similar drugs and a piece of drugs with a high frequency of use as consistent as possible, so as to improve the space utilization of storage equipment.

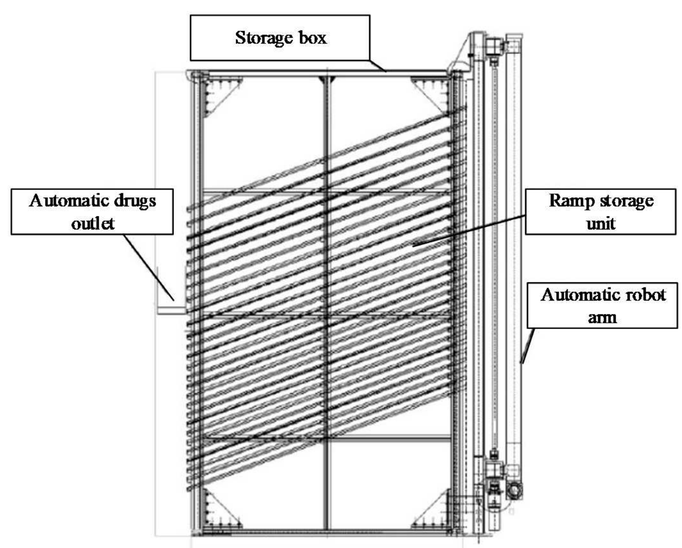

Fig. 3. Storage equipment diagram

- The principle of regional priority. The priority of drug types shall be classified according to the different types of drugs and frequency used of related drugs. At the same time, the storage equipment is divided according to the principle of the regional division of similar drugs, and the priority of the storage area is divided according to the absolute distance from the drug inlet and outlet. The high-priority drug types are assigned to the high-priority storage area. So as to reduce the consumption of time cost and realize the rational use of space.

- The improved first-in-first-out principle. The first-in-first-out principle is often adopted in drug delivery and dispensing at the present stage, regardless of the batches and storage methods of the drug. The improved first-in-first-out principle pays more attention to the timeliness and safety of drugs. The same drug of different batches must be dispensed in strict chronological order, and the same batch of drugs should be dispensed in accordance with the principle of proximity. This not only ensures the safety of drugs but also ensures the efficiency of dispensing.
- The principle of the shortest path. Without conflict with the above principles, according to the prescription demand list obtained in the hospital information system, the shortest path is selected to complete the replenishment and dispensing task, so as to improve the work efficiency of the automatic pharmacy.

D. Shortest time algorithm-based RAPP

The optimization process of ASDS in AP is divided into three parts, including decision-making of the initial storage location of all kinds of drugs, replenishment sequence and path decision of automatic robot arm, dispensing sequence and path decision of automatic robot arm. Based on the above five principles, the specific initial storage location of each drug can be determined. By numbering the storage device of the ASDS, the distance between the initial storage location and the conveyor belt and the automatic robot arm can be known, the problem is transformed into the shortest path problem. In this paper, the shortest time algorithm-based RAPP is a small-scale accurate shortest path algorithm.

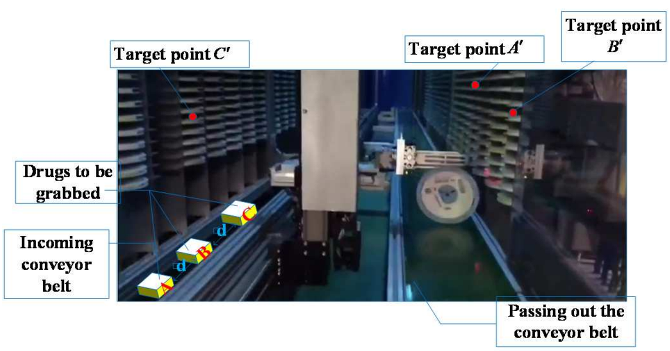

Fig. 4. Automatic storage system dosing diagram

The initial storage location of drugs can be determined according to the storage decision model based on data-driven region division. At present, there are drugs A, B, C through the transmission belt, and the storage decision model based on data-driven region division has determined its initial storage location, and the interval distance of each type of drugs is expressed by d. For convenience, each type of drug in the picture below is represented by a yellow box, but in the actual modelling process, the shape and size of the drug package cannot be ignored. In this paper, without losing generality, it is assumed that drug A is packed in a single product, the length of the box is L_A, the width is W_A, and the height is H_A. Drug B is a multi-product package and consists of multiple single-product packages, the length, width, and height of the package are respectively L_B, W_B, H_B. Drug C is a multi-product drug in a bottle, and its packaging is approximated as a rectangular parallelepiped, its length, width, and height are respectively L_C, W_C, H_C.

