Development of Automated Vertically Stacked Hard Disk Drive Sorting Configurations Through Simulation Modeling

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Abstract This paper focuses on discrete-event simulation (DES) model of a vertically stacked HDD sorting system using the Arena software. We propose an approach decreasing the throughput time of sorting department that are inefficient. We find that the automated system can decrease the average waiting time, the work-in-process and the average total time in system by 59.24%, 59.87%, and 72.67%, respectively, compared with the current system.

1. Introduction
In 2019, Thailand’s export market of hard disk drives (HDDs) continuously grows. KBank Research estimates that the overall HDDs exported in 2019 can reach around 252-262 million units, an increase of 3.6-7.8 percent from 2018 and equivalent to 12,576 -13,089 million USD [1].
The company in this case study is a HDD manufacturer. The current HDD sorting process uses manual labor. Many problems include insufficient working hours and too many HDD transfers so the HDD manufacturer wants to use vertical alignment technology to sort HDDs immediately after they leave the testers.
We develop a simulation model of the vertically stacked HDD process in Arena (Rockwell software) as a proof of concept before actually deploying it in the sorting department.

2. Literature review
Simulation model is a tool for process improvement to analyze alternatives before actual implementation, to study the system in a computer program, and to determine the guidelines for decision making to solve the problems without wasting time and cost of real experimentation.
Simulation is “the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system” [2]. The Discrete-Event Simulation (DES) model is “the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system” [3].
Simulation models are constructed for many problems, such as in manufacturing settings and traffic problems. For the manufacturing industry problems, [4] use Arena software to find the bottleneck, calculate the productivity and determine the requirement units. The result shows better efficiency of
optimal productivity and utilization. In [5], the Arena simulation model helps to understand and analyze the bottlenecks and the solutions to improve system.

3. Methodology
The procedure in this research consists of 5 steps as follows.

3.1. Study the process
The HDD production process under this case study is shown in figure 1.

![Figure 1. The HDD production process.](image)

The process starts with HDD assembly, and they are tested in the tester. When HDDs leave testers, they are mixed, and they must be sorted before being packed.

Our HDD sorting process sorts 6 product families. Each product family consists of many stock keeping units (SKU). When testing finishes on the 2nd floor, the HDDs are packed in trolleys and transported via elevators to the sorting department on the 1st floor. Each trolley has 2 sides and can stock 60 HDDs per side.

The current process of sorting uses human labor and barcode technology to sort products. There are 26-worker shifts per day. About 80,000 HDDs can be sorted per day. The demand of HDDs fluctuates a lot; it can reach up to 150,000 HDDs per day so the manufacturer needs to hire up to 12 workers per shift. Due to this demand variability and high volume, the plant manager wants to change the manual sorting to the automated system to increase the productivity and lower cost.

The manager is interested in using the vertically stacked sorting system because it is space saving and probably more accurate than humans, and it requires less manual handling. The proposed layout of the HDD sorting process is shown in figure 2.

![Figure 2. The proposed layout of the HDD sorting process.](image)

In this paper, we construct a simulation model on Arena to simulate the vertically stacked sorting process.
3.2. Data collection
To simulate the operation of the sorting department, the following data is required: the arrival rates from the testing department, the transportation time to the sorting department, and the waiting time to stack 120 HDDs in a trolley at the tester. Tables 1 and Table 2 show the probability distributions for all random processes.

**Table 1.** The probability distributions of interarrival time to the sorting process.\(^a\)

| Process                  | Probability distributions (Minutes)                  | Sample size (Day) |
|--------------------------|------------------------------------------------------|-------------------|
| Product A interarrival time | LOGN(0.31, 0.348)                                   | 26                |
| Product B interarrival time | 0.04 + 0.04 * BETA(4.78, 3.93)                       | 26                |
| Product C interarrival time | 0.2 + 0.12 * BETA(1.2, 1.19)                        | 26                |
| Product D interarrival time | WEIB(7.16, 0.431)                                   | 26                |
| Product E interarrival time | 0.05 + LOGN(0.0172, 0.0109)                       | 26                |
| Product F interarrival time | 0.01 + WEIB(0.0127, 7.31)                           | 26                |

\(^a\)Surached Wongnibunkit(2019)

**Table 2.** The probability distributions of process and transportation times in the sorting process.\(^a\)

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

\(^a\)Surached Wongnibunkit(2019)

3.3. Developing a simulation model of the current system
Figure 3 shows the process flow diagram on Arena.

![Figure 3. Arena model structure of current sorting department.](image)

In a simulation model, Create Modules are starting points for Entities which are HDDs. Sorting types and sorting SKUs are represented by the Process modules.
3.4. Verification and validation of the model
The simulation model is validated by the two-sample T-test of the WIP from the simulation and that from actual data is shown in figure 4. They are not statistically different because p-Value of this test is greater than 0.05.

