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Full Length Research Paper

Evaluation of automated guided vehicle systems in thin film transistor liquid crystal display (TFT-LCD) Array manufacturing process

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In real bay layout of automated guided vehicle (AGV) systems for thin film transistor liquid crystal display (TFT-LCD) Array manufacturing, excessive inter-bay transfers in such systems will degrade performance. Thus, this paper presents two models which capture the elements of the material handling time of both bay and conventional AGV systems. Five case simulation studies are conducted to determine whether bay systems are more suitable than conventional AGV systems for particular applications under consideration of inter-bay transfer rate.

Key words: Automated guided vehicles, material handling systems, simulation, thin film transistor liquid crystal display (TFT-LCD).

INTRODUCTION

The fact that the life cycle of products has become shorter and shorter, has continually forced industries, including the thin film transistor liquid crystal display (TFT-LCD) panel industry, to emphasize innovative product designs or production improvements to survive the intense competition of the global market. This research targets one of two important trillion-dollar industries in Taiwan, that is, the TFT-LCD industry. Generally, its production can be divided into three processes. Array process is a fundamental processing of glass substrate. Then, Cell process continues to process and to combine TFT array substrate and CF (Color Filter) into cells. Module process, a final process, assembles the module according to customized specifications and coordinates the packing of finished goods. The entire process normally takes almost two weeks from raw material to final product ready for delivery. In order to further reduce the response time, lower the cost and diminish human error, most manufacturers are focusing on automating the process, especially in the application of automated material handling systems (AMHS) in the Array process, due to its complicated operations and high-quality requirements.

A typical Array process includes 5 major mask processes in TFT-LCD array manufacturing process. They are Gate Electrode (GE), Semiconductor Electrode (SE), Source Drain Electrode (SD), Contact Hold (CH) and Pixel Electrode (PE) processes, and each of which will repeat the sub-process of thin-film developing, photo transferring, etching and stripping process. For a TFT-LCD display panel, it must process through the sub-process for about five times to fabricate. Hence, the manufacturing process layout becomes a key point because of the increasing manufacturing complexity and the characteristic of manufacturing process reentrant.

Most of today's TFT-LCD Array process facilities use a so-called bay layout or a functional layout, as shown in Figure 1. In a bay layout, the facility is divided into a number of bays that contain similar functions of equipment. An automated guided vehicle (AGV) or rail guided vehicle (RGV) is used to facilitate the intra-bay transfers. In this configuration, a large amount of material flow between bays or inter-bay transfers can occur. When an inter-bay transfer is applied, the production lot will be stored in a Stocker (STK) first; and an overhead shuttle system (OHS) is then used for moving material to the designated Stocker. A stocker is usually used for temporary storage of work-in-process. Note that an OHS, which is usually

