Singularity Functions To Enhance Monitoring In The Last Planner System

Ali Ezzeddine, Masters Student, Department of Civil and Environmental Engineering, AUB, Lebanon, ame109@mail.aub.edu

Lynn Shehab, Masters Student, Department of Civil and Environmental Engineering, AUB, Lebanon, aas113@mail.aub.edu

Farook Hamzeh, Associate Professor, Civil and Environmental Engineering Dept., University of Alberta, Canada, hamzeh@ualberta.ca

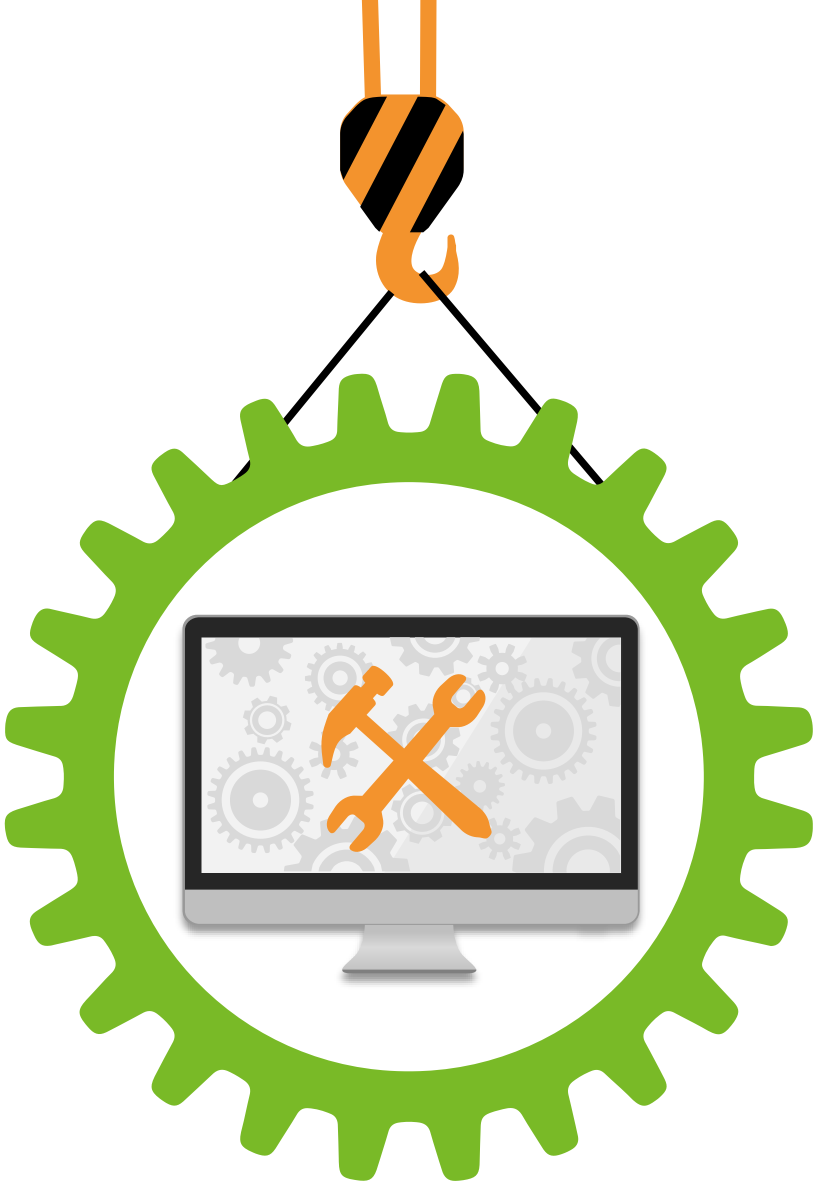
Gunnar Lucko, Professor of Civil Engineering and Director, Construction Engineering and Management Program, Dept. of Civil Engineering, Catholic University of America, Washington, lucko@cua.edu

1866 AUB American University of Beirut الجامعة الأميركية في بيروت

UNIVERSITY OF ALBERTA EDMONTON·ALBERTA·CANADA

IGLC IRELAND 2019
INTERNATIONAL GROUP FOR LEAN CONSTRUCTION
DUBLIN | IRELAND | 1ST - 7TH JULY 2019

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


Last Planner System

Last Planner System

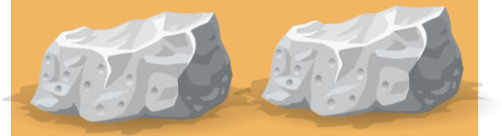
Master Scheduling

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)

SHOULD

Phase Scheduling



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

(Hamzeh 2009)

CAN

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)

WILL

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)

DID

LPS Metrics Used

PPC
Percent Plan Complete

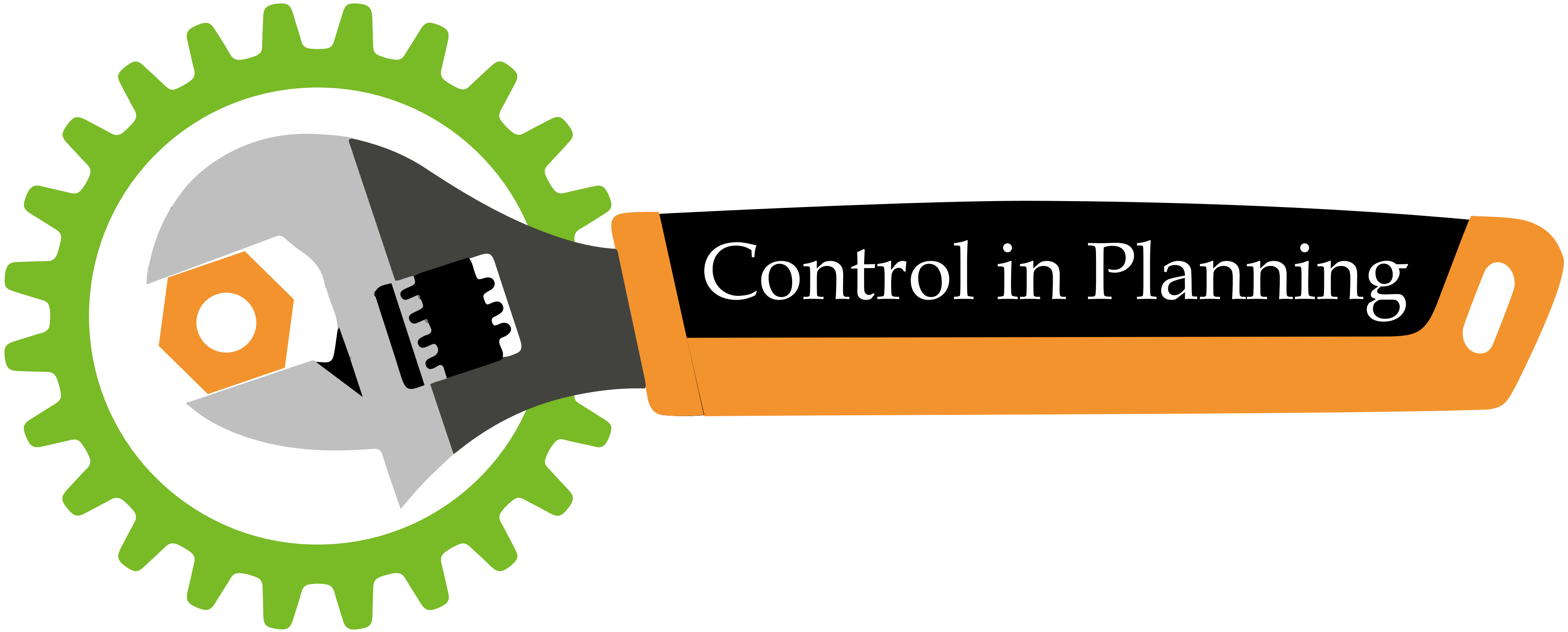
Indicates the reliability of planning on the WWP level
(El Samad et al. 2017)

