UPDATE ON MATERIAL LOGISTIC CONCEPT
Simulation assumptions, processes and parameters. Preliminary results

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Content

Topics for today

1. Material flow simulation with Plant Simulation
2. Simulation assumptions, process and parameters
3. Result overview and analysis
4. Recommendations and next steps
Material flow simulation with Plant Simulation

Simulation procedure and simulation tool

Procedure of a material flow simulation study

Validation

Modelling

Process dynamics

Scenario experiments

Interpretation and evaluation

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Screenshot from Tecnomatix Plant Simulation 11
Assumptions for the simulation study

What are the circumstances for the simulation? (non-exhaustive list)

**General**
- Tunnel is handed over from civil engineering in a completed state
- Technical infrastructure is installed → ready to transport and install magnets
- During the time of magnet transport and installation there is no other traffic in the tunnel
- Each shaft for magnet transport is a separated system and not influenced by the other shafts

**Infrastructure**
- For each magnet shaft there is an overground storage area nearby to load the crane
- A limited number (tbd) of magnets can be stored at the bottom of the shaft
- Magnet transports access the installation front from the front and instalment teams from the back
- There is a limited number of enlargements in the tunnel so that vehicles can pass each other

**Process**
- Magnet transports are not allowed to pass positions where installation teams are working
- Collider ring and booster ring can be installed simultaneously
- Dipoles arrive in transport units of three
- Quadrupoles and sextupoles arrive preinstalled on a girder as a transport unit
Process for the simulation study

Which process steps are considered in the simulation?

- Retrieve vehicle to loading site
- Unload magnets
- Delivery of magnets to top of shaft // Blackbox //
- Retrieve crane Load magnets onto crane, lower down and unload
- Transfer magnets to trailer
- Transport vehicle loop (4 steps)
- Transport of magnets to drop off point
- Align / connect magnets (generic)
Parameters for the simulation study

What information is the simulation based on?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Information maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of tunnel</td>
<td>91200 m</td>
<td>Given by CERN</td>
</tr>
<tr>
<td>Enlargements for transport passing</td>
<td>16 overall (8 shafts + 8 enlargements)</td>
<td>Given by CERN</td>
</tr>
<tr>
<td>No. of magnets overall</td>
<td>8832 (2944 half cells with 2 dipoles + 1 girder)</td>
<td>Given by CERN</td>
</tr>
<tr>
<td>Load crane, lower down magnet and retrieve crane</td>
<td>90 min</td>
<td>Rough guess by CERN</td>
</tr>
<tr>
<td>Magnet transfer time from crane to vehicle and enter tunnel</td>
<td>50 min</td>
<td>Estimated by IML</td>
</tr>
<tr>
<td>Unloading time vehicle</td>
<td>23 min</td>
<td>Estimated by IML</td>
</tr>
<tr>
<td>Vehicle driving velocity loaded</td>
<td>10 km/h</td>
<td>Estimate by IML / design value</td>
</tr>
<tr>
<td>Vehicle driving velocity unloaded</td>
<td>20 km/h</td>
<td>Estimate by IML / design value</td>
</tr>
<tr>
<td>Aligning and connecting time per magnet / girder</td>
<td>4 h</td>
<td>Rough guess by IML</td>
</tr>
<tr>
<td>No. of installation teams per magnet shaft</td>
<td>4 teams</td>
<td>Variable in further experiments</td>
</tr>
<tr>
<td>Underground buffer capacity for magnets at shaft</td>
<td>2 transport units</td>
<td>Variable in further experiments</td>
</tr>
<tr>
<td>No. of shafts for magnet transport</td>
<td>2 or 4 shafts</td>
<td>Variable</td>
</tr>
<tr>
<td>No. of vehicles operating per shaft</td>
<td>2 or 4 vehicles</td>
<td>Variable</td>
</tr>
</tbody>
</table>
Result overview