As shown in Fig.4, medicines A, B and C are located at the incoming conveyor belt, above which are different storage units and storage boxes, different storage units, which are suitable for storage of different types of medicines, have different specifications. The red dots in the figure are the storage unit locations of medicines A, B and C determined by the storage decision model based on data-driven region division, which are denoted respectively as A', B', C'. The horizontal distance between the position of the medicine A, B, C on the conveyor belt and the position of the medicine storage unit A', B', C' is recorded as l_1, l_2, l_3, and the vertical distance is recorded as h_1, h_2, h_3. Taking into account that the position of the medicine on the conveyor belt is not necessarily at the edge of the conveyor belt, so without loss of generality, suppose the distance that the automatic robot arm needs to stretch when grabbing medicines A, B and C is recorded as w_1, w_2, w_3. Similarly, the position where the medicine is put into the storage unit is not necessarily at its edge, assuming that the distance that the automatic robot arm needs to expand and contract at this time is recorded as w_1', w_2', w_3'. The automatic robot arm needs to switch between the two storage boxes, during the switching process, it needs to rotate horizontally 180 degrees. At the same time, the rotation arc of the manipulator itself is recorded as l. The specific automatic robot arm tonic distance model is as follows.

According to the above assumptions, without considering the initial position of the automatic robot arm, the total distance that the automatic robot arm needs to move from store the medicine A to the storage unit A' is $w_1 + l + l_1 + h_1 + w_1'$, similarly, it can be obtained that the automatic robot arm stores medicine B, and the distance that medicine C needs to move is $w_2 + l_2 + h_2 + w_2'$ and $w_3 + l + l_3 + h_3 + w_3'$ respectively. It can be seen that the distance from the grasping point of each medicine to the corresponding target point of the automatic robot arm is fixed, and only the intermediate process is different, that is, the order of grasping the medicine is different. Therefore, only the distance of the intermediate process needs to be considered, and the distance difference of the automatic robot arm movement in different grasping sequences can be obtained. Among them, the distance from the initial distance of the automatic robot arm to the grasping point 1 is simply referred to as distance 1, the moving distance from the target point 1 to the grasping point 2 is referred to as distance 2, and the moving distance from the target point 2 to the grasping point 3 is simply referred to as distance 3, then the distance in the intermediate process is the sum of them. It is used to analyze by the enumeration method, there are $3! = 6$ routes for transporting medicine A, B and C to the corresponding storage unit by the automatic robot arm. The specific analysis is shown in Table I (assuming that the initial position of the automatic robot arm is at the edge of the conveyor belt corresponding to drug A).

TABLE I
ENUMERATION PATH TABLE

The Order	Distance 1	Distance 2	Distance 3	The Middle Distance
$A-B-C$	0	$l+h_1+l_1-d$	h_2+d-l_2	$h_1+h_2+l+l_1-l_2$
$A-C-B$	0	$l+h_1+2d-l_1$	$l+h_3+l_3-d$	$h_1+h_3+l-l_1+l_3+d$
$B-A-C$	d	h_2+l_2+d	$l+h_1+2d-l_1$	$h_1+h_2+l-l_1+l_2+4d$
$B-C-A$	d	h_2+d-l_2	$l+h_3+l_3-2d$	$h_2+h_3+l-l_2+l_3$
$C-A-B$	$2d$	$l+h_3+l_3-2d$	$l+h_1+l_1-d$	$h_1+h_3+2l+l_1+l_3-d$
$C-B-A$	$2d$	$l+h_1+l_1-d$	h_2+d-l_2	$h_1+h_2+l+l_1-l_2$