PPC
=
DID / WILL

PRI
Percent Reliability Index

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

PRI
=
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

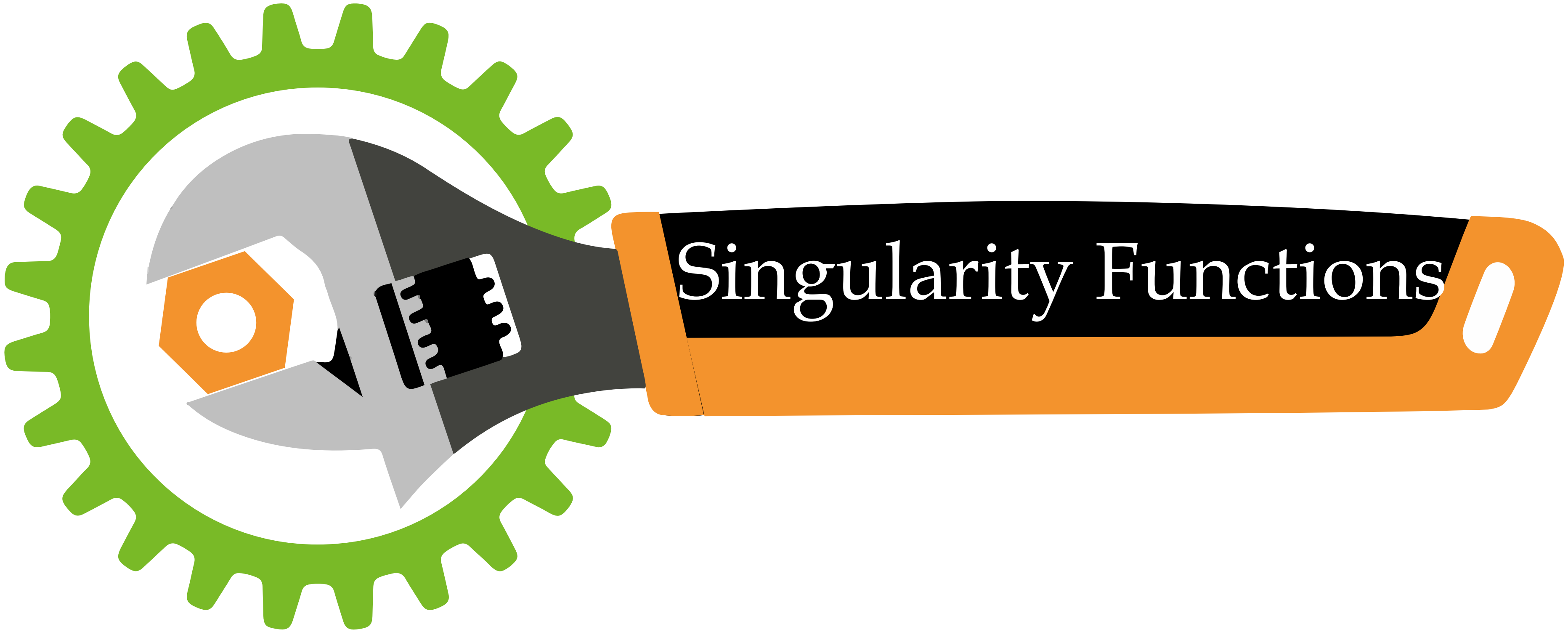
Future Progress

Alert

Cascading Delays and Clashes (Seppänen 2013)

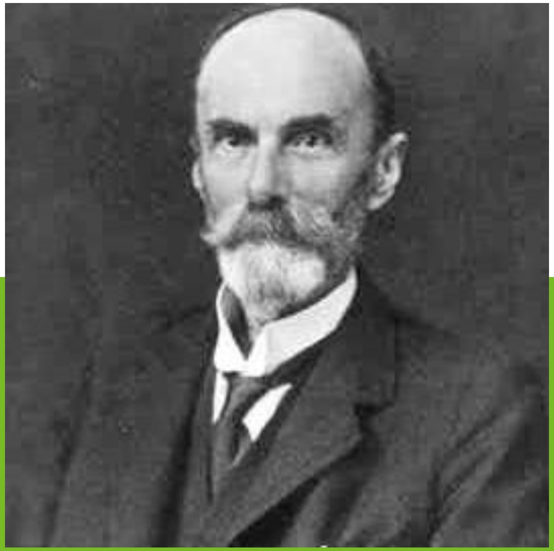
Buffer

Time - Space – Plan (Frandson 2015)


Singularity Functions

Singularity Functions

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



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)

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

2009

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

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

2010

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

Detailed analysis of cash flows in projects

Modeling Resource Profiles with Singularity Functions (Lucko 2010b)

Deals with optimum use of resources (primarily specialized labor or equipment) by using singularity functions to level them

