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A GA-based method to reduce material handling: the case of TFT-LCD array Fabs in Taiwan

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This study proposes a genetic algorithm (GA)-based Material Handling Strategy Function (MHSF) method to increase the productivity of a TFT-LCD array fabrication to improve the traditional FIFO method in TFT-LCD fabrication by the reduction of the material handling for a Rail Guided Vehicle (RGV), because costs of material handling count up to about 50% of production costs. In this article, the MHSF is provided to help material handling commands choice, where a novel GA approach is used to adapt the weights of affecting factors in the function. Finally, to evaluate the performance of the proposed method, experiments using the data from a major TFT-LCD manufacturing plant in Taiwan have been carried out, and the results indicate that it can indeed reduce fabrication time and increase productivity.

Keywords: Material Handling Strategy Function, TFT-LCD, RGV, material handling, array process, productivity

1. Introduction

The way to decrease activities of material handling, waiting time, and material storage, are important issues to increasing productivity. In manufacturing, the largest percent of product cost is related to material handling (Yang *et al*. 2005). Material handling cannot add product value but does waste costs. Reducing lead times and costs become important factors for material handling in a Flexible Manufacturing System (FMS) (Kulak 2005). Material handling accounts for 30–75% of the total manufacturing cost, but a good design of a material handling system can reduce a plant's costs by 15–30% (Kulak 2005). An automatic guided vehicle (AGV), including the rail guided vehicle (RGV) discussed in this study, is a way to reduce the cost of material handling. An AGV can be a buffer to decrease storage activities (Wu and Zhou 2007), and an efficient policy of AGV can decrease waiting time and material handling time. Hence, this study aimed to better the policy of RGV material handling by proposing a genetic algorithm-based Material Handling Strategy Function (MHSF) to decrease material handling time. Raw data from a major Thin Film Transistor Liquid Crystal Display (TFT-LCD) factory are offered as an example for MHSF.

TFT-LCD manufacturing is an important industry in Taiwan (Park *et al*. 2003, Hung 2006, Pan *et al*. 2007). It has become an important technology because it is widely used in

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electric devices, such as cell phones, PDAs, computers, and TVs (Lu and Tsai 2004, Tsai and Hung 2005, Tsai *et al*. 2007, Huang *et al*. 2009). With a piece of glass substrate, TFT is a switch to control light and shade of each pixel on the LCD to reach color purposes. The fabrication of a TFT-LCD mainly consists of three processes: array, cell, and module processes (Lin *et al*. 2006). The array process, including the sub-processes of depot, photo, etch, and strip of glass substrates, creates TFT circuit. Several machines are put in an area for the array process and each machine in the array process can perform only one production operation. Each array process may need to perform the same operation more than once as a normal FMS does. Therefore, a lot of material handling work occurs among these machines in the array fabrication. As for the cell process, it only puts machines into a production line by combining colour filter and TFT panel, pouring liquid crystal into the panel, and cutting the LCD panel into the final product size without using any extra material handling facilities. The module process adds driver IC (integrated circuit) into the LCD panel and prepares to ship the final products only. Because machines for the array process are costly, high productivity in the array process can reduce fabrication cost, and a material handling strategy can influence the effectiveness of productivity. Therefore, how to design the array process is the key issue for all TFT-LCD manufacturers.

2. Preliminaries

In this study, GA-based MHSF is applied in the material handling strategy to increase the TFT-LCD fabrication performance. In this section, related works about material handling efficiencies, GA, and TFT-LCD fabrication performances are reviewed.

2.1 *Material handling system*

A material handling system which is used to transport parts, WIPs, and products within machines or storehouses plays an important role in a manufacturing system (Gabbert and Brown 1998, Dongmin *et al*. 2006). AGVs and RGVs which can load, unload, and transport materials automatically are the most often used facilities for material handling to save costs in a manufacturing system (Heragu 1997, Jawahar *et al*. 1998, Malmborg 2003, Berman *et al*. 2003, Wu and Zhou 2005). Gabbert and Brown (1998) pointed out that material handling and its relative overhead account for about 55% of product cost. Also, Asef-Vaziri *et al*. (2008) mentioned that 20–50% of the total production costs are for material handling. Therefore, it is very important to have an efficient method to reduce the cost of the material handling system. One previous research in 1994, by Lee *et al*. proposed a system modeled by Petri Nets to integrate AGV models for material handling and models for part processing into a single coherent model to reduce labor cost in a flexible manufacturing system (FMS) (Lee *et al*. 1994). In 2004, Wakabayashi *et al*. developed a high speed automated material handling system to shorten cycle time by one half or less with new concepts, hardware improvements, and new operation methods in a wafer process for the 300-mm fab (Wakabayashi *et al*. 2004). Later, Wu *et al*. (2007) showed that a robot or an AGV can be both a material handling device and a buffer. In their study, a resource-oriented Petri Nets (ROPN) was modeled and a new policy was proposed by treating robots as both material handling devices and buffers. At the same time, Nazzal *et al*. (2007) proposed an analytical approach to assess the expected time of an automated material handling system for lots ready to move in a wafer fab, while Asef-Vaziri *et al*. (2008) invented an optimal model for the integrated design of the material flow path and the location of the pickup and delivery stations to reduce the material handling cost. Recently, Ventura *et al*. (2009) provided a dynamic programming algorithm to locate the idle AGV position and find out the optimal dwell point to minimise the maximum response time to improve the efficiency of an AGV system. In brief, AGV and RGV can decrease material handling cost, and a suitable strategy for AGV, and RGV can improve productivity.

2.2 *Genetic algorithms*

GA which was proposed by Holland (1975) is based on the natural evolution concept. It has been successfully applied in many NP-hard problems in many different areas (Miller *et al*. 1993). In GA, a chromosome represents a possible solution. With genetic operations, new generations are created. This process repeats again and again until the new generation solution cannot improve results. The genetic operations include encoding, evaluation (fitness), crossover, and mutation. An encoding transforms problems into binary digits to represent chromosomes in GA. The evaluation tests the fitness of the solution. The crossover and mutation are used to create new generations that are different from their parents (Miller *et al*. 1993). GA has often been used for FMS schedule or material handling strategy generation (Jawahar *et al*. 1998). For example, Jawahar *et al.* proposed a genetic algorithm based method to generate dynamic schedules in FMS (Jawahar *et al*. 1998). In addition, Liu *et al*. (2007) presented a genetic approach to a garment handling system strategy in 2007. Our study also applies GA using decimal fraction encoding chromosomes to generate material handling strategies in a TFT-LCD factory aimed at increasing fabrication productivity. In this study, due to seeking a group of suitable weights which are between 0 and 1 for our MHSF solution, decimal fraction encoding chromosomes are proposed and applied.

