USING 5D models and CBA for planning the foundations and concrete structure stages of a complex office building

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Commonly adopted methodologies by building contractors in Peru:

**Last Planner System**, which is one of the *most widely accepted techniques* by construction companies that are starting to adopt the Lean Construction. (Orihuela 2015)

**BIM** is being rapidly adopted in the Peruvian industry, a study conducted in 2017 showed that *1 out of 4 building projects in Peru used BIM*. Commonly used to improve the visualization, automate the QTO process and identify incompatibilities (Murguia 2018).

**Critical Path Method (CPM)**, which is mentioned as a contractual tool in the Peruvian government contracting laws. (Brioso et al. 2016)
Introduction

Two main problems in the Contractor’s traditional methodologies, tools, and procedures:

1. Lack of synergy between planning and control methodology of the Contractor (CPM) and Lean Construction philosophy.

2. Lack of integration within the tools/procedures used for methodologies that has explicit synergy.
Introduction

1. Lack of synergy

Reasons:

- **PUSH control type.** (Seppänen 2009).
- Downsides of the controlling phase of the CPM (Arditi et al. 2002; Olivieri et al. 2018): (i) not focusing on the workflow, (ii) neglecting production rates, (iii) omitting the work disparity in locations, (iv) demoting resource management, and (v) inefficient on repetitive projects.

Methodology Proposed:

**Location Based Management system**

- Enables continuous workflow and aims Lean goals (Seppänen 2009).
- Transforms quantities in locations, determines reliable durations based on productivity information, makes buffers explicit, and alarms of future production problems based on its forecasts (Kenley & Seppänen 2010).
1. Lack of Integration

Reasons:

- **BIM** mostly used 3D dimension approach (visualization, QTO, compatibilization) (Murguia 2018).
- **Activities based approach** of CPM do not integrate the location approach of construction.
- More effort and tools (unconnected software) needed to integrate the information of cost, durations and quantities.

Methodology Proposed:

- **5D BIM models**: budget line items are associated with specific measurable features of model objects (Sacks et al. 2018).
- LBMS determines reliable durations based on productivity information and location quantities.
- **5D software** that integrates LBMS, BIM and LPS tools, exists in the market.
Introduction

Traditional (current) Methodologies:
- CPM + 3D BIM model + Lean
  - 3 unconnected software

Proposed Methodologies:
- Flowlines + 5D BIM model + Lean
  - 1 software for 3d, cost & Schedule information

Choosing by Advantages: to support sound decision-making using comparisons among advantages of alternatives (Arroyo et al. 2013)

The research shows the benefits of integrated scope-cost-time solution for lean management compared to traditional methods, following a standardize decision-making.
Case of study:
Planning the foundations and concrete structure stages of an office building: 24 000 m² constructed area:

1) Framework of traditional methods
2) Gather scope, cost & schedule information
3) 3D & 5D modelling
4) Model presented to the Contractor
5) CBA elaboration

*This research focuses on setting the basis in the planning phase of foundations and concrete structure, future research can cover the construction phase and other disciplines.*
5D Model based in Flowlines

1) 3D modelling involved:
   - Foundations
   - Soil filling
   - 4 types of slabs
   - Vertical and horizontal elements
   - Ramps, stairs

1.1) Define locations:
Floors (6) → Blocks (3 per floor) → Sectors (one per day)

2) Integrate 3D model-locations -quantities -schedule & cost information in one database

3) Elaborate the flowlines
3) Flowlines:

- Overview of the constructive sequence
- Identify the **bottlenecks** to ensure *continuous flows*.

*Concrete mixers were allowed in specific hours during the night shift*

*Soil filling case*
5D Model based in Flowlines

3) Flowlines:
   • Align the **slope of the bottlenecks** to the contractual milestones, plan all the activities around **this slope** (per location). *Efficient flows*

   ![Diagram showing flowlines and bottlenecks]

   **Blue square** indicates the internal milestone
   **Red arrows** indicate the bottlenecks’ slope = “Backbone”
3) Flowlines:
   • When adjusting the slope of all the activities, identify **opportunities to improve** the planned resources. *Efficient processes*

4) Automated resource and budget items histograms for all the detail needed (per time or per level of detail in cost)

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2 problems identified

1) **Rebar** needed more than 20 crews to achieve the production demanded. Solution: preformed rebar

2) **Soil filling** needed lots of manhours per day, critical activity for resources.
Evaluating the models

**ALTERNATIVES:**
1. 3D models + CPM + Lean,
2. 4D models + CPM + Lean, and
3. 5D models + LBMS + Lean

**Factors, attributes (Att:) and advantages (Adv:) criteria:**

<table>
<thead>
<tr>
<th>FACTOR 1:</th>
<th>Plan an effective Lean Production System</th>
<th>Alt. 1</th>
<th>Alt. 2</th>
<th>Alt. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion:</strong></td>
<td>Ensuring an effective Lean Production System is better</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1. Alt. 1</td>
<td>Att: CPM to plan</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2. Alt. 2</td>
<td>Att: Flow lines to plan and balance the production rate based on the bottlenecks</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>3. Alt. 3</td>
<td>Adv: continuous flows, efficient flows and efficient processes</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FACTOR 2:</th>
<th>Sinergy with Earn Value reports</th>
<th>Alt. 1</th>
<th>Alt. 2</th>
<th>Alt. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion:</strong></td>
<td>Less time spent with more possible detail, is better</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>1. Alt. 1</td>
<td>Att: Spreadsheets manual integration</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>2. Alt. 2</td>
<td>Att: CPM and quantities integrated</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>3. Alt. 3</td>
<td>Adv: automated QTO vs time</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>3. Alt. 3</td>
<td>Adv: planned value automated, in control forecasts automated</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
</tbody>
</table>
Evaluating the models

