PRODUCTION PROCESS EVALUATION FOR EARTHWORKS

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Background - Earthworks

• Continuous process -
  • Strictly sequenced, repetitive cycles of material processing operations
  • Heavy plant equipment, surveying team, and a material lab

• Continuous products -
  • Product geometry derived from existing landscape, 3D alignment, and cross-sections
  • Not composed of assemblies of discrete elements
  • Do not have a straightforward Location Breakdown Structure (Kenley and Seppanen 2010).
Technology in Earthworks

- Machine Control (MC) technology - 3D design, GNSS locations systems, and a set of sensors, enabling automation of operations
- How can we utilize the monitored data for process improvements and for production control?
Methodology

• Design Science Research
• Artifacts –
  • Product information schema (Haronian and Sacks, 2019)
  • Production evaluation procedure
• Validation – by case study
Roadel = road element
Case Study

- **Material Supply**: 4,375 [Products/hr]
  - Actual Mean = 2,048 [Products/hr]
  - Actual Max = 3,172 [Products/hr]

- **Spread**: 3,500 [Products/hr]
- **Watering**: 16,000 [Products/hr]
- **Compact**: 4,900 [Products/hr]
- **Inspections**: Surveyor and lab
Data Monitoring

- The embankment was divided into 75,000 roadels
- Data obtained from the MC systems was linked to the elements
Waste Evaluation

- Over-processing
- Resource Waiting Time
## Results - Production Process Evaluation (PPE) Index

<table>
<thead>
<tr>
<th>Week</th>
<th>32</th>
<th>35</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift time [h:m]</td>
<td>122:00</td>
<td>122:00</td>
<td>122:00</td>
</tr>
<tr>
<td>Gross working time [h:m]</td>
<td>103:57</td>
<td>107:54</td>
<td>112:41</td>
</tr>
<tr>
<td>Waiting times in work packages [h:m]</td>
<td>55:11</td>
<td>35:08</td>
<td>35:25</td>
</tr>
<tr>
<td>Net processing times [h:m]</td>
<td>48:45</td>
<td>72:45</td>
<td>77:16</td>
</tr>
<tr>
<td>Over-processing time [h:m]</td>
<td>5:10</td>
<td>17:53</td>
<td>6:56</td>
</tr>
<tr>
<td>Value adding time [h:m]</td>
<td>43:35</td>
<td>54:51</td>
<td>70:19</td>
</tr>
<tr>
<td>Non-value adding time [h:m]</td>
<td>78:24</td>
<td>67:08</td>
<td>51:40</td>
</tr>
<tr>
<td>Production volume (Total fill) [m³]</td>
<td>19,465</td>
<td>20,620</td>
<td>19,745</td>
</tr>
<tr>
<td>Over production (Over fill) [m³]</td>
<td>2,062</td>
<td>5,073</td>
<td>1,773</td>
</tr>
<tr>
<td>Actual Production [m³]</td>
<td>17,402</td>
<td>15,547</td>
<td>17,972</td>
</tr>
<tr>
<td>Theoretical Throughput [m³/hr]</td>
<td>267</td>
<td>283</td>
<td>271</td>
</tr>
<tr>
<td>Production Process Evaluation [%]</td>
<td>53%</td>
<td>45%</td>
<td>54%</td>
</tr>
</tbody>
</table>
Further Work

• Implementation of Little’s Law (Little 2011; 2008)
• Evaluation according to Factory Physics (Hopp and Spearman 2008)
• Seven production metrics
Evaluation by Little’s Law

- **Throughput (TH)**
  \[ P = \sum_{1}^{n} \left( \frac{h_{\text{end shift, } i} - h_{\text{start shift, } i}}{d_{\text{layer}}} \right) * A_{i} \]
  \[ \text{TH} = \frac{P}{T} \]

- **Cycle time (CT)**
  \[ CT = \frac{\sum_{1}^{n} (T_{\text{end, } i} - T_{\text{start, } i})}{P} \]

- **Work in progress (WIP)**
  \[ WIP (t) = \sum_{1}^{n} \left\{ \text{if } T_{\text{start, } i} \leq t \leq T_{\text{end, } i} \rightarrow 1 \right\} \]
  \[ \text{else} \rightarrow 0 \]

- \( W_{o}, T_{o}, \) and \( r_{b} \)
Evaluation by Little’s Law, and Factory Physics (Hopp and Spearman 2008)
# Production Metrics

<table>
<thead>
<tr>
<th>Category</th>
<th>Metric</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>$\alpha_1$ – CPPC</td>
<td>$\frac{Actual \ Production \ Volume}{Panned \ Production \ Volume}$</td>
</tr>
<tr>
<td>Planning</td>
<td>$\alpha_2$ - Shift duration</td>
<td>$1 - \frac{</td>
</tr>
<tr>
<td>Productivity</td>
<td>$\alpha_3$ – Productivity</td>
<td>$\frac{actual \ TH}{\eta_b}$</td>
</tr>
<tr>
<td>Waste</td>
<td>$\alpha_4$ – Waiting times</td>
<td>$\frac{Actual \ Shift \ Duration - Waiting \ Time}{Actual \ Shift \ Duration}$</td>
</tr>
<tr>
<td>Waste</td>
<td>$\alpha_5$ - Over processing</td>
<td>$\frac{Actual \ Production \ Volume - Overprocessing}{Actual \ Production \ Volume}$</td>
</tr>
<tr>
<td>Flow</td>
<td>$\alpha_6$ - WIP</td>
<td>$WIP &gt; W_0 \rightarrow \frac{W_0}{WIP}$</td>
</tr>
<tr>
<td>Flow</td>
<td>$\alpha_7$ - CT</td>
<td>$CT &gt; T_0 \rightarrow \frac{T_0}{CT}$</td>
</tr>
</tbody>
</table>
Production Metrics

Four categories for evaluation, on location and daily resolution:

- Planning reliability
- Productivity
- Waste
- Flow
Conclusion

- LC for earthworks and road construction may have a significant impact – processes, operations, and technology adoption
- Advanced technologies can be utilized for process analysis and to support production control
- The potential of LC combined with advanced technologies is demonstrated by the developed metrics
- Further implementation of LC for earthworks requires development and adaptation of production theory, principles, and tools