

Techniques of Automatic Modeling for Four-Way-Shuttle Based Storage and Retrieval System Based on Flexsim

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Abstract. With the rapid development of China's logistics technology, four-way-shuttle based storage and retrieval system (FWSBS/RS) is gaining more and more attention by virtue of its flexibility, convenience and efficiency as a new automated storage technology, but it takes more time for the conventional simulation, which brings inconvenience to the early planning and modeling of the logistics system. Based on Flexsim, an automatic 3D modeling system of four-way shuttle with user-defined parameters is developed by using the idea of automatic modeling. The corresponding task list was automatically executed and the warehousing operation was performed. The utilization rate of relevant equipment and the efficiency of the system were counted. The system makes modeling more efficient and convenient. In addition, it reduces the difficulty of using Flexsim and extends its application in intelligent manufacturing simulation. The example application shows that the system has excellent performance and good interactivity, which can better meet the needs of planners and designers.

1 Introduction

In recent years, with the development of e-commerce B2C business field, distribution center orders show the characteristics of small batch and high frequency. In response to high frequency of stock-in and stock-out operation, various automated storage systems have been rapidly developed. As the latest automatic storage equipment in the past two years, four-way-shuttle based storage and retrieval system (FWSBS/RS) have gained more and more attention. The shuttle in this system can run in four directions, work efficiently and flexibly, and cooperate with lift to realize quick access of goods. Compared with the common multi-shuttle system, FWSBS/RS has more running tracks and greatly enhanced system flexibility; Compared with the miniload, FWSBS/RS can increase the number of shuttles according to the actual situation, and the overall cost of the system is lower. Therefore, FWSBS/RS has become an important development direction of automated logistics system. It is an important method to study the equipment configuration and system performance of the system by simulation.

Due to the diversification of operation mode and scheduling strategy, the system capacity of automated logistics system is generally determined by many factors, which is difficult to be calculated directly, and generally needs to be obtained through simulation analysis. For example, T. Lerher[1] et al. also simulated and modeled the SBS/RS system, using the advantages of the SBS/RS system design to reduce the average operation cycle time of equipment and improve the system's in and out capability; Y. Jia [2] studied the application of simulation

technology in distribution center by Flexsim, and improved the efficiency of distribution center by modeling three kinds of distribution models in J mall; G L. Zhou et al. [3] designed and analyzed a case of AS/RS storage location allocation by Flexsim, and finally concluded that the optimized storage location allocation model can effectively solve the storage location in AS/RS. F. Zhang et al. [4] applied Flexsim system simulation software to build logistics sorting system simulation model. In addition, H. Sun, H F. Yu [5] also developed the second development based on Flexsim, developed the motion simulation model of letter shuttle; X R. Luo [6] optimized the storage operation system through Flexsim simulation. It can be seen that simulation analysis is an important method and means for analysis and optimization of automated logistics system. Through the 3D simulation observation system model, analysis of system operation efficiency, find the good technical means of bottleneck.

At present, there are many kinds of logistics simulation software which can be used for 3D modeling, but generally based on the design drawings, the simulation model is established manually. The modeling process is complex and time-consuming. Flexsim is a powerful 3D logistics simulation software, especially for complex systems with high operating efficiency. Its visual 3D dynamic simulation model can fully realize the operation of the system, and can help planners make wise decisions in the design and operation of the system, and effectively evaluate and optimize the scheme. In view of this, this paper takes the FWSBS/RS as the research object, and studies the automatic modeling technology based on Flexsim. Based on the research of the parameterized model

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of the FWSBS/RS, an automatic modeling system of four way shuttle is developed based on Flexsim, which can make the modeling more efficient and convenient. This system also reduces the difficulty of using Flexsim, expands the practicability of Flexsim. Besides, this paper verifies the effectiveness of the automatic model for FWSBS/RS through an example.

