Singularity Functions To Enhance Monitoring In The Last Planner System

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Presentation Outline

Research Gap / Goal
Last Planner System
Control in Planning
Singularity Functions
Methodology
Developed Tool
Simulation
Conclusion
Research Gap / Goal
Research Gap

01
Proactivity VS “Thermostat” Approach (Liker 2004)

02
PRI linkage to workers’ ability

03
No Improvement -Related Metric

04
No Singularity Functions integration with project control
Goal

- Simple Tool
- Dynamic
- Proactive
- New Metric
Master Scheduling

Planners identify project milestones and major activities and perform push scheduling using the critical path method (CPM) to estimate the total project's duration (Hanzeh et al. 2008)

Phase Scheduling

Planner break down phases developed in the master schedule into activities, identify gross constraints, and perform reverse phase scheduling (Hamzeh 2009)

Lookahead Planning

Planners break down tasks from the phase schedule, design and detail their execution, and remove constraints to make tasks ready (Junnonen and Seppänen 2004)

Weekly Work Plan (WWP)

Planners should include sound assignments that are made ready by removing any constraints that prevent them from becoming ready for execution. (Ballard 2000)
LPS Metrics Used

**PPC**
Percent Plan Complete

Indicates the reliability of planning on the WWP level (El Samad et al. 2017)

\[
PPC = \frac{DID}{WILL}
\]

**PRI**
Percent Reliability Index

Indicates the reliability of planning at activity level (planning effectiveness) (González et al. 2008)

\[
PRI = \frac{Actual PR}{Forecasted PR}
\]
Control in Planning
Control in LPS & Linear Scheduling

**SHOULD & CAN**
SHOULD and CAN rather than just SHOULD and DID (Howell and Ballard 1996)

**Production Unit & Workflow**
Ensure better workers assignments & ensure the best work sequence (Ballard 2000)

**Early Constraints Identification and Removal**
To facilitate work plans’ reliability (Hamzeh 2009)

**Metrics**
For continuous improvement and learning from failures

**Monitor**
Actual Progress

**Forecast**
Future Progress

**Alert**
Cascading Delays and Clashes (Seppänen 2013)

**Buffer**
Time - Space – Plan (Frandson 2015)
Singularity Functions

\[ S < x - a >^n = \begin{cases} 
0 & \text{for } x < a \\
(x - a)^n & \text{for } x \geq a 
\end{cases} \]

If \( n = 0 \) ➔ step

If \( n = 1 \) ➔ slope

Macaulay (1919)

Föppl (1927)

S = strength
x = variable under consideration
a = activation point
n = behavior shape
If \( n = 0 \) ➔ step
If \( n = 1 \) ➔ slope
Singularity Functions in Construction Management

2007
Computational Analysis of Linear and Repetitive Construction Project Schedules with Singularity Functions (Lucko 2007)

2009
Productivity Scheduling Method: Linear Schedule Analysis with Singularity Functions (Lucko 2009)

2010
Modeling Cash Flow Profiles with Singularity Functions (Lucko 2010a)

2014
Spatially-Constrained Scheduling with Multi-Directional Singularity Functions (Lucko et al. 2014)

2016
A Unified Quantitative Model for Project Management with Singularity Functions (Su and Lucko 2016)

2017
Work-Path Modeling and Spatial Scheduling with Singularity Functions (Lucko et al. 2017)

Used for any construction project characterized by its longitudinal spatial or repetitive nature, e.g. high-rise buildings, highway construction, piping.

Used for projects with horizontal (highways, tunnels, pipelines) or vertical (high rises and towers) linear geometry, and projects with repetitive operations. Singularity functions can be used for time and amount buffers to detect the critical path regarding each.

Used in most projects because they all depend on the available workspace within a physical location. Starts by activity ordering, stacking, then finally spatial conflict resolution, taking into account possible time gains.

Used for projects that are geometrically linear or repetitive in their operations. Unifies schedules, cash flow, and resources and transforms them from 2D into 3D.