Key data at a glance

<table>
<thead>
<tr>
<th>Summary</th>
<th>Scenario</th>
<th>2s2v</th>
<th>2s4v</th>
<th>4s2v</th>
<th>4s4v</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>KPI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall simulation time [h]</td>
<td>5928*</td>
<td>5496*</td>
<td>2760*</td>
<td>2760*</td>
<td></td>
</tr>
<tr>
<td>Magnet transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport time [h]</td>
<td>5424</td>
<td>4584</td>
<td>2304</td>
<td>2280</td>
<td></td>
</tr>
<tr>
<td>Magnets transported per day and shaft</td>
<td>20</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Magnet aligning and connecting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aligning and connecting time [h]</td>
<td>5904*</td>
<td>5472*</td>
<td>2736*</td>
<td>2736*</td>
<td></td>
</tr>
<tr>
<td>Magnets aligned and connected per day and shaft</td>
<td>18*</td>
<td>19*</td>
<td>19*</td>
<td>19*</td>
<td></td>
</tr>
<tr>
<td>Transporters waiting at shaft for crane with magnet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of times waiting for magnet</td>
<td>865</td>
<td>2440</td>
<td>865</td>
<td>1223</td>
<td></td>
</tr>
<tr>
<td>Avg waiting for crane time [hh:mm:ss]</td>
<td>0:51:00</td>
<td>1:17:27</td>
<td>0:51:27</td>
<td>1:25:07</td>
<td></td>
</tr>
<tr>
<td>Transporter waiting for other transporters to pass by</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of encounters</td>
<td>0</td>
<td>2449</td>
<td>0</td>
<td>1221</td>
<td></td>
</tr>
<tr>
<td>Accumulated total encounter waiting time [hh:mm:ss]</td>
<td>0:00:00</td>
<td>2664:00:52</td>
<td>0:00:00</td>
<td>1866:18:18</td>
<td></td>
</tr>
<tr>
<td>Avg encounter waiting time [hh:mm:ss]</td>
<td>0:00:00</td>
<td>1:05:21</td>
<td>0:00:00</td>
<td>1:31:56</td>
<td></td>
</tr>
</tbody>
</table>

Important notes
- The results are pure absolute values and don't include a contingency margin.
- Data basis and therefore results for magnet alignment and connecting time are not sufficient yet (marked with *)

s = shafts
v = vehicles per shaft
Result key learnings

Scenario similarities

- For all scenarios, lowering down the magnets into the shaft via crane is the bottle neck of the process, to be seen in:
  - High waiting time of transporters at the shaft
  - Magnet transport frequency is as high as magnet lowering frequency
  - Low underground buffer utilization

- Underground buffer is only needed in the beginning
Result key learnings

Scenario differences - focus on 2s4v and 4s2v

- In terms of magnet transport frequency 2s4v and 4s2v are equal, however, due to twice as much magnet access shafts, 4s2v (2760 hours) is twice as fast as 2s4v (5496 hours) → about 4 months
- In 4s2v, transporters have a higher utilization due to less waiting time for magnets and other transporters → about a third of the waiting time in 2s4v
- Using more than 2 vehicles in a 4-shaft setting has no effect due to the crane already working on its limit
- 4s2v is more resilient to crane failure

No. of units in underground buffer over time (4s2v)
Recommendations

What actions do we recommend

1. Trade-off between time and resilience vs. costs to decide whether to use 2 magnet shafts or 4.

2. Validate crane times and explore possibilities to increase the frequency of lowering down the magnets into the shaft.

3. Reserve space for a small magnet buffer (2–4 units) at the bottom of the shaft.

- Is it worth preparing two additional shafts for lowering the magnets and doubling the number of vehicles to halve the total transport time and be more resilient to crane failure?
- Being the bottleneck, reducing the crane time can have a significant effect on the overall transport time (to be tested).
- This might be even more important, if it is possible to increase the crane speed (to be tested).
Further experiments

**Next potential steps for exploration** (non-exhaustive list)

- Include mature information on magnet alignment and connection
- Add transport of further material (technical infrastructure etc.) to simulation
- Fine tune parameters and do further experiments with different parameters (in general)
- Set the number of alignment and connection teams
- Quantify the potential of improvement for faster crane time
- Check how crane failure affects the overall duration
- Review the importance of the underground buffer with different crane times
- ...
Thank you for your attention
Appendix A

Full list of assumptions for the simulation study

- Tunnel is handed over from civil engineering in a completed state
- Technical infrastructure is installed → ready to transport and install magnets
- Cooling and ventilation
- Marking
- Cabling
- Alignment jacks and supporting structure / racks
- Quadrupoles and sextupoles arrive preinstalled and aligned on a girder and represent one transport unit
- One girder at a time can be transported (crane and vehicle)
- Three dipoles at a time can be transported as one unit (on crane and vehicle) → three dipoles = dipole pack
- Handling, loading and transferring times of girder and dipole pack don’t differ
- Dipole pack will be unloaded by one dipole at a time, resulting in three times the unloading time for a dipole pack in comparison to the girder
- During the time of transport and installation of the magnets there is no other traffic in the tunnel
- A limited number (tbd) of dipole packs and girders can be stored underground at the bottom of the shaft to keep the crane running
- 2 or 4 shafts are access points for magnets
- All 8 shafts are access points for people
- Magnet transports are not allowed to pass positions where installation teams are working on aligning and connecting the magnets
- Magnet transport and people transports can drive next to installed collider and booster ring
- Girder and dipole packs can be transported with the same type of trailer
- Loaded transporters have the right of way -> good assumption? Maybe adjust simulation
- Collider ring and booster ring can be installed simultaneously
- For each shaft there is a overground storage area nearby to directly load the crane from there
- Each shaft for magnet transport is a separated system and not influenced by the transporters of other shafts