2 Model analysis and parametric design of FWSBS/RS

2.1 Physical model and operation process

2.1.1 Physical model

As the latest automation equipment in recent two years, the main equipment of FWSBS/RS includes: shelf system, four-way shuttle, lift, conveying system and picking workstation. The physical model is shown in Figure 1. The system has the following characteristics: the system of stock-in and stock-out is located on the same side of the roadway, the first layer is in storage, the second layer is out of storage and online picking; the storage and transportation unit is the storage case; the lift can transport and transfer goods; the four-way shuttle can not work across layers; each roadway has a stock-out lift and stock-in lift, and the aisle port has a buffer area.

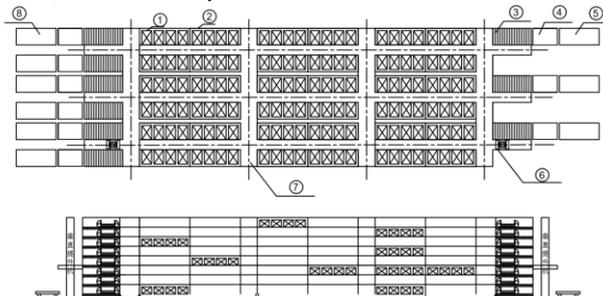


Figure 1. General model of four-way-shuttle based storage and retrieval system (FWSBS/RS)

- ①rack ②storage case ③buffer area ④lift ⑤stock-in conveying line ⑥four way shuttle ⑦shuttle track ⑧online sorting system

2.1.2 Operation process

(1) Process of stock-in

The process of stock-in is: the storage case is transmitted to the designated conveyor belt mouth through the conveyor belt to wait for the lift, the lift drives to the bottom to grab the storage case, the lift carries the storage case to the designated floor, the lift carries the storage case to the warehousing temporary storage area, the goods wait for the idle shuttle, the shuttle transplants the goods to the designated location to complete the stock-in operation once.

(2) Process of stock-out

The process of stock-out is that the idle shuttle is unloaded to the designated storage location to be outbound, the shuttle moves the goods, and the storage case is moved to the designated temporary storage area, the storage case

is waiting for the lift, the outbound lift is driven to the designated floor empty, and the storage case moved to the outbound port on the first floor. The above process is to complete the stock-out operation once.

(3) Process of sorting

The storage cases enter the sorting table in turn. Before entering the sorting table, judge whether there is any task of the sorting table. If there is, the storage cases will enter. If there is no task, they will continue to be transported to the next sorting table. After sorting the goods at the sorting table, judge whether the storage cases are empty. If it is empty, Recycle them. If it is not empty, continue to work until the last sorting table is completed and carry out stock return operation.

2.2 Entity parametric model

The parameterized model of FWSBS/RS includes three modules: rack system module, conveying system module and equipment module. The rack system includes rack module, track layout, storage and transportation unit and buffer zone. The conveying system includes one layer conveying system module and two layer conveying system module. The equipment system includes multi-direction shuttle module and lift module. System parameters structure parameters, size parameters, performance parameters. The real-world parametric model is shown in Figure 2.

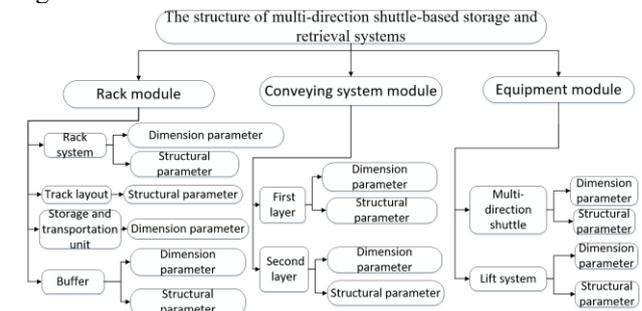


Figure 2. Entity parametric model

The parameters of the entity model include: the number of rack rows, the number of rack columns, the number of rack layers, the number of shuttles in each layer, the number of aisles, the number of horizontal tracks, the number of lifts, the number of picking workstations and other main parameters, as shown in table 1. The meanings of partial parameter are as follows:

The number of rack rows: the number of racks in the direction of horizontal tracks; The number of rack columns: the number of racks in the direction of aisles; The total number of racks: The total number of racks(The number of layers is generally no more than 20); The number of aisles is equal to half of the number of rows; The number of lifts is equal to the number of aisles.