2.3 *TFT-LCD*

Although the process of production operations for a work-in-process (WIP) is fixed, the WIP may be moved in and out of the same machine more than once. Mainly, the material handling device used in a TFT-LCD factory is an RGV. In order to maximise the benefit of material handling, WIPs are grouped by a unit of "lot" containing 20 glass substrates to be fabricated and moved. Additionally, a factory may be divided into several working areas according to the different features of machines as shown in Figure 1. For example, there are nine machines, a stocker, and a material handling device in a working area as illustrated in Figure 2, where four machines are with the same machine type Ma and three machines are with the same machine type Mb.

For a given area, a lot may be moved in and out more than once, but each production process is not necessarily the same. For example in the working areas given in Figure 1, a kind of LCD production is moved through Area A five times:

$$\begin{aligned} &Start \rightarrow S \rightarrow A(1) \rightarrow B(1) \rightarrow C(1) \rightarrow A(2) \rightarrow B(2) \rightarrow E(1) \rightarrow A(3) \\ &\rightarrow B(3) \rightarrow C(2) \rightarrow \cdots \rightarrow A(4) \rightarrow \cdots \rightarrow A(5) \rightarrow \cdots \rightarrow End \end{aligned}$$

Where A(n) indicates the nth production process in Area A.

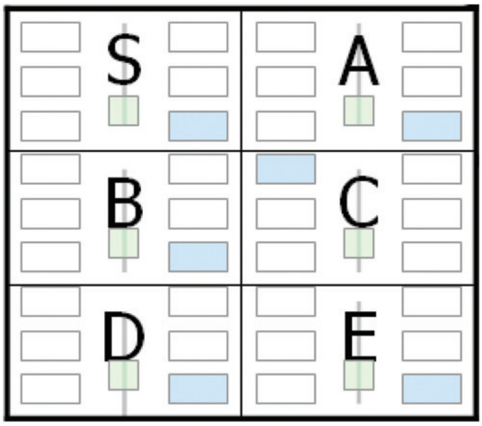

Figure 1. Six working areas in a TFT-LCD array manufactory.

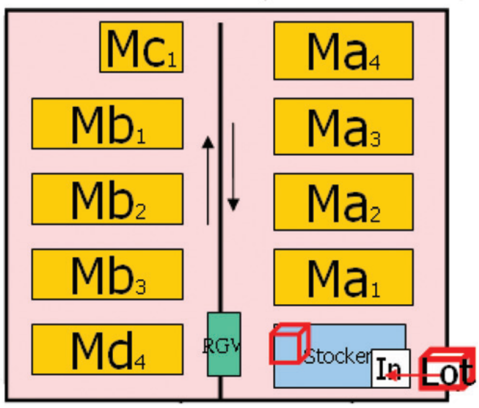

Figure 2. Nine machines, a stocker, and a RGV in a working area.

When a lot finishes a fabrication process in an area, it is moved to a stocker in the next area by a RGV. There are two rules for this lot in the next area:

- If the target machine for the next operation is idle, then the lot must be sent to this idle machine directly.
- Otherwise, the lot must be sent to the stocker for waiting.

Within a process of a lot, when an operation in a machine is finished, the following rules are applied:

- The lot should stay at the current machine and wait for the next machine available after finishing an operation if no other lot is waiting for the current machine.
- The lot should be sent directly to the next desired machine if the machine is idle.
- For all lots waiting for a specific machine in the stocker, the lot will be chosen by the longest waiting time first rule, when the machine is available.

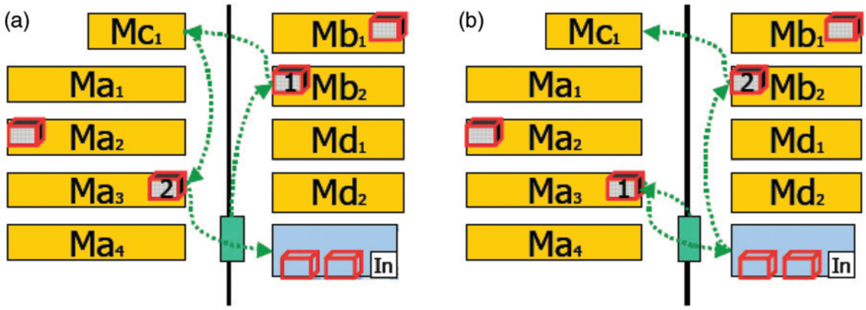

Figure 3. Different moving routes and system productivities due to different command orders.

It should be noted here that all the movements of the lots are made according to the material handling commands, where a material handling command consists of the current position of a lot and the machine where the lot will be sent to. A RGV performs a material handling command by moving to the position of the lot, taking the lot to the RGV, carrying the lot to object position, and taking the lot to the object machine. It may take about 20–40 s to perform a material handling command, depending on the distance between the positions of RGV and machine.

As the RGV can only perform one material handling command listed in a command table at a time, how to choose a suitable material handling command from the table to maximise the system productivity or minimise the fabrication time becomes an interesting and challenging issue. Suppose two commands (1) $Ma_2 \rightarrow Mc_1$ and (2) $Ma_3 \rightarrow$ Stocker can be chosen in the TFT-LCD fabrication, then Figures 3(a) and (b) illustrate different moving routes corresponding to the command order of $(1) \rightarrow (2)$ and $(2) \rightarrow (1)$, respectively. Hence, different command conditions may affect moving route and system productivity.

The command performance time RMt is a time period from the creation to the completion of a material handling command. It consists of two parts, one is the waiting time CWt, and the other is the real material handling time CMt.

