Development of Material Control System for Next Generation Liquid Crystal Glass

HASEGAWA Fumio : Senior Researcher, Control System Project Department, Products Development Center, Corporate Research & Development
OKAJIMA Kazumichi : Control System Project Department, Products Development Center, Corporate Research & Development
SHIDA Michinori : Control System Project Department, Products Development Center, Corporate Research & Development
MURAMATSU Yuya : Electrical System Department, Products Development Center, Corporate Research & Development
NAKAMA Mitsuaki : Manager, Quality Assurance Department, Logistics Systems Operations

The material control system (MCS) that controls the transportation between process equipment and stockers is indispensable to improve productivity because the process flow is complex and production is high in the LCD production line. It is difficult to transfer the LCD glass with the cassette transfer method, as the LCD glass substrate is becoming larger. Therefore, a single substrate transfer method to transport individual LCD glass substrate is needed. IHI has developed the MCS with optimum cassette transfer function and single substrate transfer function for the TFT array process of the LCD glass production line. The system outline of the developed MCS and the main features are introduced.

1. Introduction

In recent years, conventional cathode-ray tube televisions have begun to be replaced by liquid crystal and plasma televisions. Manufacturers of electric appliances are actively investing in new factories. Thus far we have been delivering physical distribution equipment and systems mainly for liquid crystal manufacturing lines. A liquid crystal manufacturing line consists of four main processes; (1) an array process to make a thin film transistor (TFT) array circuit on a glass substrate, (2) a color filter process to generate the three primary colors, RGB, on another glass substrate, (3) a cell process to stick the completed array substrate and the color filter substrate together and inject liquid crystal, and (4) a module process to integrate a driver (driving circuit), backlight and other components into the completed cell to make a display. (1)

The TFT array process flow consists of four or five cycles of (1) a washing process, (2) a photolithography process, (3) an etching process, (4) an inspection process, (5) a repair process, and other processes. The production flow is complicated and the production volume is large. Efficient production requires a material control system (hereinafter called MCS) which controls transfers between process devices and glass substrate stockers in a TFT array process.

As the average liquid crystal television gets larger (mainstream television sets are currently 30 to 40 inches), the glass substrates used for liquid crystal displays must also get larger. Because of this, the conventional cassette transfer method that transfers glass substrates in cassettes is approaching its limit, and the single substrate transfer method, which transfers each glass substrate individually, is being considered in its stead.

We developed the MCS that has a function for controlling cassette transfer and single substrate transfer for TFT array processes on liquid crystal manufacturing lines. We also established a technology to verify MCS functions and capacity by using a physical distribution simulator, and verified the functions and capacity of the MCS.

2. Development of the MCS

2.1 System configuration

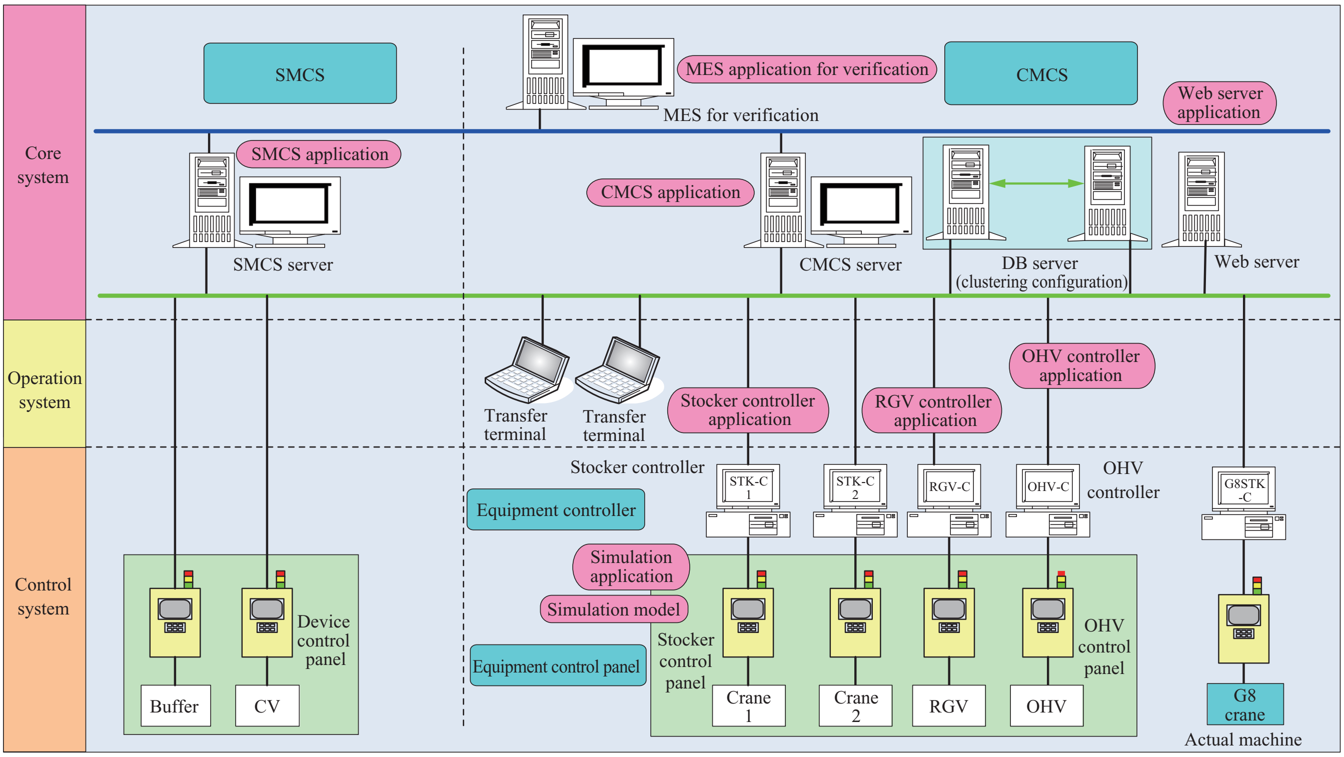
The MCS is a computer system that receives instructions for transferring glass substrates from a manufacturing execution system (hereinafter called MES) in a factory and controls transfers of glass substrates from the current process to the next process by using cranes, vehicles, conveyors and other transfer devices in the factory. The MES is a computer system that performs (1) production planning, (2) liquid crystal manufacturing process control, (3) process device control, and (4) lot control.

The MCS we have developed consists of (1) the MCS that controls cassette transfer (hereinafter called CMCS), (2) the MCS that controls single substrate transfer (hereinafter called SMCS), (3) equipment controllers that control individual transfer facilities, and (4) equipment control panels that control transfer devices. **Figure 1** shows the system configuration.

