# Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 14 (3): 245-251, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.245.251

# Logistics Priority Management under Multiple Performance Metrics

Yunjung Suh and Jaewoo Chung
School of Business Administration, Kyungpook National University, Daegu, 702-701, South Korea

---

**Abstract:** This research develops a scientific procedure to manage the priorities of delivery jobs that are moved by automated material handling systems in manufacturing facilities. An efficient management of the priorities makes the capacity of the automated material handling even increased without extra hardware investment. The procedure developed by this research consists of three steps including determination of static priorities, estimating delivery urgencies and combining static priorities with delivery urgencies. A stochastic approach together with heuristic models is used to address this problem. The developed procedure was applied in an actual production facility that fabricates LCD (liquid crystal display) panels and a set of actual data was collected after the application to analyze the performance of the new procedure. The analysis results show that the new procedure suggested by this research significantly improves the existing method used in the facility.

**Key words:** Priority management, delivery priority, manufacturing system, stochastic model, arrival time estimation

---

## INTRODUCTION

Production management nowadays involves many complicated factors due to such new trends as diversified customer requirements, short product life cycles and facilitated globalization. One such case is observed in the LCD (liquid crystal display) industry. Recently demands of LCD products are rapidly increasing because they become essential parts of mobile devices such as smart phones and tablet PCS that are gaining a great popularity in these days. As a consequence, the product variety in the industry has proliferated to meet the new demands as well as traditional ones in the market such as PCS, monitors and TVs (Chung, 2013). On the other side, the competition among semi/LCD makers are also growing and they adopt more complicated processes for fabrication (fab) to survive in the cost reduction race driven by the markets. These recent phenomena charge a great deal of difficulties to operation managers who are responsible for maintaining efficiencies of fab facilities.

To increase efficiency and competitiveness, LCD firms adopt automated material handling systems that transfer parts under processing from one toolset to other toolsets without human intervention. Hence the facility requires high initial investment and sometimes costs more than 3 billion US dollars to build a new facility. The material handling automation helps not only reduce labor cost but also increase job standardization. In turn it increases visibility of operations in fabs and supports various engineering activities indirectly for improving the yield of the fab. Advantages of fab automation described in the literature (Chung and Hur, 2012; Chung and Jeng, 2004; Campbell and Laitinen, 1997; Weiss, 1997) include: Enhancing toolset utilization by reducing wafer/glass delivery time under fabrication, increasing operational visibility by standardization and complexity reduction, reducing direct and indirect labor cost, enabling to implement higher level production support systems such as the real-time dispatching system, scheduling system, SPC (statistical process control) system and APC (advanced process control).

The purpose of this research is to develop an analytical procedure enhancing the performance of the Automated Material Handling System (AMHS) which is one of the important cost drivers in semi/LCD fab operation. The procedure focuses on the prioritization of unit loads considering such various factors as process urgencies, storage full rates and material flow congestion levels. Efficient determination of unit load priorities can reduce average delivery time and toolset starvation due to delays in transportation. It increases the capacity of the highly expensive material handling systems without extra investment on the fixed cost. One characteristic of the systems is that the frequencies of transportation jobs requested are highly variable for material handling as shown in Fig. 1. An efficient prioritization procedure enables to serve transportation jobs in the peak point of the variability. The procedure was developed by an academic-industry collaboration project and contributed to improve the performance of the existing AMHS in an LCD fab.

**Corresponding Author:** Jaewoo Chung, School of Business Administration, Kyungpook National University, Daegu, Republic of Korea Tel: +82-53-950-7416