2014

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

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

2016

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

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

2017

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

Minimizing project duration and spaces occupied by crews

Singularity Functions Example

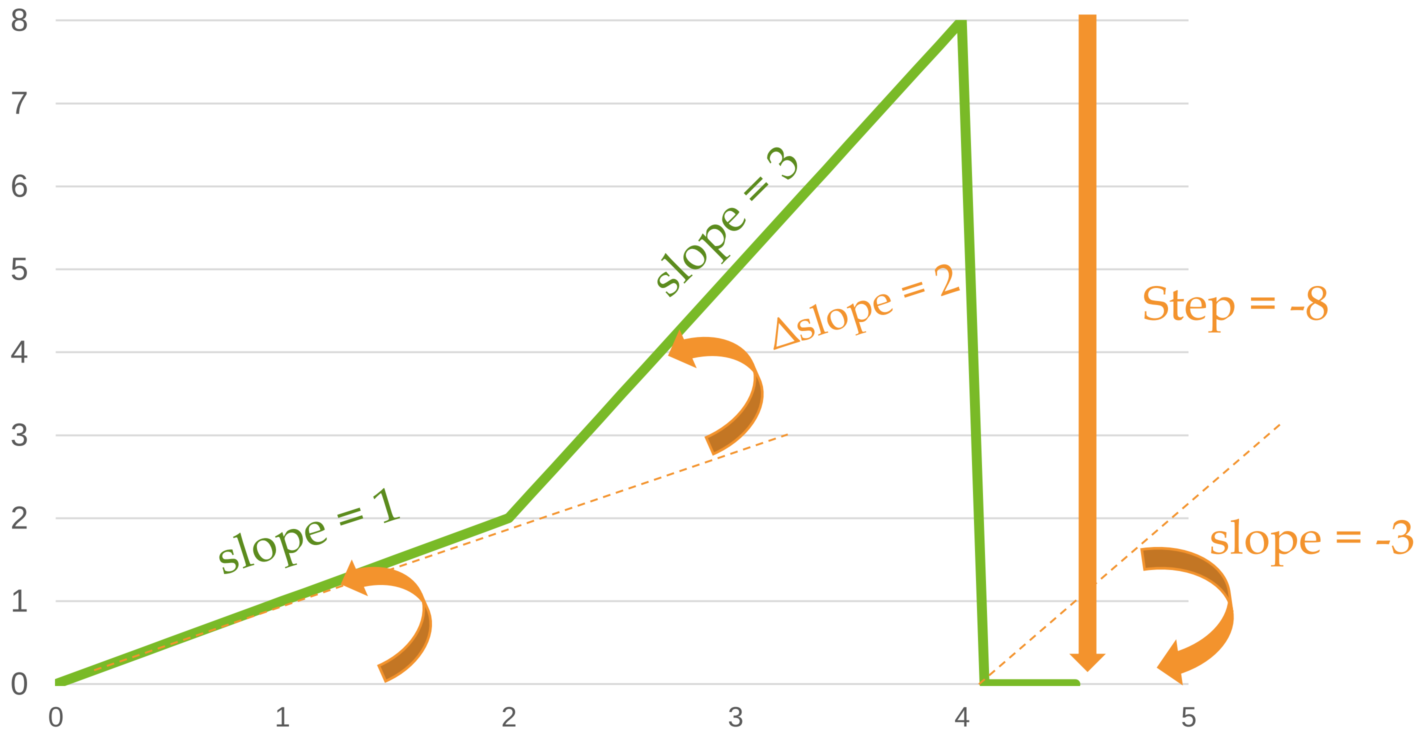
$$W(t) =$$

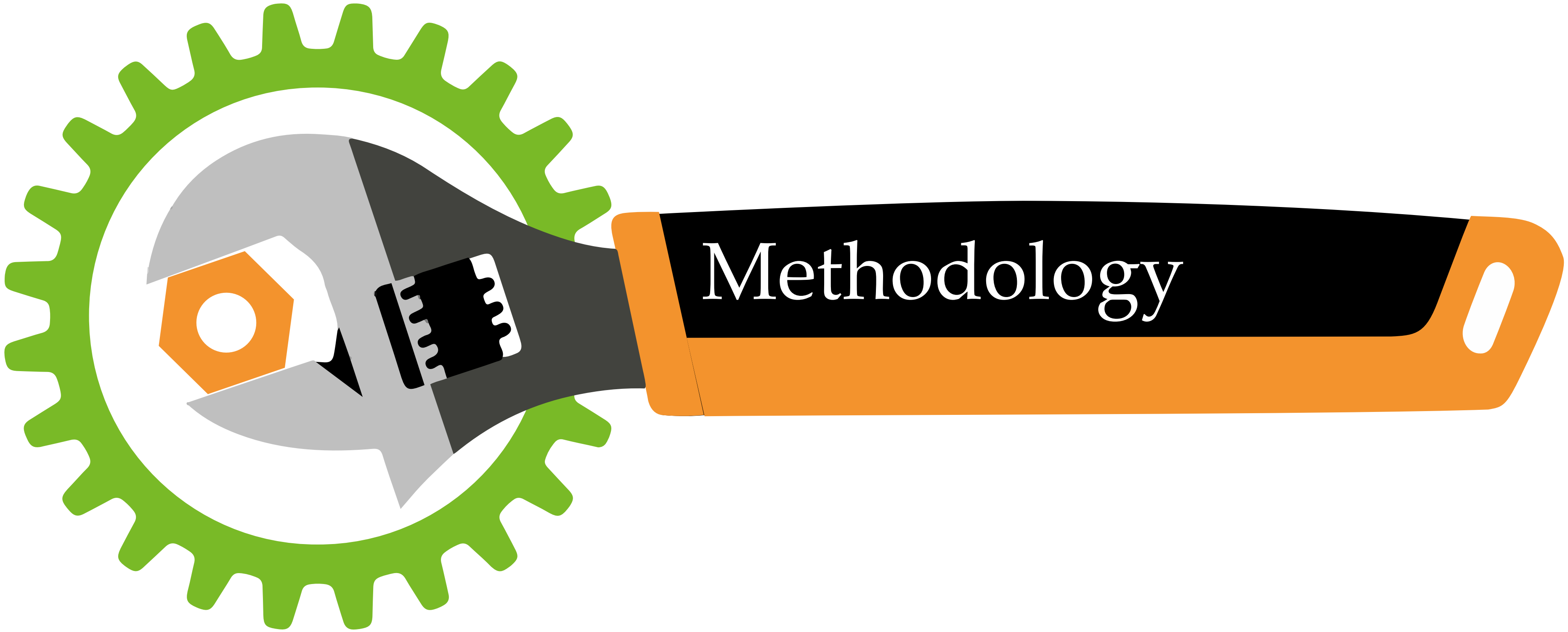
$$+1\langle t-0\rangle^{1}$$

$$+2\langle t-2\rangle^{1}$$

