Elemental Time Studies

- Elemental time studies record times for machine activities:
  - from continuous observation of the machine
  - for a longer period of time

- Machine time is divided into elements.

- Each element:
  - has clearly recognizable starting and ending points
  - allows consistent timing in the field
Elemental Time Studies

• For example, the activities of a cable skidder are commonly broken down into the following elements:
  – Travel empty
  – Choking logs
  – Travel loaded
  – Unchoking logs
  – Deck maintenance
  – Delays

These elements make up a skidder’s work cycle.
Elemental Time Studies

• To determine the productivity of a cable skidder, we need to know:
  – time and payload in each work cycle
  – skidding distance, slope, ground conditions, and other variables associated with the cycle

• With enough data, cycle time could be predicted from one or more of these measured variables.
Elemental Time Study
Example for a Cable Skidder

- Cycle time (min.) = 9.918 + 0.0049SD - 0.0000006SD^2 + 0.0338TV
- Productivity (ft^3/PMH) = 196.771 - 0.096SD + 0.00001SD^2 + 2.2425TV

SD = average skidding distance (feet)
TV = turn volume (ft^3)
PMH = productive machine hour

(Source: Wang et al. 2004)
Elemental Time Study

- Can be used to provide detailed and unbiased information.
- However, this method requires trained operators and can be costly and time consuming.
- Field personnel may have to work close to a machine and are placed in a dangerous position.
Productivity

For a skidder using equation developed from elemental time study

(Source: Wang et al. 2004)
Comparisons

Time Study Methods

• Each of three time study methods is a useful tool for examining logging operations.

• The selection of an appropriate time study technique depends on
  – the information you need,
  – the type of operations to be studied, and
  – the personnel and equipment available to do the task
Comparisons

Time Study Methods

• Well planned and designed gross time studies and work samples
  – can yield a substantial amount of information
  – do not have the complexity of performing elemental time study
Comparisons

Example

- Graphically illustrates the relationships among three time study methods.
- Covers 35 minutes of scheduled time for a grapple skidder.
- Five turns of wood are delivered to the landing during this time period.
## Relationships of Three Methods

<table>
<thead>
<tr>
<th>Time</th>
<th>TE</th>
<th>GL</th>
<th>TL</th>
<th>DL</th>
<th>UG</th>
<th>DM</th>
<th>DE</th>
<th>Total</th>
<th>Cords</th>
<th>Work Sample</th>
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<td>GL</td>
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<td></td>
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</tr>
</tbody>
</table>
## Gross Time Study

(Example)

<table>
<thead>
<tr>
<th>Elapsed Time (minutes)</th>
<th>Payload (cords)</th>
<th>Productivity (Cords/PMH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.50</td>
<td>0.64</td>
<td>5.91</td>
</tr>
<tr>
<td>7.50</td>
<td>0.54</td>
<td>4.32</td>
</tr>
<tr>
<td>7.00</td>
<td>0.68</td>
<td>5.83</td>
</tr>
<tr>
<td>5.00</td>
<td>0.56</td>
<td>6.72</td>
</tr>
<tr>
<td>9.00</td>
<td>0.70</td>
<td>4.67</td>
</tr>
<tr>
<td><strong>Mean=7.00</strong></td>
<td><strong>0.62</strong></td>
<td><strong>5.49</strong></td>
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</table>
## Work Sample Study (Example)

<table>
<thead>
<tr>
<th>Element</th>
<th>Obs</th>
<th>Observed %</th>
<th>Actual %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Empty</td>
<td>3</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Grapple Logs</td>
<td>2</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Travel Loaded</td>
<td>3</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>Delimb Stems</td>
<td>2</td>
<td>20</td>
<td>9</td>
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<tr>
<td>Ungrapple Logs</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Deck Maintenance</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Delays</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>100</td>
<td>100</td>
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Elemental Time Study
(Example)

<table>
<thead>
<tr>
<th>Element</th>
<th>Elapsed Time (min.)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Empty</td>
<td>7.00</td>
<td>20</td>
</tr>
<tr>
<td>Grapple Logs</td>
<td>5.50</td>
<td>16</td>
</tr>
<tr>
<td>Travel Loaded</td>
<td>12.50</td>
<td>36</td>
</tr>
<tr>
<td>Delimb Stems</td>
<td>3.00</td>
<td>9</td>
</tr>
<tr>
<td>Ungrapple Logs</td>
<td>2.50</td>
<td>7</td>
</tr>
<tr>
<td>Deck Maintenance</td>
<td>0.50</td>
<td>1</td>
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<tr>
<td>Delays</td>
<td>4.00</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>35.00</td>
<td>100</td>
</tr>
</tbody>
</table>
Regression Models
Estimating Production

• Least square regression modeling has long been an efficient, accurate method of estimating and predicting forestry data.

