Engineering Statistics: Final Project Presentation

Jon Smith
Cameron Clark
GPSS Simulation

- Simulation using Manuf2.gps program
  - Parameters of Interest
    - Mean Time in the System
    - First Quartile
    - Second Quartile
    - Inter-Quartile Range
    - Utilization of the Clerk
    - Utilization of the Operators
    - Utilization of the Machines
Factors

- 2 Factors that will be changed to optimize floor configuration
  - Number of Operators
    - 5 through 9
  - Number of Machines
    - 2 though 5
Analysis

- ANOVA (Analysis of Variance)
  - Used to analyze simulated data and determine best combination of machines and operators
  - P-value of 0.05 used to determine significance of ANOVA results
  - Box Plots, Whisker Plots, Histograms, Normal Plots, etc. to be used for illustration
Mean Time in the System

ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>3</td>
<td>1360.25</td>
<td>453.418</td>
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<tr>
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<td>672.97</td>
<td>224.322</td>
<td>1.04</td>
<td>0.401</td>
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<tr>
<td>Interaction</td>
<td>9</td>
<td>2541.21</td>
<td>282.356</td>
<td>1.31</td>
<td>0.305</td>
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<tr>
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<td>16</td>
<td>3444.84</td>
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<td>31</td>
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</tbody>
</table>

Highly Non-Significant = No observable trend

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>218.991</td>
<td>(-----------------*)</td>
</tr>
<tr>
<td>7</td>
<td>206.919</td>
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<td>(-----------------*)</td>
</tr>
<tr>
<td>9</td>
<td>203.326</td>
<td>(-----------------*)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>209.750</td>
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</tr>
<tr>
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<td>202.329</td>
<td>(-----------------*)</td>
</tr>
<tr>
<td>4</td>
<td>214.533</td>
<td>(-----------------*)</td>
</tr>
<tr>
<td>5</td>
<td>205.505</td>
<td>(-----------------*)</td>
</tr>
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</table>

All 95% Confidence Intervals Overlap = No observable Trend
Mean Time in the System

No Observable Trend
# First Quartile (Q1)

## ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>3</td>
<td>57.402</td>
<td>19.1339</td>
<td>0.98</td>
<td>0.425</td>
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<td>0.901</td>
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<td>Error</td>
<td>16</td>
<td>311.181</td>
<td>19.4488</td>
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<td>Total</td>
<td>31</td>
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</table>

\[ S = 4.410 \quad R-Sq = 51.29\% \quad R-Sq(adj) = 5.62\% \]

Operators: Highly Non-Significant = No observable trend

Machines: Significant = Trend

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>170.0 172.5 175.0 177.5</td>
</tr>
<tr>
<td>6</td>
<td>174.796</td>
<td>(----------------*----------------)</td>
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<tr>
<td>7</td>
<td>173.493</td>
<td>(----------------*----------------)</td>
</tr>
<tr>
<td>8</td>
<td>171.834</td>
<td>(----------------*----------------)</td>
</tr>
<tr>
<td>9</td>
<td>171.454</td>
<td>(----------------*----------------)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
<th>Individual 95% CIs For Mean Based on Pooled StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>168.0 171.5 175.0 178.5</td>
</tr>
<tr>
<td>2</td>
<td>176.633</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>3</td>
<td>169.806</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>4</td>
<td>171.983</td>
<td>(--------*--------)</td>
</tr>
<tr>
<td>5</td>
<td>173.155</td>
<td>(--------*--------)</td>
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All 95% Confidence Intervals Overlap = No observable Trend
First Quartile (Q1)

Individual Value Plot of Q1 vs Operators, Machines

Normal Residuals

No Observable Trend
Third Quartile (Q3)

ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
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<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>3</td>
<td>346.00</td>
<td>115.33</td>
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<td>0.071</td>
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<tr>
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<td>550.08</td>
<td>183.36</td>
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<td>0.018</td>
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<tr>
<td>Interaction</td>
<td>9</td>
<td>442.32</td>
<td>49.14</td>
<td>1.21</td>
<td>0.356</td>
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<tr>
<td>Error</td>
<td>16</td>
<td>651.68</td>
<td>40.73</td>
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</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>1990.08</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