$$-8\langle t-4\rangle^{0}$$

$$-3\langle t-4\rangle^{1}$$





Methodology

Methodology

Planned Data
Taken from the WWP

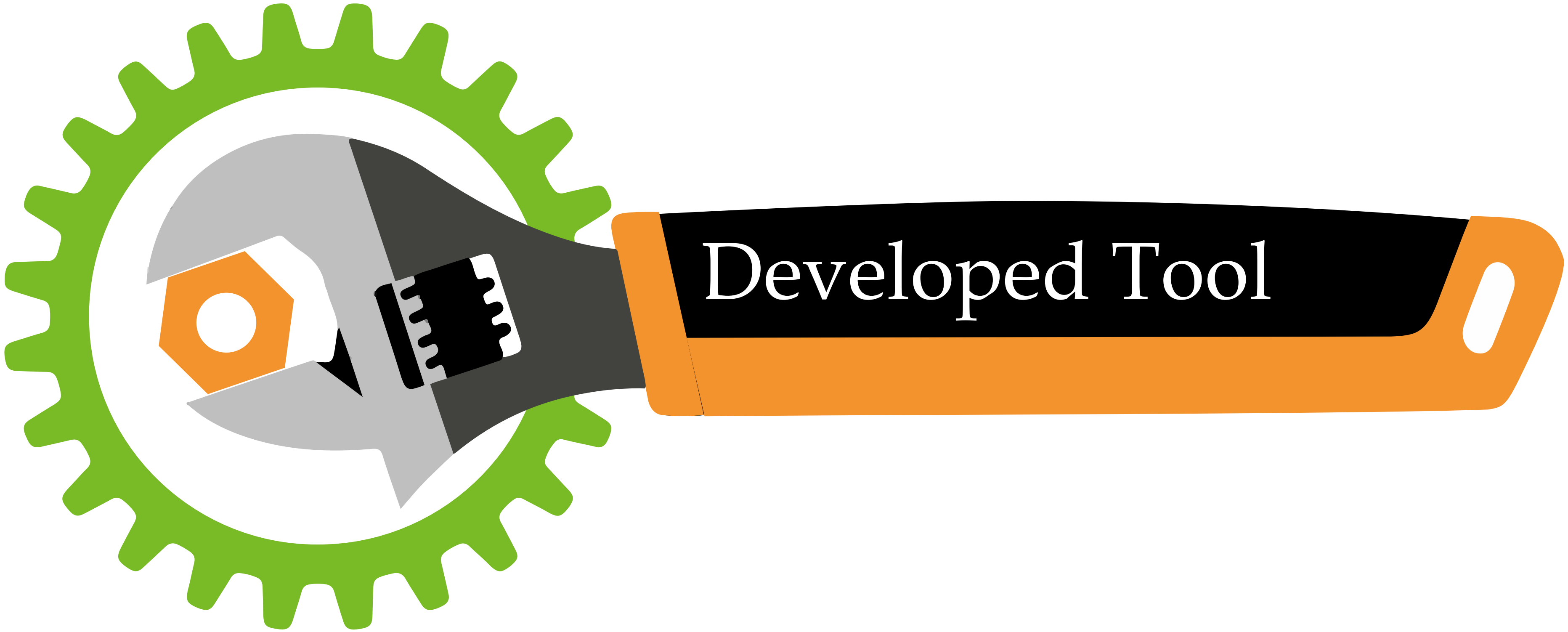
Comparison of Forecast VS Actual
Detection of deviations and calculation of the required increase in production rates

Connects Research with Practice

This study connects LPS and singularity functions with actual activities on WWP

Actual Progress
Collected by field personnel

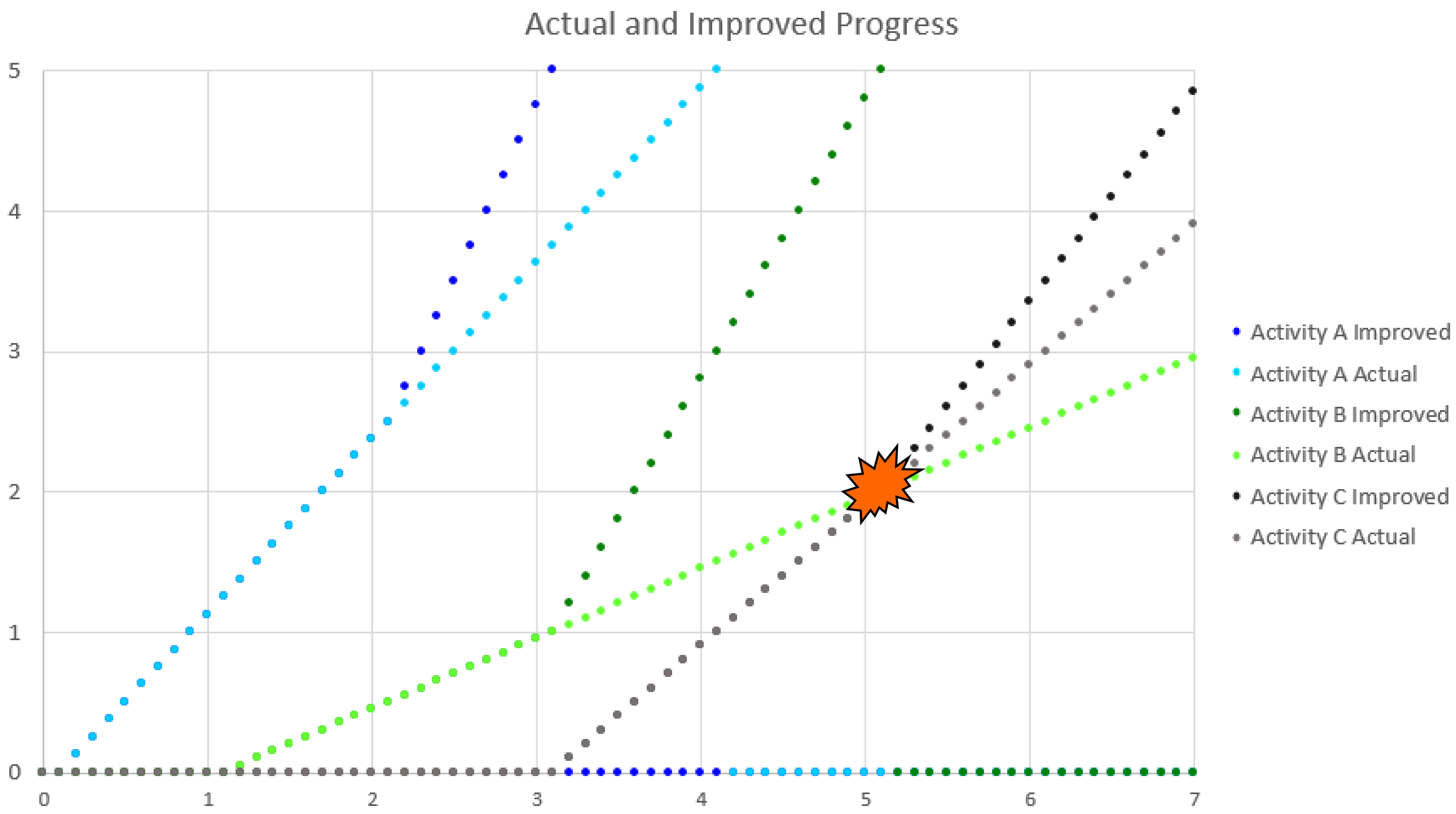
Proactive Detection
Cascading delays, congestion, LPS metrics prediction