2.4 *TFT-LCD fabrication productivity*

Since a variety of new generation production processes of TFT-LCD have been developed quickly in recent years (Park *et al.* 2003), how to increase the productivity of a TFT-LCD company becomes an important issue. To solve the above issue, some studies have improved the efficiency of the TFT-LCD industry. For example, Jeong *et al.* developed a scheduling system for a TFT-LCD assembly process to minimise the mean flow time and maximise the production progressiveness (Park *et al.* 2003). Shin and Leon (2004) improved the scheduling problem for the module process to improve the TFT-LCD manufacturing productivity. Toba (2005) presented a WIP estimation flow control method to solve the problem of controlling the maximum number of waiting lots in a limited buffer capacity in 2005. In the method, three features were used, including dividing the whole schedule into small lot schedules, reducing redundant blocking time, and WIP assessment for contiguous limited buffer scheduling. Afterwards, Lin *et al.* (2006) proposed a hierarchical planning and scheduling framework for a TFT-LCD assembly-to-order production chain, which mainly concentrates on the scheduling for the array, cell, and module processes in the TFT-LCD production. In addition, Huang pointed out the following four factors which influence Taiwan's TFT-LCD industry strategy in the competitive environment (Lin *et al.* 2006): government policy, human resources, capital investment, and bridging institution. Also Shin and Kang (2010) proposed a rework-based dispatching algorithm to improve the productivity for module process in TFT-LCD manufacture. Also, Chen *et al.* (2008) proffered a statistical process control (SPC) method to evaluate the LCD industry performance, while Hsieh (2008) proposed a method incorporating fuzzy adaptive resonance theory and a stepwise regression approach for the clustering analysis on the abnormal position defect status in TFT-LCD process to increase the production performance. Recently, Wang *et al.* (2008) analysed the RFID enabled supply chain in the TFT-LCD industry to decrease inventory cost. Their study indeed lowers the production cost from the view point of inventory.

3. Proposed method

In this section, the proposed GA-based MHSF method with an explanation for the real array fabrication processes in the factory is described. It consists of two novel approaches, one is the MHSF, and the other is an adapted GA method to find the optimal set of values of MHSF for material handling commands.

3.1 *Simulator*

As the manufacturing environment is very complex in the TFT-LCD array fabrication, many unexpected conditions may affect the system, and some experiment results cannot be gained easily. In order to evaluate the proposed method well, we use a simulator to simulate the fabrication process. In our simulation model, a lot is generated first, goes to area *S* for an initialisation process, and then goes into area *A* for fabrication. After finishing its fabrication process in area *A*, the lot goes to another area for the next process. After a period of time, this lot is coming back to area *A* again. All the conditions are given for the simulator, including the number of lots for fabrication every day, the number of production machines, time to operate a lot by each machine, the TFT-LCD fabrication process, and time intervals between two subsequent arrival times of a lot back and forth to area *A* which are gained from the real company records. Some other attributes are also given, such as the types of machines, distances between each machine, RGV speed, time for bringing a lot in to a RGV or out from a RGV, and time for the internal material handling within a stocker. Figure 4 represents the fabrication process from the viewpoint of area *A*.

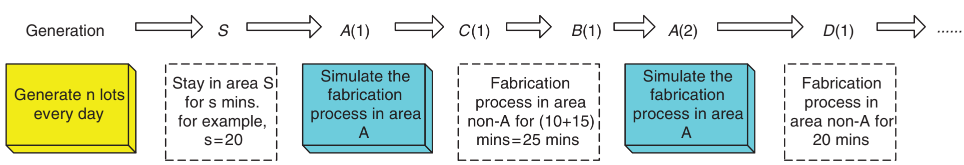

Figure 4. The fabrication process from the viewpoint of area *A*.

For example, assume there are a total of two machines in area S and there are six lots to be processed by them. It takes 10 min to process two new lots in the generation process; 20 min are needed for every two lots in the initialisation process in area S as shown in Figure 4. Based upon the FIFO rule, these six lots begin their fabrication process in area A and their leaving time is shown in Table 1, where each lot is sent to area A twice. Since each lot takes at least 20 min the first time and at least 10 min the second time in area A, the real process time for each lot in area A is greater than or equal to above 20 or 10 min after adding the waiting time. Table 2 records the lots to be processed in area A during every 10 min, where $Li(\mathrm{A}(j))$ means the jth time of lot i in area A. Figure 5 illustrates the time series by a Gantt chart.

Table 1. The leaving time of six lots in area A.

Lot	Generation	Area $non-A$ (20 min in S)	Leaving time of $A(1)$	Area $non-A$ (10 min in $C(1)$, 15 min in $B(1)$)	Leaving time of $A(2)$
$L1$	00:10	00:30	00:50	01:15	01:27
$L2$	00:10	00:30	00:52	01:17	01:29
$L3$	00:20	00:40	01:01	01:26	01:43
$L4$	00:20	00:40	01:06	01:31	01:46
$L5$	00:30	00:50	01:17	01:42	02:02
$L6$	00:30	00:50	01:20	01:45	02:10

Table 2. The lots to be processed in area A during each time period.

Time period	Processes in area A
01:00–01:10	$L3(A(1))$, $L4(A(1))$, $L5(A(1))$, $L6(A(1))$
01:10–01:20	$L1(A(2))$, $L2(A(2))$, $L5(A(1))$, $L6(A(1))$
01:20–01:30	$L1(A(2))$, $L2(A(2))$, $L3(A(2))$, $L4(A(2))$, $L6(A(1))$
01:30–01:40	$L3(A(2))$, $L4(A(2))$, $L5(A(2))$
01:40–01:50	$L4(A(2))$, $L5(A(2))$, $L6(A(2))$
01:50–02:00	$L5(A(2))$, $L6(A(2))$

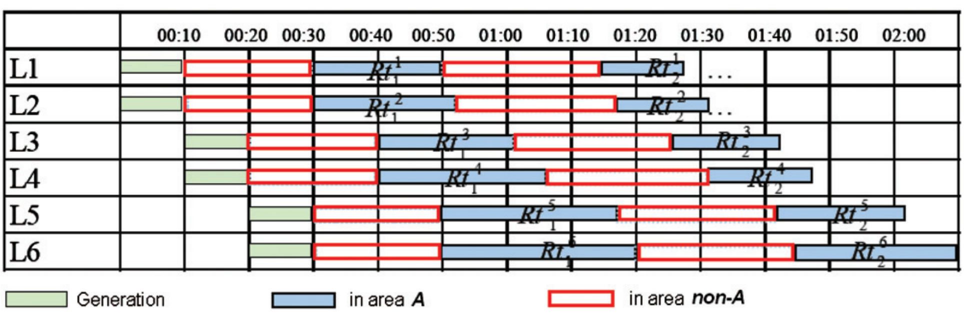

Figure 5. The Gantt chart for six lots fabrication.

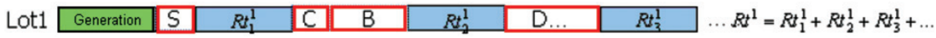

Figure 6. The fabrication time of lot 1 in area A.

For a single lot i, let the jth process time in area A be Rt_j^i, where i is the lot number. Hence the total fabrication time in area A for lot i shall be $Rt^i = Rt_1^i + Rt_2^i + \cdots$. As illustrated in Figure 6, the amount of blue areas is the total fabrication time for lot 1 in area A.