![Figure 4. The result of Two-Sample T-Test.](image)

3.5. Developing a simulation model of the vertically stacked system
In the new system, the sorting process is moved to be in front of the testers on the 2nd floor. The automatic sorting system consists of 8 stackers, each of which can contain 8 HDDs of the same SKU. Eight stackers are chosen because each tester has at most 8 SKUs product mix. The process starts with HDDs from the testers, and barcodes are scanned. Cartesian robots pick and place in onto conveyors, moving HDDs to HDD shelves, and the stacker move it down 1 slot. When HDDs leave stackers, they are loaded into trolleys and transported to be packed. The simulation model of the automated sorting system is shown in figure 5.

![Figure 5. Arena model structure of automated vertical stack sorting.](image)
4. Simulation results
The key performance indices (KPIs) of the current sorting system model simulation are shown in table 3. The number of replications is 500, and the replication length is 24 hours.

Table 3. The 95% confidence intervals of the simulation KPIs of for the current sorting department

| Product Family | Waiting time (Minute) | Work-in-process (Piece) | Time in system (Minute) |
|----------------|-----------------------|-------------------------|-------------------------|
| Product A      | 127.33 ± 0.27         | 460.13 ± 0.88           |                         |
| Product B      | 98.80 ± 0.18          | 1804.11 ± 2.86          |                         |
| Product C      | 121.13 ± 0.30         | 516.40 ± 0.72           |                         |
| Product D      | 69.00 ± 1.73          | 18.09 ± 0.51            | 150.35 ± 0.21           |
| Product E      | 99.39 ± 0.18          | 1674.67 ± 2.65          |                         |
| Product F      | 94.11 ± 0.17          | 4968.17 ± 7.95          |                         |

The KPIs of the automated sorting system is shown in table 4. The comparison results of 3 KPIs are calculated into percentages as shown in table 5.

Table 4. The 95% confidence intervals of the simulation KPIs of the automated sorting system

| Product Family | Waiting time (Minute) | Work-in-process (Piece) | Time in system (Minute) |
|----------------|-----------------------|-------------------------|-------------------------|
| Product A      | 59.38 ± 0.17          | 225.67 ± 0.38           |                         |
| Product B      | 39.62 ± 0.02          | 689.12 ± 0.26           |                         |
| Product C      | 49.73 ± 0.06          | 204.29 ± 0.19           | 41.09 ± 0.01            |
| Product D      | Not showing results¹  | 40.47 ± 1.09            |                         |
| Product E      | 39.05 ± 0.02          | 629.18 ± 0.26           |                         |
| Product F      | 34.58 ± 0.02          | 1801.20 ± 0.68          |                         |

¹Not showing results because the product D enters a very small amount of system compared to other products and therefore cannot be logged out.

Table 5. The percentage reduction results when compared the current system with automated sorting system.

| Product Family | Waiting time | Work-in-process | Time in system |
|----------------|--------------|-----------------|----------------|
| Product A      | 53.37%       | 50.96%          |                |
| Product B      | 59.90%       | 61.80%          |                |
| Product C      | 58.94%       | 60.44%          |                |
| Product D      | Can't compare¹ | -50.64%       | 72.67%         |
| Product E      | 60.17%       | 62.43%          |                |
| Product F      | 63.26%       | 63.75%          |                |

¹Can’t compare because there is no waiting time the product D in automated sorting system.
Table 5 shows the percent improvement from the manual system to the automated sorting system. The result shows the reduction of the average waiting time, the work-in-process, the average total time in system by 59.24%, 59.87% and 72.67% respectively.

5. Conclusions
Our simulation study of the automated vertically stacked sorter shows that this automated system can increase the efficiency of the sorting process which reduces the waiting time, the work-in-process, and the time in system by 59.24%, 59.87% and 72.67%, respectively.

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