S = 6.382   R-Sq = 67.25%   R-Sq(adj) = 36.55%

Operators: Non-Significant = No observable trend

Machines: Significant = Trend

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>233.498</td>
<td>(225.0 - 230.0)</td>
</tr>
<tr>
<td>7</td>
<td>234.203</td>
<td>(230.0 - 235.0)</td>
</tr>
<tr>
<td>8</td>
<td>228.078</td>
<td>(225.0 - 230.0)</td>
</tr>
<tr>
<td>9</td>
<td>226.661</td>
<td>(223.0 - 225.0)</td>
</tr>
</tbody>
</table>

All Overlap

Overlap

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>237.425</td>
<td>(230.0 - 235.0)</td>
</tr>
<tr>
<td>3</td>
<td>227.544</td>
<td>(223.0 - 225.0)</td>
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<tr>
<td>4</td>
<td>227.020</td>
<td>(223.0 - 225.0)</td>
</tr>
<tr>
<td>5</td>
<td>230.450</td>
<td>(225.0 - 230.0)</td>
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Overlap
Third Quartile (Q3)

Individual Value Plot of Q3 vs Operators, Machines

Normal Residuals

Slight Trend as a function of Machines
### ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
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<td>99.953</td>
<td>33.3176</td>
<td>1.95</td>
<td>0.162</td>
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<td>Machines</td>
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<td>141.727</td>
<td>47.2423</td>
<td>2.76</td>
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<td>Interaction</td>
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<td>327.038</td>
<td>36.3375</td>
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<td>0.090</td>
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<td>842.146</td>
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S = 4.134  R-Sq = 67.53%  R-Sq(adj) = 37.09%

**All Non-Significant = No observable trend**

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**Individual 95% CIs For Mean Based on Pooled StDev**

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
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<tbody>
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<td>59.5838</td>
<td>(--------*-----)</td>
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<tr>
<td>7</td>
<td>56.2413</td>
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<td>8</td>
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<tr>
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<td>60.7900</td>
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<tr>
<td>10</td>
<td>56.6125</td>
<td>(--------*-----)</td>
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<tr>
<td>11</td>
<td>55.0375</td>
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<td></td>
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<td></td>
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<tr>
<td>12</td>
<td>57.2450</td>
<td>(--------*-----)</td>
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**Individual 95% CIs For Mean Based on Pooled StDev**

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
<td>60.7900</td>
<td>(--------*-----)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>56.6125</td>
<td>(--------*-----)</td>
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<td>3</td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
<td>54.0</td>
<td>57.0</td>
<td>60.0</td>
<td>63.0</td>
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<td></td>
</tr>
</tbody>
</table>

**All Overlap**
Inter-Quartile Range

No Trend

Normal Residuals

Individual Value Plot of Q3-Q1 vs Operators, Machines

Residual Plots for Q3-Q1

Normal Probability Plot of the Residuals

Residuals Versus the Fitted Values

Histogram of the Residuals

Residuals Versus the Order of the Data
Utilization of Clerk

ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4.65750</td>
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<td>11.8200</td>
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<td>0.715</td>
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<td>30.8300</td>
<td>1.92688</td>
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<td>31</td>
<td>61.9350</td>
<td></td>
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</tbody>
</table>

\[ S = 1.388 \quad R-Sq = 50.22\% \quad R-Sq(adj) = 3.56\% \]

All Non-Significant = No observable trend

---

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>85.9750</td>
<td>(--------*--------)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>85.8625</td>
<td>(--------*--------)</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>8</td>
<td>84.7000</td>
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</tr>
<tr>
<td>9</td>
<td>84.5125</td>
<td>(--------*--------)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

84.0  85.0  86.0  87.0

---

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>85.5500</td>
<td>(--------*--------)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>5</td>
<td>85.5250</td>
<td>(--------*--------)</td>
<td></td>
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</tr>
</tbody>
</table>