2.2 Cassette material control system (CMCS)

2.2.1 Main functions

This section describes the main functions of the CMCS; the transfer control function, the inventory management



(Note) CV : Conveyer
STK-C : Stocker crane controller
RGV-C : Rail guided vehicle controller
OHV-C : Over head vehicle controller
G8STK-C : Stocker crane controller of G8

Fig. 1 MCS system configuration

function, and the equipment control function.

2.2.1.1 Transfer control function

The transfer control function mainly consists of three types of processing; transfer route search, transfer command creation, and transfer command execution.

Transfer instructions transmitted from the MES to the CMCS designate a starting point, a destination, and a cassette ID in a From-To format, for example, "Transfer cassette ID001 from process A to process G."

To transfer the cassette from process A to process G, the transfer route search process searches for the fastest route to the destination from among several transfer routes. **Figure 2** shows a transfer route example.

After a transfer route is determined, the transfer instruction creation process creates transfer instructions for cranes, vehicles, and other transfer facilities on the transfer route. The created transfer instructions are transmitted to individual transfer facilities by the transfer instruction execution process. It is possible to cancel the transfer or change the destination on the way. The transfer states are monitored and displayed in real time. **Figure 3** shows a tracking monitor screen that displays transfer states.

2.2.1.2 Inventory management function

This function controls the positions and IDs of cassettes being transferred and those stored in automatic stockers,

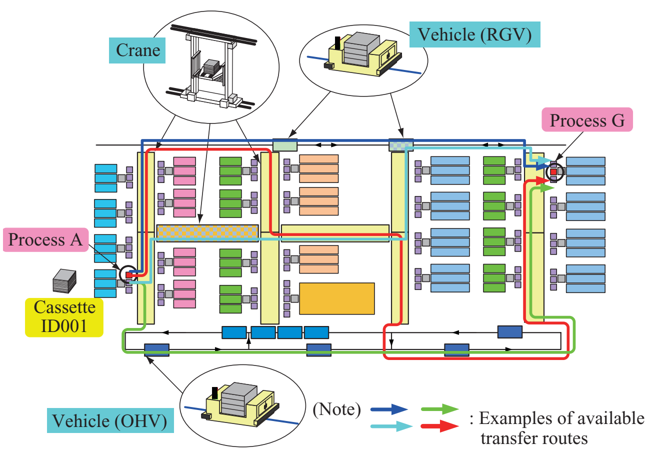


Fig. 2 Transfer route

Fig. 3 Tracking monitor

and the number of empty cassettes stored in automatic stockers. **Figure 4** shows the entire-line inventory management monitor and **Fig. 5** shows the inventory management monitor for buffer.

2.2.1.3 Equipment control function

This function controls the working states and operating conditions of cranes, vehicles, and other transfer devices, glass substrate stockers and ports before devices.

Equipment working states can be checked on the tracking monitor screen.

2.2.2 Features

2.2.2.1 Optimum transfer route algorithm

To improve the production efficiency of a factory, it is important to reduce transfer time between processes and improve transfer efficiency.

The CMCS has an algorithm that searches for a route to reach the destination in the shortest time by ascertaining equipment states in real time and taking into account the states of process devices and transfer devices in the factory at the moment. **Figure 6** shows an example of a search by the optimum transfer route algorithm.

2.2.2.2 High availability

For the most part, liquid crystal lines are operated continuously, 24 hours a day, 365 days a year, only stopping production for several days of maintenance work. If a line is stopped due to system trouble, it has

Fig. 4 Inventory management monitor

Fig. 5 Inventory management monitor for buffer

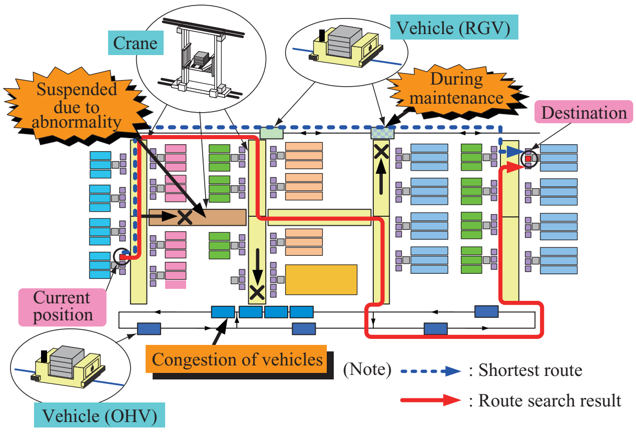


Fig. 6 Example of search result of the optimum transfer route algorithm

a significant impact on production. Therefore, it is important to improve system availability.

Availability of a computer system is generally measured in terms of the mean time between failures (MTBF) and the mean time to repair (MTTR) of the system. In the CMCS, the system control process monitors the operation of each process. When it detects a process has gone down, it automatically restores that process. The system is equipped with this function to minimize the frequency and time of system stoppage and improve the availability. **Figure 7** shows the concept of process monitoring method.

2.2.2.3 Flexibility of system changes

On a liquid crystal manufacturing line, equipment and ports may be added or changed in order to change manufacturing processes and improve the manufacturing capacity. Such system additions and changes should be able to be done without stopping the line.

The CMCS collectively controls system data in a database server and the communication between processes also takes place via the database, rather than directly between processes. Such architecture allows processes to be changed or added without stopping the system when a change or addition of equipment or

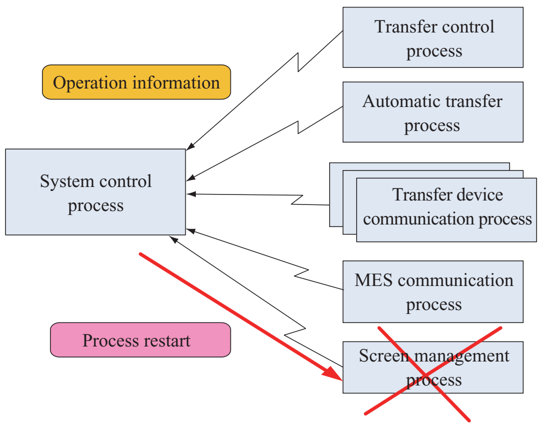


Fig. 7 Concept of process monitoring

process maintenance is required.

2.2.3 Optimum transfer route algorithm

2.2.3.1 Outline

Optimum route search on a liquid crystal line has the following issues:

(1) The process flow is complicated and contains many processes, so it is virtually impossible to register all transfer routes in the system in advance. It is necessary to determine a transfer route for each transfer.

(2) There are two or more transfer devices that connect processes. Several transfer routes are available to reach the same destination. It is necessary to select the optimum transfer route from among several routes.

(3) A process may have devices that are suspended due to trouble or for maintenance, making some routes unavailable or causing congestion in some routes due to concentrated transfer instructions. It is necessary to determine a transfer route that avoids such routes.

In short, it is necessary to have an algorithm that takes the states of process devices and transfer devices in a factory into consideration in real time during transfer and then selects the route from among several that will reach the destination in the shortest time.