**FACTOR 3:**
Scheduling automation

*Criterion:*
Less time spent is better

- **Alt. 1** 0
- **Alt. 2**
  - Att: CPM, input needed: durations and n° of crews
- **Alt. 3** 80
  - Att: Flow lines for the schedule
  - Adv: durations and resources needed per activity are automated.

**FACTOR 4:**
Schedule understanding

*Criterion:*
Better understanding from the engineers

- **Alt. 1** 60
  - Att: CPM for the scheduling and visualization
  - Adv: All the staff understands
- **Alt. 2** 80
  - Adv: Understanding + visualization
- **Alt. 3** 0
  - Att: flowlines represent the schedule.

**FACTOR 5:**
Learning process

*Criterion:*
Less training hours needed is better

- **Alt. 1** 80
  - Att: 3D, spreadsheets and CPM
  - Adv: Commonly used in Peruvian industry
- **Alt. 2** 50
  - Att: 4D models, spreadsheets and CPM
  - Adv: Regularly used in Peruvian industry
- **Alt. 3** 0
  - Att: 5D models and LBMS
### Evaluating the models

#### FACTOR 6: QTO and Cost in time automation

<table>
<thead>
<tr>
<th>Alt.</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt. 1</td>
<td>0</td>
<td>Att: Automated QTO and cost distribution in time associated with cost</td>
</tr>
<tr>
<td>Alt. 2</td>
<td>30</td>
<td>Adv: Schedule information synchronized</td>
</tr>
<tr>
<td>Alt. 3</td>
<td>70</td>
<td>Adv: Automated QTO and distribution in time associated with cost</td>
</tr>
</tbody>
</table>

**Criterion:** Less time spent and more detail capacity

#### FACTOR 7: Schedule understanding

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Alt. 1</td>
<td>0</td>
<td>Att: Automated QTO and distribution in time associated with cost</td>
</tr>
<tr>
<td>Alt. 2</td>
<td>0</td>
<td>Adv: All the staff understands</td>
</tr>
<tr>
<td>Alt. 3</td>
<td>50</td>
<td>Adv: Much more info. displayed,</td>
</tr>
</tbody>
</table>

**Criterion:** More relevant information that do not complicates the Schedule analysis.

#### FACTOR 8: State contract laws

<table>
<thead>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt. 1</td>
<td>50</td>
<td>Adv: Automated process to determine the Critical Path and effective visualization</td>
</tr>
<tr>
<td>Alt. 2</td>
<td>50</td>
<td>Adv: Understanding + visualization</td>
</tr>
<tr>
<td>Alt. 3</td>
<td>0</td>
<td>Att: Flow lines schedule for planning and control</td>
</tr>
</tbody>
</table>

**Criterion:** Easier determination and better visualization of the critical path is better
Evaluating the models

<table>
<thead>
<tr>
<th></th>
<th>(1) 3D models + CPM + Lean</th>
<th>(2) 4D models + CPM + Lean</th>
<th>(3) 5D models + LBMS + Lean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>190</strong></td>
<td><strong>240</strong></td>
<td><strong>390</strong></td>
</tr>
</tbody>
</table>

**Key outputs:**

- Ensures an effective Lean Production System.
- Automated distribution of resources, costs and quantities.
- Automated calculation of resources and durations guided by bottlenecks and milestones.
- More detail capacity in the Schedule.
Discussion

• Lack of synergy and integration in methodologies / tools \(\Rightarrow\) more working hours

• Proposed methodology: 5Dmodels + LBMS + Lean
  • Implemented in parallel into the planning stage

• Flowlines Schedule guided by the slope of the bottlenecks (backbones).
  • ready-mix concrete pouring process
  • soil filling process
Discussion

• CBA: 5D models based on the LBMS.
  • *Planning an effective Lean Production system*
    Continuous flows → Identify the bottleneck per medium level location
    Efficient flows → Align activities to the Backbone
    Efficient processes → Optimize the construction process and resources
  • *Reporting the baseline automatically, more detail capacity*
  • *Automation*
    QTO process
    Resources and durations based on milestones and backbone
    Histograms and cost reports
  • QTO difference < 1%
Conclusion

• **Integrated scope-cost-time (5D + LBMS)** is the preferred solution for *lean management* compared to traditional methods.

• **5D + LBMS allows**
  - More automation (duration, resources, QTO, reports)
  - More essential details in visualization
  - More reliable process

• **Further research for:** Automated results in construction phase, automated early warnings, easier earn value control.
THANKS