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PRODUCTION PROCESS EVALUATION FOR EARTHWORKS

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Background - Earthworks

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- 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

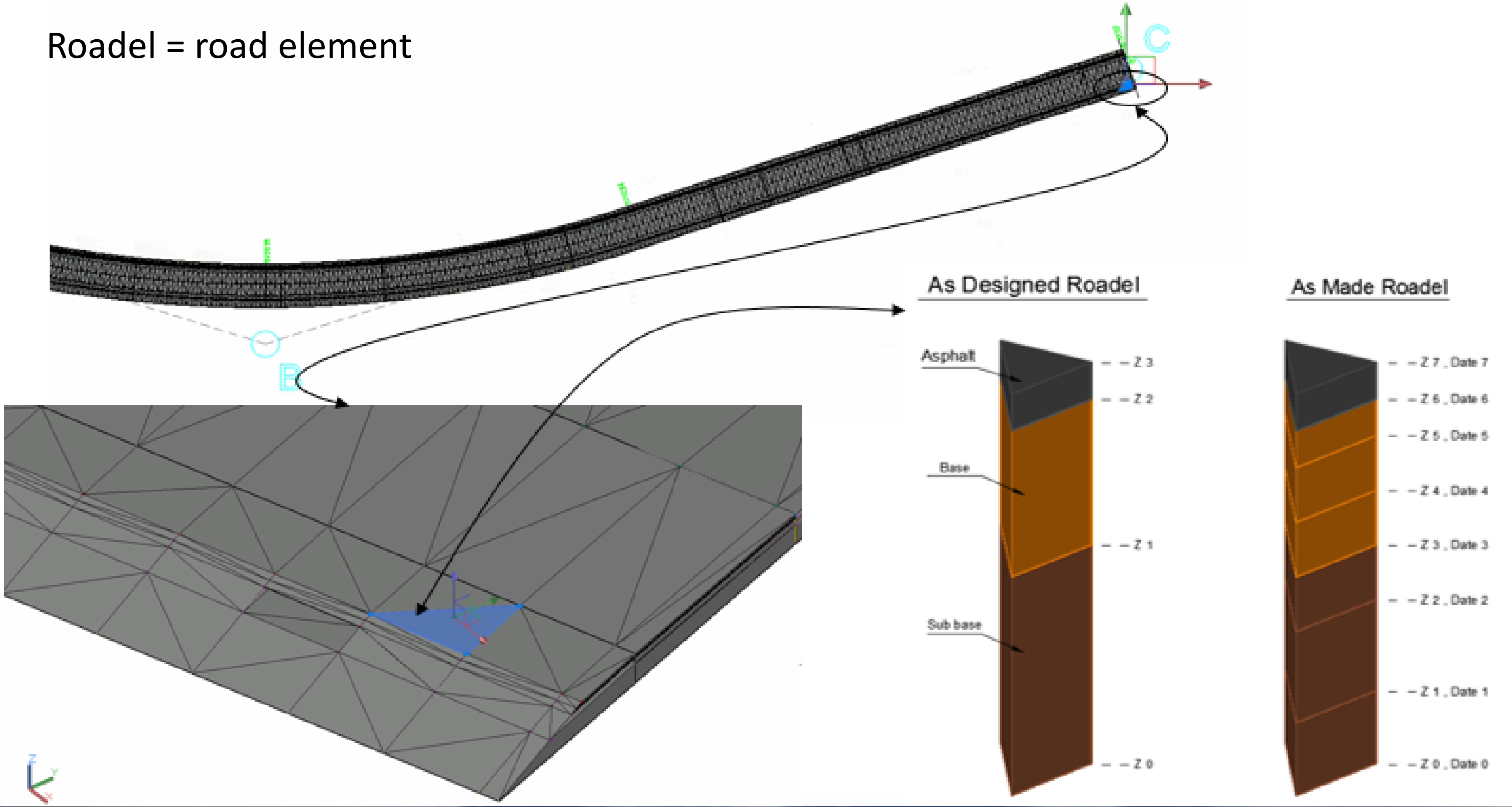
- Machine Control (MC) technology - 3D design, GNSS locations systems, and a set of sensors, enabling automation of operations
- How can we utilize the monitored data for process improvements and for production control?