84.00  84.80  85.60  86.40

All Overlap  All Overlap
Utilization of Clerk

No Trend

Normal Residuals
## Utilization of Operator

### ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>3</td>
<td>1914.61</td>
<td>638.202</td>
<td>630.32</td>
<td>0.000</td>
</tr>
<tr>
<td>Machines</td>
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<td>150.94</td>
<td>50.312</td>
<td>49.69</td>
<td>0.000</td>
</tr>
<tr>
<td>Interaction</td>
<td>9</td>
<td>7.31</td>
<td>0.812</td>
<td>0.80</td>
<td>0.621</td>
</tr>
<tr>
<td>Error</td>
<td>16</td>
<td>16.20</td>
<td>1.013</td>
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<td>Total</td>
<td>31</td>
<td>2089.05</td>
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</tbody>
</table>

\[ S = 1.006 \quad R^2 = 99.22\% \quad R^2(\text{adj}) = 98.50\% \]

All Highly-Significant = No observable trend

### Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Operators</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>61.0500</td>
<td>(---*)</td>
</tr>
<tr>
<td>7</td>
<td>52.5625</td>
<td>(---*)</td>
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<tr>
<td>8</td>
<td>45.7250</td>
<td>(---*)</td>
</tr>
<tr>
<td>9</td>
<td>40.3875</td>
<td>(---*)</td>
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None Overlap

<table>
<thead>
<tr>
<th>Machines</th>
<th>Mean</th>
<th>95% CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
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<tr>
<td>3</td>
<td>48.3250</td>
<td>(---*)</td>
</tr>
<tr>
<td>4</td>
<td>48.6375</td>
<td>(---*)</td>
</tr>
<tr>
<td>5</td>
<td>49.1000</td>
<td>(---*)</td>
</tr>
</tbody>
</table>

One does not Overlap
Utilization of Operator Trend as a function of both Machine and Operators

Normal Residuals

Trend as a function of both Machine and Operators
## Utilization of Machines

### ANOVA Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>3</td>
<td>19.05</td>
<td>6.35</td>
<td>1.29</td>
<td>0.312</td>
</tr>
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<td>9534.74</td>
<td>3178.25</td>
<td>645.12</td>
<td>0.000</td>
</tr>
<tr>
<td>Interaction</td>
<td>9</td>
<td>50.88</td>
<td>5.65</td>
<td>1.15</td>
<td>0.388</td>
</tr>
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<td>16</td>
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<td>31</td>
<td>9683.49</td>
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</tbody>
</table>

\[ S = 2.220 \quad R-Sq = 99.19\% \quad R-Sq(adj) = 98.42\% \]

All Highly-Significant = No observable trend

### Individual 95% CIs For Mean Based on Pooled StDev

#### Operators

| Operators | Mean   | +--------+--------+--------+--------+ |
|-----------|--------|---------|--------|--------|--------|
| 6         | 49.9500| (--------*--------) |
| 7         | 51.3750| (--------*--------) |
| 8         | 49.4875| (--------*--------) |
| 9         | 49.5000| (--------*--------) |

| Operators | Mean   | +--------+--------+--------+--------+ |
|-----------|--------|---------|--------|--------|--------|
| 6         | 49.5   | 48.0    | 49.5   | 51.0   | 52.5   |

All Overlap

#### Machines

| Machines | Mean   | +--------+--------+--------+--------+ |
|----------|--------|---------|--------|--------|--------|
| 2        | 77.3750| (-*)    | (-*)   | (-*)   | (-*)   |
| 3        | 51.2375| (*)     | (*)    | (*)    | (*)    |
| 4        | 40.3500| (*)     | (*)    | (*)    | (*)    |
| 5        | 31.3500| (*)     | (*)    | (*)    | (*)    |

| Machines | Mean   | +--------+--------+--------+--------+ |
|----------|--------|---------|--------|--------|--------|
| 2        | 30     | 45      | 60     | 75     |

None Overlap
Utilization of Machine Trend as a function of Machine but not Operators

Trend as a function of Machine but not Operators
## Correlation

+ Correlation Includes Significant Region
- Does not include Significant Region

<table>
<thead>
<tr>
<th></th>
<th>Mean Time</th>
<th>Q1</th>
<th>Q3</th>
<th>Q3-Q1</th>
<th>Util Clerk</th>
<th>Util Oper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3-Q1</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Util Clerk</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Util Oper</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Util Mach</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- Should Use 6 Operators and 4 Pallets
  - 60% utilization of Operators
  - 50% utilization of Machine
- Balance machine use with operator use
  - Don’t under work or over work either
- Mean Time in System not effected by either selection
- Should do more extensive simulation with more trials to gain a more accurate picture
GPSS Simulation