Table1. Entity model parameters

Subordinate system	parameter	Parameter name	Symbol	Unit
Rack system	The number of rack rows	Row	r	Row
	The number of rack columns	Bay	b	Bay
	The number of rack layers	Tier	l	Tier

Equipment system	The number of lifts	EleNum	/	Individual
	Number of shuttles on each layer	AGVNum	a_1	Individual
Conveying system	The number of aisles	AisleNum	/	Individual
	The number of tracks	TrackNum	t	Individual
	The number of picking tables	PickingtableNum	/	Individual

2.3 Layout method of entities

It is important to realize the automatic modeling and the automatic determination of the relative position between entities. The main entity layout parameters include rack group position coordinates, shuttle travel path position coordinates, shuttle pick point position coordinates, buffer zone position coordinates, lift position coordinates, first floor conveyor line position coordinates and second floor conveyor line position coordinates. Next, taking the calculation of the position coordinates of the rack group as an example, the method of determining the entity position parameters is explained.

In order to arrange the racks, it is necessary to define the coordinates of a certain vertex of the racks (the dot of the lower left end of the rack is the end point (shown by the red dot in Figure 3), rack length, rack width and transverse and longitudinal roadway width. Through the above information, the rack layout plan can be determined. Set the top left vertex of the lowest rack of the first row and the first column (the rack shown in No. 1 in the figure) as the origin point(0,0). R_x represents the X coordinate value of the rack, R_y represents the Y coordinate value of the rack. i_1 is the row of racks. j_1 is the row of racks.

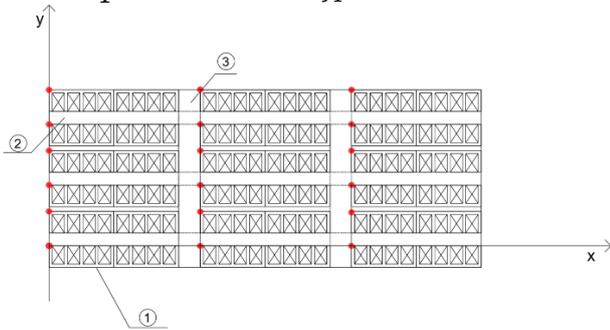


Figure 3. Schematic diagram of rack group
 ①rack group ② lateral track ③ longitudinal track

$$R_x(j_1) = (j_1 - 1) * \frac{r}{t+1} * b_1 + (j_1 - 1) * w_1 \quad (1)$$

$$R_y(i_1) = \begin{cases} (2 * r_1 + w_2) * \frac{(i_1-1)}{2}, i_1 \text{ is odd} \\ (2 * r_1 + w_2) * \frac{(i_1-2)}{2} + r_1 + w_2, i_1 \text{ is even} \end{cases} \quad (2)$$

2.4 Operation logic model

2.4.1 Main entity connection logic

In order to realize the normal circulation of goods / the storage cases, the operation logic needs to be set. The

realization of the operation logic can depend on the connection between entities or the custom circulation logic (process flow)

The entity connection diagram from stock-in to stock-out is shown in Figure 4. The method of entity connection includes "A" connection and "S" connection, "A" connection is to connect the input / output port of an entity with the output / input port of another entity, and "S" connection is an intermediate port of an entity and input port of the transporting entity. For example, "A" is connected between the stock-in conveyor line and the buffer zone, and "S" is connected between the stock-in conveyor line and the lift, that is, the lift is used as the intermediate handling tool for the flow of goods.

Since the number of entities created may be different, the number of connected entity lines is different. The single connection mode is fixed, and the connection mode is as follows: The branch lines of the first-tier and second-tier stock-in conveyor lines are connected with the corresponding lifts by "S"; The branch lines of the first-tier and second-tier stock-in conveyor lines are connected with the buffer zone of each tier of the corresponding aisle by "A"; There are about hundreds of connections in total.