Methodology

- Design Science Research
- Artifacts –
  - Product information schema (Haronian and Sacks, 2019)
  - Production evaluation procedure
- Validation – by case study

Roadel Information Schema

Roadel = road element



Case Study


Material Supply 4,375 [Products/hr]
Spread 3,500 [Products/hr] Actual Mean = 2,048 Actual Max = 3,172
Watering 16,000 [Products/hr]
Compact 4,900 [Products/hr]
Inspections: Surveyor and lab

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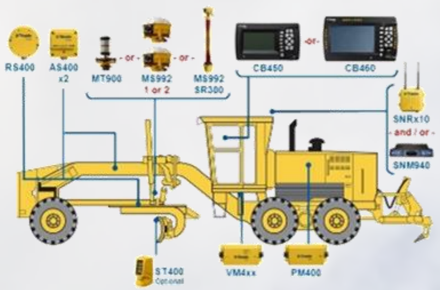
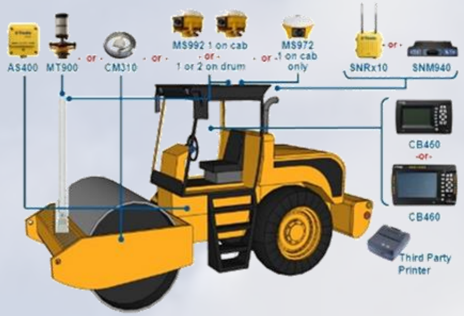
Data Monitoring

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





Waste Evaluation

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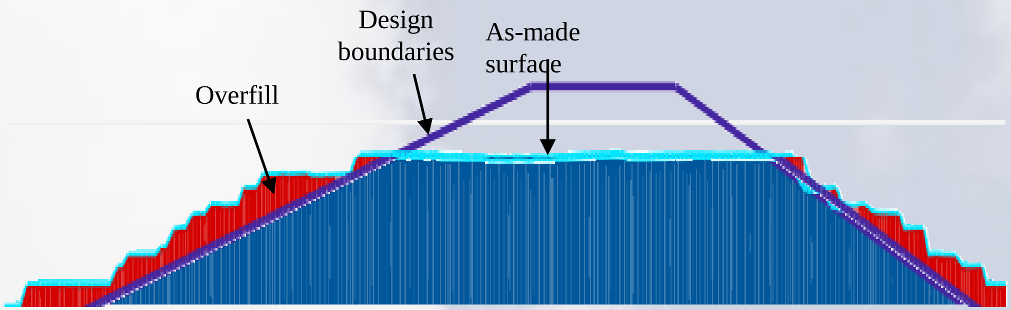
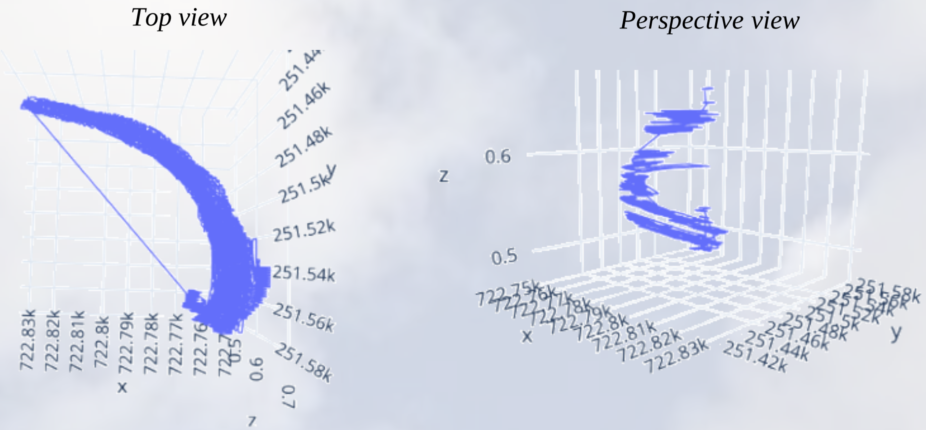
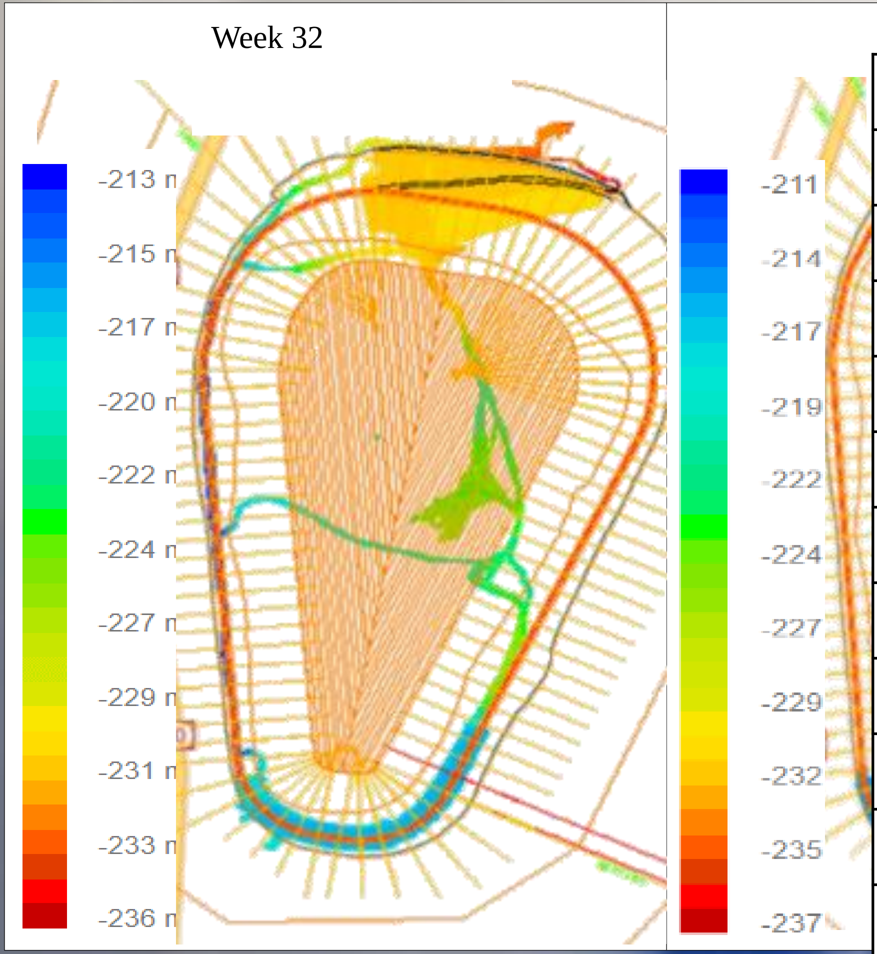
- Over-processing