If the parameters $h_1, h_2, h_3, l_1, l_2, l_3, l$ and d are known, the transport sequence with the smallest intermediate distance can be found. On the assumption that the moving speed of the automatic robot arm is constant, it can be ensured that the selected transportation sequence consumes the least time, that is the optimal transportation sequence is screened out for the drug transporting to on the Storage unit. It is the same to analyze the process of dispensing medicine, the medicine on the Storage unit is used as the grab point and the medicine outlet is the target point. It can be calculated that the total distance moved by the automatic robot arm under various conditions, and it can be selected that the optimal medicine delivery sequence by comparison. Although the enumeration method can find the shortest path for tonics and dispense, it will be losing the original intention of saving time and cost, because the amount of calculation will increase explosively when the scale of the problem is expanded to n. Based on this, this paper proposes a shortest time algorithm-based RAPP.

III. TWO-PHASE HMSLA STRATEGY

Through the above enumeration demonstration, it can be seen that it is the key to determining the efficiency of the ASDS of the AP that the distance, the automatic robot arm needs to move when completing the same tonic and dispensing task. It can be described by the following mathematical model: $\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}(p_{ij}) + \sum_{k=1}^{n} d_k y_k(p'_k, p''_k) + d_0 z + d_{n+1}q$. The specific meanings of symbols are shown in the following Table II:

TABLE II
PATH MODEL NOTATION

Symbol	Instructions
d_{ij}	The distance from the storage unit of drug i to the grabbing drug j.
d_k	The distance between the position where the drug k is grabbed and the position where the drug k is stored.
d_0	The distance between the robot arm and the initial position of the drug 1.
d_{n+1}	The distance from the storage unit of drug n to the stop position of the robot arm.
x_{ij}	The number of times the path between the storage location of drug i and the grabbing location of drug j is used.
y_k	The number of times the path between the grasping position of drug k and the storage position of drug k is used.
z	The number of times the path taken by the robot arm to grab drug 1 is used.
q	The number of uses of the path of the robotic arm from the drug n to the stop position.
p_{ij}	The degree of relevance between drug i and drug j.
p'_k	Frequency of use of drug k.
p''_k	Frequency of drug category to which drug k belongs.

Through mathematical model drawn, it can be affirmative that they, the correlation between various drugs, the frequency of use of various drugs, the maximum turnover rate of various drugs and the proportion of multiple drugs when used together, are the keys to minimizing the total distance of the automatic robot arm moving, and they are the breakthrough of minimizing the above mathematical model. It can reduce the total distance of the automatic robot arm moving by determining the initial storage location of the drugs after knowing the relevance of various drugs, the frequency of use of various drugs, the fluctuation of the turnover rate of various drugs, and the proportion of multiple drugs when used together. So as to improve the work efficiency of the AP, based on this we propose a data-driven decision-making model for region partition and storage.

A. *Phase 1:A Data-Driven Decision-Making Model For Region Partition And Storage*

1) *Data driven based on Apriori algorithm*

A data-driven decision-making model for region partition and storage (ADDM) consists of three parts, the first is a data-driven model (DDM) based on the Apriori algorithm, the model is to mine a combination of drugs with strong relevance from the prescription data issued by the hospital, and prepare for the subsequent prediction frequency of different regional drugs and