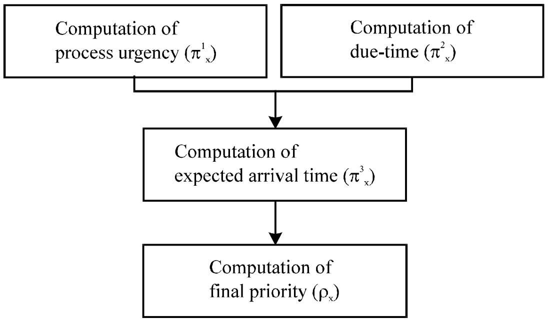

Fig. 1: Overall procedure to determine priorities

## RESEARCH BACKGROUND

A cassette which contains 15 to 30 wafers/glasses is used as a unit load for material storage and transportation in semi/LCD fabs. A cassette can be exchangeable with the unit load in this article. The most popular types of the automated material transportation systems used in LCD fabs are AGV (automated guided vehicle), OHS (overhead shuttle system), inter-floor lifter system and stocker system. The stocker system is another name of the AS/RS (automated storage and retrieval system) used in the LCD fabs. The different types of the AMHS are integrated by the Material Control System (MCS) in a fab.

There are hundreds of toolsets are in an LCD fab and unit loads are moved around the toolsets. The AMHS is responsible for transporting the unit loads from one toolset to the next. Jang and Choi (2006) explain types of the AMHS used in the LCD fab together with important issues in designing, controlling and operating the systems. An LCD fab uses similar material handling systems with a semiconductor fab which has been studied for many years in the academia. Improving the performance of the AMHS (Agrawal and Heragu, 2006; Montoya-Torres, 2006) provide comprehensive reviews related to the AMHS in the semiconductor industry.

Performance evaluation is an important part of the AMHS operation. Many simulation experiments have been conducted for the fabs. Their performance measures are generally throughput, utilization, lead time, delivery time and fixed cost; however, they vary by focuses of problems. Analytical models based on the queuing theory are also used for analyzing layout and AMHS designs. Although, an analytical model cannot consider a problem as detailed as a simulation model it has a great benefit from quick response times.

Simulation studies are used to analyze different types of facility layouts (Hase *et al*., 1994; Geiger *et al*., 1997). They analyze a few different types of the cell layout that differ by the degree of dedication of tools to the cells and compare them with a conventional bay layout. Their analysis shows that out of the different types of cell layout, the dedicated cell layout outperforms since it reduces setup time, improves yield and simplifies material flow. However it is pointed out that one disadvantage of the cell layout is in its inflexibility since the layout assigns tools into cells depending on its process routings of a few product types. The simulation studies are also used to analyze the performances of the automated material handling systems (Campbell and Ammenheuser, 2000; Noben *et al*., 2001; Mackulak and Savory, 2001). Especially, if there are a few to several alternatives being compared, computer simulations are popularly used in practice. However its limitations caused by the long implementation time are frequently pointed out in the research papers. Mackulak *et al*. (1998) study reusable simulation models to reduce a simulation cycle time. They adopt a modular design in a computer simulation and generic models with a reasonably small set of unique components are repeatedly used to model different situations. Pillai *et al*. (1999) also study a dynamic simulation model that can be reused for different problems using five elements: Automated input data integration system with the automatic model builder and simulation configuration, production equipment and WIP management rules simulator, intra-bay and inter-bay AMHS simulator and model validation capability. Kong (2007) introduces a two-step simulation approach. His method has been used for practical fab simulations and consists of production capacity simulation and AMHS simulation. Data including utilization of toolsets from the first simulation are used as input data in the second simulation.

Analytical methods are also used to evaluate layout and AMHS designs while simulation analyses take longer time and higher investment. The biggest advantage of the analytical method is its very short modeling lead time. Chen *et al*. (1988) develop a queuing network model to predict the performance of a wafer fab which is presented by the output quantities of the fab. They consider individual toolsets as servers in their model. Non-processing wafers are presented by an open queuing network model and productive wafers are presented by a closed queuing network model. Connors *et al*. (1996) and Hopp *et al*. (2002) determine required number of toolsets meeting a targeted production quantity using a queuing network model. To estimate performance of AMHS, Nazzal and McGinnis (2007) develop a queuing network model that considers relatively detailed aspect of an OHT loop in the conventional bay layout. The authors estimate throughput and rate of delayed move requests where unit loads are served by the FIFO (first come first service) polity. States of the pickup and drop off stations are modeled with a discrete set of states. The loop and stations are represented by Markov chain of which transfer requests are arrived with a Poisson process. Using relations between states and stations, a transition matrix and its stead state probabilities are obtained using the positive recurrent Markov chain.