- Simulation using Pallets2.gps program

  - Parameters of Interest
    - Mean Time in the System
    - First Quartile
    - Second Quartile
    - Inter-Quartile Range
    - Times in the System
    - Utilization of the Servers
    - Times in the Station Queues
Factors

- 3 Factors that will be changed to optimize line configuration
  - Number of Spaces
    - 3 through 5
  - Number of Pallets
    - 10 through 15
  - Number of Stations
    - 4 to 9
Analysis

- Multivariate Regression
  - Used to analyze simulated data and determine best combination of spaces, pallets and stations
  - P-value of 0.05 used to determine significance of Regression results
  - Probability Plots, Histograms, Residual Plots, etc. to be used for illustration
Mean Time in the System

Regression Results

- TINSYS = 383 - 54.2 SPACES + 35.2 PALLETS + 126 STATIONS

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>382.6</td>
<td>346.6</td>
<td>1.10</td>
<td>0.276</td>
</tr>
<tr>
<td>SPACES</td>
<td>-54.19</td>
<td>45.18</td>
<td>-1.20</td>
<td>0.237</td>
</tr>
<tr>
<td>PALLETS</td>
<td>35.22</td>
<td>21.33</td>
<td>1.65</td>
<td>0.106</td>
</tr>
<tr>
<td>STATIONS</td>
<td>126.11</td>
<td>19.24</td>
<td>6.56</td>
<td>0.000</td>
</tr>
</tbody>
</table>

- S = 255.553  R-Sq = 51.1%  R-Sq(adj) = 47.8%

Highly Significant

Analysis of Variance Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>3007728</td>
<td>1002576</td>
<td>15.35</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>44</td>
<td>2873522</td>
<td>65307</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>5881250</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mean Time in the System

**Predicted Values for New Observations**

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>Fit</th>
<th>SE Fit</th>
<th>95% CI</th>
<th>95% PI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1471.2</td>
<td>37.2</td>
<td>(1396.3, 1546.2)</td>
<td>(950.8, 1991.7)</td>
</tr>
</tbody>
</table>

**Values of Predictors for New Observations**

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>SPACES</th>
<th>PALLETs</th>
<th>STATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4.00</td>
<td>12.0</td>
<td>7.00</td>
</tr>
</tbody>
</table>

**Good Fit**
Mean Time in the System

Residual Plots for TINSYS

Normal Probability Plot of the Residuals

Residuals Versus the Fitted Values

Histogram of the Residuals

Residuals Versus the Order of the Data

Standardized Residual

Percent

1 10 50 90 99

Standardized Residual

-2 -1 0 1 2

Fitted Value

1000 1200 1400 1600 1800

Standardized Residual

0 1 2

Fitted Value

-2 -1 0 1 2

Observation Order

1 5 10 15 20 25 30 35 40 45

Standardized Residual

0 1 2

Observation Order

-2 -1 0 1 2

Frequency

0 4 8 12 16

Standardized Residual

-2 -1 0 1 2

Frequency

0 4 8 12 16

Standardized Residual

-2 -1 0 1 2

Frequency

0 4 8 12 16

Standardized Residual

-2 -1 0 1 2

Frequency
Max. Utilization of the Servers

Regression Results

\[ \text{MAX. UTIL.} = 0.961 - 0.0156 \text{ SPACES} + 0.0217 \text{ PALLETS} - 0.0474 \text{ STATIONS} \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.9611</td>
<td>0.1030</td>
<td>9.33</td>
<td>0.000</td>
</tr>
<tr>
<td>SPACES</td>
<td>-0.0156</td>
<td>0.01343</td>
<td>-1.16</td>
<td>0.253</td>
</tr>
<tr>
<td>PALLETS</td>
<td>0.021719</td>
<td>0.006340</td>
<td>3.43</td>
<td>0.001</td>
</tr>
<tr>
<td>STATIONS</td>
<td>-0.047390</td>
<td>0.005718</td>
<td>-8.29</td>
<td>0.000</td>
</tr>
</tbody>
</table>

\[ S = 0.0759574 \quad R^2 = 66.0\% \quad R^2(\text{adj}) = 63.6\% \]

