Performance Evaluation of Hard Drive Sorting Systems Using Discrete-Event Simulation

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Abstract. We propose an approach for enhancing the throughput level and decreasing the throughput time of the hard disk drive sorting department that are congested and inefficient. We model the hard disk drive sorting department with discrete-event simulation on Arena. The proposed automated loop conveyor system can reduce the waiting time, the work-in-process and the time in system by 74.78%, 85.09% and 96.85% respectively when comparing with the current sorting system.

1. Introduction
The technology of magnetic plate storage as we know in the hard disk drive (HDD) is now replaced with the solid state drives that is energy-saving, fast and convenient to use than HDDs. This new technology depresses the price of HDDs so some HDD manufacturers adapt by integrating the production bases. For example, Western Digital closed its plant in Malaysia and moved its operations to Thailand [1]. Thailand is now the world's largest HDD production base.

In addition to consolidating its production bases, the production must be more efficient and cost effective. For the company in this case study, the HDDs are sorted by humans via barcodes. The throughputs are 80,000-150,000 pieces/day which is not fast enough and too costly for the management, and an automatic system on the loop conveyor is being considered.

In this paper, we develop simulation models of the current manual sorting system and the automated conveyor system on ARENA (Rockwell Software) as a design prototype.

2. Simulation in the Automated Conveyor Sorting System Design Context
The DES technique is used to design the automated sorting process of the Brazilian Air Force which has problems in terms of throughput level and throughput time in the sorting system of the army uniforms [2]. The solution to this problem proves that the automated sorting process can increase the ability to manage tasks and reduce the average time of moving the workpiece in the system significantly. [3] shows that Delta robots can identify products by the physical characteristics but cannot prove that the product sorting system can be sorted correctly and faster than the human labor system.

The DES technique is not only applicable for manufacturing settings but can be applied to other settings, such as the traffic modeling and out-patient clinics [4], [5] and [6]. [7], [8] and [9] model the health examination centers in hospitals with DES to experiment with strategies for reducing the waiting time of the patients.
3. HDD Sorting Process
Our HDD sorting process sorts 6 product families. Each product family consists of many stock keeping units (SKU). The current layout of the HDD process is shown in Figure 1 and Figure 2 shows the proposed conveyor system.

![Current layout of the HDD sorting process.](image1)

**Figure 1.** Current layout of the HDD sorting process.

At the present, the sorting process requires 6-12 people per shift. HDDs are transported by trolleys which have two sides and can stock 60 HDDs per side. The sorting department is located on the 1st floor, and it is preceded by the testing department on the 2nd floor. The factory manager is interested in using an automated loop conveyor system for the sorting process because it is space-saving and probably more accurate than humans.

![Proposed layout of the HDD sorting process.](image2)

**Figure 2.** Proposed layout of the HDD sorting process.

The simulation model is built on ARENA. First, the data is collected and fit with statistical distributions. The DES model of the current system is constructed and verified. Then, the current sorting system is modified to the automated sorting system. The numerical performance of the two systems are then compared.
3.1. Data Collection and Analysis
To simulate the operation of the sorting department, the following data is required: the data of the arrival rates from the testing department, the transportation time delay to the sorting department, and the waiting time to stack 120 HDDs in a trolley at the tester. Table 1 and 2 shows the probability distributions for all random processes.

Table 1. Interarrival times at the sorting department

| Process                        | Probability distributions      | Sample size |
|--------------------------------|--------------------------------|-------------|
| Type A interarrival time       | LOGN(0.31, 0.348)              | 26          |
| Type B interarrival time       | 0.04 + WEIB(0.0244, 3.61)      | 26          |
| Type C interarrival time       | 0.2 + 0.12 * BETA(1.2, 1.19)   | 26          |
| Type D interarrival time       | WEIB(7.16, 0.431)              | 26          |
| Type E interarrival time       | 0.05 + LOGN(0.0172, 0.0109)    | 26          |
| Type F interarrival time       | 0.01 + 0.02 * BETA(24.3, 16.5) | 26          |

Table 2. Process and transportation times at the sorting department

| Process                                      | Probability distributions      | Sample size |
|----------------------------------------------|--------------------------------|-------------|
| Transportation time from testing to sorting Dept. | 52 + GAMM(23, 0.713) | 30          |
| Transportation time from sorting to packing Dept. | 52 + WEIB(29.3, 3.21) | 30          |
| Process time to sorting type of product      | TRIA(319, 411, 428)           | 30          |
| Process time to sorting SKU of product       | 407 + 68 * BETA(0.577, 0.631) | 30          |

The simulation model is validated by the two-sample t-test of the work in process (WIP) between the simulation data and actual data in Minitab Software. Each data needs to verify the distribution because two-sample t-test can test only normal distribution. In the Figure 4 and 5, they are demonstrated that the simulation data have P-Value = 0.062 and actual data have P-Value = 0.340 respectively. Both data are greater than 0.05. Therefore, we can decide that they are the normal distribution.