Therefore, we developed an algorithm that determines routes and transfer devices that will minimize transfer time at each passing point on the transfer routes. It selects the optimum route and devices depending on the states of the line, and if a route has a device that is out of order, it searches for a new optimum route in order to complete the transfer without stopping. It can also avoid any route where congestion occurs.

Figure 8 shows the process flow of the optimum transfer route algorithm.

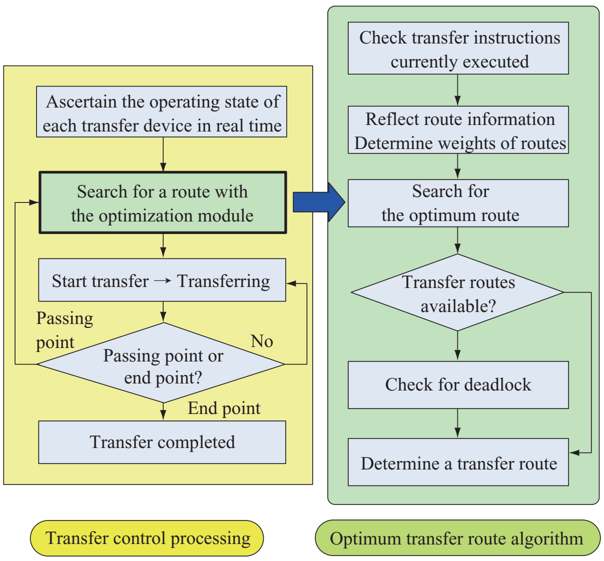


Fig. 8 Process flowchart of the optimum transfer route algorithm

2.2.3.2 Optimum transfer route algorithm

(1) Modeling of transfer

Build models of cranes, vehicles, transfer units, and other transfer devices and cassette buffer stockers in charts. **Figure 9** shows an example of the layout and modeling. A chart consists of points and branches that connect adjacent points. Branches have directions that indicate the directions in which cassettes can be moved.

(2) Determining the weight of a route

Define weights for all branches in a model. Select the route that minimizes the sum of the weights of the branches as the optimum route from among the many transfer routes that connect a starting point and a destination. Weight each branch based on the time required for a cassette to go through the branch, and the weight is increased as a function of the volume of transfer. The volume of transfer is expressed as the number of transfer instructions being executed and transfer instructions to be executed in a transfer route. Increased weight means that the route is congested and requires a longer time to complete a transfer. In the example shown in **Fig. 10**, the lower route is the optimum transfer route if $W_U > W_D$.

As shown in the example in **Fig. 11**, when transfers are concentrated in a particular route, the weight of the route increases due to the weight

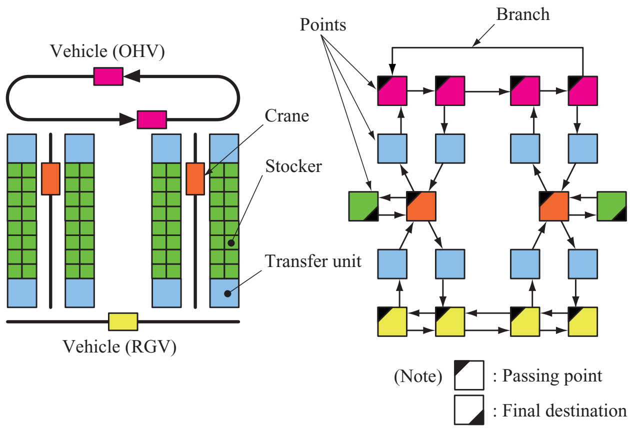


Fig. 9 Layout and model

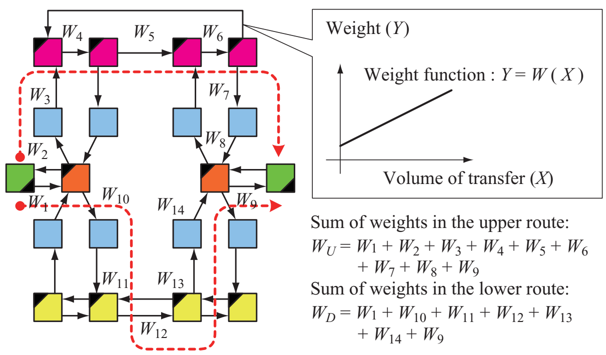


Fig. 10 Model and weighting

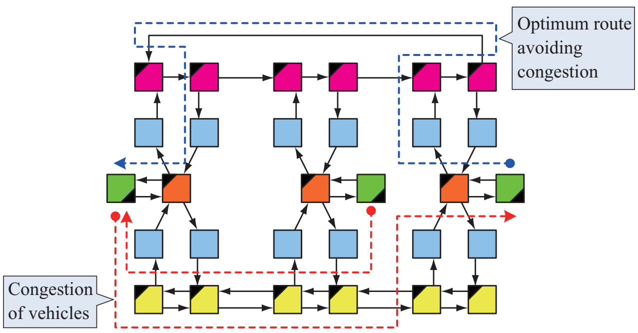


Fig. 11 Optimum transfer route to avoid congestion

function. As a result, another route with a smaller sum of weights is determined to avoid congestion.

It is possible to make a particular route unavailable when a device is suspended for maintenance by increasing the weight of the route sufficiently as shown in **Fig. 12**.

(3) Check for deadlock

For example, as **Fig. 13** shows, when a transfer of cassette ID1 from point A and a transfer of cassette ID2 from point B are executed at the same time, both cassettes have no space available at the next transfer point and cannot be transferred. Such a state is called deadlock.

To prevent deadlock, the system checks whether or not there is space available for transferring a cassette at the next transfer device at and the final

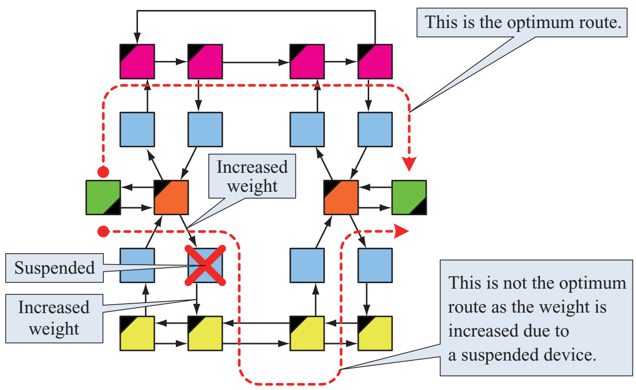


Fig. 12 Optimum transfer route to count equipment status

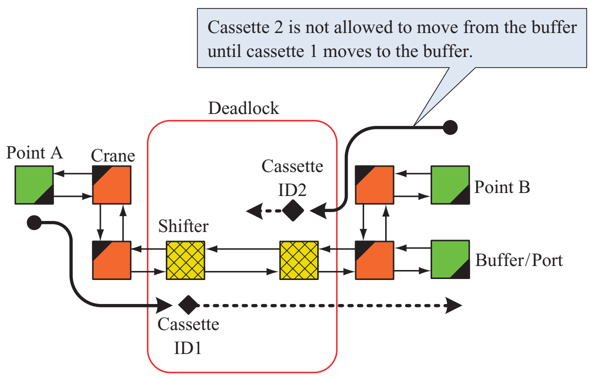


Fig. 13 Deadlock condition

destination and determines the order of transfer (**Fig. 14**).