- Resource Waiting Time



Results - Production Process Evaluation (PPE) Index



Week	32	35	37
Shift time [h:m]	122:00	122:00	122:00
Gross working time [h:m]	103:57	107:54	112:41
Waiting times in work packages [h:m]	55:11	35:08	35:25
Net processing times [h:m]	48:45	72:45	77:16
Over-processing time [h:m]	5:10	17:53	6:56
Value adding time [h:m]	43:35	54:51	70:19
Non-value adding time [h:m]	78:24	67:08	51:40
Production volume (Total fill) [m^3]	19,465	20,620	19,745
Over production (Over fill) [m^3]	2,062	5,073	1,773
Actual Production [m^3]	17,402	15,547	17,972
Theoretical Throughput [m^3/hr]	267	283	271
Production Process Evaluation [%]	53%	45%	54%

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

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- Throughput (TH)

$$\mathrm{P} = \sum_{1}^{\mathrm{n}} \frac{\left(\mathrm{h}_{\text{end shift,i}} - \mathrm{h}_{\text{start shift,i}}\right) * \mathrm{A}_{\mathrm{i}}}{\mathrm{d}_{\text{layer}}}$$

$$\mathrm{TH} = {}^{\mathrm{P}}/_{\mathrm{T}}$$

- Cycle time (CT)

$$CT = \frac{\sum_{1}^{n}\left(T_{end,i} - T_{start,i}\right)}{P}$$

- Work in progress (WIP)

$$WIP\ (t) = \sum_{1}^{n} \begin{Bmatrix} if\ \ T_{start,i} \leq t \leq T_{end,i} & \rightarrow & 1 \\ else & \rightarrow & 0 \end{Bmatrix}$$