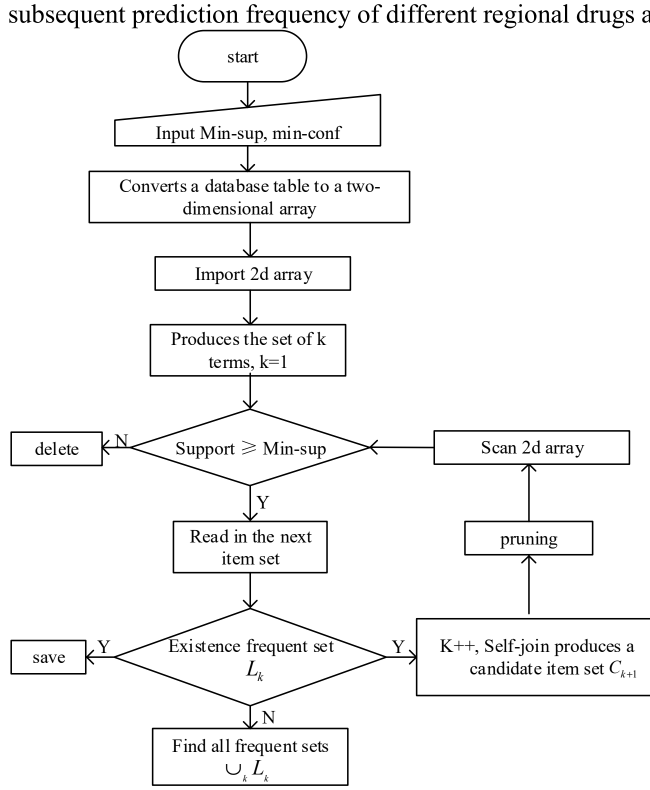

Fig. 5. Flow chart of Apriori algorithm

different types of drugs, so as to determine the storage area of each drug and the specific location in the area. The Apriori algorithm was proposed by Agrawal and Srikant in 1994, it has become the core algorithm of simple association rule mining technology and an effective algorithm for mining frequent item-sets of single-dimensional Boolean association rules after continuous improvement. The algorithm is mainly composed of two parts: generating frequent item-sets and generating association rules based on frequent item-sets. It effectively reduces the possibility of generating a large number of invalid rules because it is a simple search for the sample set, and improves the efficiency of generating effective association rules. The specific algorithm of DDM is shown in Fig.5.

According to the medication and dispensing data of the hospital database, many association rules can be obtained through DDM, but not all association rules are valid. The confidence extent and support degree of the association rules are usually used to judge the validity of the association rules. Rule confidence extent is a measure of the accuracy of association rules, rule support degree is a measure of the universality of association rules, it is also the probability of two types of drugs appearing at the same time. By setting different minimum rule confidence extent levels and minimum condition support degrees, different drug association analysis models can be obtained, so that it is possible to judge drug pairs with strong correlations.

2) Region Partition based on BP Neural Network algorithm

Followed by region partition based on bp neural network algorithm (RPB), the BP neural network is very suitable for non-stationary prediction because it does not depend on the model, and so on, however, the shortcomings of the BP neural network, such as easy to fall into the local minimum and unstable network structure, often limit the widely used of the BP neural network in practical. Combining the genetic algorithm (GA) with the BP neural network can fully integrate the advantages of the two algorithms so that the new algorithm has both the powerful learning and generalization capabilities of the neural network and the global search capabilities of the genetic algorithm. In this paper, it can be obtained that the average frequency of tonic and dispensing of drugs in different regions by preprocessing the tonic and dispensing data of drugs in different regions, using GA to optimize the initial weight threshold of the network, and through the established BP neural network and the weights of various drugs.

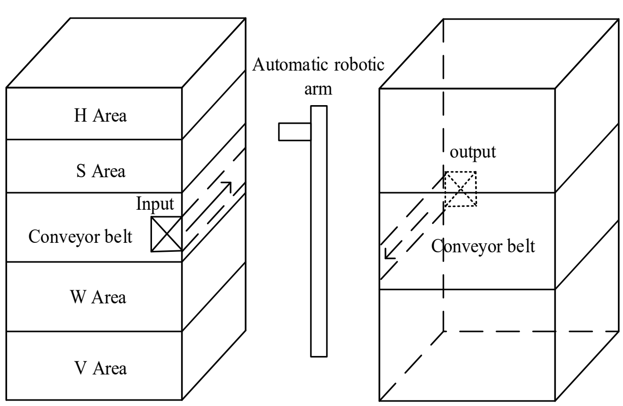

Fig. 6. Region partition model diagram

According to the storage principle described above, combined with the average tonic and dispensing frequency of medicines in different regions, specific storage areas for different types of medicines can be determined. As shown in Fig.6, with the conveyor belt as the center, the storage box is divided into four areas, and the four areas are arranged in ascending order by the vertical distance between each area and the conveyor belt, assuming that the area sequence after the ascending order is S area, W area, H area, V area. Existing four types of medicines, powders, tinctures, tablets, and capsules, require distribution areas, the storage area can be obtained based on the average tonic and dispensing frequency predicted by various drugs through the RPB, combined with the principle of proximity. When the total frequency does not exceed 10, one area is allowed to store multiple types of drugs.