One of the difficulties in design of the large-scale AMHS is the estimation of system capacity. Although the computer simulation has been popularly used its feed back cycle from modeling to results analysis is very slow for a large problem that the available timing of the solution is sometimes very important. Also a simple deterministic analysis using from-to charts of material flows cannot provide a precise estimation on variances in the system. As an alternative approach studied for the capacity analysis, the queuing network shows good performance (Nazzal and McGinnis, 2007).

## PRIORITIZATION MODEL

**Notations:** This section defines the notations used in this study as follows:

- **Indices**
    - x : Index for unit loads being transported in a fab
    - i, j: Index for toolsets
- **Input data**
    - $p^p_x$: Priority of the processing step for unit load x
    - $p^s_x$: Priority of the starting toolset or material handling system for unit load x. The value is determined based on the level of bottleneck
    - $p^d_x$: Priority of the destination toolset or material handling system for unit load x
    - $p^t_x$: Types of unit load x. This represents overall urgency of unit load x. If a unit load has a greater value of the type it is more urgent
    - $t^s_x$, $t^d_x$: Processing time of unit load *x* per one unit of WIP at the source or destination
    - $Q_k$: A set of loaders in toolset k, $\{1, 2, ...\} \in Q_k$
    - R: A set of loader statuses, 0: empty, 1: load waiting, 2: process waiting, 3: processing, 4: unload waiting, 5: unavailable due to breakdown, maintenance and so on
    - $g^s_{i,j}$: WIP level of toolset k, loader i loader status j where $i \in Q_k$, $j \in R$
    - $A_k$: A set of process steps that toolset k can process
    - $w_j$: WIP level of process step j in the MHS, for all $j \in A_k$
- **Decision variables**
    - $\pi^1_x$: Urgency of unit load x due to its process statuses. This priority is determined by combining $p^s_x$, $p^d_x$, $p^1_x$. It is called 'process urgency' of unit load x hereafter
    - $\pi^2_x$: Transportation due-time imposed to unit load x due to the level of starvation at the source or destination toolset
    - $\pi^s_x$: Transportation due-time of unit load x at the source toolset. If the source is MHS it sets to infinity
    - $\pi^d_x$: Transportation due-time of unit load x at the destination toolset. If the destination is MHS it sets to infinity
    - $\pi^3_x$: Expected arrival time of unit load x from source to destination
    - $\rho_x$: Final delivery priority of unit load x. As the priority is greater it is served earlier by the AMHS

**Prioritization model:** This section explains the proposed prioritization model by this research. It first introduces an overall procedure to determine the priorities of unit loads under delivery or waiting for delivery. Next it explains the prioritization model step by step. The prioritization procedure starts when a move request arrives to the material control system and every time a move request arrives the system calculates its priority. The move request of a unit load includes a source location and a destination that are a toolset or material handling device. The overall procedure consists of three steps as seen in Fig. 1. In the first step, the urgency of unit load that are determined by process statuses including the importance of the source toolset, the importance of the destination toolset and the type of the unit load. Also the delivery due-time of the unit load is calculated in the first step. In the second step, the expected arrival time of the unit load from source to destination is calculated. Finally the third step combines three factors calculated above to determine the final priority. The final step can be described as follows $f(x: \pi^1_x, \pi^2_x, \pi^3_x) = \rho_x$ where, x indicate the unit load under move request.