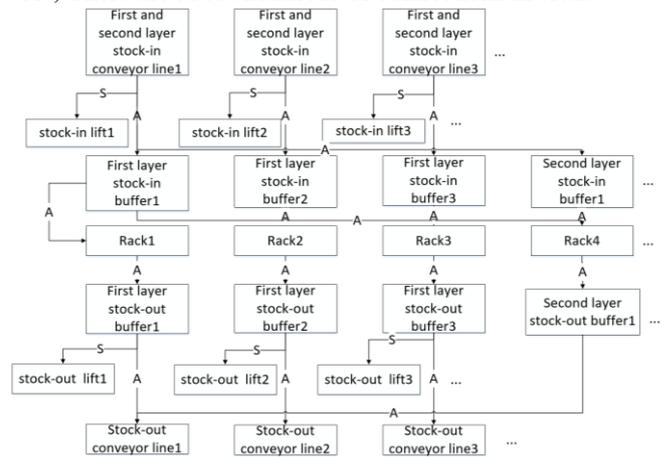


Figure 4. Entity connection logic

2.4.2 Path connection logic

The four way shuttle path network consists of straight paths and control points. A total picking point, a total control point, and a picking point corresponding to the cargo grid must be set for each floor of each aisle. Therefore, the number of picking points required for each tier of each aisle is the number of cargo grids plus two. The connection logic between the picking point of each aisle and other entities is shown in Figure 5.

The total picking point is connected with the stock-in buffer zone and the stock-out buffer zone. The total control point is connected with the shuttle and the picking and discharging point corresponding to the cargo grid position in the aisle. The connection mode of each tier of each aisle is the same, with about thousands of connecting lines.

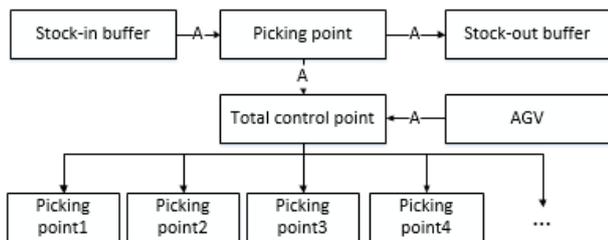


Figure 5. Path connection logic

3 Design and implementation of automatic modeling for FWSBS/RS based on Flexsim

Based on the idea of parametric modeling, this chapter puts forward the overall framework of the development of the automatic modeling system, and defines the functional elements of the system: interface parameter input, physical model creation, logical setting, operation parameter statistics, as well as the connection between various functions and key technologies of simulation modeling with each function.

3.1 System total framework

The total framework of four way shuttle automatic modeling and simulation system based on Flexsim is created is shown in Figure 6.

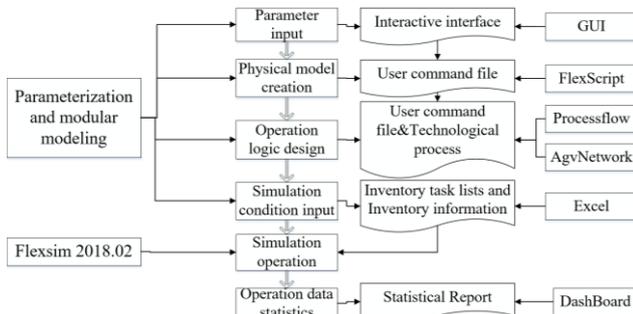


Figure 6. The framework of the system

The automatic modeling system of four-way shuttle is composed of five modules: system parameter input, physical model creation, logic setting, simulation condition input and operation parameter statistics. The system has the functions of parameterization, automation and modularization. The structure of the system is shown in Figure 7.

3.2 System implementation

3.2.1 Interface design based on GUI

The interface design is using the GUI design module of Flexsim to design a parameter input interface convenient for users. The interface of parameter input includes: shelf parameter input interface, storage and transportation unit parameter input interface, track layout parameter input interface, shuttle parameter input interface, hoist parameter input interface, conveying system parameter

input interface, and picking system parameter input interface.

Taking the interface of the picking system as an example, the interface design and structural layout are performed first, and the interface structure is arranged with a GUI design tool of Flexsim. Secondly, the input parameters are dynamically linked to global variables for subsequent invocations. Finally, relevant diagrams are inserted.