- W_o, T_o, and r_b

Evaluation by Little's Law, and Factory Physics *(Hopp and Spearman 2008)*

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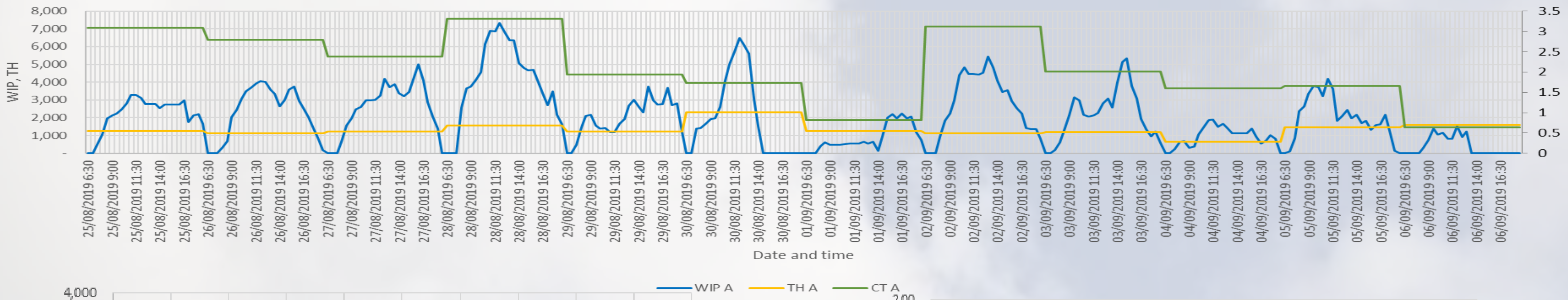
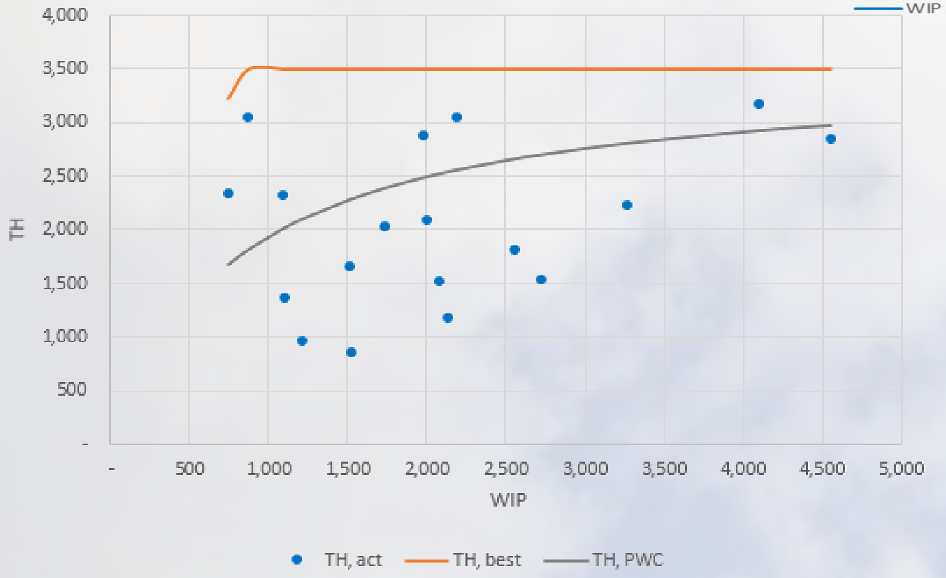
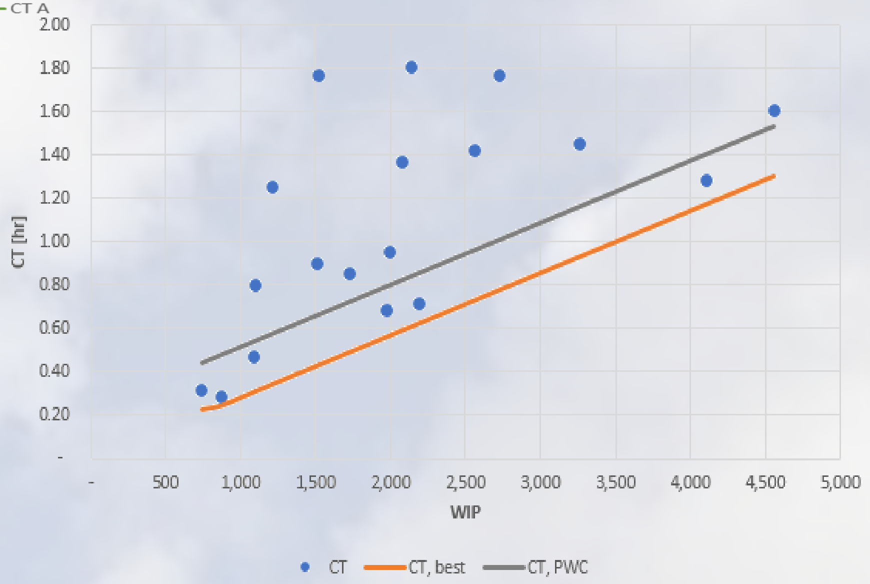