**Determination of $\pi^1_x$:** The determinant of process urgency on unit load x ($\pi^1_x$) is summarized in Table 1. There are two different types in the source or destination which are 'toolset' and 'MHS (material handling system)'. If the source or destination is MHS it is usually a storage system called 'stocker system'. The equation to determine $\pi^1_x$ is as follow:

$$\pi^1_x = \max \lfloor p^p_x + p^t_x, \max (p^s_x, p^d_x) + p^t \rfloor \tag{1}$$

Table 1: Determinant of process urgency depending on source and destination

| Source | Destination | Determinant of $\pi^1_x$ |
|---|---|---|
| Toolset | MHS* | The priority of source toolset plus the unit load type |
| MHS* | Toolset | The priority of destination toolset plus the unit load type |
| Toolset | Toolset | The maximum priority between the source and destination toolsets plus the unit load type |

*MHS: Material handling system

**Determination of $\pi^2_x$:** The delivery due-time is determined by the WIP (work-in-process) level in time for the source or destination toolset. As the WIP level is higher, the due-time is longer while the chance of the starvation at the toolset is lower. The delivery due-time of unit load x is in the case that the source or destination is a toolset as follow:

$$\pi^2_x = \min(\pi^s_x, \pi^d_x) \tag{2}$$

$$\pi^s_x = t^s_x \sum_{i \in Q_1} \sum_{j \in S \setminus \{4,5\}} g^s_{i,j} \tag{3}$$

$$\pi^d_x = t^d_x \sum_{i \in Q_1} \sum_{j \in S \setminus \{1,2,3\}} g^d_{i,j} \tag{4}$$

In Eq. 2, the delivery due-time of unit load x is the minimum of source and destination due-times. The due-time of destination is processing time of the toolset multiplied by the sum of the WIP level in the loaders as explained in Eq. 3. The due-time of source is determined with a similar method as that of the source in Eq. 4.

If the destination of the unit load is an MHS, the following steps are used to calculate $\pi^d_x$:

**Step 1:** Computing WIP load rate in the MHS $W_j$: The load rate of WIP for process step j:

$$w^*_j = \frac{w_j}{|A_j|}$$

where, $|A_j|$ is the number of toolsets that can process step j in the MHS.

$w^*_k$: WIP load rate that toolset k should process:

$$w^*_k = \sum_{j \in A_k} w^*_j$$

**Step 2:** Modifying the WIP rate to processing time:

$$\pi^d_x = \min_k \{w^*_k t^d_x\} \tag{5}$$

Among the toolsets that can process the unit load, the one that has the lowest load rate is selected and its load rate is converted to time as explained in Eq. 5.

**Determination of $\pi^3_x$:** This step determines an expected arrival time of the unit load based on the expected waiting time on the route and the pure transportation time:

- $S_i$: Pure transportation time of node i
- $C_i$: The number of waiting unit loads at node i
- $L_i$: The average transportation time of node i
- $\lambda_i$: The arrival rate of node i
- M: The due-time slack of the transportation for the unit load
- $\overline{C}_i$: The average of waiting unit loads at node i:

$$\overline{C}_i = \frac{L_i}{S_i} - 1$$

- $\mu_i$: Processing rate of node i
- $T_i$: The time to take passing node I:

**Case1:** if $C \geq \overline{C}$, then:

$$P_i = \frac{\max\left(C_i + \sum_{i=1}^{i-1} P_k(\lambda_i - \mu_i), \overline{C}_i\right) S_i}{V} + S_i \tag{6}$$

**Case2:** if $C \geq \overline{C}$, then:

$$P_i = \frac{\min\left(C_i + \sum_{i=1}^{i-1} P_k \lambda_i, \overline{C}_i\right) S_i}{V} + S_i \tag{7}$$

$$\pi^x_3 = \sum_{j=1}^{n} T_j \tag{8}$$

where, n is all the node in the rout of unit load x.

As mentioned before, the transportation of a unit load includes a minimum of two nodes to a maximum of ens of nodes in its route. The procedure to estimate the arrival time of unit load x at a node can be broken into two parts. First, if the average of waiting unit loads at a node is smaller than the number of unit loads at the node, the procedure is explained in Eq. 6 while the opposite case is described in Eq. 7.