2.3 Single substrate material control system (SMCS)

In the conventional cassette transfer method, all cassette transfer instructions are transmitted from the MES which is a higher-order system of the MCS. If all transfer instructions are received from the MES for each substrate in the single substrate transfer method, the following problems occur:

(1) The volume of communications between the MES and MCS becomes huge.

(2) The MES needs to control tracking of each substrate which causes the volume of processing to increase.

Therefore, we have developed a mechanism that allows the SMCS to receive process information and sort information for each lot from the MES and utilize the information to control the flow of glass substrates in a single substrate transfer process without receiving any transfer instruction from the MES. **Figure 15** shows the SMCS system configuration.

2.3.1 Assumed layout

In comparison to the cassette transfer method, the single substrate transfer method is more effective when it is applied to processes with complicated substrate flow. Our development targeted inspection processes and repair processes where defects are repaired after inspection (hereinafter called inspection and repair processes).

In inspection and repair processes, substrates are divided into those to be transferred directly to the next process and those to be repaired before being transferred to the next process, depending on inspection results (this is called a branch point). The next inspection process receives substrates that have passed inspection in the previous process and substrates that have been repaired (this is called a confluence point). As the number of inspection processes increases, the number of branch and confluence points increases and the flow of glass substrates becomes more complicated.

Figure 16 shows the layout of a single substrate transfer line that we assumed as the basis for development of the SMCS.

The glass substrate flow is outlined below:

(1) Glass substrates are placed into a cassette and transferred to a carry-in port in the single substrate transfer process.

(2) The loader/unloader device carries out each glass

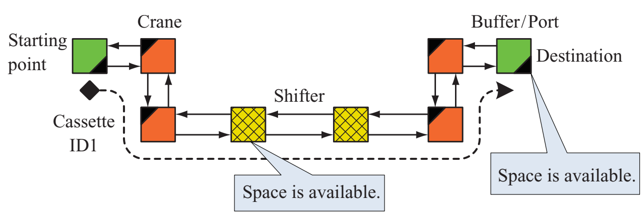
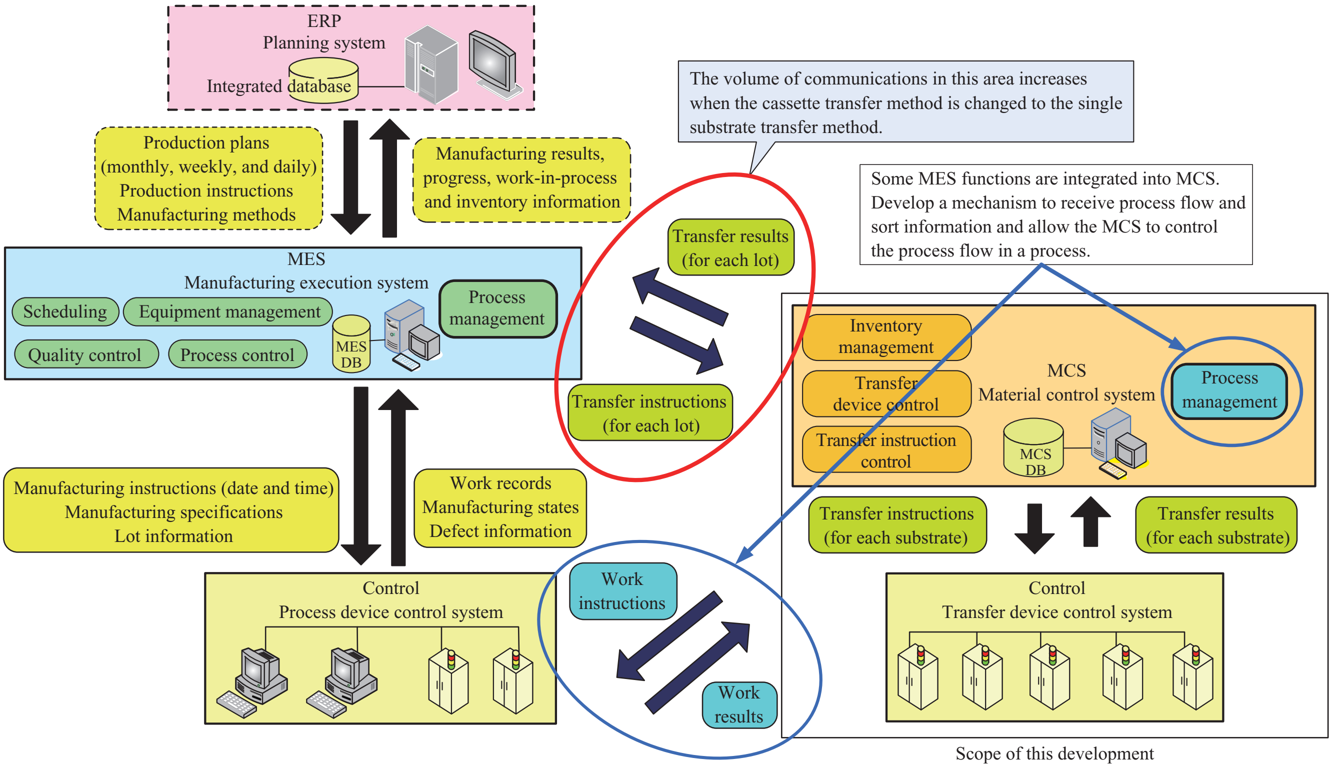
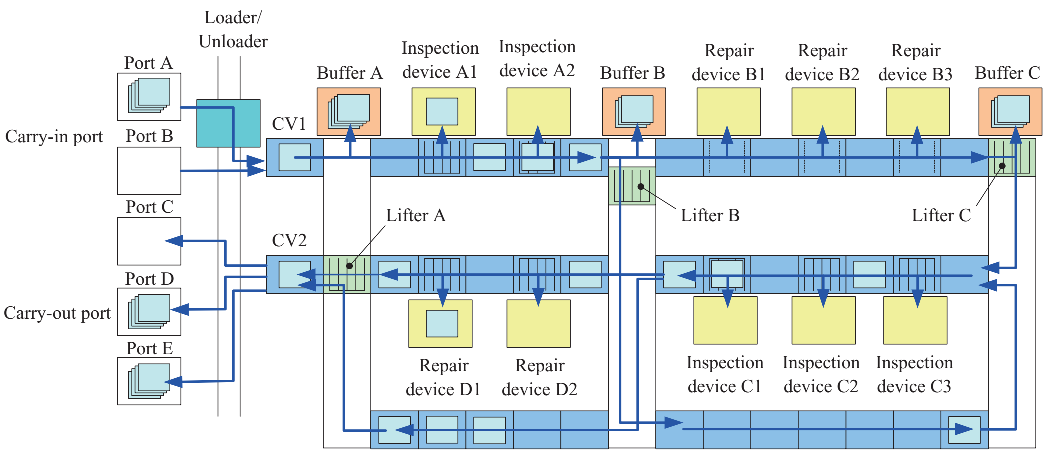


Fig. 14 Checking for free space of equipment



(Note) ERP : Enterprise Resource Planning

Fig. 15 SMCS system configuration



(Note) CV : Conveyor

Fig. 16 Layout for single substrate transfer line

substrate and transfers it to the single substrate transfer process.