In addition, fabrication time for a lot in area A each time Rt_j^i includes machine operation time RPt_j, waiting time RWt_j^i, and material handling time RMt_j^i. Therefore,

$$Rt_j^i = RPt_j + RWt_j^i + RMt_j^i$$

For every lot, the machine operation time RPt_j are the same. The waiting time RWt_j^i can be divided into waiting for material handling time $RW_{mh}t_j^i$ and waiting for machine time $RW_{ma}t_j^i$. Therefore, the variable fabrication time for a lot in area A each time $R't_j^i$ is defined as:

$$R't_j^i = RW_{mh}t_j^i + RW_{ma}t_j^i + RMt_j^i.$$

3.2 *Material handling strategy function f (MHSF)*

As we have known, factors to affect productivity include the utility rates of machines, RGV, and stocker. A high utility rate of machines can reach high productivity. Low utility rates of either RGV or stocker can also have a high productivity. Therefore, high machine utility rate, low RGV and low stocker utility rates are our three material handling strategies. We use the following attributes in the proposed method:

L_S	Number of lots waiting for source machine which a WIP is moved from.
M_S	Number of machines whose type is the same as the source machine.
T_S	Operation time of a source machine.
L_O	Number of lots waiting for object machine which a WIP is moved to.
M_O	Number of machines whose type is the same as the object machine.
T_O	Operation time of an object machine.
D_{RS}	Distance between a RGV and a source machine.
T_I	Time interval from the creation of the command.
T_w	Time waiting for a stocker to be free.

Table 3 is an example of a command table with three commands. For each command, a material handling strategy function f is proposed to calculate its priority of execution in this study. The command with a higher f value has the higher priority will be chosen to perform first. This material handling strategy function is defined as:

$$f_{w_1,w_2,w_3,w_4,w_5} = w_1 Att_{From} - w_2 Att_{To} - w_3 Att_{RGV} + w_4 Att_{LOT} - w_5 Att_{STK},$$

where

Att_{From} Status of source machine from which a WIP is moved.

Table 3. Example of a command table.

	Lot	From	To	L_S	M_S	T_S	L_O	M_O	T_O	D_{RS}	T_I	T_w
1	$L1$	Ma_1	STK	5	4	1800	0	0	0	9	80	0
2	$L2$	STK	Ma_2	0	1	0	5	4	1800	0	70	40
3	$L3$	Mb_1	STK	4	2	300	0	1	0	12	65	0

Att_{To} Status of object machine to which a WIP is moved.
Att_{RGV} Distance between a RGV and a source machine.
Att_{LOT} Time interval from which a command is generated.
Att_{STK} Time waiting for a stocker to be free.

$$0 \le w_1, w_2, w_3, w_4, w_5 \le 1,\ w_1 + w_2 + w_3 + w_4 + w_5 = 1$$

Att_{From} is the status of the source machine which a WIP is moved from. If a source machine is busier, more WIP should be removed from it as soon as possible and w_1 is higher. On the contrary, Att_{To} is the status of the object machine to which a WIP is moved to and therefore, if an object machine is busy, it should not allow more WIP to be moved in, and w_2 has a negative impact to f. Att_{RGV} is the distance between a RGV and a source machine. When the distance is shorter, the efficiency is better. Hence w_3 has a negative sign. Att_{LOT} represents the waiting time of a command to be executed once it is generated. To reduce the waiting time, a command with a longer Att_{LOT} is given a higher priority. The last factor Att_{STK} is time waiting for a stocker to be free. Because only one stocker is provided for a WIP, the weight w_5 has a negative sign.

To balance the influence power of the above affecting factors, these affecting factors are normalised to be between 0 and 1 as the following:

$$Att_{From} = Normalise_{From}\left(\frac{L_S \times T_S}{M_S}\right), \quad 0 \le Att_{From} \le 1$$

$$Att_{To} = Normalise_{To}\left(\frac{L_O \times T_O}{M_O}\right), \quad 0 \le Att_{To} \le 1$$

$$Att_{RGV} = Normalise_{RGV}(D_{RS}), \quad 0 \le Att_{RGV} \le 1$$

$$Att_{LOT} = Normalise_{LOT}(T_I), \quad 0 \le Att_{LOT} \le 1$$

$$Att_{STK} = Normalise_{STK}(T_W), \quad 0 \le Att_{STK} \le 1$$

Since the variable fabrication time for a lot in area A consisting of waiting for material handling time $RW_{mh}t_j^i$, waiting for machine time $RW_{ma}t_j^i$, and material handling time RMt_j^i, our goal is to minimise the total time $\sum_{i=1}^{n}\sum_{j=1}^{v}(R't_j^i) = \sum_{i=1}^{n}\sum_{j=1}^{v}(RW_{mh}t_j^i + RW_{ma}t_j^i + RMt_j^i)$, where n is the total number of lots sent to the fabrication system, and v is the number of a lot moved into area A. Therefore, the purpose of this study is to find out a material handling strategy f_{w_1,w_2,w_3,w_4,w_5} with a set of weight $(w_1, w_2, w_3, w_4, w_5)$ to minimise $\sum_{i=1}^{n}\sum_{j=1}^{v}(R't_j^i)$ and get the best productivity for fabrication process R in area A.

3.3 *Methodology*

Assume n lots are sent to a factory, and a material handling strategy f_{w_1,w_2,w_3,w_4,w_5} can be formulated as a linear combination of $Att_{From}, Att_{To}, Att_{RGV}, Att_{LOT}, Att_{STK}$. GA is applied

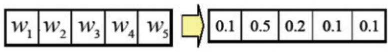

Figure 7. An example of a chromosome of GA in this study.

for seeking the suitable weights $(w_1, w_2, w_3, w_4, w_5)$ to have the largest productivity. Each time, the command that has the largest value of f_{w_1,w_2,w_3,w_4,w_5} is chosen to be performed.

(1) *Encoding*

When a research problem is going to be solved by GA, encoding is the first step. Among a variety of encoding methods, the selection of encoding depends on the problem style. The most common method is binary encoding, which gives every chromosome Boolean values of 0 and 1. Permutation, direct value, and tree encoding are also successful in some cases. However, this study proposed a new kind of decimal fractions encoding, where the vector of weights $(w_1, w_2, w_3, w_4, w_5)$ are treated as chromosomes, for $0 \le w_1, w_2, w_3, w_4, w_5 \le 1$ and $w_1 + w_2 + w_3 + w_4 + w_5 = 1$ as illustrated in Figure 7.