**Determination of $\rho_x$:**

- $\omega_x$: The priority of unit load *x* before standardized:

$$\omega_x = M - (\pi^x_2 - \pi^x_3) + K\pi^x_1 \tag{9}$$

- $\rho_x$: The final priority of unit load x:

$$\rho_x = \left[ 99 \left( \frac{\omega_x}{\max\limits_{\text{for all } x}(\omega_x)} \right) \right] \tag{10}$$

Table 2: The final priority depending on due-time slack (in minutes) and process urgency

| | Due slack | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Process urgency | 68 | 66 | 64 | 62 | 60 | 58 | 56 | 54 | 52 | 50 | 48 | 46 | 14 | 4 | 3 | 2 | 1 | 0 |
| 18 | 95 | 94 | 93 | 93 | 92 | 91 | 90 | 90 | 89 | 88 | 87 | 87 | 74 | 71 | 70 | 70 | 69 | 69 |
| 16 | 87 | 87 | 86 | 85 | 84 | 84 | 83 | 82 | 81 | 80 | 80 | 79 | 67 | 63 | 63 | 62 | 62 | 61 |
| 14 | 80 | 79 | 78 | 77 | 77 | 76 | 75 | 74 | 74 | 73 | 72 | 71 | 59 | 55 | 55 | 55 | 54 | 54 |
| 12 | 72 | 71 | 71 | 70 | 69 | 68 | 68 | 67 | 66 | 65 | 64 | 64 | 52 | 48 | 47 | 47 | 47 | 46 |
| 10 | 64 | 64 | 63 | 62 | 61 | 61 | 60 | 59 | 58 | 58 | 57 | 56 | 44 | 40 | 40 | 39 | 39 | 39 |
| 8 | 57 | 56 | 55 | 55 | 54 | 53 | 52 | 52 | 51 | 50 | 49 | 48 | 36 | 32 | 32 | 32 | 31 | 31 |
| 6 | 49 | 48 | 48 | 47 | 46 | 45 | 45 | 44 | 43 | 42 | 42 | 41 | 29 | 25 | 24 | 24 | 24 | 23 |
| 4 | 42 | 41 | 40 | 39 | 39 | 38 | 37 | 36 | 36 | 35 | 34 | 33 | 21 | 17 | 17 | 16 | 16 | 16 |
| 2 | 34 | 33 | 32 | 32 | 31 | 30 | 29 | 29 | 28 | 27 | 26 | 26 | 13 | 10 | 9 | 9 | 8 | 8 |
| 0 | 26 | 26 | 25 | 24 | 23 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 6 | 2 | 2 | 1 | 1 | 0 |

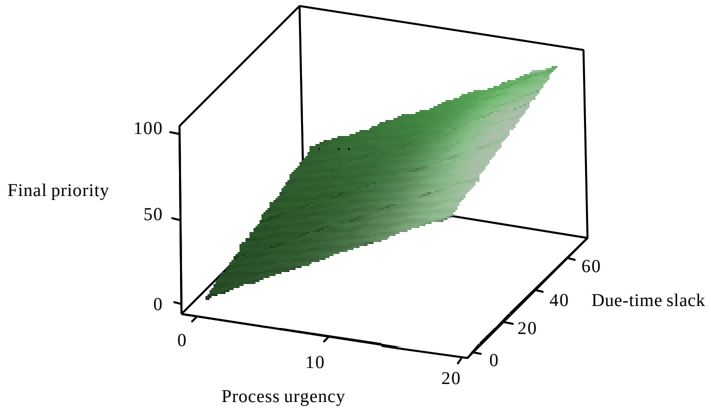

Fig. 2: Distribution of the final priorities with the combination of process urgency and due-time slack

To determine the final priority of unit load x, the three variables calculated above are combined in Eq. 9 below. The combined value is standardized in Eq. 10 to give a range that is used in an existing system. Table 2 illustrates the combination procedure. The final priority values depending on the due-time slack in the first row and the process urgency in the first column are displayed in the table. Note that the due-time slack values between 44 and 16 are omitted in the table. Fig. 2 shows the priority distribution depending on the due-time slack and process urgency.