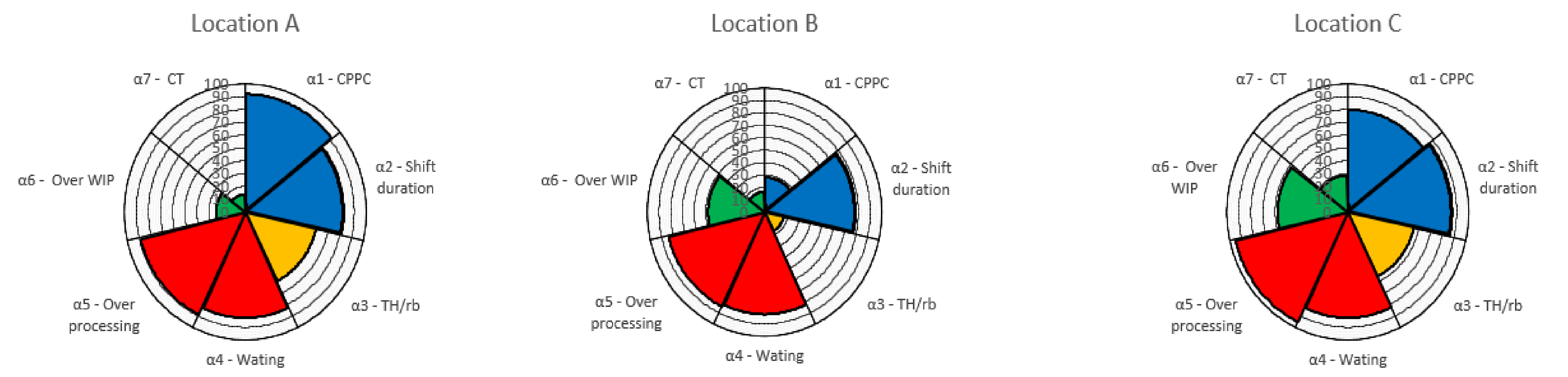
Production Metrics

Category	Metric	Calculation
Planning	α1 – CPPC	$\frac{Actual\ Production\ Volume}{Panned\ Peoduction\ Volume}$
Planning	α2 - Shift duration	$1 - \frac{\lvert Actual\ Shift\ Duration - Planned\ Shift\ Duration \rvert}{Planned\ Shift\ Duration}$
Productivity	α3 – Productivity	$\frac{actual\ TH}{r_b}$
Waste	α4 – Waiting times	$\frac{Actual\ Shift\ Duration - \mathrm{Waiting}\ Time}{Actual\ Shift\ Duration}$
Waste	α5 - Over processing	$\frac{Actual\ Production\ Volume - \mathrm{Overprocessing}}{Actual\ Production\ Volume}$
Flow	α6 - WIP	$\mathrm{WIP} > \mathrm{W}_0 \rightarrow \frac{\mathrm{W}_0}{\mathrm{WIP}}$
Flow	α7 - CT	$\mathrm{CT} > T_0 \rightarrow \frac{T_0}{\mathrm{CT}}$

Production Metrics

Four categories for evaluation, on location and daily resolution:

- **Planning reliability**
- **Productivity**
- **Waste**
- **Flow**



Conclusion

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- 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