Minimizing project duration and spaces occupied by crews.
Singularity Functions Example

\[ W(t) = \\
+ 1 < t - 0 > ^1 \\
+ 2 < t - 2 > ^1 \\
- 8 < t - 4 > ^0 \\
- 3 < t - 4 > ^1 \]
Methodology
Connects Research with Practice
This study connects LPS and singularity functions with actual activities on WWP

Planned Data
Taken from the WWP

Forecasted Data
Design Science Research

Actual Data
Actual Progress
Collected by field personnel

Comparison of Forecast VS Actual
Detection of deviations and calculation of the required increase in production rates

Improvement

Warnings
Proactive Detection
Cascading delays, congestion, LPS metrics prediction
Developed Tool
<table>
<thead>
<tr>
<th>Item</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast Activity Data</td>
<td>Start Time</td>
<td>Planned Production Rate</td>
</tr>
<tr>
<td></td>
<td>Start Time</td>
<td>Actual Production Rate</td>
</tr>
<tr>
<td></td>
<td>End Time</td>
<td>PRI</td>
</tr>
<tr>
<td></td>
<td>Work to be done</td>
<td>Warning of Cascading Delays</td>
</tr>
<tr>
<td>Actual Activity Data</td>
<td>Actual Start Time</td>
<td>Prediction of Metrics</td>
</tr>
<tr>
<td></td>
<td>End Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Before Improvement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work Done So Far</td>
<td></td>
</tr>
<tr>
<td>Improvement of Activity</td>
<td>Required End Time</td>
<td>Required Improved Production Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resources Data</td>
<td>Number of Workers</td>
<td>Modified Maximum Production Rate</td>
</tr>
<tr>
<td></td>
<td>Maximum Production Rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working Area</td>
<td>Warning of Resource Allocation if needed</td>
</tr>
<tr>
<td></td>
<td>Congestion Limit</td>
<td>Warning of Congestion</td>
</tr>
</tbody>
</table>
Proposed Metric

Percent Improvement Complete
PIC

\[ PIC = \frac{\text{No. of Activities That Needed Improvement and Were Completed}}{\text{No. of All Activities That Needed Improvement}} \]

\[ PIC = \frac{\text{Should & Did Improve}}{\text{Should Improve}} \]

Purpose
Shows the reliability, ability, and commitment of the team in finishing the tasks that needed improvement
Example

<table>
<thead>
<tr>
<th># of Tasks that need Improvement</th>
<th># of Tasks that need Improvement + were completed</th>
<th>Percent Improvement Complete (PIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>67%</td>
</tr>
</tbody>
</table>
Simulation
THE NEED FOR SIMULATION

Lack of an ABM & DES Simulation Model

Metrics Not Used In Production Rate Calculation
Simulation in Construction
First introduced by Teicholz in 1963 at Stanford

Usage
To study, analyze, understand and improve systems and processes (lowering costs, optimizing schedules, …)

Software
Cyclone
Stroboscope
Anylogic

DES
• Dynamic
• Stochastic
• Process-centric
  (chain of activities and resources linked together)

ABM
• Agents and their interactions
• High complexities and interdependencies
• 3 aspects
  o Identify agents (attributes)
  o Agent relationships
  o Agent environment
Overview

Purpose: Achieve more accurate values of the Improved Production Rate (IPR) obtained from singularity functions

Inputs from EXCEL
- Congestion
- Time remaining for improvement
- Minimum, mode and maximum values for PIC, PRI, PPC and CLR

Input Analysis
- DES
- ABM

Output
- Modified Time left for improvement and converted into a graphical production rate form in EXCEL
- Find the “most likely” production rate
Figure 1 – Discrete-Event Process

Figure 2 - User Dashboard

Figure 3 - Crew Statechart
The "most likely" IPR is automatically calculated. Realistic approximation of the rate that the crew will most probably work at to execute the work required, by taking into account congestion, idleness, and the LPS metrics.
## Simulation Runs

Time left for improvement = 1 day

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Min. Metrics</th>
<th>Mode Metrics</th>
<th>Max. Metrics</th>
<th>Congestion</th>
<th>Mean Duration</th>
<th>Most Likely IPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good performance</td>
<td>0.7</td>
<td>0.9</td>
<td>1</td>
<td>0.2</td>
<td>1.65</td>
<td>6.84</td>
</tr>
<tr>
<td>Average performance</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>0.5</td>
<td>3.38</td>
<td>4.18</td>
</tr>
<tr>
<td>Bad performance</td>
<td>0.1</td>
<td>0.4</td>
<td>0.5</td>
<td>0.9</td>
<td>7.41</td>
<td>2.54</td>
</tr>
</tbody>
</table>
• A tool to monitor project performance at the level of the WWP of LPS
• Singularity functions to monitor and forecast activity progress
• Several metrics from the LPS are used
• A new metric (PIC) is suggested for the reliability to implement required improvements during execution.
  ○ Shows the reliability of the promises made during the week of execution
  ○ Use along with the maximum production rates that are modified by PRI to ensure that the required improvements are rational and within the crew’s capacity.

• Additional metrics can be developed showing the volume of improvement
• This method should be tested on an actual project as a case study and refinements could be made.
• Improvements in the production rates should be linked to Takt Time for all the activities.
Thank You