## RESULTS

The developed procedure was applied for two LCD fabs located in South Korea. There were many useful performance improvements of the AMHS after applying the procedure such as reducing average delivery time, reducing the number of moves under request and reducing full rates of the stocker systems. All of these results contributed to increase the capacity of the AMHS without an extra investment on those sites.

Figures 3 and 4 illustrate the improvements. Figure 3 shows the average delivery times of the unit loads depending on their process priorities after applying the procedure. The average delivery times of the unit loads that have higher priorities were significantly smaller than those of the lower priorities. This means that those unit loads in urgent requests were delivered with a higher priority.

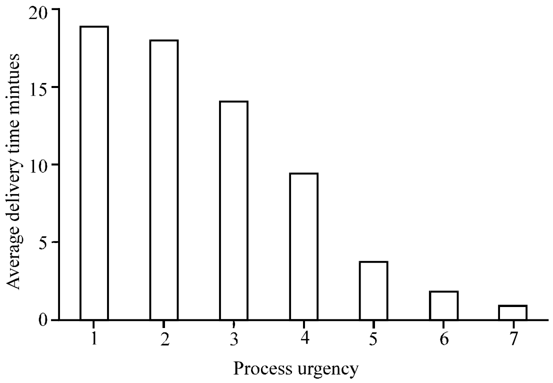

Fig. 3: Delivery times depending on process urgencies after applying the new procedure

A more meaningful observation is charted in Fig. 4. compares average delivery times before and after applying

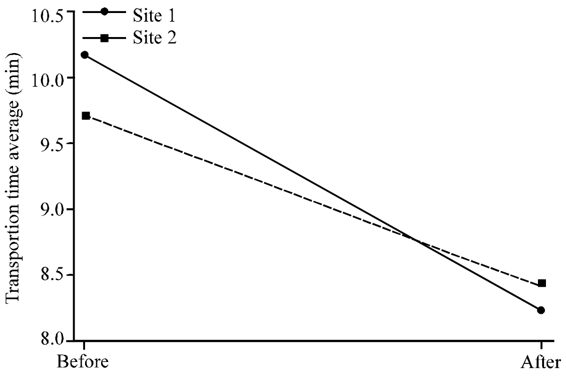

Fig. 4: Average delivery times with two different sites after applying the new procedure

the procedure in the two sites. As seen in the figure, both the two sites experienced a significant improvement on average delivery time. Site 1 shows slightly larger improvement than site 1. About a 16.7% of improvement in the average delivery time was observed after the procedure was applied in the two sites. This improvement was evaluated as a significant because a large amount of extra investment is required to obtain a similar outcome.

## CONCLUSION

This study has developed a prioritization procedure based on a heuristic procedure for the AMHS (automated material handling system) used in LCD fabrication facilities. In the study, a heuristic model that consists of three hierarchical steps was used to determine the priorities of unit loads under transportation or move request. The prioritization aims to reduce material flow congestion in a fab. The study reported detailed practices to implement the developed method for actual fabrication facilities in the LCD industry. The results of this research show that there have been improvements on important performance measures in actual practices. The new method proposed in this study has been used for various improvement tools. Also the new method has helped the managers in the facilities to standardize their processes in the system since less human interventions were required after using the new system.

The accuracy of the delivery time estimation has been an issue during the implementation which has raised a few other issues on this problem. Most of all, the event scheduling procedure needs to reflect detailed policies used by AMHS devices to increase to accuracy of the estimation. Next, the time taking to estimate the arrival times has been an issue since there are thousands of unit loads in the system at the same time. However, at maximum about one minute is given to the system for the estimation. Reducing the computation time will provide extra room to take into account further minute details.

## REFERENCES

Agrawal, G.K. and S.S. Heragu, 2006. A survey of automated material handling systems in 300-mm semiconductor fabs. IEEE Trans. Semiconductor Manuf., 19: 112-120.

Campbell, P.L. and G. Laitinen, 1997. Overhead intrabay automation and microstocking. A virtual fab case study. Proceedings of the IEEE/SEMI Advanced Semiconductor Manufacturing Conference, September 10-12, 1997, Cambridge, MA., USA., pp: 368-372.