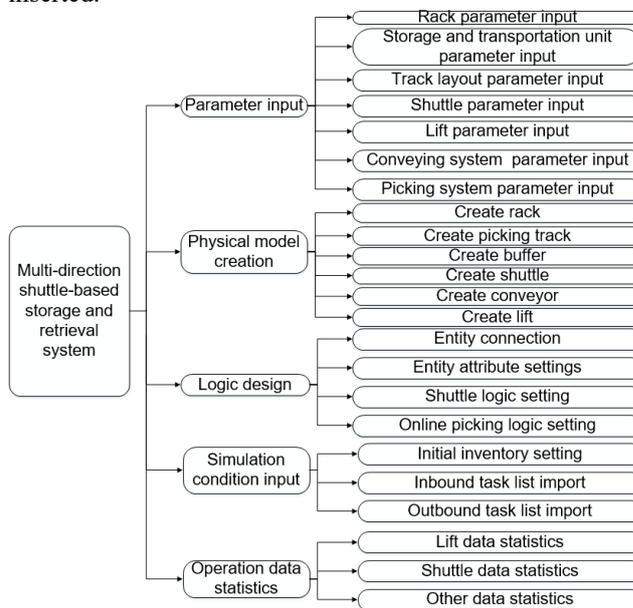


Figure 7. The structure of the system

The dynamic linking of parameters and the insertion of pictures need to be implemented using a Model Tree. The tree file is composed of various nodes, including 5 types of nodes: Standard node, Treenode, Attribute / Variable node, C++ node, Flexscript node. The parameter dynamic link is implemented as follows: find the tree node corresponding to the input box, insert treenode with the proprietary attribute "hotlink", and set the link path of "hotlink", for example: "the number of picking stations" corresponds to the global variable "PickingtableNum". Therefore, the link path is set to "MODEL: / Tools / GlobalVariables / PickingtableNum / Data". The method of inserting the diagram is the same as the dynamic linking of the parameters. The command used is "bitmap". The schematic diagram of the picking system interface is shown in Figure 8.

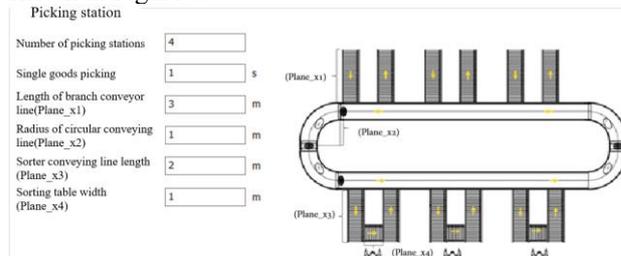


Figure 8. The schematic diagram of the picking system

3.2.2 Physical model creation based on Flexscript

Create a physical model, that is, create an entity in Flexsim. Use Flexscript language in conjunction with developer commands to implement code-driven modeling. Write the

corresponding code to a user command and call the user command to complete the automatic entity creation process.

Taking the creation of the rack as an example, using flexscript, a high-level computer language, to create a rack system of corresponding structure and size. Firstly, identify the required parameters, including: Row, Bay, Tier, Rowwidth, Baywidth, AisleWidth, LevelHeight, etc. Secondly, because there is no rack with lateral tracks for the four-way shuttle system in Flexsim, using multiple groups of basic racks to build the entire rack system requires the creation of multiple basic racks. Use the "createinstance" command combined with for loop and if conditional statement to create multiple groups of rack with specified size. The coordinates of each rack position depend on the number of columns, rows, aisle width, and lateral track width.

3.2.3 ProcessFlow-based operation logic setting

Logical setting is more theoretical and abstract than physical model. It pays more attention to the logical relationship between entities and provides a detailed description for system design. In this system, logical settings mainly include: entity connection, entity property settings, logic settings of picking, logic settings of online picking, and data import.

(1) Entity connection

The entity connection mainly includes: a layer of storage and conveying line connection to the lift, connection of the lift to the buffer zone, connection of the buffer zone to the shelf, connection of the shuttle to the control point, and connection of the picker to the conveyor line of the sorting station. There are tens of thousands of connection lines.

By setting its connection logic, it reduces the shortcomings of manual and manual connection workload, which is prone to errors, and facilitates the implementation of modeling.