(3) Each transfer device transfers the glass substrates to each process device (inspection or repair device) according to the process flow.

(4) If all process devices in the next process are occupied for processing, the glass substrates are temporarily transferred to a buffer located in front of the device.

(5) After processing, the substrates are transferred to different points, depending on the processing results. For example, a substrate that has passed the processing inspection at inspection device A is transferred to inspection device C, while a substrate that has been rejected is transferred to repair device B.

(6) The glass substrates are transferred to cassettes at specified carry-out ports, depending on the processing results at each process device. **Figure 16** shows the flow of glass substrates with blue arrows.

2.3.2 Main functions

The SMCS has the following main functions; (1) a transfer control, (2) an inventory management, and (3) an equipment control. The inventory management and equipment control functions are basically the same as those for the CMCS, so this section describes the transfer control section only. **Figure 17** shows an example of the SMCS monitor.

The transfer control function consists of (1) process control processing, (2) dispatch processing, (3) optimization logic processing, and (4) transfer device control processing. Dispatch here means the processing of assigning work commands generated based on transfer instructions to transfer devices.

(1) Process control processing

Determines the next destination and makes transfer instructions based on process information and sort information received from the MES and results of processing at process devices.

(2) Dispatch processing

Makes work commands and divides transfer instructions generated in the process control section into work units that can be processed by the transfer device control section.

(3) Optimization logic processing

Determines the order of processing transfer instructions and destinations in consideration of the current positions and stand-by time for transfer instructions, process device operating states, buffer states, and substrates and transfer device states in a process.

(4) Transfer device control processing

Outputs transfer commands to control panels of individual transfer devices based on work commands generated in the dispatch section. Also manages the states of individual transfer devices, process devices, and buffers and substrate tracking information. **Figure 18** shows the SMCS operation block.

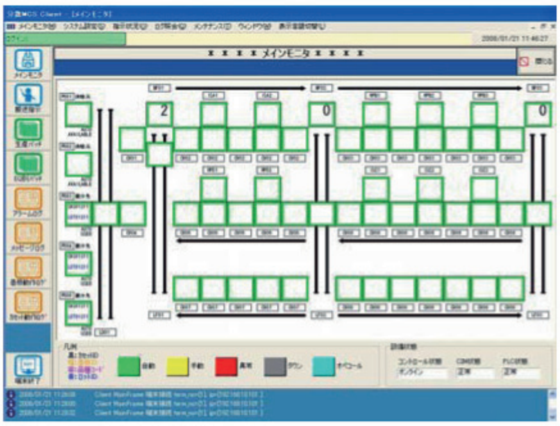


Fig. 17 SMCS monitor

2.3.3 Features

2.3.3.1 Optimization dispatch algorithm

We developed an algorithm that improves the efficiency of glass substrate flows at branch and confluence points where transfer instructions are centralized in a single substrate transfer process. Single substrate transfer processes may have various line forms, and we created the algorithm by combining simple rules independent from the layouts.

2.3.3.2 Process flow control

The SMCS receives process information and sort information from the MES and controls process flows of glass substrates that were conventionally executed by the MES. **Table 1** gives description about process

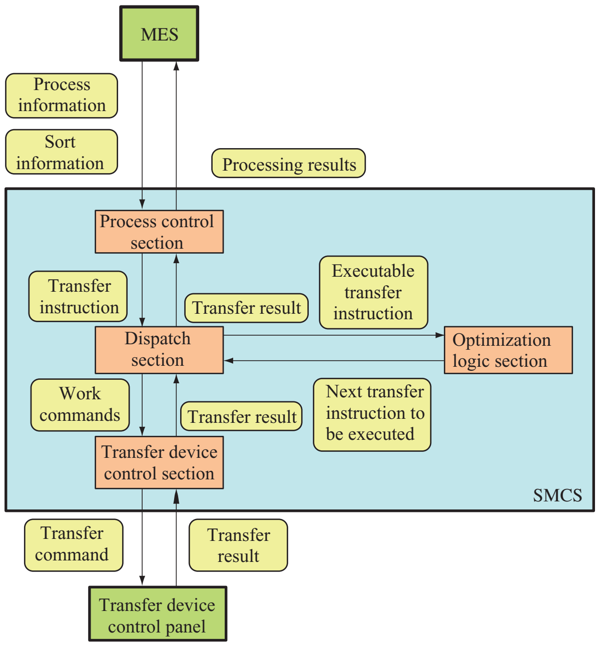


Fig. 18 SMCS operation block

Table 1 Process information and sort information

Item	Description	Example
Process information 1	Information on which process a substrate processed by a process device is to be transferred next (Transferred to different destinations depending on processing results).	• Product successfully processed by process device A → Transferred to process device B • Product not successfully processed by process device A → Transferred to process device C
Process information 2	Information on processing rules for each lot	• Lot A is to be processed by process device A • Lot B is not to be processed by process device A
Process information 3	Recipe information for processing with a process device	• Lot A is to be processed based on a recipe • Lot B is to be processed based on a recipe
Sort information	Information as to which carry-out port a substrate is to be transferred depending on the processing results of a process device.	• Product successfully processed by process device C → Transferred to port 3 • Product not successfully processed by process device D → Transferred to port 4

information and sort information.

The SMCS creates a process flow for each glass substrate based on that information in order to control it.

2.3.4 Optimization dispatch algorithm

2.3.4.1 Outline

Glass substrates are transferred from several directions at branch and confluence points in a layout, and transfer instructions are concentrated at these points. The dispatch algorithm is intended to improve the efficiency of glass flows at these branch and confluence points by optimizing the processing order of transfer devices to which transfers are concentrated.

Improved glass flow efficiency reduces the glass substrate transfer time and minimizes the time from carrying a glass substrate into a process to carrying it out. **Figure 19** shows branch and confluence points to which transfer instructions are concentrated.