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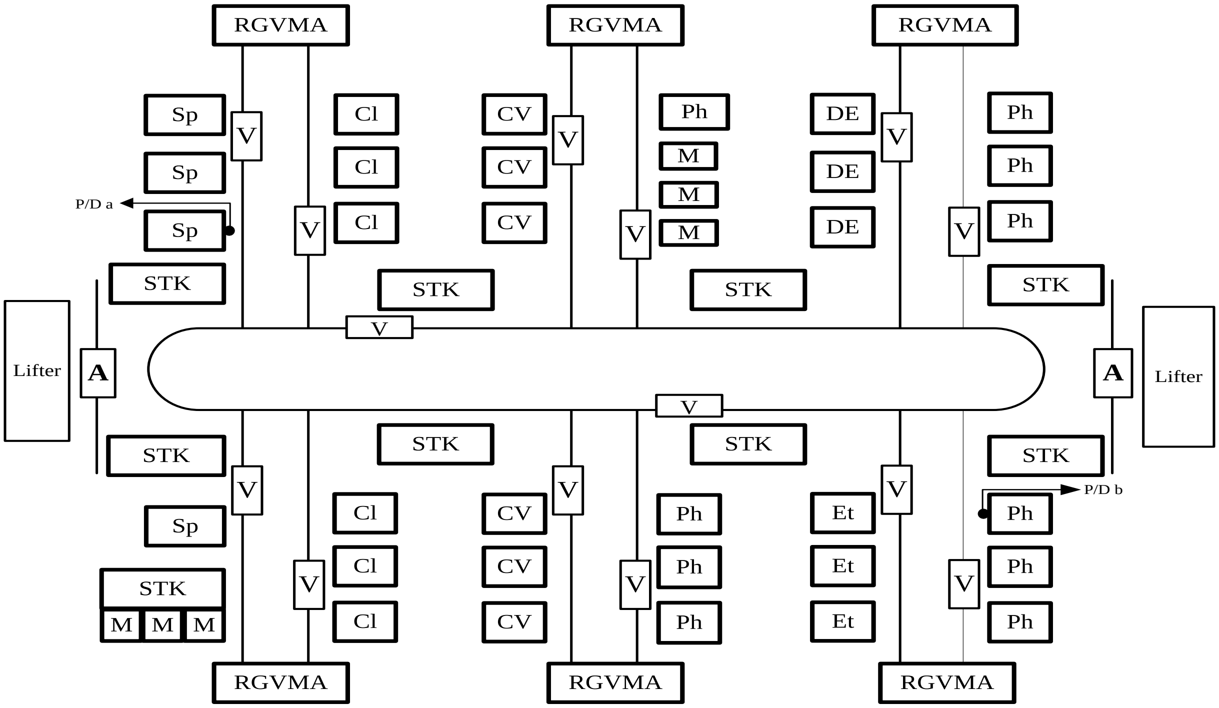

Figure 1. Layout for a bay AGVs system. Sp = Sputter; Cl = Cleaner Stripper; CV = CVD, Chemical Vapor Deposition; Ph = Photo, Exposing the photo; Et = Etcher; DE = Photo, Develop the screen; RGV MA = AGVs Maintenance Area; M = Measure; STK = Stocker.

designed with a spine configuration, typically has one directed flow loop. Because of the bay layout of the Array process, the inter-bay material handling transfers become extremely important. A major drawback of the bay design is that aproduction lot will have to travel between bays via OHS before processing is completed; this results in inter-bay transfers. Each inter-bay transfer will require additional pick-up and deposit operations with extra delays occurring at the transfer points. Thus, excessive inter-bay transfers will have a negative effect on the overall system performance. It is expected that bay design systems may not always be superior to the other path designs such as conventional AGV systems, as shown in Figure 2.

To achieve the benefits of improved performance and justify the large investment costs of an Array process fabrication facility, a good installation of an AMHS in a manufacturing system is required. Therefore, this paper will investigate two common AGVs path designs, namely bay design and conventional design, as shown in Figures 1 and 2, respectively. The objective is to establish the design where the bay concept can be best applied in the TFT-LCD Array process in terms of inter-bay transfer rate.

The remainder of this paper is organized as follows: First is a review of AGVs design and control issues. This is followed by a presentation of two models estimating AGVs system performance for both bay and conventional AGVs systems. A comparison of the two types of AGVs systems by using five case simulation studies was done and conclusions and recommendations for future study was therefore presented.

LITERATURE REVIEW

AGV systems have received attention for years, mainly because of their consistency, flexibility, and automation, among other factors. Although these types of systems can provide many advantages, due to their high installation costs, careful designs are needed to avoid potential failure. The AGV-related research reviewed here includes topics covering both design issues (Maxwell and Muckstadt, 1982; Kulwiec, 1985; Newton, 1985; Gaskins and Tanchoco, 1987; Egbelu, 1987; Mahadevan and Narendran, 1990, 1992; Tanchoco and Sinriech, 1992; Corréa et al., 2007; Asef-Vaziri and Goetschalckx, 2008; Chiba et al., 2009; Ventura and Rieksts, 2009) and control issues (Egbelu and Tanchoco, 1984; Taghaboni and Tanchoco, 1988; Bartholdi and Platzman, 1989; Bozer and Srinivasan, 1989, 1991a, b; Lee et al., 1990; Sabuncuoglu and Hommertzheim, 1992; Hwang and Kim, 1998; Kim and Kim, 1998; Hong, 2004; Maza and Castagna, 2005; Kim and Chung, 2007). These issues are important and must be carefully considered in planning if the system's full potential is to be realized.

