Abstract—The automotive industry in Thailand is under constant pressure to improve production performance while simultaneously eliminating production bottlenecks and improving process efficiency. The demand of car grows every day. Then in case of the unstoppable production line, it is very difficult to manage and optimize the production system without disturbing the actual system. Process simulation can be suitably applied for studying and analyzing the system.

This research presents how to implement simulation tools in the real production planning. Our goal is to reduce the bottleneck problem in a paint shop process. The procedure starts with input data collection, data fitting. Then simulation model building, model validation, Identification of bottlenecks, and developed methods to improve production performance accordingly.

**Keywords**—Automotive Paint Shop, Bottleneck Analysis, Plant Simulation, Process Simulation.

I. INTRODUCTION

With the growing demand for luxury cars in the ASEAN countries, one of the big German car companies in Thailand is forced to increase the production capacities in this region. The company predicts an increasing in production of about 20% in the coming years. Hence Thonburi Automotive Assembly Plant (TAAP) is the partner of them in Thailand as authorized assembler of completely-knocked-down (CKD) passenger cars, TAAP realizes to early prepare for it.

To achieve the production target, a standard time of 10 minutes per workstation has to be achieved. However, in reality many workstations cannot reach this time. Therefore TAAP is working very intensively to optimize the production line.

An automotive assembly plant of TAAP has three major sections with respect to the stages of the assembly process: Body shop, Paint shop and Final assembly (See Fig. 1). One of major bottlenecks is the paint shop, which was installed about 20 years ago. Except the dipping process, all other major processes in the paint shop require 15 to 20 minutes each. The longest standard time appears in the top coat painting workstation with about 20 minutes.

This paper extracts some of the research to discuss the use of computer simulation to design and reduce the bottleneck in the top coat painting process.

II. BACKGROUND

The painting processes start after the body of vehicle is assembled. The purpose of these processes are to give more attractive appearance to the vehicles and to provide the layer of protection against corrosion and weathering. There are four major processes in painting processes; (a) pre-treatment and electro-deposition (ED), (b) PVC sealing, (c) primer painting and (d) top coat painting [2]. This paper will focus on the top coat painting process as it is the biggest problem in the production.

The TAAP’s top coat process has several steps, for example surface cleaning, dust blowing, wiping, painting and finalize with baking. The complete diagram is shown in Fig. 2 and Fig. 3. Except the paint baking oven, every process requires manual human operators.

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III. OBJECTIVE

The simulation and analysis of different types of systems was conducted for the purposes of: developing operating or resource policies to improve system performance and testing new concepts before implementation without disturbing the actual system.

The main idea for optimizing this production system is to rearrange the station and reduce the bottleneck in the system to make the better workflow.

The Siemens PLM software, Tecnomatix Plant Simulation was used in this study [3].

IV. INPUT DATA COLLECTION AND DATA FITTING

The important step to work with simulation tools is data collection. A total of seven stations information which needs to be collected for the model was determined to include: Interarrival times, Processing times, Spacing and Conveyor transferred time of paint shop’s oven. According to [4], the observing data are classified as:

1) Probabilistic data, which in this study is processing times.
2) Deterministic data, which is the conveyer transferred time and spacing.

All this information should be collected in order to make the simulation model work.

A. Interarrival times and Processing times

Interarrival times for cars coming into a system are almost always probabilistic data because the time varies in values. It is best to begin by managing the data collection in a chart, the example chart is shown in Table I.

The processing time of each station were obtained by observing the interval during two units of item was started processing and ended processing at the station. With this Top Coat painting system, we got seven collected data sets.

<table>
<thead>
<tr>
<th>Arrival num.</th>
<th>Arrival time</th>
<th>Begin time</th>
<th>End time</th>
<th>Processing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12:00:00</td>
<td>12:00:00</td>
<td>12:10:00</td>
<td>00:10:00</td>
</tr>
<tr>
<td>2</td>
<td>12:10:00</td>
<td>12:11:00</td>
<td>12:19:00</td>
<td>00:08:00</td>
</tr>
<tr>
<td>3</td>
<td>12:19:00</td>
<td>12:20:00</td>
<td>12:30:00</td>
<td>00:10:00</td>
</tr>
<tr>
<td>4</td>
<td>12:30:00</td>
<td>12:32:00</td>
<td>12:44:00</td>
<td>00:12:00</td>
</tr>
<tr>
<td>5</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>6</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>

The time format is HH: MM: SS.