2.3.4.2 Process flow

(1) Checking states in a process

Ascertain the operating conditions of process devices and conveyors and the congestion states of glass substrates in a process.

(2) Making a list of executable transfer instructions

Get information on each substrate and device in the process from a list of transfer instructions currently issued in the process, check whether or not each transfer instruction is executable, and extract executable transfer instructions.

Figure 20 shows an example of executable transfer instructions. Green substrates in the figure correspond to executable transfer instructions. Specifically, substrates waiting for transfer in buffers and a substrate first in line for a lifter are executable. Note that transfer instructions for substrates in buffer C and substrates suspended first

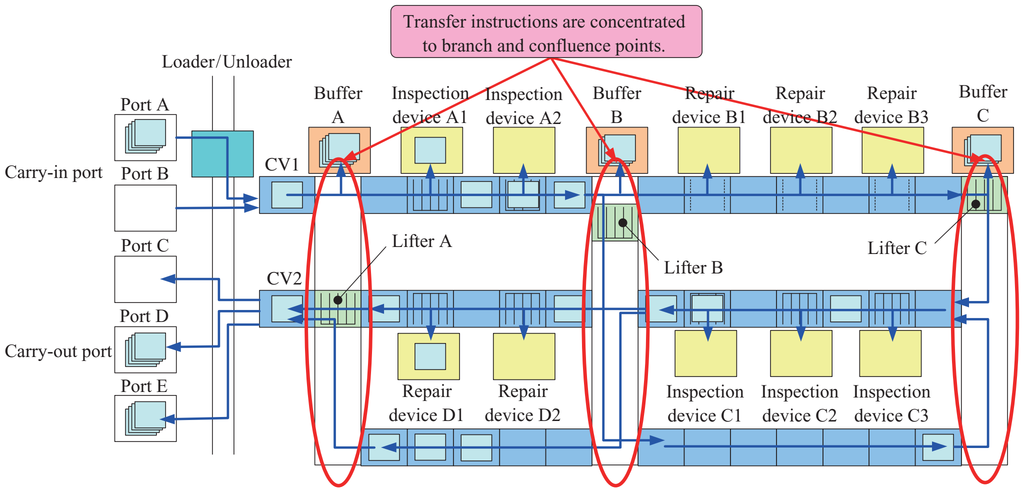


Fig. 19 Branches and confluence points that concentrate transfer instructions

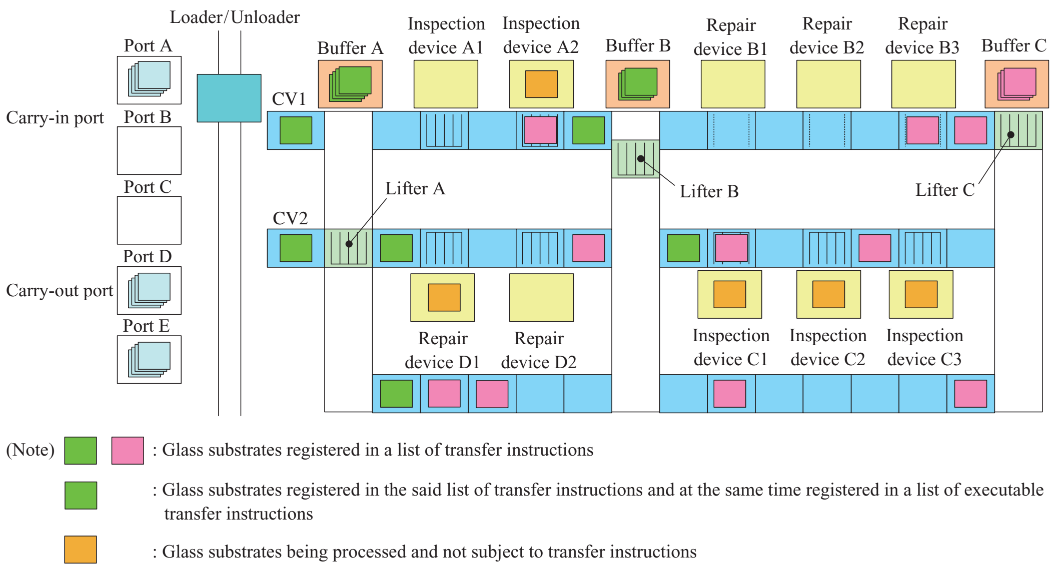


Fig. 20 Example of executable transfer instruction

in line for lifter C are not included in executable transfer instructions, because all inspection devices in the next process, process C, are occupied for processing.

(3) Determining the priority of transfer instructions by calculation

Prioritize transfer instructions in the list of executable transfer instructions by calculation. Multiply six evaluation items, (1) destination, (2) substrate stand-by time, (3) load on a destination process device, (4) load on a starting point process device, (5) the number of substrates in the process, and (6) load on transfer facilities in the transfer direction, by weight, and then multiply the calculated values under conditions by weight.

3. Establishment of a system verification technique

3.1 System verification method

Using a physical distribution simulator, we have verified functions and capacities of the CMCS and the SMCS.

Specifically, we integrated the functions of factory machines and control panels that directly control the machines in simulation models, connect equipment controllers and the SMCS at lower levels of the CMCS to the simulation models, and make an imaginary factory based on these simulation models. We also connected verification MESs at higher levels of the CMCS and the SMCS to verify their functions and capacities.

3.1.1 Simulation models

We built a TFT array process and a single substrate transfer process for a liquid crystal manufacturing line in the physical distribution simulator. **Figures 21, 22** show images of the simulation models.

3.1.2 Process flow for system verification

As an example, the process flow for the CMCS is described below.

(1) The CMCS receives a transfer instruction from the MES.

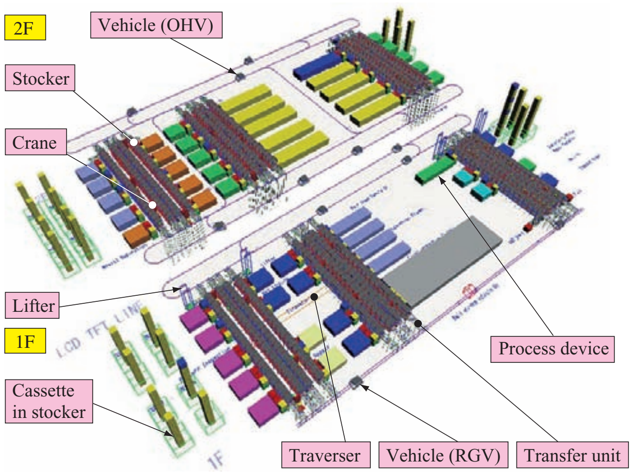


Fig. 21 Simulation model of TFT array process

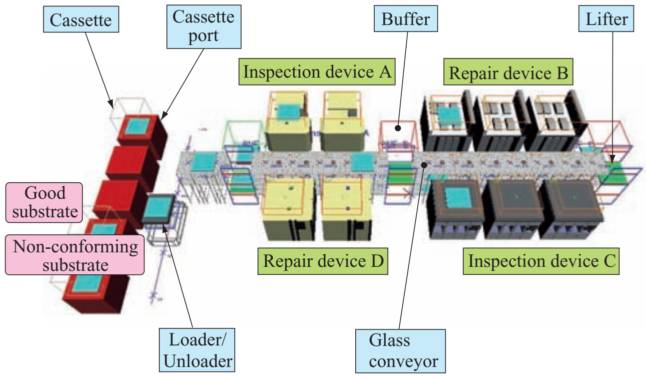


Fig. 22 Simulation model of single substrate transfer line

(2) The CMCS makes transfer commands for individual transfer devices based on the received transfer instruction and transmits the transfer commands to individual equipment controllers.