From the review above, most of the studies related to the design of AMHS have suggested the use of simulation as well as the mean handling time (MHT) as tool and main performance measure to analyze alternative AMHS

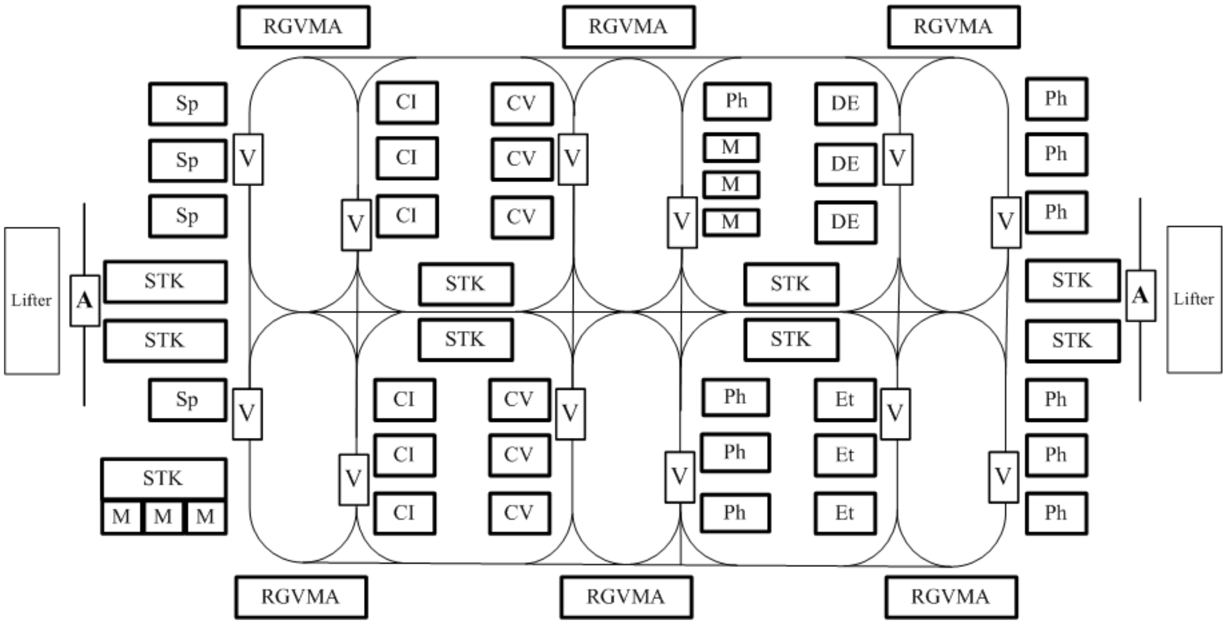

Figure 2. Layout for a conventional AGVs system. Sp = Sputter; Cl = Cleaner Stripper; CV = CVD, Chemical Vapor Deposition; Ph = Photo, Exposing the photo; Et = Etcher; DE = Photo, Develop the screen; RGV MA = AGVs Maintenance Area; M = Measure; STK = Stocker.

layouts. However, these studies did not provide information on how to calculate inter-bay transfer time nor how to select the proper material handling systems under the consideration of inter-bay transfer rates, especially in the TFT-LCD industry. Thus, this paper provides method in assessing the MHT for bay and conventional AGV systems, and also simulation study for comparisons.