The entity connection mode includes "A" connection and "S" connection. "A" is to connect the input / output port of the entity with the output / input port of another entity. "S" is to connect the intermediate port of the entity with the input port of the handling entity.

(2) Entity attribute setting

The setting of entity attributes includes: the modification of temporary storage area capacity, shuttle parameters, lift parameters and conveyor parameters.

The parameter modification of all entities is also based on the Model Tree. The capacity of the temporary storage area, the maximum speed, acceleration and deceleration of shuttle, the lift, and the conveyor are all entity data, so the change method is the same.

First, find the corresponding tree node and change the value of it. Take the change of the capacity of the temporary storage area as an example:

"area,treenodenode1=variables(queue).subnodes["maxcontent"];" (find the entity parameters that need to be changed, such as "maxcontent")

"node1.value=1;" (change the value of parameter)

(3) Shuttle control logic setting

Entity task actuator is used of Flexsim as a shuttle, AGV module is used to set the running track and controlpoint of the shuttle, and process flow is used to set in and out logic of the shuttle. By using the set process flow, the shuttle entity can be added to the process flow, that is, to realize automatic logic setting.

1) Create running track of the shuttle

Path in the AGV module is used first to set the path in the aisle. The path setting is related to the layout of the rack. Therefore, the modeling of this part changes with the layout of the rack. The position of the picking point is the midpoint of the corresponding cargo position in the aisle. Use this path setting to specify running trajectory to conform to the reality.

2) Logic setting of stock-in and stock-out

As shown in Figure 9, for the target system, all shuttles implement the same process flow to reduce the amount of program design. When defining the operation logic of the shuttle, only add the corresponding shuttle entity into the process flow.

The logic process flow of stock-in and stock-out can be designed in advance, the process flow can be saved in the program. The number of shuttles is parametric data, so it has uncertainty factors. If set the created shuttles as the same group, and then add the group into the process flow, the logic realization of all shuttles of stock-in and stock-out can be satisfied.

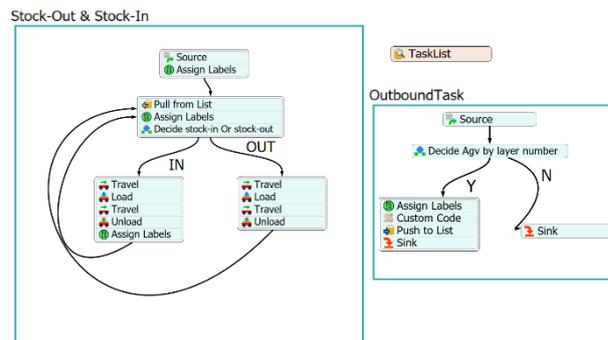


Figure 9. Logic setting of stock-in and stock-out

(4) Online picking logic setting

The realization of the sorting logic is based on DecisionPoint and ProcessFlow. It is the same as the stock-in and stock-out process, adding the picker entity to the process after the basic picker process is established.

The process flow is shown in Figure 10. After the sorting station finishes sorting the goods, determine whether the storage case is empty. If it is empty, recycle the case. If it is not empty, continue to operate until the last sorting station completes the operation. When returning to the warehouse, DecisionPoint is also set in the process of returning to the warehouse to judge the aisle where the bin is located, and the storage case is transported to the corresponding transport line to complete the sorting and returning operation of the entire task.

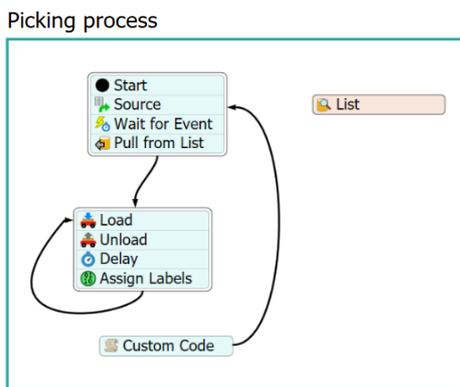


Figure 10. Logic setting of picking

(5) Simulation condition setting

Data import includes initialization inventory import, stock-in task import, stock-out task import. The import is based on the GUI and Excel, which can directly import Excel tables into the system as stock-in and stock-out tasks.