• It is very common to employ regression modeling to estimate tree volume based on tree diameter (DBH) and total height.
Estimating and Predicting

• **Estimation** involves the calculation of means and other statistics about a population from which the samples were drawn.
• **Prediction** on the other hand is determining what will happen in the future based on past experiences.

In tree volume example, estimate and predict?
Regression Modeling

Timber Harvesting Data

• First requires an understanding of what we want to accomplish.

• Our goal is usually to:
  – develop estimation equations
  – predict machine production rates – production per unit time under a variety of conditions
Regression Modeling

• Three types of data for each work cycle should be produced by time and production studies:
  – Times
  – Units of production
  – Work conditions
Regression Modeling

Example

- An example for feller-buncher’s productivity:
  - We would like to know how many cords per hour a FB would produce.
  - Working under a set of conditions, say trees with DBH’s from 4-22 inches.
Regression Modeling (Times)

• Time cycle is a period of time for felling a tree or several trees.

• Times collected during elemental time studies may include such times as:
  – Move-to-tree
  – Position and cut
  – Move-to-dump
  – Dump and delays
Regression Modeling (Production and Condition)

• The production of each cycle is the volume or weight of the tree or trees.
• The work conditions surrounding that tree are things like:
  – tree size,
  – slope, and
  – other terrain conditions
Procedures for Regression Modeling

• A time study of feller-buncher should include several hundred cycles or trees.

• Procedures:
  – Means
  – Plotting Data
  – Fitting Models
  – Testing Fits
## Data Format

<table>
<thead>
<tr>
<th>DBH</th>
<th>Fell-Time (min.)</th>
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<td>13</td>
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<td>14</td>
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<tr>
<td>...</td>
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</tbody>
</table>
Means

Example

• One way to calculate productivity is to add all times together and all volume together and divide the sums to get average volume per hour.

• Means are limited to the set of conditions observed.

• Means just give you the overall average productivity.
Plotting Data

Example

• Trees in the example are not in the same size.
  – DBH ranged from 4 to 22 inches.
  – It takes more time for a FB to cut a large tree than a small one.
Plotting Data

Example

• We calculate the average time for each-inch DBH and draw the plot.

• Now, instead of having the overall average time per tree, we have average time for each DBH class.
Data Plot

The graph shows a scatter plot with Time Per Tree (minutes) on the y-axis and DBH (inches) on the x-axis. Each point represents a measurement of time taken to process a tree of a certain diameter. The data points suggest a trend where larger trees take longer to process.
Fitting the Model
Remove an outlier from the dataset.
Regression Modeling Tool
SAS Programming

```
data FB;
    infile 'e:\wjx\teaching\wdsc132\labs\Bell_fb.dat';
    input DBH time;
    data FBReg; set FB;
    if time=1.4737 then delete;
    dd=dbh*dbh;
    proc reg;
    model time=dbh;
    proc reg;
    model time = dd;
    run;
```
Regression Models

Time per tree (minutes) vs. DBH (inches)

- Time = 0.4797 + 0.0005*DBH^2
- Time = 0.4051 + 0.0123*DBH

WDSC 422
Testing Fits

• Based on:
  – **R-Square** checks the correlation of independent and response variables, $0 < R^2 \leq 1$.
  – **Root MSE** is the root of mean squared sum of errors. The smaller the better.
  – **F&P values** are the probabilities to check the significance of variables and the model.
Which Equations to Use?

• Where the study was conducted?
• What sizes of the trees were harvested?
• What was the range of work conditions?
• What were the terrain and weather conditions?
• What products were harvested, both species and type?
• Which machines and models were used?