Highly Significant

Analysis of Variance Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
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<td>0.49171</td>
<td>0.16390</td>
<td>28.41</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
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<td>0.25386</td>
<td>0.00577</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>0.74557</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Max. Utilization of the Servers

Predicted Values for New Observations

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>Fit</th>
<th>SE Fit</th>
<th>95% CI</th>
<th>95% PI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.8277</td>
<td>0.0111</td>
<td>(0.8054, 0.8500)</td>
<td>(0.6730, 0.9824)</td>
</tr>
</tbody>
</table>

Values of Predictors for New Observations

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>SPACES</th>
<th>PALLETS</th>
<th>STATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4.00</td>
<td>12.0</td>
<td>7.00</td>
</tr>
</tbody>
</table>

Good Fit
Max. Utilization of the Servers

Residual Plots for MAX. UTIL.

- Normal Probability Plot of the Residuals
- Residuals Versus the Fitted Values
- Histogram of the Residuals
- Residuals Versus the Order of the Data

Histogram of the Residuals

- Frequency
- Standardized Residual
- Standardized Residual
- Observation Order
Mean Time in the Queues

Regression Results

\[ TINQUEUE = 47 - 40.0 \text{ SPACES} + 63.8 \text{ PALLETS} - 37.7 \text{ STATIONS} \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>47.2</td>
<td>246.2</td>
<td>0.19</td>
<td>0.849</td>
</tr>
<tr>
<td>SPACES</td>
<td>-39.97</td>
<td>32.09</td>
<td>-1.25</td>
<td>0.219</td>
</tr>
<tr>
<td>PALLETS</td>
<td>63.77</td>
<td>15.15</td>
<td>4.21</td>
<td>0.000</td>
</tr>
<tr>
<td>STATIONS</td>
<td>-37.70</td>
<td>13.66</td>
<td>-2.76</td>
<td>0.008</td>
</tr>
</tbody>
</table>

\[ S = 181.512 \quad \text{R-Sq} = 39.1\% \quad \text{R-Sq(adj)} = 35.0\% \]

Highly Significant

Analysis of Variance Results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>931476</td>
<td>310492</td>
<td>9.42</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>44</td>
<td>1449648</td>
<td>32947</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>2381124</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Mean Time in the Queues

**Predicted Values for New Observations**

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>Fit</th>
<th>SE Fit</th>
<th>95% CI</th>
<th>95% PI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>388.7</td>
<td>26.4</td>
<td>(335.4, 441.9)</td>
<td>(19.0, 758.4)</td>
</tr>
</tbody>
</table>

**Values of Predictors for New Observations**

<table>
<thead>
<tr>
<th>New</th>
<th>Obs</th>
<th>SPACES</th>
<th>PALLETS</th>
<th>STATIONS</th>
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<td>12.0</td>
<td>7.00</td>
</tr>
</tbody>
</table>

Good Fit
Mean Time in the Queues

![Residual Plots for TINQUEUE](image)

- Normal Probability Plot of the Residuals
- Residuals Versus the Fitted Values
- Histogram of the Residuals
- Residuals Versus the Order of the Data

---

**Standardized Residual**

- Percent
- Standardized Residual
- Fitted Value
- Standardized Residual
- Observation Order
## Correlation

<table>
<thead>
<tr>
<th></th>
<th>Mean Time</th>
<th>Max. Util.</th>
<th>Time in Queue</th>
<th>Mean/Median</th>
<th>Q1</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Util.</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time in Queue</td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean/Median</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Q1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Q3</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>IQR</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+ Correlation Includes Significant Region
- Does not include Significant Region
Conclusion

- The following configuration is recommended:
  
  Spaces = 4; Pallets = 12; Stations = 7

- This combination will result in:

<table>
<thead>
<tr>
<th></th>
<th>Fit</th>
<th>SE Fit</th>
<th>95% CI</th>
<th>95% PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TinSys</td>
<td>1471.2</td>
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<td>(1396.3, 1546.2)</td>
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</tr>
<tr>
<td>Max. TinQueue</td>
<td>388.7</td>
<td>26.4</td>
<td>(335.4, 441.9)</td>
<td>(19.0, 758.4)</td>
</tr>
</tbody>
</table>

- More extensive simulation with more trials necessary to gain a more accurate picture