Improving delivery performance by using simulation, FMEA, and FTA

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Abstract. Delivery performance is one of the indications of enterprise’s success to provide products to customers. In this research, simulation is done to measure the delivery performance and all the processes included in delivery process. In fact, every process has their own risks could delay delivery process that the delivery performance is reduced. The methods used to identify the risks and the causes are Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). Risks analysis is done with the help of Pareto diagrams and scatter plot to determine the risks need to be corrected immediately. The proposed improvements are integrating the systems in form of e-cargo ready and implementing bar-coding. After the proposed e-cargo ready applied and being simulated, the delivery performance in terms of average total time reduced by 29.398%.

Keywords: Delivery performance, FMEA, FTA, Simulation

1. Introduction

Nowadays, the industrial sector is developing rapidly. Supply chain process is one of the important processes in industrial business activities. Supply chain process must be carried out properly so that it can be effective and efficient. An effective and efficient supply chain process considered as one of the keys to competitive advantage of company’s success [1]. In every industry, a fast and reliable delivery process is one of the keys of consideration for selecting supplier. Excellence delivery performance could motivate customers to buy repeatedly or even pay more the quality of the delivery [2]. A study conducted by Bain & Company shows that a company with excellence delivery performance could charge higher prices and attract customers to buy more [3]. Delivery performance includes two high level dimension which are reliability and speed, that could be broken down into 4 more detailed dimensions; on-time delivery rate, inaccuracy of initial delivery, inaccuracy in late delivery, and speed of delivery [2].

The company where we conducted this research is an Indonesian pulp & paper company. The delivery achievement is below the delivery target during January 2019 - May 2019 period. There is gap between delivery target and achievement each month. Therefore, improvement is needed to improve the delivery performance so the company could meet the target set by stakeholders.

Every process in supply chain has its own risks that could be categorized as supply chain risks. Supply chain risks could be identified using Failure Mode and Effect Analysis (FMEA). FMEA helps
improving product quality and delivery performance by proactively identifying and reducing risks [4]. Fault Tree Analysis (FTA), one of the most frequently used techniques in various fields of industry, is a graphical method that describes how failures spread within the system (how component failures cause system failures) [5]. Simulation can be used to determine the impact of improvements applied to the real system [6]. In this paper, simulation will be used to determine the impact of improvement given based on the risks and its causes identified using FMEA and FTA so the enterprise could do corrective and preventive steps to improve its delivery performance.

2. Literature Review

2.1 Simulation
Ramirez, Lopez, and Hernandez conducted a study regarding simulation software used to analyze and improve automotive supply chain. The study demonstrates the importance of simulation software because in the real system, the time and cost to validate different scenarios are high so using simulation is advantageous. It shows that long cycle time of one process would impact the overall system’s time negatively. Delays in processes such as finished goods inventory could slow down the shipments rate. Simulation helps to find the best scenarios to successfully fulfill the demand of customers with certain cycle time, adjustment time, delivery time, and inventory [7].

2.2 FMEA & FTA
A study done by Shirani and Demichela shows that FMEA appeared to be a valuable tool to identify risks that was not directly covered by classical analytical validation. The steps and risks that were initially neglected or were considered uncritical before performing FMEA turned out to be a major importance [8]. On a study on exportable pineapple fresh fruits in Ghana by Anin, Alexander, and Adzimah, FMEA used to identify and examine the supply chain risks associated with some pineapple production organization, so the strategies to mitigate the risks could be developed. The risks could be internal that can be controlled by implementing the right measures to address them whilst others are external and difficult to anticipate [4]. Held and Bronnimann, investigated battery fire using FMEA, FTA and practical experiment, found that FMEA lacks in directly identifying combinations of failure and effects but FTA on the other hand allows the free combination or separation of failure, effects and external influences. Using FMEA and FTA requires a comprehensive understanding of the system and failure modes of the whole chain. Both FMEA and FTA help to design experiments for cause and effects verification as well as evaluating mitigation strategy [9].

3. Methodology
The study was conducted at a pulp and paper company within 4 months (Feb-May 2019) in finished goods warehouse section, therefore the intended delivery performance is monthly performance and based on the warehouse perspective. This study relied on primary data obtained by field observation and company’s data; and secondary data obtained by Focused Group Discussion (FGD) activities with supervisors, group leaders and supply chain staffs.

This study used simulation with the help of ARENA simulation to determine the performance before the improvement. FMEA was used to determine the risks of each operation in the process and its effects. Each risk was scored for its likelihood of occurrence (O), severity of impact (S), and detection level (D). The scoring was done by doing FGD and based on primary data. This phase followed by calculation of Risk Score Value (RSV) and Risk Priority Number (RPN) for each risk. The multiplication of likelihood of occurrence, severity of impact, and detection level would give the value of RPN. The multiplication of likelihood of occurrence and severity of impact would give the value of RSV. We used MINITAB 17 Statistical Software to make pareto and scatter diagram of RPN and RSV to determine which risks should be prioritized. We used Fault Tree Analysis (FTA) to identify the root cause of each prioritized risk so the right mitigation strategy could be developed.
Based on the developed mitigation strategy, we could give some proposed improvement to improve the delivery performance. The delivery improvement could be seen by comparing the simulation results of before and after the implementation of proposed improvement.