1) Input Distribution

Twenty samples of processing time data sets, obtained from the data chart were imported to Minitab, the statistical software [5], to identify the distribution that best fits to the data. (See Table II and Fig. 4)

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning</td>
<td>20</td>
<td>302.1</td>
<td>42.56</td>
<td>244</td>
<td>389</td>
</tr>
<tr>
<td>Blow-off</td>
<td>20</td>
<td>280.7</td>
<td>50.5</td>
<td>211</td>
<td>403</td>
</tr>
<tr>
<td>Wipe</td>
<td>20</td>
<td>305.7</td>
<td>34.5</td>
<td>241</td>
<td>354</td>
</tr>
<tr>
<td>Base Coat Painting</td>
<td>20</td>
<td>1202.8</td>
<td>104.5</td>
<td>1016</td>
<td>1426</td>
</tr>
<tr>
<td>Base Coat Color Setting</td>
<td>20</td>
<td>580.0</td>
<td>102.8</td>
<td>304</td>
<td>779</td>
</tr>
<tr>
<td>Clear Coat Painting</td>
<td>20</td>
<td>576.0</td>
<td>87.5</td>
<td>395</td>
<td>691</td>
</tr>
<tr>
<td>Clear Coat Setting</td>
<td>20</td>
<td>537.2</td>
<td>74.1</td>
<td>409</td>
<td>656</td>
</tr>
</tbody>
</table>

The unit is second.
Fig. 4 An example of identifying the best distribution fitting for cleaning process

**Distribution Summary:**

- **Cleaning Station:** Lognormal
- **Blow-off Station:** Lognormal
- **Wipe Station:** Normal
- **Base Coat Painting Station:** Lognormal
- **Base Coat Color Setting:** Weibull
- **Clear Coat Painting:** Normal
- **Clear Coat Setting:** Lognormal

B. Converyer transferred time

Most conveyers operate at a specific velocity. This mean it is deterministic data because it needs to be collected only once because it never varies in value.

In this study, the conveyer data was collected by interviewing from the engineers. The data consists of the transferred length and the conveyer speed. Then the transferred time can be calculated. Because of the transferred times between each station are very small, they were neglected to consider.

V. MODEL VALIDATION

The statistical data were applied to the simulation software, Tecnomatix Plant Simulation, to model the system and to represent the actual process, as shown in Fig. 5. The model cannot be confidently used if it is not validated.

The model validation is the process of insuring that the model represents reality [6]. Statistical validity was performed by statistically comparing the output from the actual system with the data from the model that was developed using the software. The twenty samples from the system and the model were collected and tested for a null hypothesis by Minitab. The t-test was used to determine statistical significance. The resulting t value of 1.01 was between the critical values of -2.093 and +2.093 at 0.05 levels of significant. Because the model was not statistically significantly different from the actual system, it was considered to be valid.

VI. BOTTLENECK IDENTIFICATION

The useful feature of the software is able to displays the statistical data of station utilization that was recorded during the simulation run [3]. The location of the bottleneck was identified by the percentage of blocking. The data help scheduling and designing the new models which will be shown in the following topic.

VII. EXPERIMENTAL DESIGNS

Three designing alternative models were conducted from the Model A (See Fig. 6) that represents a present production process to improve the performance of the existing system. The various alternatives in this research focused on rearranging the workstations, dividing the task of each station and reducing the bottleneck in the system to make the better workflow. Each alternative was analyzed in the view of practical feasibility and no effecting to the quality of item with respect to workers and engineers' opinions.

One major bottleneck of Model A appeared at the base coat station (See Fig. 10) which is the process of two layers base coat painting. One possibility to reduce the processing time of it is to divide the tasks of the station into two stations, the space at base coat station is used for the first layer painting and the space at the base coat color set station is used for second layer painting and color setting as represented by Model B which illustrated in Fig. 7.

Regarding to Model B, Model C used idea of removing the Cleaning Station in order to obtain more workspace for
splitting the base coat color set task from the base coat2 station as shown in Fig. 8 to make a better workflow.

The last alternative is Model D, it was considered to reduce all major bottlenecks in the system. With respect to Model C, to reduce the processing time of Base coat1 station, the inspection task was split from Base coat1 station and Blow-off station was removed and was replaced with Base coat1 station as shown in Fig. 9.

VIII. RESULTS AND CONCLUSION

Four models were run with TAAP’s working hours (eight hours of two shifts with one hour break time each shift) in condition of sufficient number of workers. The average result of each model was shown in Table III.

<table>
<thead>
<tr>
<th>Model</th>
<th>Throughput (car) per day</th>
<th>Longest Cycle time (minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>34.6</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>45.35</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>46.5</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>59</td>
<td>10</td>
</tr>
</tbody>
</table>

The performance of models was measured by a number of throughputs per day. The result obviously showed that Model D performs better than other alternatives. Bottlenecks in the system were reduced and achieved better workflow, by comparing with Model A and Model D as illustrated in Fig. 10 and Fig. 11. However, this report was just demonstrated the method to find the better solution. If the model will be chosen to use, the cost analysis should be considered in addition.

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REFERENCES