(2) *Fitness*

Each chromosome has an associated objective function called the fitness. A good chromosome is the one that has low fabrication time $\sum_{i=1}^{n} \sum_{j=1}^{v} R' t_j^i$. The strength of a chromosome is represented by its fitness value. Fitness values indicate which chromosomes are to be carried to the next generation. A set of chromosomes and associated fitness values are called the population. This population at a given stage of GA is referred to as a generation. As for different material handling strategies which are performed in the simulator of this study, the fitness function in the simulator can be used to find the minimum fabrication time $\sum_{i=1}^{n} \sum_{j=1}^{v} R' t_j^i$ and the highest productivity. Since the chromosome with a larger fitness value should have a higher possibility to the next generation in GA, we use inverse function $\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{v} R' t_j^i}$ to seek max $\left(\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{v} R' t_j^i} \right)$ for the chromosomes. When a chromosome is specified, e.g. $w_1, i = 1, 2, \ldots, 5$, are known, the simulator will be run to simulate TFT-LCD array factory and obtain the fabrication time $\sum_{i=1}^{n} \sum_{j=1}^{v} R' t_j^i$, and then calculate the fitness value of this chromosome.

(3) *Crossover*

In a genetic algorithm, crossover combines two parent chromosomes to produce a new offspring chromosome. If the new chromosome takes the best characteristics from each of the parents, it may be better than both of the parents. Some crossover types, include one-point, two-point, uniform, arithmetic, and heuristic.

Since this study proposed a new kind of decimal fractions encoding, the crossover method should be modified. We use arithmetic (convex) crossover as an example. For two parent material handling strategies, a float value between 0 and 1 is generated randomly, where the new *ith* weights w_i is the convex combination of the *ith* weights w_i in two parent strategies (chromosomes). Figure 8 explains the arithmetic (convex) crossover process in our GA.

(4) *Mutation*

Mutation operator alters one or more values in a chromosome from its original values. Mutation is an important part of the genetic search to help get better results. There are several types of mutation, including flip bit, boundary, non-uniform, uniform, and Gaussian. Different from the traditional GA mutation method of using 0 and 1 to control

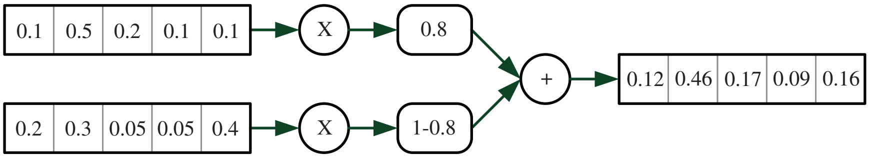

Figure 8. An example of arithmetic (convex) crossover process in our GA.

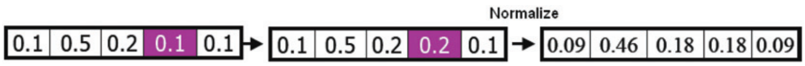

Figure 9. An example of the process of mutation in our GA.

mutation, this study generates a new value between 0 and 1 for a randomly chosen weight. To assure $w_1 + w_2 + w_3 + w_4 + w_5 = 1$, all five weights in the strategy have to be normalised by $w_{i,normalized} = w_i/(w_1 + w_2 + w_3 + w_4 + w_5)$ as illustrated in Figure 9.

Our GA proceeds as follows:

Genetic Algorithm()
Begin Initialise population;
while (not terminal condition) **do**
Begin
choose parents from population; /* Selection */
construct and normalise off_spring by combining parents;/* Crossover */
mutate and normalise off_spring; /* Mutation */
if suited (off_spring) **then** replace worst (population) with better off_spring;
End;
End.

4. Computational results

To evaluate the performance of our methods, we have carried out experiments using the historical data of Chunghwa Picture Tubes Company, including the fabrication process, object working area features, other working areas features, machine operation time, and the way to send lots for fabrication. As mentioned above, this TFT-LCD factory is divided into six areas: *S*, *A*, *B*, *C*, *D*, and *E*. To simplify our discussion, only area *A* is used as an example for the proposed method. The interval between two subsequent entries of area *A* is defined according to the average time from the historical records. All fabrication processes through different areas are shown in Figure 10.

Where *S* is a process to initiate a new lot and the related information of area *A* is listed in Table 4.

4.1 *Methodology*

As mentioned before, it takes 20 min (1200 s) to initiate a lot for each machine in *S* area. In a real factory, the number of lots to be processed varies for each hour, each day,

$$Generation \rightarrow S \rightarrow (8200\,\text{sec } in\ B(1)) \rightarrow A(1) \rightarrow (13500\,\text{sec } in\ C(1), B(2)) \rightarrow A(2)$$
$$\rightarrow (10400\,\text{sec } in\ D(1), B(3)) \rightarrow A(3) \rightarrow (13800\,\text{sec } in\ E(1), B(4)) \rightarrow A(4)$$
$$\rightarrow (11200\,\text{sec } in\ C(2), B(5)) \rightarrow A(5)$$

Figure 10. The processes of a TFT-LCD array fabrication.

Table 4. The related information of area *A*.

Item	Content
Type of machine	Ma, Mb, Mc, Md
Number of each type of machine	Ma: 4 (Ma01, Ma02, Ma03, Ma04) Mb: 3 (Mb01, Mb02, Mb03) Mc: 1 (Mc01) Md: 1 (Md01)
Operation time for machines	Ma: 540 s Mb: 400 s Mc: 300 s Md: 80 s
Distance between two adjoined machines	3 m
RGV speed	1 m/s
Time for a RGV takes a lot	8 s
Material handling time within a stocker	40 s

each week, and each month. Hence, we use the current FIFO material handling command choosing strategy for our simulator to seek the relation between number of lots generated and productivity. At the beginning, there is no lot in the system and the utility ratio is low. To avoid the bias of the data, we calculate the productivity from the second day. For the given different number of lots, the FIFO strategy using $w_1 = 0$, $w_2 = 0$, $w_3 = 0$, $w_4 = 1$, and $w_5 = 0$ can be described as:

$$f_{w_1,w_2,w_3,w_4,w_5} = 0 \times Att_{From} - 0 \times Att_{To} - 0 \times Att_{RGV} + 1 \times Att_{LOT} - 0 \times Att_{STK}$$

Figure 11 shows time for material handling, time for waiting for material handling, time for waiting for machines, and variable fabrication time. As you can see both time waiting for material handling and waiting for machines increases when the number of lots increases. However, there is only a little increase in time waiting for material handling. Hence, time waiting for machines significantly influences the variable fabrication time. The variable fabrication time rises sharply at the number of lots approaches 62, 69, and 74. Before the previously mentioned numbers, the variable fabrication time stays almost the same. Hence, such certain numbers are sought because they have the largest number of lots in the same level of variable fabrication time.