EVALUATING MEAN HANDLING TIME (MHT)

MHT is the average time per trip, that is, the average time elapsed between the time at which a request for material transfer is initiated until the part is delivered to the destination station. For calculations, the following variables are defined:

For conventional systems,

L_{ij} = distance traveled by an empty vehicle to a requesting station *i* when it becomes available at station *j*;
L_{ik} = distance traveled by loaded vehicle between station *i* and destination station *k*;
t_i = time station *i* waits for a vehicle to become available after a vehicle request for job transfer is initiated;
V = average vehicle travel speed (ft/min); It is assumed that vehicles travel at a constant speed which includes averages of all acceleration and deceleration.

For bay systems,

L_{ab} = see L_{ij};
L_{ac} = see L_{ik};
t_a = see t_i;

These values apply only to intra-bay transfers.

Mean MHT for conventional AGV systems

The time elements per trip for conventional systems include: (1) vehicle response time (*VRT*): the time a requesting station *i* waits for a vehicle to become available after a request for job transfer is initiated plus the time to move the vehicle (without load) to the requesting station where loads reside, and (2) moving time (*MT*): the time to move a loaded vehicle from station *i* to station *k*. Vehicle response time and moving time are given by Equations 1 and 2, respectively.

$$VRT = \frac{L_{ij}}{V} + t_i \quad (1)$$

$$MT = \frac{L_{ik}}{V} \quad (2)$$

Therefore, the time per trip, *HT*, is

$$HT = VRT + MT$$

$$= \left(\frac{L_{ij}}{V} + t_i\right) + \frac{L_{ik}}{V} \quad (3)$$

Thus, mean time per trip *MHT* is given by

$$MHT = (\frac{\overline{L}_{ij}}{V} + \bar{t}_i) + \frac{\overline{L}_{ik}}{V}$$

$$= \overline{VRT} + \overline{MT} \quad (4)$$

Variables with the bar represent values averaged over all stations, links, or loops.

MHT in Equation 4 assumes that there is no traffic congestion or blocking. This *MHT* can be designated as MHT_{ideal}. In reality, blocking of vehicles, waiting time at intersections, poor scheduling, and poor layout can contribute to degradation in performance. A traffic factor *b* accounts for all these and lies between 0.0 and 1.0. One suggested value is $0.10 \le b \le 0.15$ (Kulwiec, 1985). After taking the traffic factor into account, *MHT* becomes

$$MHT = MHT_{ideal} * (1+b) \quad (5)$$

Then, number of deliveries per hour can be obtained from *MHT* and is given as

$$MHR = \frac{1}{MHT} \quad (6)$$

Mean MHT for bay AGV systems

The time per trip for bay systems may include intra-bay trip time (*IRALT*) and inter-bay trip time (*IERLT*), which are calculated as follows.

Intra-bay Trip Time (IRALT)

Intra-bay transfers are those load transfers between stations in the same bay, such as transfers between station *a* and station *b* in Figure 1. Pickup and dropoff locations are designated *P/D*. The calculation of an intra-bay trip time is similar to *HT* of conventional systems and has both: (1) vehicle response time (*VRT*) and (2) moving time (*MT*). Vehicle response time and moving time are calculated in Equations 7 and 8, respectively.

$$VRT = \frac{L_{ab}}{V} + t_a \quad (7)$$

$$MT = \frac{L_{ac}}{V} \quad (8)$$

Therefore, the intra-bay trip time, *IRALT*, is given by

$$IRALT = VRT + MT$$

$$= (\frac{L_{ab}}{V} + t_a) + \frac{L_{ac}}{V} \quad (9)$$

Inter-bay trip time (IERLT)