3) Storage decision based on combination forecasting Model

The combination forecasting-based storage decision (CFSD) model is finally used to determine the specific storage location of each drug. The combination forecasting model was first proposed by J.N.Bates and G.W.J.Granger in 1969. It is also proved that the forecast results of multiple individual forecasts are better than each individual forecast after the proper combination. The combination forecasting model is aimed at the same forecasting problem, using two or more different forecasting methods and making appropriate combinations to comprehensively utilize the information provided by various methods, absorb the advantages of each method, avoid the disadvantages of each method, and make full use of to predict the information expressed by the sample, improve the prediction accuracy as much as possible. The combination forecasting model is aimed at absorbing the advantages of each method, avoiding the disadvantages of each method, making full use of to predict the information expressed by the sample, and improving the prediction accuracy as much as possible for the same forecasting problem by using two or more different forecasting methods, and making appropriate combinations to comprehensively utilize the information provided by various methods. Combining the ARIMA-BP forecasting model and the GA-BP forecasting model based on the idea of combined forecasting, the ARIMA-BP forecast is considered from the perspective of time series, and the GA-BP forecast is considered from the perspective of drug relevance and combined with the results of the Apriori algorithm correlation analysis, the tonic and dispensing frequency of different drugs are obtained after synthesis. Combining the basic storage principles described above with the predicted tonic and dispensing frequency of various drugs can establish accurate storage decision-making rules.

Set the storage box on one side of the robot arm as side A, and set the storage box on the other side as side B. Numbering different storage areas in the manner shown in Fig.7, you can determine any storage unit of ASDS according to a three-digit array like $3-A-2$, where 3 represents the third row of storage boxes, A represents the storage box on the side of the incoming conveyor belt (B represents the storage box on the side of the outgoing conveyor belt), and 2 represents the second row of storage boxes.

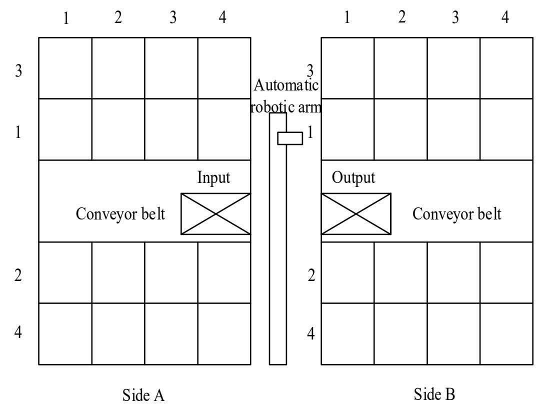

Fig. 7. Store decision model diagrams

The storage units are numbered by this way, and the storage units are arranged in ascending order according to the numbering order, and the obtained storage unit sequence is the order sequence of the absolute distance between each storage unit and the conveyor belt from near to far. The obtained storage unit sequence is the sequential sequence of the absolute distance between each storage unit and the conveyor belt from near to far, the row number has the highest priority, the storage box has the second priority, and the column number has the lowest priority. Combined with the determined storage decision rules, the initial storage location of each drug can be obtained. The specific process is shown in Fig.8.