Developed Tool

Overview

Item	Input	Output
Forecast Activity Data	Start Time End Time Work to be done	Planned Production Rate
Actual Activity Data	Actual Start Time End Time Before Improvement Work Done So Far	Actual Production Rate PRI Warning of Cascading Delays Prediction of Metrics
Improvement of Activity	Required End Time	Required Improved Production Rate
Resources Data	Number of Workers Maximum Production Rate Working Area Congestion Limit	Modified Maximum Production Rate Warning of Resource Allocation if needed Warning of Congestion

Visual Monitoring



Proposed Metric

Percent Improvement Complete

PIC

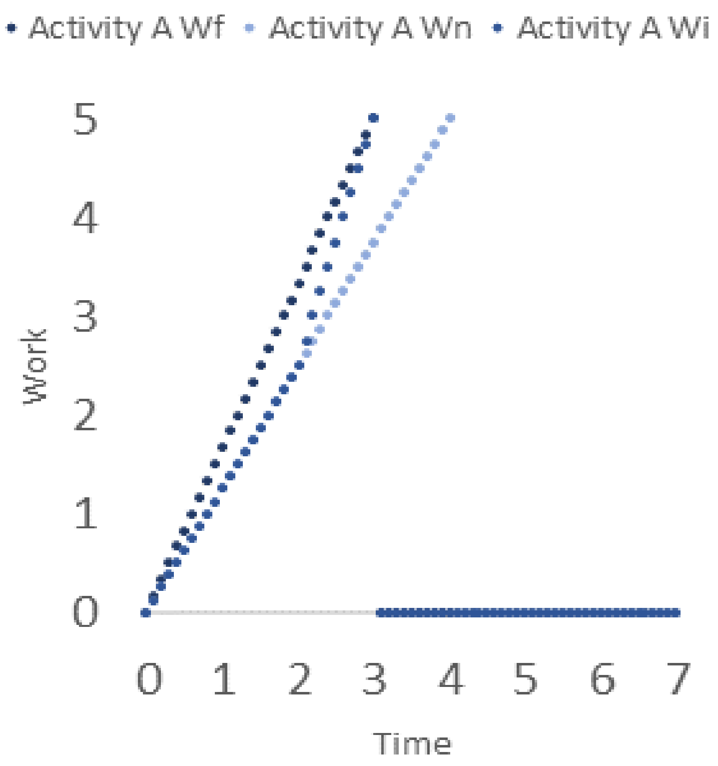
$$PIC = \frac{No.of\ Activities\ That\ Needed\ Improvement\ and\ Were\ Completed}{No.of\ All\ Activities\ That\ Needed\ Improvement}$$

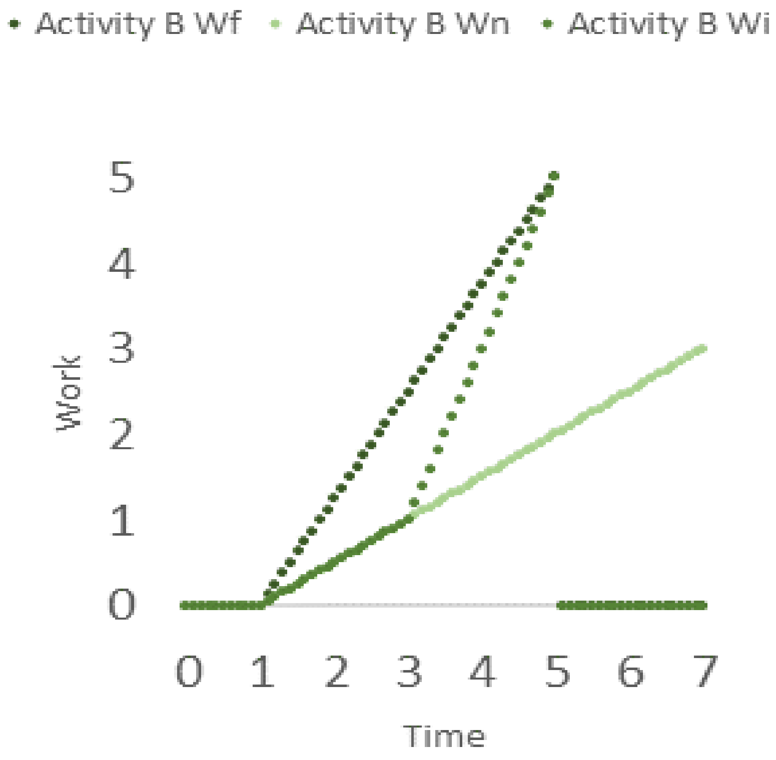
$$PIC = \frac{Should\ \&\ Did\ Improve}{Should\ Improve}$$