3.2.4 Dashboard-based parameter statistics

The dashboard module is a data statistics module. During the operation of the model, the charts and statistics data can be viewed in the dashboard window, and the parameter differences of multiple entities can be clearly compared, such as the statistical comparison of the operation state of the lift. This system collects statistics on the running status of all lifts and all shuttles. The statistical parameters include no-load time, no-load ratio; full-load time, full-load ratio; idle time, idle ratio; total loading time, total loading time. In addition to equipment statistics, it also includes: warehousing order statistics and returning tasks statistics.

In the Dashboard module, use the code to add the required statistical entities to the pie chart, and run the simulation model to automatically get the statistical parameters. Take the four way shuttles status statistics as an example: First, a shuttle entity group is needed to be created. Because the number of shuttles created each time is different, all shuttles are added to Group 2 to form a group, and then add Group2 to the statistics table, and it will automatically calculate the time and proportion of each state according to the status of the shuttle, such as: no-load time, no-load ratio, etc.

4 Application of automatic modeling for FWSBS/RS.

In this section, an example is used to verify the effectiveness of FWSBS/RS.

4.1 Experimental scheme

With the four way shuttle automatic modeling system, a 8 rows * 80 columns * 11 layers system is created. The storage and transportation unit is the storage case, there are four horizontal tracks in total. there are two shuttles in each layer, and four picking workbench is set up. According to the operation process

in 2.1.2, set the stock-in / stock-out and online picking process, all system parameters are shown in Table 2.

Table2. System parameters

Parameter name	Value	Unit	Parameter name	Value	Unit
Row	8	Row	MaterialsWidth	0.1	mm
Bay	80	Bay	MaterialsHeight	0.05	mm
Tier	11	Tier	TrackNum	4	individual
RowWidth	1.25	m	HorAisleWidth	1	m
BayWidth	0.54	m	AGVNum	2	set/layer
LevelHeight	0.5	m	AGVMaxSpeed	2	m/s
Conveyor_x1	4	m	AGVAcceleration	1	m/s ²
Conveyor_x2	15.5	m	AGVDeceleration	1	m/s ²
Conveyor Width	1	m	AGVLoadTime	1	s
Conveyor Speed	1	m/s ²	AGVUnloadTime	1	s
Conveyor Num	4	individual	EleMaxSpeed	5	m/s
ContainerLength	0.6	mm	EleAcceleration	7	m/s ²
ContainerWidth	0.4	mm	EleDeceleration	7	m/s ²
ContainerHeight	0.3	mm	EleLoadTime	1	s
Materials Length	0.15	mm	EleUnloadTime	1	s

4.2 Model creation

Create a model by entering parameters in the system interface, which mainly include: rack system parameters, conveyor system parameters, operating equipment parameters. After setting the parameters, the Flexscript user command is called to automatically create the model. The model is shown in Figure 11.

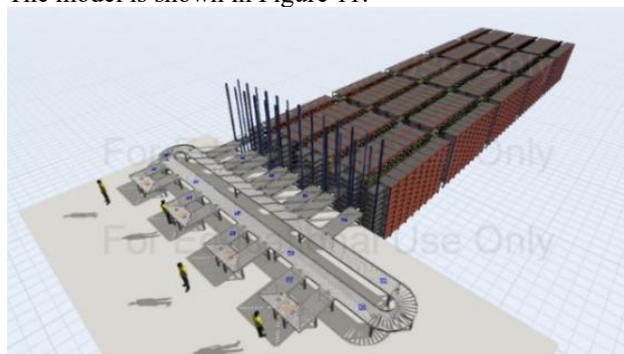


Figure 11. The model

4.3 Work task import

Work task import is to create an Excel import interface with GUI and connect with Excel importer of Flexsim in

order to import excel tables. Work tasks include the initial inventory list, stock-in task list and stock-out task list.

There are 1760 initial inventory information in the initial inventory table. Table 2 is the field information of the inventory table, where "Row", "Bay" and "Tier" represent the row, column and layer. Respectively, "ItemQ" represents the quantity of goods stored.