Figure 12 plots the utility rate of four kinds of machines, RGV, and the stocker, where Ma and Mb have higher utility rates which can not be increased even if the number of lots is greater than 69. As mentioned above, 62, 69, and 74 are the suitable lot numbers for generation, because generating 69 lots has a higher machine utility rate and a lower RGV utility rate than generating 74 lots. Therefore, we generated 69 lots for further experiments in the system.

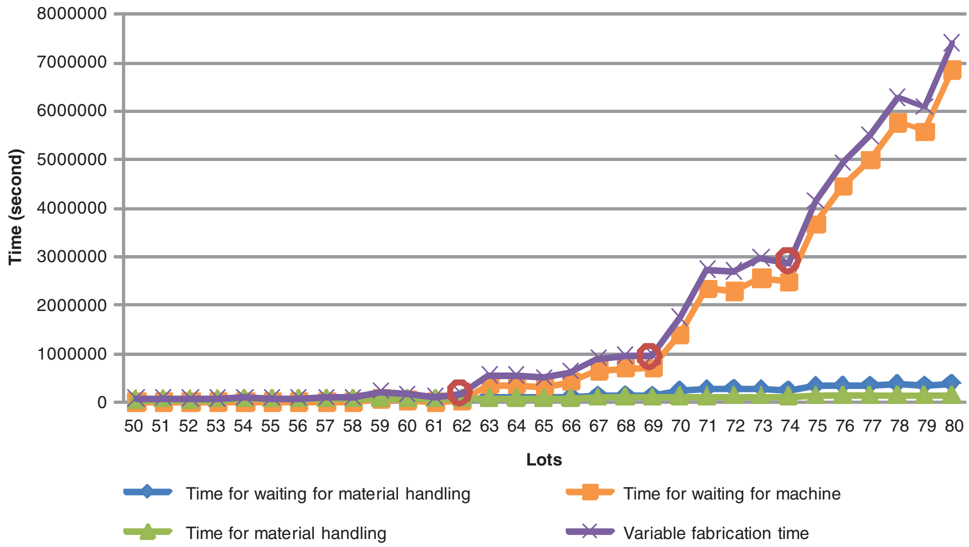

Figure 11. The fabrication time for different number of lots.

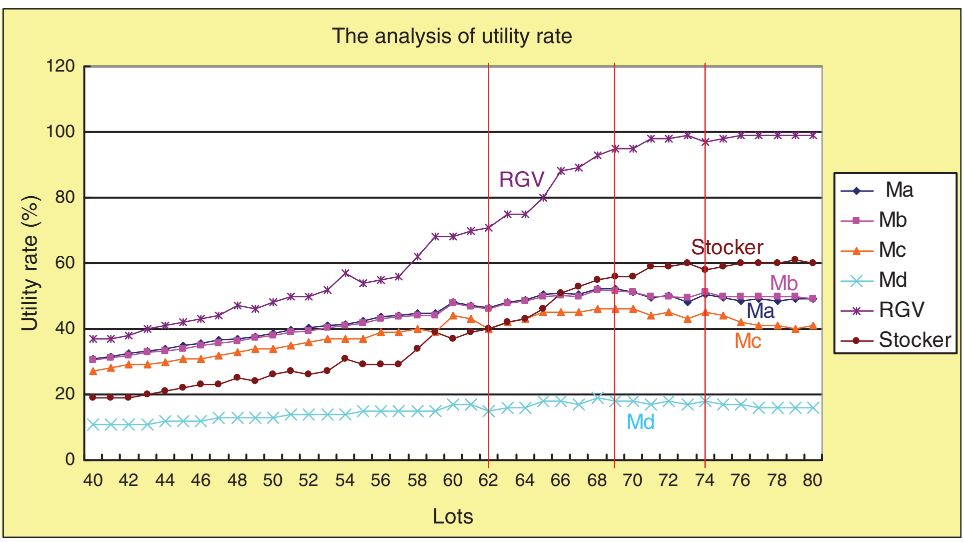

Figure 12. The analysis of utility rate.

4.2 *Finding the weights of MHSF*

In our experiment, 69 lots are generated in the manufacturing system, and the proposed method based on GA is applied to seek the best set of weights for the material handling strategy function. Population size is set as 100. The first population is generated randomly, crossover rate is 0.9, and mutation rate is 0.05. Many kinds of crossover methods are proposed, such as one-point, two-point, uniform, and arithmetic (convex) methods. The Arithmetic crossover method was used in this study. When the productivity stayed the

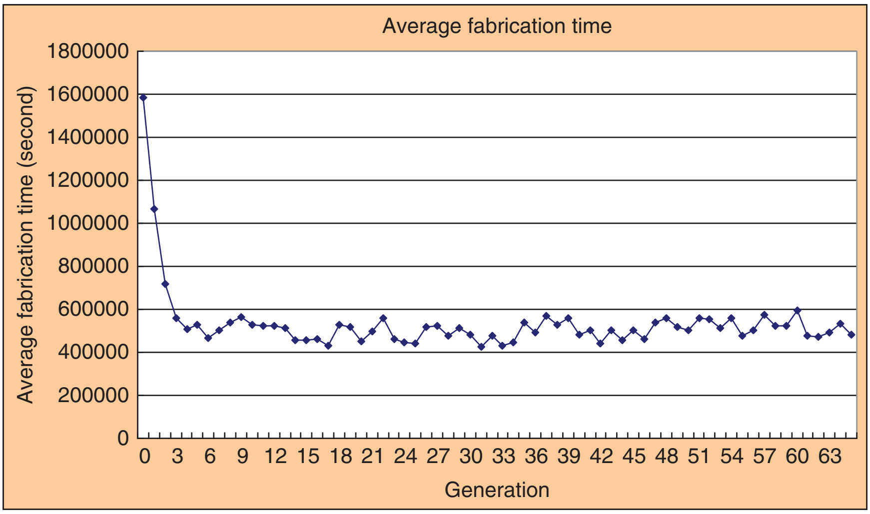

Figure 13. Average fabrication time for each generation.