4. Results and Discussions

4.1 Simulation

The delivery process can be seen in Figure 1. The baseline delivery performance can be seen in Table 1.

![Figure 1. Delivery Process](image)

**Table 1. Baseline Delivery Performance**

|                  |          |
|------------------|----------|
| **Number In**    | 2175 vehicles |
| **Number Out**   | 2160 vehicles |
| **Total Time**   | 689.405 minutes |
| **Total Tonnage**| 60292329.45 kg |
| **Average Tonnage/Vehicle** | 27913115 kg |

The simulation conducted using ARENA Simulation with 6 replications. The results can be seen in Table 2.

**Table 2. Simulation Result**

|                  |          |
|------------------|----------|
| **Number In**    | 2353 vehicles |
| **Number Out**   | 2312 vehicles |
| **Average Value-added Time** | 125.55 minutes |
| **Average Waiting Time** | 265.75 minutes |
| **Average Non-Value-added Time** | 289.08 minutes |
| **Average Total Time** | 680.38 minutes |
| **Total Tonnage** | 64535121.88 kg |

The results of the simulation with 6 replications show the number of results in as many as 2,353 vehicles and number out as many as 2,312 vehicles with an average total time spent in the system for 680.38 minutes. The average total time for activities that add value (value-added) for 125.55 minutes, the average time to wait for a vehicle for 265.75 minutes, and the average time for activities that do not add value (non-value-added) for 289.08 minutes. Using an average tonnage/vehicle of 27,913,115 kg, the total tonnage produced is 64,535,121.88 kg. Non-value-added activities consist of vehicle delays that do not directly register the IML in the Paper Delivery Unit after entering from Main Gate.
2, waiting for orders for DM, coordinating with the Delivery Unit related to stock shortages, and vehicle not directly go to weighing bridge after getting the Delivery Note.

### 4.2 FMEA and FTA

Failure modes of each process and its level of severity, occurrence and detection can be seen in Table 3.

| Operation | Failure Mode | Negative Effects | Code | S  | O  | D  | RPN | RSV |
|-----------|--------------|------------------|------|----|----|----|-----|-----|
| IML Registration | Vehicle can not get delivery queue | Vehicle shortage to fulfill delivery target given in daily basis | A1 | 3  | 4  | 3  | 36  | 12  |
| Create DM (Delivery Memo) | Vehicle wait for order in long time | Low effectiveness and vehicle turn over rate | B1 | 6  | 8  | 4  | 192 | 48  |
| | Lack of vehicles | DM can not be created | B2 | 6  | 4  | 4  | 96  | 24  |
| Weighing In | Increased vehicle queue | Uncontrolled vehicle queue & high potential risk of broken scaling equipments | C1 | 4  | 5  | 4  | 80  | 20  |
| Check In and Picking List printing | Increased waiting time | Increasing lead time | D1 | 2  | 5  | 2  | 20  | 10  |
| Stuffing | Vehicle must go back to registration office & wait for new DM | Ineffective stuffing process & high time-wasted | E1 | 7  | 6  | 4  | 168 | 42  |
| | Vehicle must be unloaded & cancelled | Potential product damage due to high movement activity | E2 | 7  | 6  | 4  | 168 | 42  |
| | Long stuffing queue and long waiting time | Uncontrolled stuffing process and product taken from warehouse | E3 | 6  | 7  | 3  | 126 | 42  |
| | On-going stuffing process must be delayed & aided while waiting for other product fulfillment | Limited/narrow loading area | E4 | 6  | 5  | 4  | 120 | 30  |
| | Stuffing activity must be held until driver could get complete equipments as requested | Potential damaged or wet cargo while being delivered to customer | E5 | 4  | 4  | 2  | 32  | 16  |
| | Vehicles abnormal condition (broken, storing, etc) | Longer stuffing lead time & ineffective stuffing process | E6 | 4  | 6  | 3  | 72  | 24  |
| Delivery Note Making and Check Out | Incomplete Slip B | Delivery Note making process delayed | F1 | 3  | 3  | 2  | 18  | 9   |
| Weighing Out | Increased vehicle queue | Uncontrolled vehicle queue & high potential risk of broken scaling equipments | C2 | 4  | 4  | 4  | 64  | 16  |

Using Pareto’s principle of 80/20, the critical value of RPN is 153.6 (80% of 192) and the critical value of RSV is 38.4 (80% of 48) to be used as the scatter diagram reference line as can be seen in Figure 2.

![Scatterplot of RPN vs RSV](image)

**Figure 2. Risk Scatter Diagram**

Risks in the right top quadrant of the scatter have high impact on the business activities and high level of occurrences, risks in this quadrant are B1, E2, and E1. Risks in the lower-right quadrant of the scatter have high level of occurrence however; the impact ranges from low to medium. Even though the result indicates that E3 has moderate impact, since it has high likelihood of occurrence, the impact
can easily rise and get out of hand. Thus, the risks that should be prioritized for improvement are B1, E2, E1, and E3.