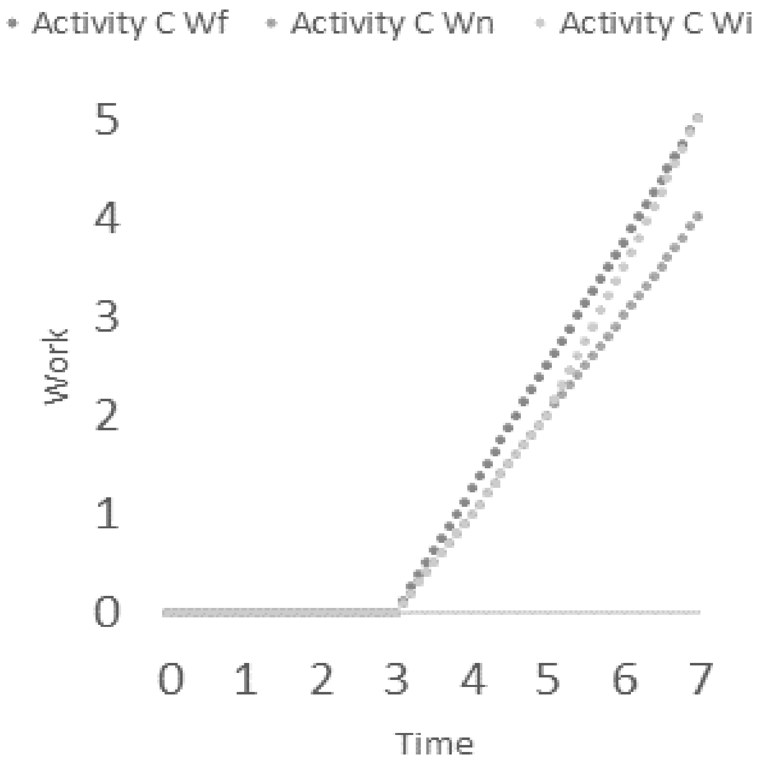
Purpose

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

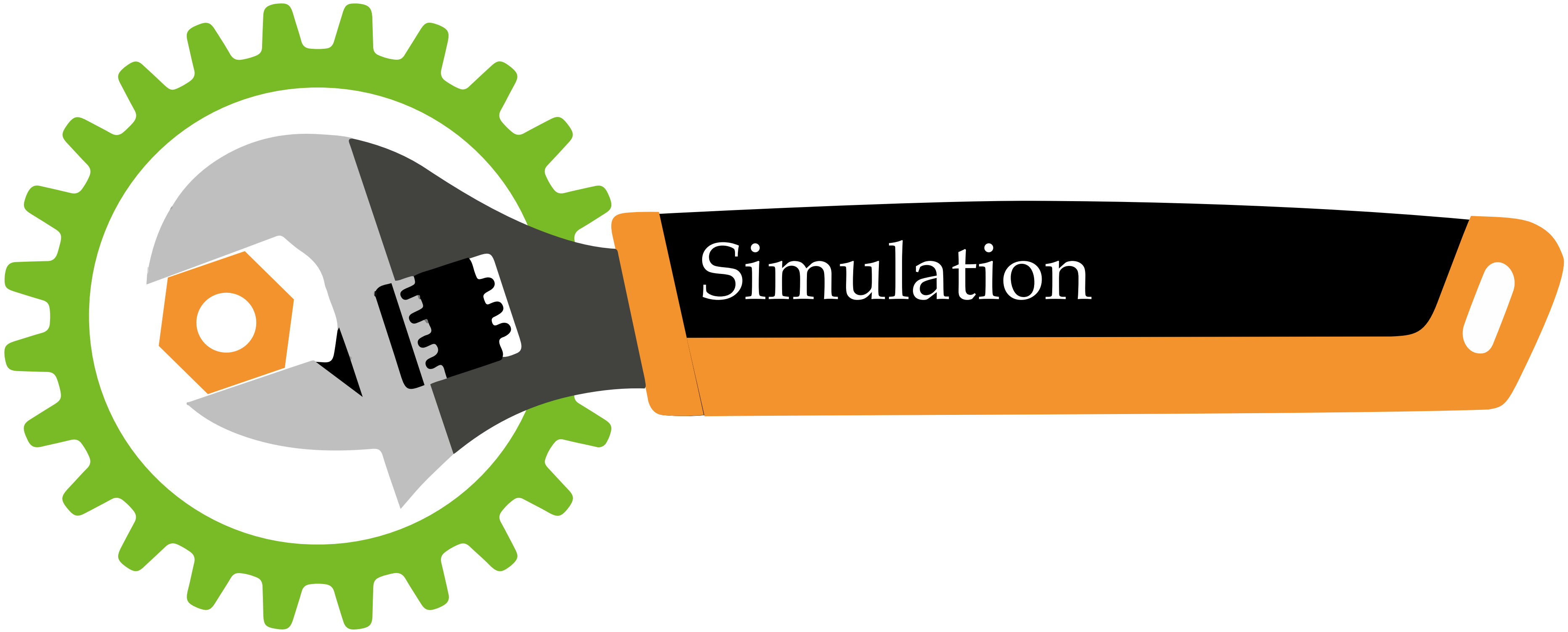
Example







# of Tasks that need Improvement	# of Tasks that need Improvement + were completed	Percent Improvement Complete (PIC)
3	2	67%


Simulation

THE NEED FOR SIMULATION

Lack of an ABM & DES Simulation Model

Metrics Not Used In Production Rate Calculation

American University of Beirut
الجامعة الأميركية في بيروت

IGLC IRELAND 2019
INTERNATIONAL GROUP FOR LEAN CONSTRUCTION
DUBLIN | IRELAND | 1ST - 7TH JULY 2019

Simulation

Simulation in Construction	Usage	Software
First introduced by Teicholz in 1963 at Stanford	To study, analyze, understand and improve systems and processes (lowering costs, optimizing schedules, …)	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
  - Identify agents (attributes)
  - Agent relationships
  - 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**