(3) An equipment controller breaks down the transfer command to work commands for individual transfer devices and transmits them to the simulation model.

(4) The simulation model makes transfer devices in the model operate based on the work commands.

(5) After a transfer is completed, the simulation model transmits a work command completion report to the equipment controller.

(6) The equipment controller gives the CMCS a transfer complete report and in turn the CMCS gives a transfer complete report to the MES.

We use communication messages in the same format as that for actual commands. We use software and devices for the CMCS, SMCS, and equipment controllers that are the same as the real ones. By creating equipment control panels and transfer devices connected to the CMCS and equipment controllers in the simulation model, we are able to check transfer and production states of glass substrates under the same conditions and in the same process flow as in an actual factory. Offline system verification contributes to improved software reliability and faster system startup.

Figure 23 shows the process flow of the system verification method.

3.2 System verification results

This section describes the results of verifying functions and capacities of the CMCS optimum transfer route algorithm and the SMCS transfer efficiency improvement algorithm.

3.2.1 CMCS verification results

3.2.1.1 Algorithm functions verification results

(1) Avoiding congestion

When transfer instructions were simultaneously generated to transfer multiple cassettes from one stocker to another in a factory, the congestion avoidance function prevented transfer instructions from concentrating in the same route.

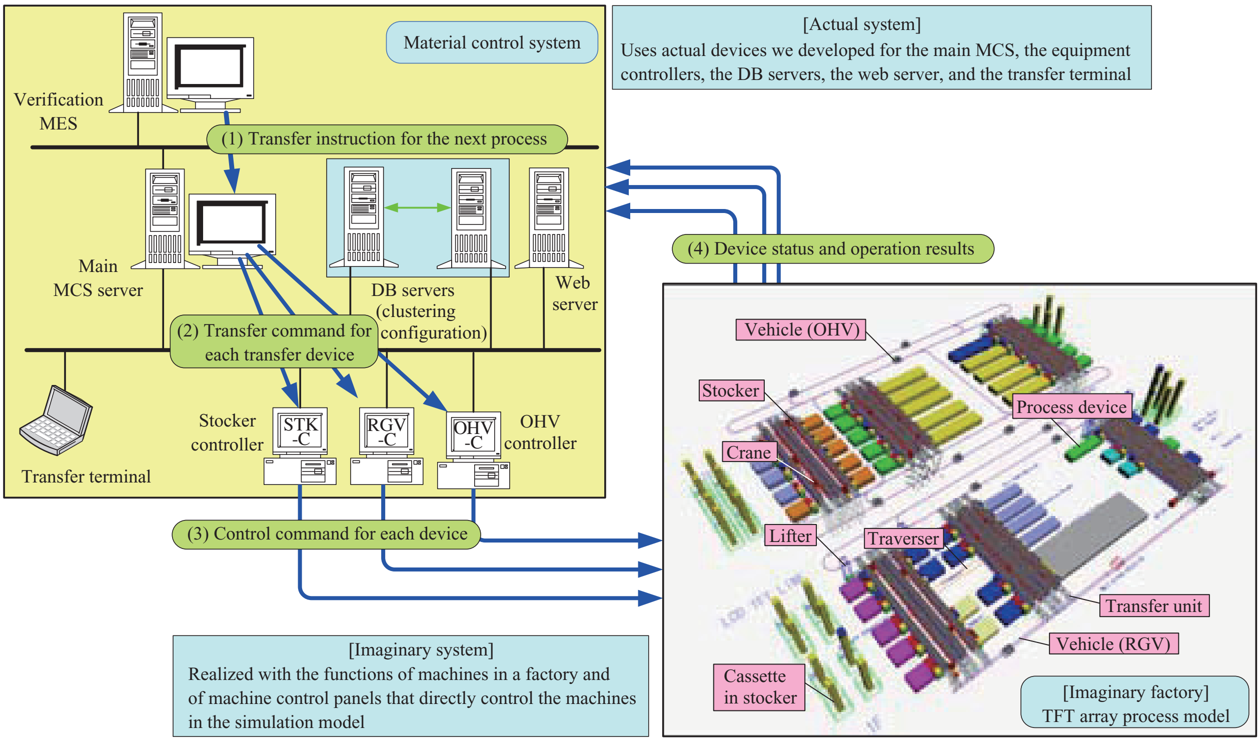


Fig. 23 Process flow of system verification method

Figure 24 shows an example of avoiding congestion. When four transfer instructions were simultaneously generated from the starting point to the destination in the figure, the upper route was assigned to two transfer instructions (with a different route selected for part of the way), and the lower route was assigned to the other two transfer instructions (with the same route).

(2) Avoiding suspended devices

Figure 25 shows an example of avoiding suspended devices. Route searching was attempted with several transfer devices suspended due to trouble or for maintenance on transfer routes from the starting point to the destination. Even when there were suspended transfer devices in the factory, the algorithm selected a route avoiding the suspended devices.

3.2.1.2 Algorithm capacity verification results

We verified differences in transfer time between transfers executed in a route searched by the optimum transfer route algorithm and in a route registered in advance (conventional transfer method). In this test, we compared the transfer time when four transfer instructions were simultaneously generated from a starting point to a