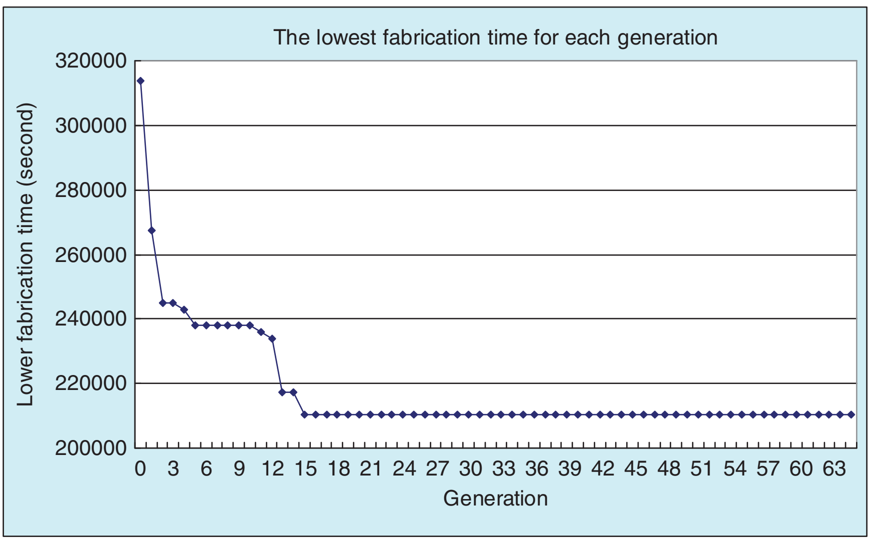

Figure 14. The lowest fabrication time for each generation.

same after 50 generations, GA is converged and reduces the fabrication time. In Figure 13, the average fabrication time decreases very quickly and reaches around 500,000 s after the fifth generation in GA. In Figure 14, the lowest fabrication time value is gained after the 15th generation. Therefore, the proposed method can find the best solution quickly by the following best MHSF:

$$f_{w_1,w_2,w_3,w_4,w_5} = 0.064456Att_{From} - 0.415093Att_{To} - 0.185991Att_{RGV} + 0.039848Att_{LOT} - 0.294612Att_{STK}$$

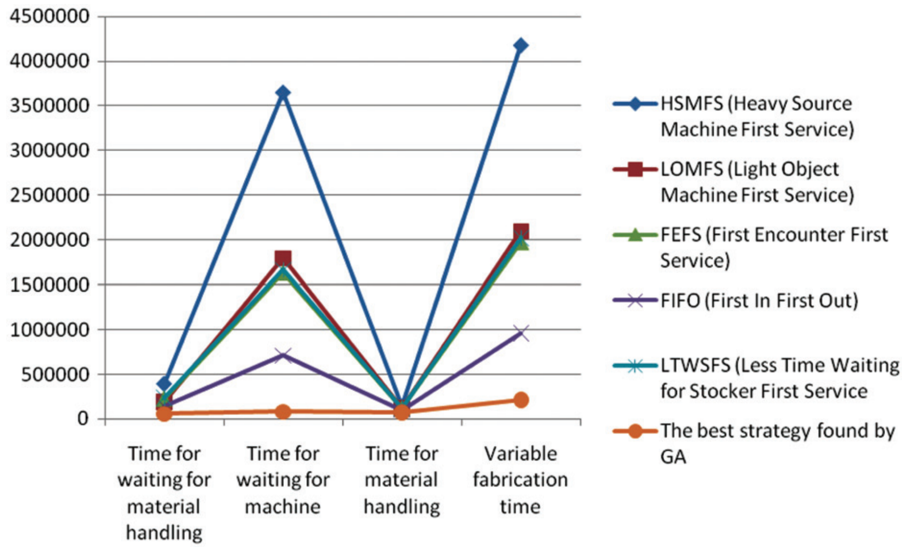

Figure 15. The comparison of the lowest time for product of several methods.

It can be easily seen that w_2 has the largest absolute value, or the most important item is Att_{To}. It means that when the next machine is busy, a material handling command has a low possibility of being chosen, and the lot has to wait in the current machine. The lot also has a greater opportunity to be sent directly to the next machine in order to reduce the number of material handling commands required. In our experiment, there were 86.7% of commands directly sent for this set of weights in the system.

A comparison of the productivity of several methods using status data in Table 4, including HSMFS, LOMFS, FEEFS, FIFO, LTWSFS, and the proposed methods, is illustrated in Figure 15. The results indicate that the proposed method reached the best solution comparing with other methods.

4.3 *Comparison with different number of lots generated*

To seek the optimal weight set, the proposed method with 20 generations has been applied to different numbers of lots. In Figure 16, it is clear that when the number of lots increases, the total fabrication time increases. When the lot number is greater than 74, fabrication time and time difference increase greatly, where time difference is the distance between the largest and the smallest fabrication times. It indicates that the lot numbers from 71 to 74 have better results.

4.4 *Further comparison in dynamic status*

In some fabrication processes such as, wafer fabrication, the production process and machine operation status may affect the productivity. In order to evaluate the performance of the proposed method, two experiments have been done under different dynamic status. In the first experiment, four different processes were used to test the

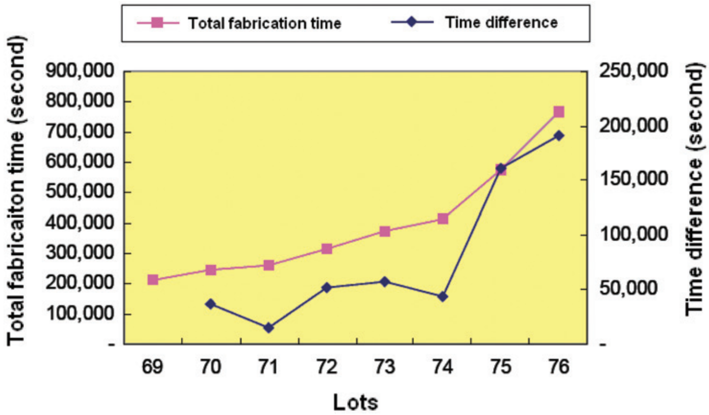

Figure 16. The minimal fabrication time for different lot numbers.

Table 5. The statuses of four processes.

	Process 1	Process 2	Process 3	Process 4
Non-A(1)	8200	12,500	10,000	13,500
Non-A(2)	13,500	14,200	12,500	14,000
Non-A(3)	10,400	10,400	12,000	10,000
Non-A(4)	13,800	14,200	15,000	13,500
Non-A(5)	11,200	10,400	11,200	13,000
Ma	540	560	520	580
Mb	400	380	400	350
Mc	300	250	320	280
Md	80	60	80	100
Stocker	40	80	80	50
Optimal lot number by FIFO	69	70	67	75

proposed method, and a machine break-down record of a real company was used in the other experiment.