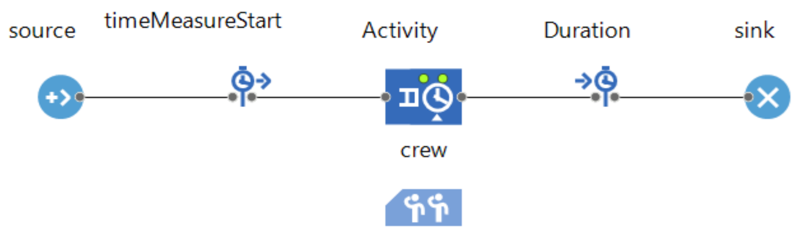


Figure 1 – Discrete-Event Process

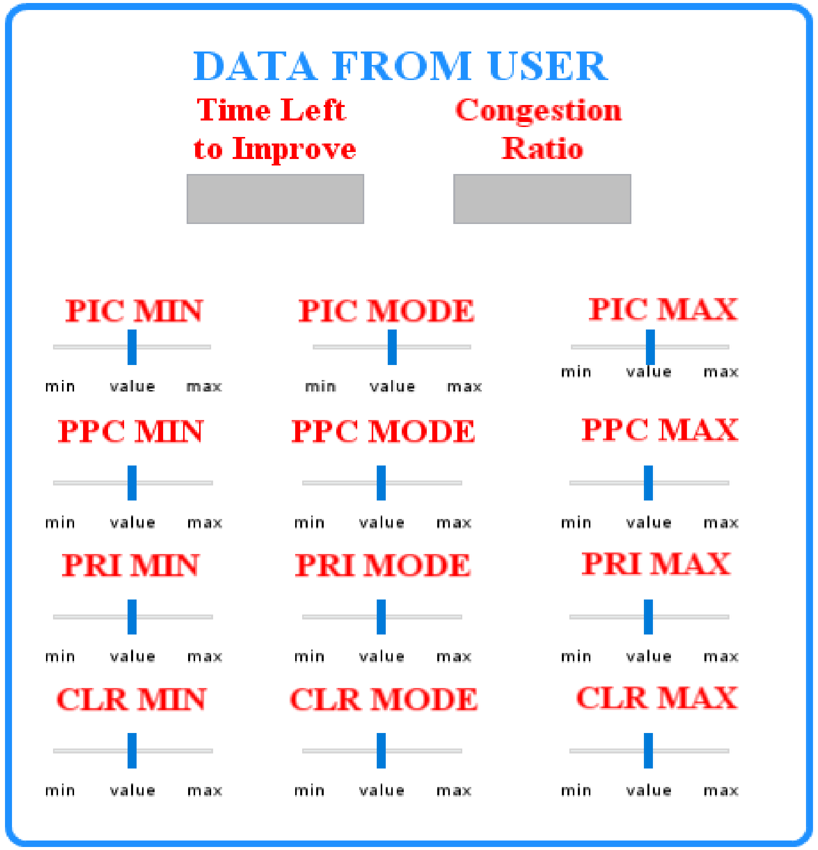


Figure 2 - User Dashboard

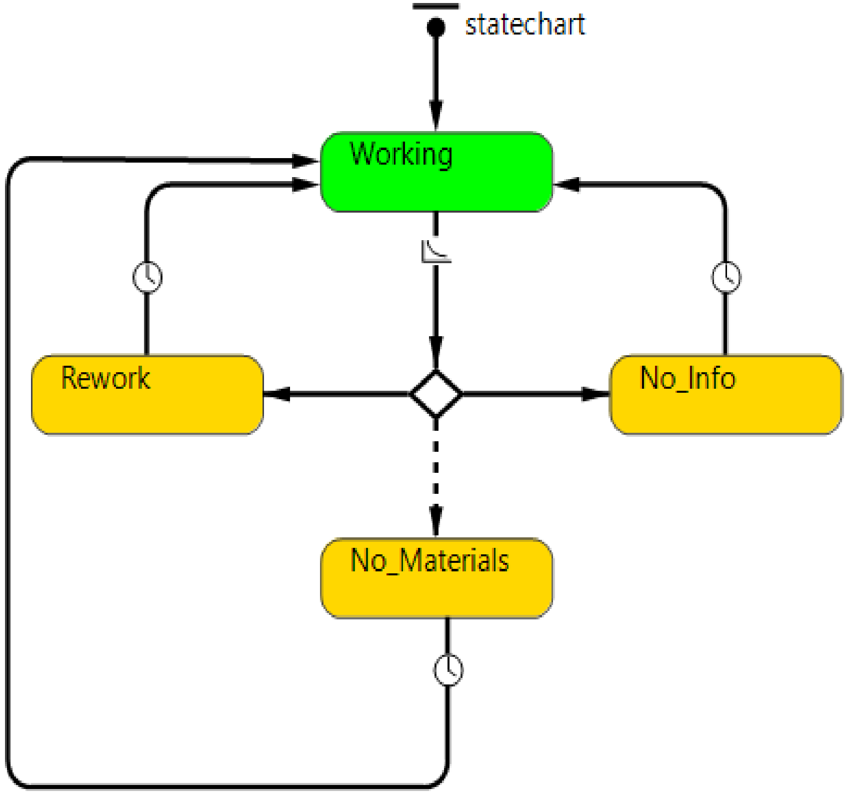


Figure 3 - Crew Statechart

Run the model

Calculate modified duration 1000 times

Convert each modified duration into a production rate

The “most likely” IPR is automatically calculated

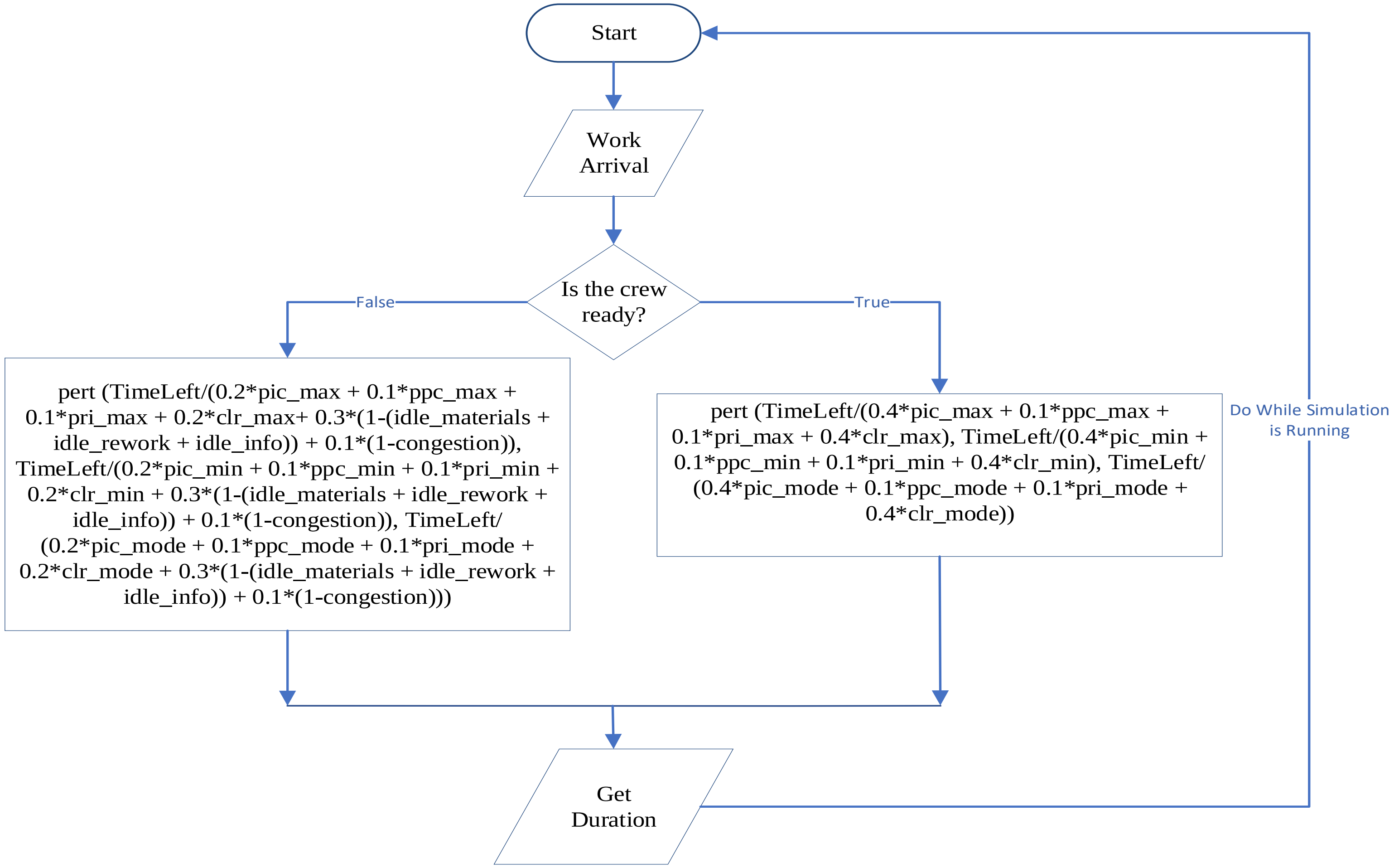


Figure 4 - Anylogic Flowchart

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

American University of Beirut

IGLC IRELAND 2019

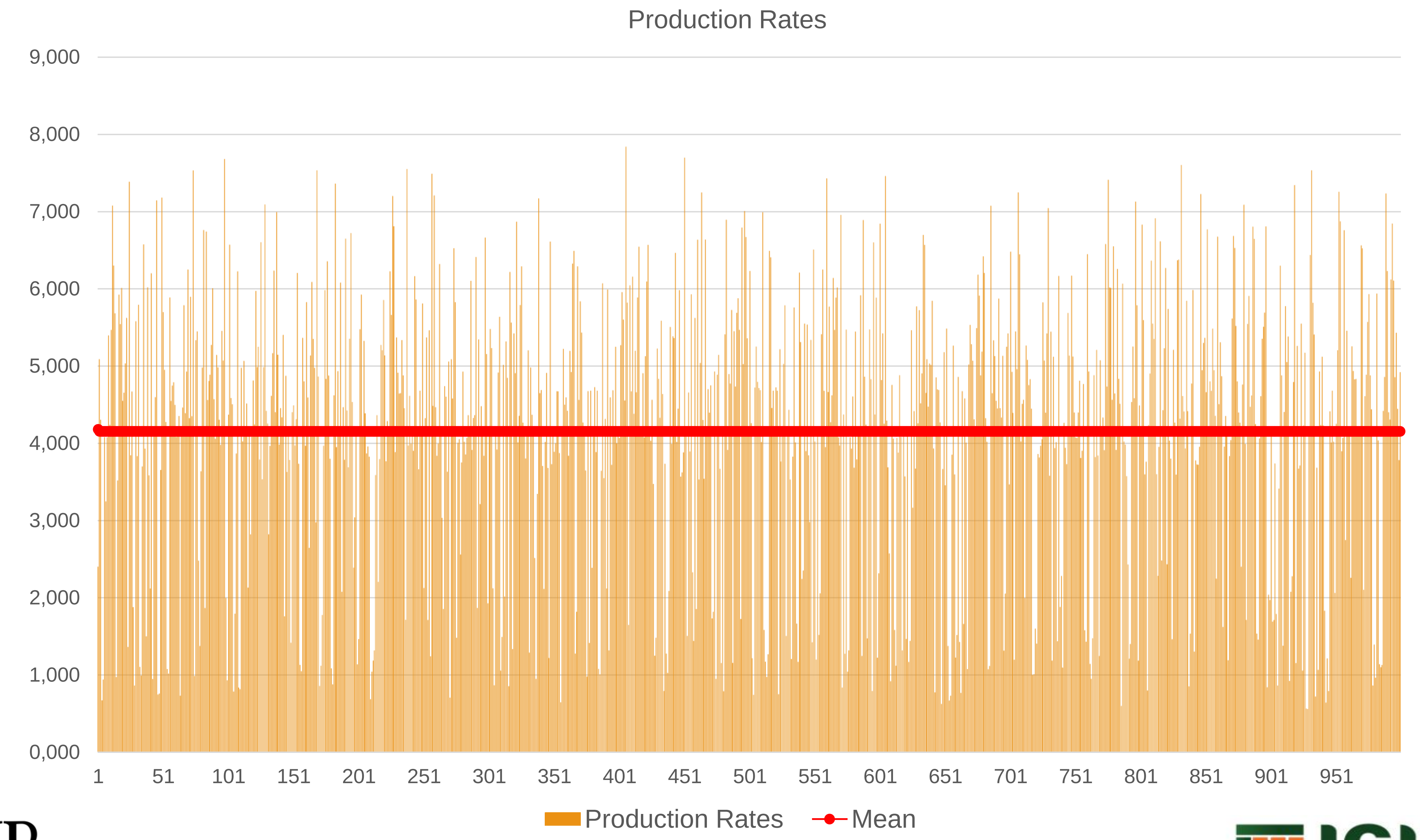
INTERNATIONAL GROUP FOR LEAN CONSTRUCTION

DUBLIN | IRELAND | 1ST - 7TH JULY 2019

Simulation Runs

Time left for improvement = 1 day

Experiment	Min. Metrics	Mode Metrics	Max. Metrics	Congestion	Mean Duration	Most Likely IPR
Good performance	0.7	0.9	1	0.2	1.65	6.84
Average performance	0.4	0.6	0.8	0.5	3.38	4.18
Bad performance	0.1	0.4	0.5	0.9	7.41	2.54


Production Rates
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0,000
1
51
101
151
201
251
301
351
401
451
501
551
601
651
701
751
801
851
901
951
Production Rates
Mean

Conclusion

Conclusion & Future Research

- 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

1866
AUB
American University of Beirut
الجامعة الأميركية في بيروت

IGLC
IRELAND 2019
INTERNATIONAL GROUP FOR LEAN CONSTRUCTION
DUBLIN | IRELAND | 1ST - 7TH JULY 2019