Inter-bay transfers are load transfers between stations in different bays. As shown in Figure 1, loads must travel from *P/D a* to *P/D b*. Loads at *P/D a* must first travel to interface transfer station (that is, Stocker), as represented by *STK*. From there, they can be picked up by the vehicle and then delivered to the corresponding *STK* at which they can be transferred to the destination *P/D b*. Here, these two bays can be viewed as source and destination bays, respectively. Thus, if source and destination bays are different, an inter-bay transfer is required. An inter-bay transfer typically includes two intra-bay transfers as transport is required in both bays. For calculation of inter-bay trip time, additional variables are defined:

I_x = interface transfer station *x*;
$L_{I_x I_k}(i)$ = distance traveled by empty vehicle in i_{th} intermediate transfer; (refer to L_{ab});
$L_{I_x I_y}(i)$ = distance traveled by loaded vehicle between two interface transfer stations during i_{th} intermediate passing-through transfer; (refer to L_{ac});
$t_{I_x}(i)$ = the time a part at interface transfer station I_x waits for a vehicle to become available during i_{th} intermediate passing-through transfer; (refer to t_a);

Therefore, inter-bay trip time may include three time elements: (1) intra-bay trip time in the source bay ($IRALT_s$), (2) intermediate trip time (*IPTT*), and (3) intra-bay trip time in the destination bay ($IRALT_d$). The calculations of the $IRALT_s$ and $IRALT_d$ are similar to that of *IRALT* given by Equation 9. Intermediate trip time is the time to move loads between interface transfer stations and has two components: vehicle response time (*IVRT*) and moving time (*IMT*). Here, vehicle response time is the time that elapsed between the time at which the request for a load transfer is initiated until the time a vehicle arrives at the requesting interface transfer station. Moving time is the time to move a loaded vehicle from one interface station to another interface transfer station. So an intermediate trip time is as given by Equation 10.

$$IPTT = \left[\frac{L_{I_x I_k}(i)}{V} + t_{I_x}(i)\right] + \frac{L_{I_x I_y}(i)}{V} \quad (10)$$

$$= IVRT + IMT$$

Thus, inter-bay trip time is given by

$$IERLT = IRALT_s + IPTT + IRALT_d$$

$$= (VRT_s + MT_s) + (IVRT + IMT) + (VRT_d + MT_d) \quad (11)$$

If all transfers were merely intra-bay transfers or inter-bay transfers, then the *HT* would be given by Equations 9 and 11, respectively. However, transfers require both inter and intra-bay transfers. The ratio of inter-bay transfers to total transfers is represented as *IBTR*. *IBTR*, as discussed above, is used to calculate the rate of inter-bay transfers in a system, and is given by

$$IBTR = \frac{E_I}{\sum_{i=1}^{N}\sum_{j=1}^{N} f_{ij}} \qquad (12)$$

where f_{ij} represents flows from machine *i* to *j*. Thus the denominator is the total flows for the given "from-to" table. The numerator, E_I, is the total inter-bay transfers.
However, the actual value of *IBTR* can only be determined after the bay system has been designed and machines have been assigned to bays. Thus *HT* is given by

$$HT = IRALT^*(1\text{-}IBTR) + IERLT^*(IBTR) \qquad (13)$$

$$= (VRT + MT)^*(1\text{-} IBTR) + [(VRT_s + MT_s) + (IVRT + IMT) + (VRT_d + MT_d)]^* IBTR$$

If the mean vehicle response time at all stations, including processing stations and interface transfer stations, is assumed equal so that $\overline{VRT} = \overline{VRT}_s = \overline{IVRT} = \overline{VRT}_d$ and the mean moving time between any two stations is equal so that $\overline{MT} = \overline{MT}_s = \overline{IMT} = \overline{MT}_d$, then, mean *HT* (*MHT*) becomes

$$MHT = (\overline{VRT} + \overline{MT}) * (1 - IBTR) + \{(\overline{VRT} + \overline{MT}) + (\overline{VRT} + \overline{MT}) + (\overline{VRT} + \overline{MT})\} * IBTR$$