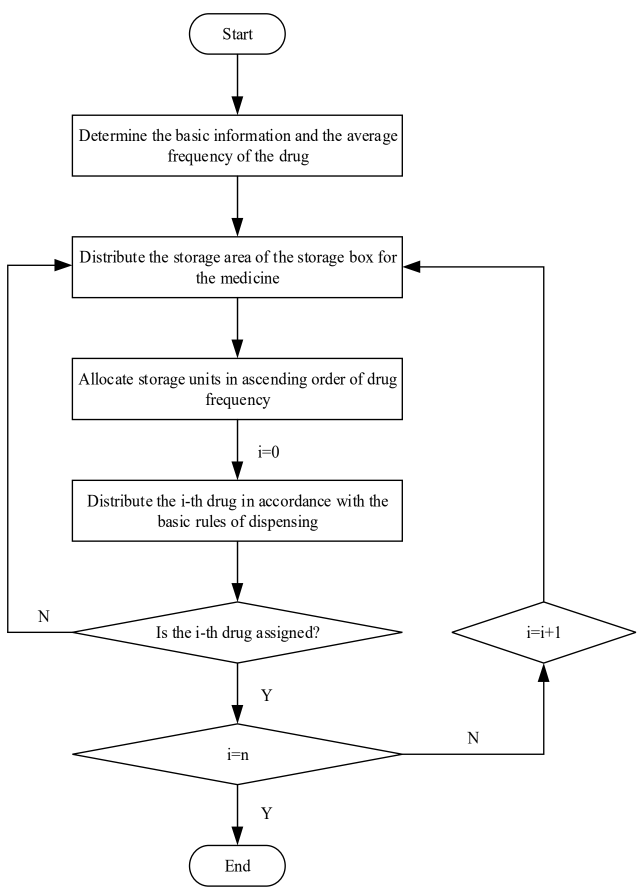

Fig. 8. Drug storage location decision flow chart

B. Phase 2: Hungarian algorithm-based RAPP model

For the problem examples solved by the enumeration method in section D of Problem Descriptions, combined with the idea of the combination model, it can be established the drug location binding rule: The fixed starting position of the robot arm is D, and the stopping position is D', and binding A, B, C, D and A', B', C', D' into $a,, b, c, d$ four groups of points, namely four nodes. As shown in Fig.9. In order to simplify the model and increase the calculation speed of the model, the distance between each node is equivalently converted into time consumed, it is worth noting that $ab \neq ba$.

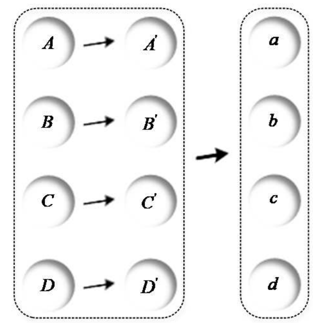

Fig. 9. Composite model diagram

Extending the problem scale to n nodes, in other words, there are $n-1$ kinds of medicines that need to be stored in the storage unit. The problem can be described by the following mathematical model. Where r_{ij} represents the time consumed by the robot arm from node i to node j, $t_{ij}=1$ means the path from node i to node j is selected by the robot arm, $t_{ij}=0$ means the path from node i to node j is not selected by the robot arm.

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} r_{ij} t_{ij}(p_{ij})$$

$$s.t. \begin{cases} \sum_{i=1}^{n} t_{ij}(p_{ij}) = 1 \\ \sum_{j=1}^{n} t_{ij}(p_{ij}) = 1 \\ i, j = 1,2,\cdots,n \end{cases}$$

Through the above mathematical model, an effective distance matrix can be established. The distance matrix can be processed in the following way to obtain the shortest path for storing multiple drugs at the same time. Of course, the initial storage unit of these drugs has been determined by the ADDM strategy. Specific steps are as follows:

Step 1: Transform the distance matrix so that each row and each column have a 0 element.

- Each element in each row minus the smallest element in the row.
- Each element in each column minus the smallest element in this column.

Step 2：Circle the 0 elements in different rows and columns for calculating the path.

- Circles 0 in a row with only one 0 element, denoting it as ◎, and crosses out the remaining 0 elements in the same column (Row search).
- Circle 0 in a column with only one 0 element, call it ◎, and cross out the rest of the 0 elements in its row (column search).
- Repeat these two steps until all 0 elements are marked.
- If each row (column) has more than one 0 element, select a 0 element in the row (column) with the fewest 0 elements, label it ◎, and cross out the remaining 0 elements in the same column with the row (column).
- The value of x_{ij} is 1 if there are n ◎ in different rows and columns and 0 otherwise. Once the optimal solution is obtained, the calculation stops, otherwise go to the Step 3.

Step 3: Cover the 0 element of the distance matrix with the least line.

- Check √ for lines without ◎.
- Put √ in the column where the 0 element in the √ row is located.
- Put √ in the row where ◎ is in the √ column.
- Repeat the above two steps until you can't type the new √.
- If you underline the rows without the √ and underline the columns with the √, all the 0 elements in the distance matrix are covered by these lines.

Step 4: Adjust the distance matrix so that the new 0 element appears.