(1) *Using four different process statuses*

Table 5 shows the statuses of four different processes of the TFT-LCD to check the proposed method, where Process 1 is the original process and Processes 2 to 4 are new processes. In the three new processes, machine operation time, stocker size, and time for a lot in a non-A area is reset. Productivities in different processes by HSMFS, LOMFS, FEEFS, FIFO, LTWSFS, and proposed methods are compared in Table 6. Still, the proposed GA method has the best productivity.

(2) *Machines break-down data*

In this subsection, a manufacturing data with machine break-down record is used to test the dynamic status for the proposed method. Using process 1, everything ran well on the first day. The status on the first day was recorded as status 1. On the second day,

Table 6. The comparison of four processes.

		HSMFS (Heavy Source Machine First Service)	LOMFS (Light Object Machine First Service)	FEFS (First Encounter First Service)	FIFO (First In First Out)	LTWSFS (Less Time Waiting for Stocker First Service	The best strategy found by GA
Process 1	Time for waiting for material handling ($RW_{mh}t_j^i$)	389,979	187,644	226,088	145,870	237,747	569,82
	Time for waiting for machine ($RW_{ma}t_j^i$)	3,646,081	179,3020	1,631,759	709,639	166,3928	809,93
	Time for material handling (RMt_j^i)	137,700	116,720	116,346	100,069	118,897	72,437
	Variable fabrication time ($R't_j^i$)	4,173,760	2,097,384	1,974,193	955,578	2,020,572	210,412
Process 2	Time for waiting for material handling ($RW_{mh}t_j^i$)	534,917	138,188	249,719	192,123	144,914	42,692
	Time for waiting for machine ($RW_{ma}t_j^i$)	7,657,363	496,348	1,533,672	506,433	344,900	13,649
	Time for material handling (RMt_j^i)	152,106	99,498	120,537	105,879	102,818	78,998
	Variable fabrication time ($R't_j^i$)	8,344,386	734,034	1,903,928	804,435	592,632	135,339
Process 3	Time for waiting for material handling ($RW_{mh}t_j^i$)	346,467	169,747	180,093	156,749	106,768	63,070
	Time for waiting for machine ($RW_{ma}t_j^i$)	2,678,492	512,485	1,510,071	589,455	1,040,596	154,753
	Time for material handling (RMt_j^i)	128,834	104,947	109,519	105,147	93,279	82,413
	Variable fabrication time ($R't_j^i$)	3,153,793	787,179	1,799,683	851,351	1,240,643	300,236
Process 4	Time for waiting for material handling ($RW_{mh}t_j^i$)	542,804	218,793	295,349	156,729	147,501	73,895
	Time for waiting for machine ($RW_{ma}t_j^i$)	11,488,346	2,591,821	4,636,849	907,298	1,268,945	263,086
	Time for material handling (RMt_j^i)	161,870	126,307	135,335	109,054	111,471	92,764
	Variable fabrication time ($R't_j^i$)	12,193,020	2,936,921	5,067,533	1,173,081	1,527,917	429,745

Table 7. The weights calculated by the proposed method in different statuses.

	Status 1	Status 2	Status 3
w1	0.06445612	0.33125799	0.16933685
w2	0.41509296	0.22320731	0.31999321
w3	0.18599089	0.16698497	0.20771212
w4	0.03984787	0.27662127	0.30160091
w5	0.29461216	0.00192846	0.00135691

Table 8. The comparison of different material handling methods for the dynamic status.

	HSMFS (Heavy Source Machine First Service)	LOMFS (Light Object Machine First Service)	FEFS (First Encounter First Service)	FIFO (First In First Out)	LTWSFS (Less Time Waiting for Stocker First Service	The best strategy found by GA
Time for waiting for material handling	445,573	122,517	225,697	159,919	280,995	105,328
Time for waiting for machine	4,401,321	500,722	1,695,013	758,641	2,448,219	441,542
Time for material handling	147,432	100,571	119,854	103,372	125,047	95,566
Variable fabrication time	4,994,326	723,810	2,040,564	1,021,932	2,854,261	642,436

machine Ma030 broke down at 09:38:52 in the morning. The manufacturing status was recorded as status 2 in Table 7. At 14:03:24 pm, machine Ma030 was repaired and the manufacturing system was restored to status 1. Unfortunately, at 21:46:37, machine Mb010 broke down and the status became status 3 until 23:32:46.

With the three different statuses described above, five weight values were calculated by the proposed GA based MHSF method as listed in Table 7. According to the comparison of the productivities in different statuses shown in Table 8, the result of the proposed method is the best among the others.

4.5 *Comparison of crossover method*

Many kinds of crossover methods are proposed. Many factors including different crossover methods, problems, and encoding should affect the performance of GA. In this subsection, the performances of four crossover methods, including one-point, two-point, uniform, and arithmetic (convex) are compared for our proposed method. Each method runs 10 times and the learning time is recorded. The population size is 100, and crossover rate is 0.9. The results are shown in Table 9 and it indicates that the arithmetic (convex)

Table 9. The comparison of four crossover methods (s).

	One-point	Two-point	Uniform	Arithmetic (Convex)
1	0.170	0.186	0.190	0.156
2	0.170	0.190	0.186	0.123
3	0.173	0.186	0.190	0.153
4	0.173	0.170	0.173	0.156
5	0.170	0.190	0.186	0.140
6	0.156	0.203	0.170	0.140
7	0.170	0.190	0.170	0.126
8	0.173	0.186	0.186	0.140
9	0.170	0.186	0.190	0.123
10	0.170	0.190	0.186	0.140

crossover method has the lowest running time and the best performance in all 10 of the experiments. Therefore, all our experiments for the proposed method apply the arithmetic crossover method.

5. Conclusions

The competition in TFT-LCD industry is extremely intense. To increase fabrication productivity, this study proposes a MHSF which is based on GA to find out the best strategy for reducing material handling and waiting time in the array process of a TFT-LCD factory. A MHSF consists of five affecting factors in the fabrication. In the GA based method, the encoding, crossover and mutation operations have been designed specifically for the five affecting factors. After the optimal set of weights are found, the corresponding optimal strategy can be used to calculate the function value for each material handling command and the command which has the highest value will be performed first. From the results, it is clear that the busy status of the object machine in the fabrication process has a high degree of influence on productivity. A better material handling strategy function reduces the utility of the RGA and the stocker. Comparing to the FIFO strategy, the proposed method can save 86% of material handling and lot waiting time. For the case in the experiments, lot numbers 71 to 74 are sought to reach higher productivity. In brief, the proposed material handling strategy function indeed raises the TFT-LCD fabrication productivity.

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