$$= (\overline{VRT} + \overline{MT}) * (1 + 2 * IBTR) \qquad (14)$$

Because bay systems experience no traffic congestion effects such as vehicle blocking or waiting at intersections, the use of a traffic factor is not required. Therefore, number of deliveries per hour (*MHR*) can be obtained directly by using *MHT*. Equation 14 shows the relationship between mean trip time and *IBTR*. For any assumed layout of a bay system, the mean trip time can be seen to be a function of *IBTR*. When *IBTR* increases, it indicates that more job transfers are required to move parts through interface transfer stations between bays. Due to the increased number of inter-bay trip times that are required, mean trip time will also increase. Therefore, bay systems can be expected to perform poorly when a large number of inter-bay transfers are required.

Although, MHT is a good indicator in managing these systems, it is difficult to assess due to the operation complexities and stochastic nature. Thus, simulation studies are conducted to reflect a particular layout design, fleet size, and a number of work stations.

AGVS LAYOUT COMPARISONS FOR THE CASE COMPANY

The case company is a medium-sized company in the southern area of Taiwan, specializing in TFT-LCD products applied in notebook computer displays and desktop computer monitors. Their customers include leading electronics companies both in Taiwan and overseas. This company now operates two plants, one is for LCD fabrication and the other is for LCM fabrication. By the means of technology transfer and self-development, the company can sustain the state-of-the-art TFT-LCD manufacturing technology with the highest efficiency for mass production. Due to its recent requirement of an increase on LCD production capacity, the company has considered to further automate its production process.

In general, the TFT-LCD production process involves in three major steps: Array process, Cell process, and Module assembly process. First, the front-end Array process places the thin-film transistors on the glass substrate. Then, the Cell process fits the array substrate to a color-filter substrate; liquid crystal is inserted between the two substrate layers. Finally, Back-end Module assembly involves with taking the panel from the Cell process and bonding the LCD driver IC, and assembling backlights, metal frame and other components to make the finished product.

Automation of the Array process is a huge investment; hence, how to select the most suitable guide path design becomes an important and urgent task for the company, which can satisfy the company's need for an increase of capacity. In this case study, only the Array process is considered here since it is the most important step in the entire manufacturing process. The machine equipments required for Array process include Sputter; Cleaner Stripper; Chemical Vapor Deposition; Photo and Exposing the Photo; Etcher; Photo, Develop the Screen; Measure Machine; Guided Vehicle Maintenance Area; and Stocker. Two potential AGV layout designs, the layout of a bay system and the corresponding conventional system as shown in Figures 1 and 2, are evaluated. The only difference between Figures 1 and 2 is the AGV guide path layout.

Five case studies each with different level of *IBTR* value are presented to make comparisons between two layout designs. These levels are: (1) very low *IBTR*, (2) low *IBTR*, (3) medium *IBTR*, (4) high *IBTR*, and (5) very high *IBTR*, representing approximately 0, 25, 50, 75 and 100% *IBTR*. The overall workload for all five case studies is kept constant. These case studies can be used for comparing bay design with conventional design and for establishing the most suitable level of *IBTR* for applying the bay design concept.

The vehicle type for this study is considered to be a generic, unit load, AGV and the AGV traffic flow assumed to be bi-directional. At the completion of each transfer assignment, the AGV remains at the same station and awaits its next assignment. For simplicity, the underlying assumptions for this study are the following:

(1) No preemptions or breakdowns are considered for AGVs and any machines.
(2) The "shortest distance" rule is used for selection of

Table 1. Simulation results of five case studies with mean trip time, mean flow time, and AGV utilization.

Case		Conventional layout	Bay layout
	TT*	30.16	10.58
1	MFT	391. 25	350.18
	U	54. 47	UV#: 34.83
	TT	31.42	18.22
2	MFT	385.15	369.53
	U	67.31	UV#: 30.00
	TT	42.75	33.58
3	MFT	423.52	394.43
	U	84.65	UV#: 56.18
	TT	42.18	70.37
4	MFT	441.65	532.51
	U	86.55	UV#: 77.87
	TT	271.87	372.78
5	MFT	1143.2	1301.6
	U	97.83	UV#: 95.53

*TT: mean time per trip in minutes; UV#: utilization of bay vehicle; U: AGV utilization (%); MFT: mean flow time in minutes.