A total of 209 stock-in tasks are created in the stock-in task list. Table 3 is the information of the stock-in task table, where "ItemQ" represents the quantity of goods to be warehoused.

A total of 293 stock-out tasks are created in the stock-out task list. Table 4 is the information of the stock-out task table, where "SQ1" represents the quantity of goods to be picked by the first sorting table, "SQ2" represents the quantity of goods to be picked by the second sorting table, and so on.

Table3. The initial inventory list

Time	Name	Quantity	Row	Bay	Tier	Item Q	TaskType
0	TI201901001	1	1	1	1	20	1

Table4. Stock-in task list

ArrivalTime	SKU	Quantity	Row	Bay	Tier	TaskType	Item Q
0	TI201910001	1	5	9	3	0	12

Table5. Stock-out task list

Time	Name	Row	Bay	Tier	Item Q	Task Type	SQ1	SQ2	SQ3	SQ4
1	TI201901012	1	45	1	20	1	3	0	4	4

4.4 Data statistics

After creating the model and importing the warehousing task lists, a simulation experiment is performed, which completes the tasks in order according to the arrival time of the goods, that is, the warehousing operations meet the FCFS (first come first service) principle. When there is an inventory return task, the inventory return task takes precedence. The simulation results are as follows.

It took 3192 seconds to complete all tasks. The utilization ratio of each shuttle is shown in Figure 12. Task executors 1 to 11 represent the first shuttle from the first floor to the 11th floor, and task executors 12 to 22 represent the second shuttle. It can be seen from the statistics table of the shuttle that the stock-in and stock-out tasks of each layer are relatively balanced. The state statistics of each lift are shown in Figure 13. Lifts 1, 3, 5, and 7 represent the lifts for stock-in. Lifts 2, 4, 6, and 8 represent the lifts for stock-out.

Comparing the state diagram of the shuttle with the state diagram of the lift, it can be seen that the capacity utilization rate of shuttles at all layers is 57%~71%, which

indicates that the equipment utilization rate is high; the capacity utilization rate of lifts is between 20% and 30%, which indicates that the equipment utilization rate is low. Therefore, the system bottleneck exists in the shuttle. The number of shelves or the number of shuttles can be increased to match equipment capabilities.

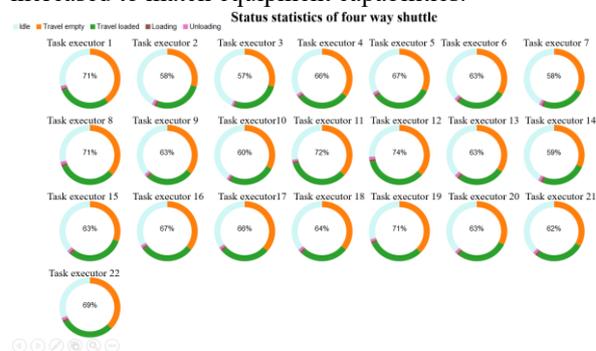


Figure 12. Statistical diagram of shuttle status

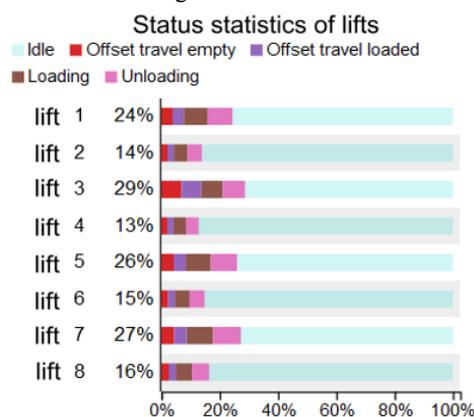


Figure 13. Statistical diagram of lift

5 Conclusion

Based on Flexsim simulation software and flexscript programming language, an automatic modeling for FWSBS/RS is built in this paper, which greatly reduces the difficulty of using Flexsim software and shortens the modeling time. For FWSBS/RS, the automatic modeling platform can be used to quickly build simulation model, analyze the system operation capability under different configuration structure, and verify the influence of different factors on the system capability.

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