- Find the smallest element in the uncrossed element and use it as the adjusting quantity.
- Subtract the adjusting quantity from each element in the square root row of the matrix, add the adjusting quantity to each element in the square root column (to keep the original 0 element), then remove all the markers, and go to Step 2.

Step 5: Start from the starting row of the distance matrix to find the zero element, the column number of this zero element is the first drug to be grasped by the automatic robot arm, and then find another zero element in this row, the column number of this zero element is the next drug number of the grasped drug, and so on, until the robot stops, the complete drug extraction path can be determined.

IV. Simulation Analysis

A. Test Instance

Firstly, the association rules of the drug combination with strong relevance are searched through the DDM algorithm. Secondly, the RPB model is used to predict the average tonic and dispensing the total frequency of drug in different regions. Finally, the CFSD model is used to predict the tonic and dispensing frequency of each type of medicine. The following Table III shows the data analysis results of a core hospital prescription drug database for five categories of drugs, respectively are MA, MB, MC, MD, and ME through the ADDM model.

TABLE III
DATA ANALYSIS RESULTS OF 20 MEDICINES

Medicine Index	Medicine Type	Medicine Frequency (1-10)	Type Frequency (1-10)	Association rules
1	MA	9.10	7.30	None
2	MD	9.00	5.00	None
3	MA	7.10	7.30	None
4	ME	7.80	4.70	None
5	MC	8.90	9.40	None
6	MC	7.80	9.40	None
7	ME	7.90	4.70	None
8	MA	6.40	7.30	8-16
9	MA	8.60	7.30	None
10	ME	8.00	4.70	None
11	MD	7.80	5.00	None
12	MA	6.40	7.30	None
13	MB	8.50	8.30	13-15-18
14	MC	6.70	9.40	14-20
15	MB	8.30	8.30	13-15-18
16	MA	8.30	7.30	8-16
17	MB	7.00	8.30	None
18	MB	3.40	8.30	13-15-18
19	MC	8.30	9.40	None
20	MC	7.30	9.40	14-20

B. Storage Location Assignment Illustration

According to the principle of regional distribution, arranged in ascending order the predicted average tonics and dispensing frequency of drugs in different regions, and MC drugs are stored in region S, MB drugs are stored in region W, and MA drugs are stored in region H, MD Class drugs will be stored in the V area, they can be stored in the V area at the same time, because it is less than 10 that the total frequency of the ME drugs and MD drugs.

1) For MC in Area S :

There are medicines 5, 6, 14, 19 and 20 that need to allocate specific storage units in area S. The DDM algorithm shows that medicine 14 and medicine 20 have a strong correlation. There

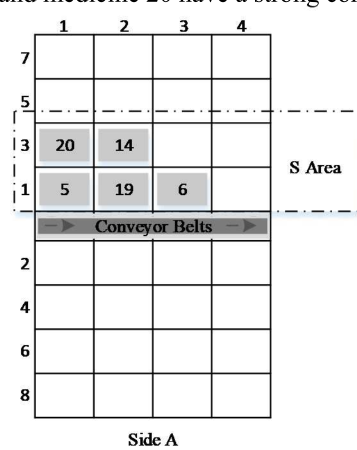

Fig. 10. Assignment illustration for MC in area S

are 8 storage units in area S: 1-A-1, 1-A-2, 1- A-3, 1-A-4, 3-A-1, 3-A-2, 3-A -3, 3-A-4. The storage units of various medicines are shown in Fig.10 by the ADDM model. Note: There is a strong association rule between medicine 14 and medicine 20, so they cannot be stored in the same row, but the sub-optimal row can be selected.

2) For MB in Area W:

There are medicines 13, 15, 17 and 18 in area W that need specific storage units to be allocated. There are 8 storage units in area W: 2-A-1, 2-A-2, 2-A-3, 2-A-4, 4-A-1, 4-A-2, 4-A -3, 4-A-4. The storage units of various medicines are shown in Fig.11 by the ADDM model. Note: If the specific storage unit of a medicine is determined, then the medicines that have a strong correlation with it will no longer allocate storage units according to the frequency, and directly allocate the storage units after the medicine.