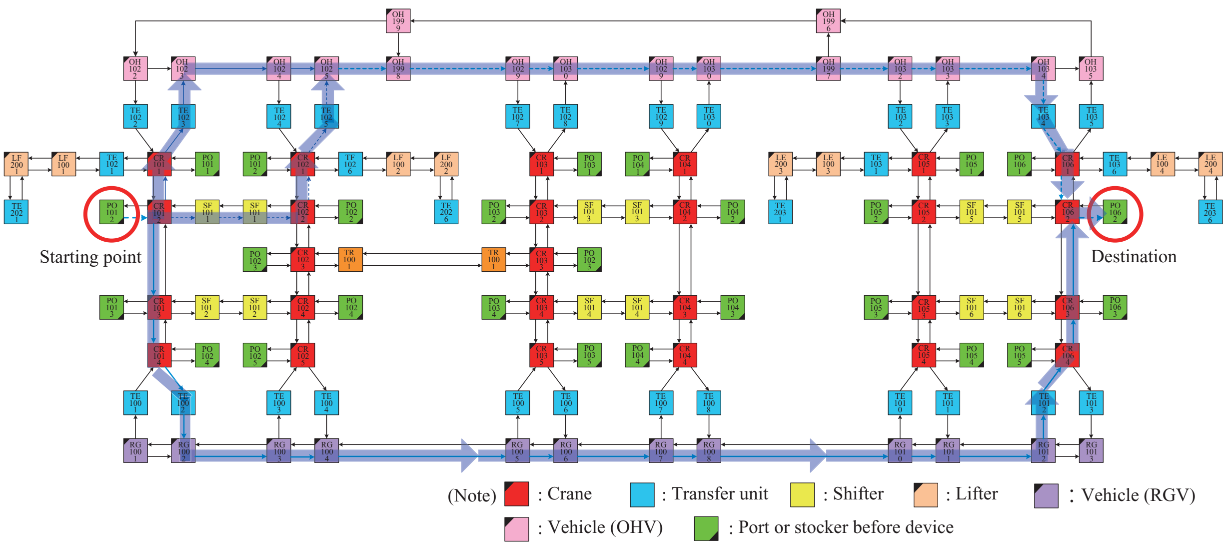


Fig. 24 Example of search result of optimum transfer route to avoid congestion

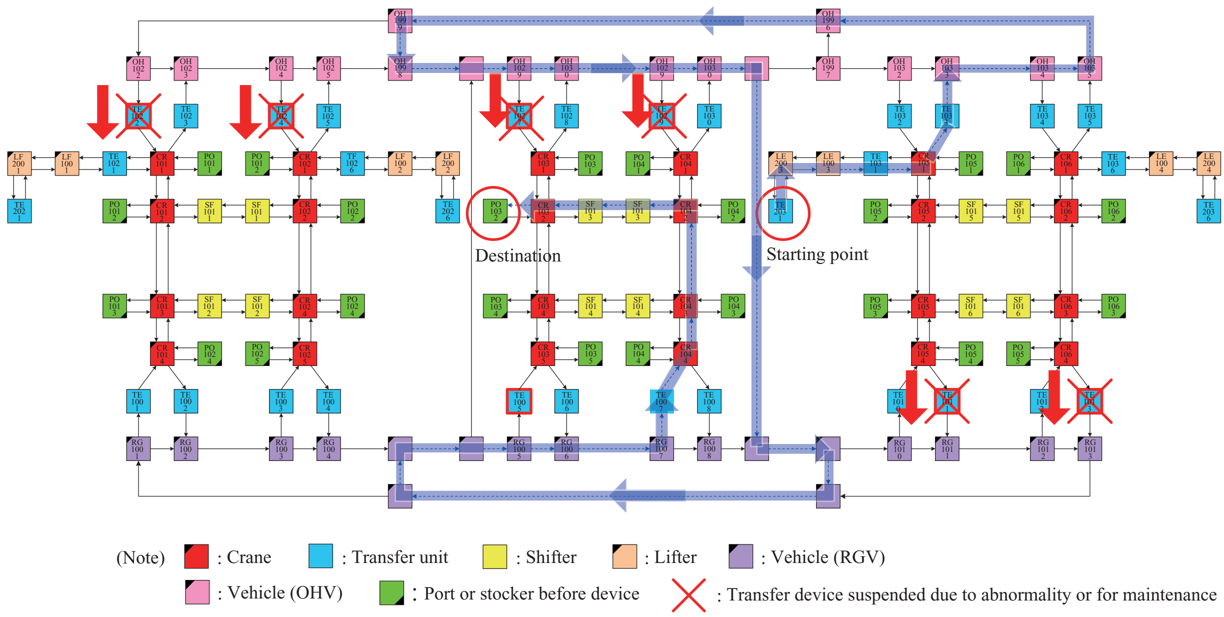


Fig. 25 Example of search result of optimum transfer route to count equipment status

destination by using the following three patterns:

(1) Transfer on the first floor
(2) Transfer on the second floor
(3) Transfer from the first floor to the second floor

Table 2 shows typical examples of verification results.

In verification pattern (2), the conventional transfer method selected the same route to execute all four of the transfer instructions, while the optimum transfer route algorithm divided the transfer instructions into two transfer routes, reducing the transfer time to approximately half.

In verification pattern (3), there was no difference in transfer route and transfer time because the transfer route was short and there were no alternatives. The verification results have indicated the superiority of the optimum transfer route algorithm.

3.2.2 SMCS verification results

We compared simply processing transfers in a congested area in order of arrival and processing them using the optimum dispatch algorithm. The following three patterns were used for the comparison. **Table 3** shows the verification results.

(1) When glass substrates flow normally
(2) When a process device is suspended for a certain period of time
(3) When a lift conveyor is suspended for a certain period of time

Table 2 Results of optimum transfer route algorithm

Verification pattern	Transfer time (h:m:s)		Improvement rate (%)	Result
	Conventional transfer	Optimized transfer		
(1)	0:59:11	0:57:37	2.6	○
(2)	1:43:06	0:55:50	45.8	◎
(3)	0:33:39	0:33:39	0.0	△

(Note) ◎ : Excellent
○ : Good
△ : Equivalent

Table 3 Results of optimum dispatch algorithm

Verification pattern	Throughput (s)		Improvement rate (%)	Result
	Order of arrival	Optimized transfer		
(1)	6 645	6 413	3.5	○
(2)	6 606	6 377	3.5	○
(3)	7 113	6 822	4.1	○

(Note) ○ : Good

Processing by using the optimum dispatch algorithm improved the throughput, which is the time from carrying a glass substrate into the process and to carrying it out, by approx. 200 to 300 s (3.5 to 4%) per cassette. This corresponds to saving of about one hour a day in a single substrate transfer process that handles 12 to 15 cassettes a day (on the assumption that the production capacity of the entire factory is 30 000 substrates a month). These results have indicated the superiority of the optimum dispatch algorithm.

4. Conclusion

We have completed development of the MCS as it applies to TFT array processes on liquid crystal manufacturing lines and to single substrate transfer processes expected to be introduced in the future. We have also established an offline system verification technique. The software architecture of this system can be applied to other fields, and we will expand applications to semiconductor lines, general distribution factory automation (FA) lines, and many other lines.

— Acknowledgements —

We would like to express our sincere appreciation to persons concerned in the Logistics Systems Operations for advising us and cooperating in development of this system, and to IHI Scube Co., Ltd. for cooperating in the software development.

REFERENCES

(1) Y. Nishimura : A separate volume of Electronic Journal 2006, LCD Fab/Equipment/Facilities, Electronic Journal corporation (2005.9) pp. 50 - 59