AGVs in the conventional system.
(3) Load inter-arrival times to the system are exponentially distributed.
(4) Machine processing times are uniformly distributed.
(5) Vehicle traveling speed is held as a constant (80 ft per min).
(6) Same number of AGVs is used for both the conventional system and bay system.
(7) Two-way I/O interface transfer stations (Stockers) are used for material flows between bays.

Arena is used to simulate both the bay and conventional systems. One simulation runs for 15,000 min about a batch production, including warm-up time. The program captures the vehicle blocking time caused by vehicle blocking and congestion in the conventional AGV systems. An equivalent traffic factor of 0.1 for the conventional systems is obtained from the simulation. The results for the five case studies are summarized in Tables 1 and 2.
According to the experimental results in Tables 1 and 2, models of the bay systems yield better performance than those of the conventional systems as long as inter-bay transfers are kept to a minimum. When the *IBTR* are 0 and 50%, the mean trip time of bay system is less than that of the comparable conventional system. As the *IBTR* increased from 50 to 75%, the mean trip time of bay system increases so that it finally exceeds that of the conventional system. Increases in *IBTR* over 75%, yields trip times that are longer than those of conventional systems due to the large numbers of inter-bay transfers involved. For mean flow time, the values for bay systems remain less than those obtained for conventional systems when the *IBTR* are 0 and 50%. At some points *IBTR* is below 75%, average flow time for the bay system exceeds that of the conventional system because the additional waiting and handling times at interface transfer stations become more significant. For other performance measures such as AGV utilization, and average numbers of waiting requests, no significant differences are observed between the conventional and bay systems. In general, the levels of *IBTR* value can determine the difference of performance for which bay systems seem to be superior to conventional systems. A suggestion given by the results of Tables 1 and 2 shows:

(1) When *IBTR* is between 0 and 50%, bay systems are expected to be superior to conventional systems;
(2) When *IBTR* is at higher values as between 50 and 75%, bay systems may have a transition and finally become worse than those of conventional systems;
(3) When *IBTR* increases over 75%, bay systems are likely to be inferior to conventional systems.

Conclusions

Although, the bay concept possess many advantages, it should not be ignored that excessive inter-bay transfers will offset some of the benefits from simplification of control, even in some cases bay systems may perform worse than conventional systems. Thus, this paper presents two models which capture the elements of

Table 2. Simulation results of five case studies with mean numbers of waiting requests.

Case	Conventional layout	Bay layout
1	MWR*: 0.04	MWRV#*: 0.03
2	MWR: 0.15	MWRV#: 0.04
3	MWR: 0.89	MWRV#: 0.25
4	MWR: 1.12	MWRV#: 1.44
5	MWR: 25.78	MWRV#: 11.5

*MWR: mean # of waiting requests; MWRV#: mean numbers of waiting requests for the bay vehicle.

material handling time for bay and conventional AGV guide path layouts in the TFT-LCD panels industry. Also, simulation studies are conducted and results show that excessive inter-bay transfers in bay systems will degrade performance. The results of five case studies suggest that *IBTR* is sufficient for determining if bay systems are more suitable than conventional AGV systems for particular applications. This can provide critical decision support in evaluation and selection between two common AGV guide path layouts.

Two extensions of this study are suggested, one is to develop more concrete guidelines for bay formation in order to minimize the total number of inter-bay material flows, the other is to develop a model to provide an inter-bay transfer prediction index to actual value of *IBTR.* It is particularly advantageous since the actual value of *IBTR* can only be calculated after the bay system is completely formed; it avoids the need to actually form bays in order to calculate *IBTR* as to determine whether the bay concept should be applied or not.

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