As can be seen from the above verification, we can use two-sample t-test to validate the simulation model. The result of validation is shown in the Figure 3. The simulation data and actual data are not statistically different because P-Value = 0.802 is greater than 0.05.

Two-Sample T-Test and CI: Simulation, System

Two-sample t for Simulation vs System

    N  Mean  StDev  SE Mean
Simulation  30 9606.31 397.72  72
System  30 9441.36 363.65  69

Difference = μ (Simulation) - μ (System)
Estimate for difference: 166
95% CI for difference: (-3170, 1500)
T-Test of difference = 0 (vs ≠): T-Value = 0.25  P-Value = 0.802  DF = 59

Figure 3. Two-Sample T-Test of the work in process report
3.2. DES Modeling

Arena logic models of the current sorting system and the loop conveyor system are shown in Figure 6 and 7. The HDD arrival processes are modeled with the Create modules. The primary sorters and secondary sorters are represented by the Process modules which provide the cycle time distribution information. Six staffs are responsible for sorting the mixed SKUs to identical SKUs.

We assume that machine failures are negligible. The automatic sorting system consists of one-way entrance and twelve plus one way exits. Because there are approximately 8 SKUs per product family,
12 exits are sufficient. The remaining exits are for some specific SKUs. The conveyor’s speed is another important factor; the appropriate belt speed is about 2 m/s.

The simulation model of the automated sorting system has the Station and the Access modules which can model twelve plus one exits. Each exit has a Decide module to check the products and their SKUs before being sent to the packing department.

![Figure 6. Arena logic models of the current sorting system](image)

![Figure 7. Arena logic models of the loop conveyor system](image)

### 4. Simulation Results

The simulation model of the current sorting system is validated by comparing the work in process of the actual system and that of from simulation. The number of replications is 500. The sorting department works 2 shifts per day. The simulation results in Table 3 show that the current system is very congested; the average work in process is more than 9,000 HDDs, and the average time from the testing department to packing department is about 150 minutes.

| Product | Waiting time | Work-in-process | Time in system |
|---------|--------------|-----------------|----------------|
|         | Minutes      | Minutes         | Minutes        |
| A       | 127.59 ± 0.26| 460.41 ± 0.83   |                |
| B       | 98.96 ± 0.16 | 1807.36 ± 2.64  |                |
| C       | 121.17 ± 0.29| 516.81 ± 0.71   |                |
| D       | 69.43 ± 1.63 | 18.11 ± 0.55    |                |
| E       | 99.51 ± 0.16 | 1676.70 ± 2.44  |                |
| F       | 94.27 ± 0.16 | 4976.48 ± 7.31  |                |

Table 3. 95% CI of simulated results in terms of KPIs for the current sorting department.
Table 4. 95% CI of simulated results in terms of KPIs for automated system

| Product | Waiting time | Work-in-process | Time in system |
|---------|--------------|-----------------|----------------|
|         | Minutes      | Minutes         | Minutes        |
| A       | 7.11 ± 0.01  | 26.55 ± 0.03    |                |
| B       | 2.53 ± β     | 60.81 ± 0.04    |                |
| C       | 6.26 ± 0.01  | 29.04 ± 0.03    |                |
| D       | 87.41 ± 7.54 | 12.48 ± 0.29    | 4.74 ± 0.01    |
| E       | 2.62 ± β     | 58.85 ± 0.03    |                |
| F       | 1.69 ± β     | 138.47 ± 0.09   |                |

β: Half width is less than 0.00

Table 4 shows the simulation results of the automated sorting system. When compared with the current system in Table 5, the waiting time, the work-in-process, and the time in system are reduced by 74.78%, 85.09% and 96.85% respectively when compared to the current system.

Table 5. Percentage improvement for the automated compared with current system

| Product | Waiting time | Work-in-process | Time in system |
|---------|--------------|-----------------|----------------|
|         |              |                 |                |
| A       | 94.43%       | 94.24%          |                |
| B       | 97.45%       | 96.64%          |                |
| C       | 94.84%       | 94.38%          |                |
| D       | -33.62%      | 31.56%          | 96.85%         |
| E       | 97.37%       | 96.49%          |                |
| F       | 98.21%       | 97.22%          |                |
| Average | 74.78%       | 85.09%          |                |

However, the reason of Product D has a negative percentage of improvement because the result of the production order of Product D is significantly less than other production orders. Therefore, when we change the sorting system, it can increase the waiting time of Product D.

Lastly, the automated sorting system can improve the performance of the current system, it requires a new conveyors and management software. The factory manager must make a decision if the investment in the new system is worth the savings.

5. Conclusions

We present simulation models of the HDD manual sorting process and its new automatic system. The overall results of automated sorting model simulation are better than the current system. The waiting time, the work-in-process and the time in system is reduced by 74.78%, 85.09% and 96.85% respectively.

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