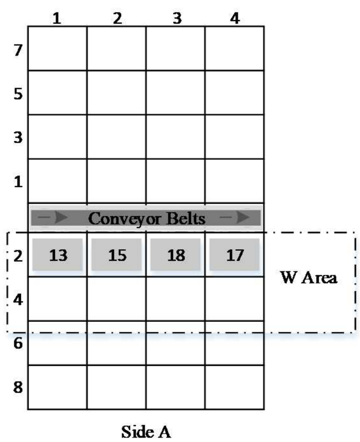

Fig. 11. Assignment illustration for MB in area W

3) For MA in Area H :

There are medicines 1, 3, 8, 9, 12 and 16 that need to allocate specific storage units in the area H. There are 8 storage units in area H: 5-A-1, 5-A-2, 5-A-3, 5-A-4, 7-A-1, 7-A-2, 7-A -3, 7-A-4. The storage units of various medicines are shown in Fig.12 by the ADDM model.

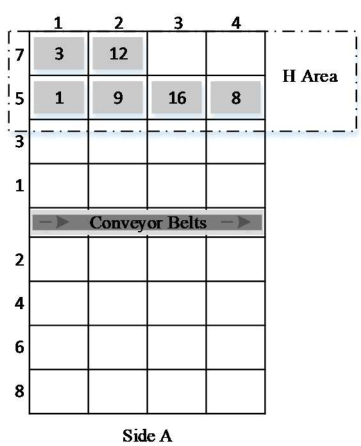

Fig. 12. Assignment illustration f for MA in area H

4) For MD and ME in Area V :

There are medicines 2, 4, 7, 10 and 11 that need to allocate specific storage units in area V, where medicines 2 and 11 belong to MD, and medicines 4, 7 and 10 belong to ME. There are 8 storage units in area V: 6-A-1, 6-A-2, 6-A-3, 6-A-4, 8-A-1, 8-A-2, 8-A -3, 8-A-4. The storage units of various medicines are shown in Fig.13 by the ADDM model. Note: When the Medicine Frequency of two medicines is the same, the medicine with the higher Type Frequency will be the first to distribute to the storage unit.

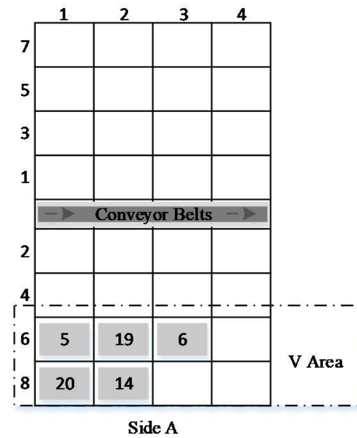

Fig. 13. Assignment illustration for MD and ME in area V

C. HM-Based Optimal Path Planning Illustration

Assume that the path data between four nodes a, b, c, d is shown in Fig.14. Through the Hungarian algorithm-based RAPP model, the optimal distribution path of the automatic robot arm can be obtained as $D \rightarrow B \rightarrow B' \rightarrow C \rightarrow C' \rightarrow A \rightarrow A' \rightarrow D'$. When the problem scale is expanded to n dimensions, the time complexity of the HM-based RAPP model is O(m*n), which is obviously much more efficient than the enumeration method.

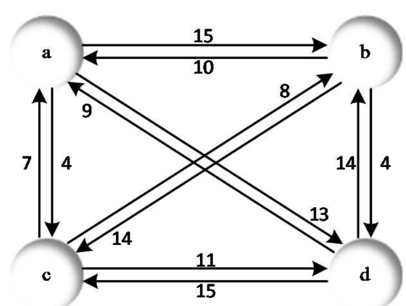

Fig. 14. Node path diagram

V. CONCLUSION

An integrated optimization problem with SLA and RAPP in AP is studied in this paper. For the trade-offs, an improved Hungarian method based on the partition characteristics is proposed. Combined with big data, the Apriori algorithm is introduced for mining association rules between medicines, and then a GA-based BP neural network model is used to predict the frequency of medicines and their types. It is observed that the proposed HMSLA strategy can improve the efficiency of AP, however, the HMSLA strategy still needs improvement. Under this strategy, the efficiency of dispensing drugs is significantly higher than the efficiency of tonics. How to balance the replenishment and dispensing process during peak dosing periods is another issue to be addressed in future work.

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