We use FTA to identify the root cause of each risk that can be seen in Figure 3 to Figure 6.

Based on the scatter diagram in Figure 2, the risks that should be prioritized for improvement are B1, E2, E1, and E3. Fault Tree Analysis is used to identify the causes of each risk. Based on Figure 3, low effectiveness and vehicle turn-over rate caused by the absence of Delivery Order or because order posted slowly but vehicle arrival rate is normal resulting increased vehicle queue and vehicles wait for order in long time. The absence of Delivery Order can be caused by customer’s credit limit or financial problem. Based on Figure 4, ineffective stuffing process and high time wasted happen because lack of stock for particular order that warehouse staffs need to coordinate with delivery unit to change DM or reduce the load. This is because stock data used for planning is not updated and planning process done manually, so it is prone to errors and increases the lead time and effecting stuffing FIFO principles.

Based on Figure 5, potential product damage due to high movement activities caused by double DM with same order number and stock requirements that the stuffing must be cancelled and products must be returned to warehouse, also because planning process before stuffing is wrong so the operator loads wrong products to the vehicle. Based on Figure 6, non-FIFO stuffing process and product taken from warehouse is caused by increased vehicle stuffing queue and increased waiting time. Long stuffing process happens because products required located far away from each other (even different warehouses) so the products are taken not according FIFO principles but based on nearest location.

4.3 Proposed Improvement

By implementing one of the mitigation strategies which is e-cargo ready system that integrates SAP, Online Weighing System (SOT), and Vehicle Status System (VSS) and implementing regulation of maximum delay from arrival to IML registration and Check Out to Weighing Out to reduce non-value-added time, could help improving the performance (Table 4).
Table 4. Mitigation Strategy

| Risk                                      | Mitigation Strategy                                                                 |
|-------------------------------------------|--------------------------------------------------------------------------------------|
| Vehicle wait for order in long time       | Implement daily DO review with related parties and set DO cut-off regulation to limit day to day vehicles requirements. |
| Vehicle must go back to registration office & wait for new DM | Do cross check with PPIC team about the required fresh product from paper machine and create e-cargo ready system to set product allocation to each order. |
| Vehicle must be unloaded & cancelled      | Planning process automation using computer program.                                  |
| Long stuffing queue and long waiting time  | Use same background system (e-cargo ready) which has been set up by IT with same retrieval cut-off time and create more advanced logic system to validate & block any doubled DM created. |
|                                           | Implement daily DO review to determine stuffing operator requirements to be able to add operators as needed. |
|                                           | Replace the process of slip B collecting with a barcode scanning.                     |

Proposed improvement which is e-cargo ready system has been implemented since mid May 2019 and the impact started to be seen on June 2019. Even though still in trial and error phase, it could reduce DM creation cycle time from average 13 minutes to 4.44 minutes and omit stuffing delay to coordinate with delivery unit because of lack of stock. To reduce non-value-added time, we propose to set up a regulation of maximum delay from arrival to IML registration (60 minutes max) and Check Out to Weighing Out (100 minutes max). Then, we apply the proposed improvements and simulate the proposed model using ARENA Simulation. The comparison of baseline and after simulation can be seen in Table 5.

Table 5. Performance Improvements After Implementing Proposed Improvement

|                 | Before     | After       | Improvement  |
|-----------------|------------|-------------|--------------|
| Number In       | 2353 vehicles | 2360 vehicles | 7 vehicles  | 0.292%       |
| Number Out      | 2312 vehicles | 2339 vehicles | 27 vehicles | 1.142%       |
| Average Value-added Time | 125.55 minutes | 117.75 minutes | -7.80 minutes | -6.664%     |
| Average Waiting Time | 265.75 minutes | 249.77 minutes | -15.98 minutes | -6.595%     |
| Average Non-Value-added Time | 289.08 minutes | 122.08 minutes | -167.00 minutes | -57.662%    |
| Average Total Time | 680.38 minutes | 489.60 minutes | -190.78 minutes | -29.398%    |
| Total Tonnage   | 64535121.88 kg | 65288775.99 kg | 753654.11 kg | 1.142%       |

5. Conclusion and Suggestions
Shorter lead time is crucial to improve the enterprise’s delivery performance. The simulation results after implementing e-cargo ready system and maximum delay policy from arrival to IML registration and Check Out to Weighing Out show an increase in the number of exits by 7 vehicles and tonnage revenues by 753,654.11 kg (1,142%). The average value added time decreased by 7.8 minutes (6.664%), the average waiting time decreased by 15.198 minutes (6.595%), the average non-value-added time decreased by 167 minutes (57.662%), and the average total time spent in the system decreased by 19.78 minutes (29.398%). The enterprise should also implement the remaining mitigation strategy other than e-cargo ready to prevent the 4 risks to happen which are vehicles wait for order in Delivery Unit in long time; vehicle must go back to registration office & wait for new Delivery Memo; vehicle must be unloaded and cancelled; long stuffing queue and waiting time.

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