Campbell, E. and J. Ammenheuser, 2000. 300 mm factory layout and material handling modeling: Phase II report. International SEMATECH, Technology Transfer No. 99113848B-ENG. http://www.sematech.org/docubase/ document/ 3848beng.pdf

Chen, H., J.M. Harrison, A. Mandelbaum, A. Van Ackere and L.M. Wein, 1988. Empirical evaluation of a queueing network model for semiconductor wafer fabrication. Oper. Res., 36: 202-215.

Chung, S.L. and M. Jeng, 2004. Fabulous MESs and C/Cs: An overview of semiconductor fab automation systems. IEEE Rob. Autom. Mag., 11: 8-18.

Chung, J. and Y. Hur, 2012. Congestion management with arrival estimation of unit loads in an automated material handling system. Korean OR/MS Soc., 27: 131-141.

Chung, J., 2013. A stochastic approach estimating arrival times of transportation jobs for LCD fabrication. Working Paper. http://webbuild.knu.ac.kr/~chung/research /Manuscript.pdf

Connors, D.P., G.E. Feigin and D.D. Yao, 1996. A queueing network model for semiconductor manufacturing. IEEE Trans. Semiconductor Manuf., 9: 412-427.

Geiger, C.D., R. Hase, C.G. Takoudis and R. Uzsoy, 1997. Alternative facility layouts for semiconductor wafer fabrication facilities. IEEE Trans. Components Packing Manuf. Technol. Part C, 20: 152-163.

Hase, R., C.G. Takoudis and R. Uzsoy, 1994. Cellular and reentrant layouts for semiconductor wafer fabrication facilities. Proceedings of the IEEE/CPMT International Electronics Manufacturing Technology Symposium, Volume 1, September 12-14, 1994, La Jolla, CA., USA., pp: 112-118.

Hopp, W.J., M.L. Spearman, S. Chayet, K.L. Donohue and E.S. Gel, 2002. Using an optimized queueing network model to support wafer fab design. IIE Transactions, 34: 119-130.

Jang, Y.J. and G.H. Choi, 2006. Introduction to automated material handling systems in LCD panel production lines. Proceedings of the IEEE International Conference on Automation Science and Engineering, October 8-10, 2006, Shanghai, China, pp: 223-229.

Kong, S.H., 2007. Two-step simulation method for automatic material handling system of semiconductor fab. Robot. Comput. Integr. Manuf., 23: 409-420.

Mackulak, G.T., F.P. Lawrence and T. Colvin, 1998. Effective simulation model reuse: A case study for AMHS modeling. Proceedings of the 30th Conference on Winter Simulation, December 13-16, 1998, Washington, DC., USA., pp: 979-984.

Mackulak, G.T. and P. Savory, 2001. A simulation-based experiment for comparing AMHS performance in a semiconductor fabrication facility. IEEE Trans. Semiconductor Manuf., 14: 273-280.

Montoya-Torres, J.R., 2006. A literature survey on the design approaches and operational issues of automated wafer-transport systems for wafer fabs. Prod. Plann. Control, 17: 648-663.

Nazzal, D. and L.F. Mcginnis, 2007. Analytical approach to estimating AMHS performance in 300 mm fabs. Int. J. Prod. Res., 45: 571-590.

Noben, R., R. van Driel and T. Claasen-Vujcic, 2001. Cycle time advantages of mini batch manufacturing and integrated metrology in a 300 mm vertical furnace. Proceedings of the IEEE International Semiconductor Manufacturing Symposium, October 8-10, 2001, San Jose, CA., pp: 411-414.

Pillai, D., T. Quinn, K. Kryder and D. Charlson, 1999. Integration of 300mm fab layouts and material handling automation. Proceedings of the IEEE International Symposium on Semiconductor Manufacturing Conference Proceedings, October 11-13, 1999, Santa Clara, CA., pp: 23-26.

Weiss, M., 1997. 300 fab automation technology options and selection criteria. Proceedings of the IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop, September 10-12, 1997, Cambridge, MA., pp: 373-379.