2024 Winter Simulation Conference

SIMULATING THE ECONOMICS OF AUTONOMOUS HAULAGE FOR MINING TRUCKS

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MINE TWIN

Introductions

Dr Andrey Malykhanov
CEO, Amalgama Software Design

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35 simulation & scheduling projects,
7 TOC (Theory of Constraints) implementations,
10+ years of experience in simulation and business consulting

Jaco-Ben Vosloo
Simulation Expert, MineTwin

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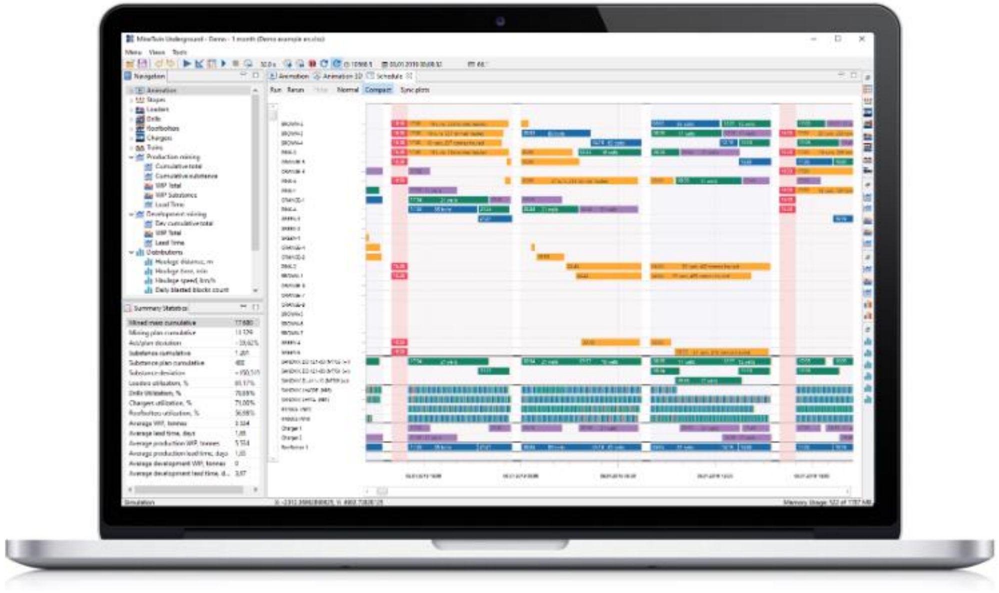
Supply chain and production simulation projects
10+ years of experience in simulation and business consulting

Presentation agenda

1. Stakeholder overview
2. Project background
3. Open pit mine haulage system
4. Simulation study design
5. Model demonstration
6. Optimal fleet composition analysis
7. Impact of pit depth
8. Net Present Value (NPV) results
9. Benefits of using MineTwin



MINE TWIN

1. Introductions of Key stakeholders

PRONTO

Pronto delivers off-road autonomous haulage systems (AHS) specifically engineered for a variety of rugged environments.

Wanted research study to test the financial and operational impact of small autonomous vs big manned mining trucks.

https://pronto.ai/

Whittle Consulting

Whittle's Integrated Strategic Planning is an approach to long-term mine planning which considers all parts of the value chain simultaneously.

Required detailed simulation modeling to accurately calculate the NPV for the research study.

https://www.whittleconsulting.com.au/

MINE TWIN

MineTwin is a detailed discrete-event simulation modeling tool used to simulate open-pit and underground mines.

MineTwin provided the fleet sensitivity analysis features to determine optimum loader to truck configurations for each truck loader combination.

https://mine-twin.com/

2. Background: Medium Manned vs Small Autonomous Trucks

Truck type	CAT-777E
Truck load	100 t
Excavator type	CAT-6020B
Shovel size	33 t

Manned

Autonomous

Truck type	Scania G460
Truck load	40 t
Excavator type	Hitachi ZX870
Shovel size	14 t

- \+ More efficient transportation
- \+ Less congestion
- \- Human factors delays
- \- Uneven trucks speed → swarming
- \- Greater impact of single unit failures

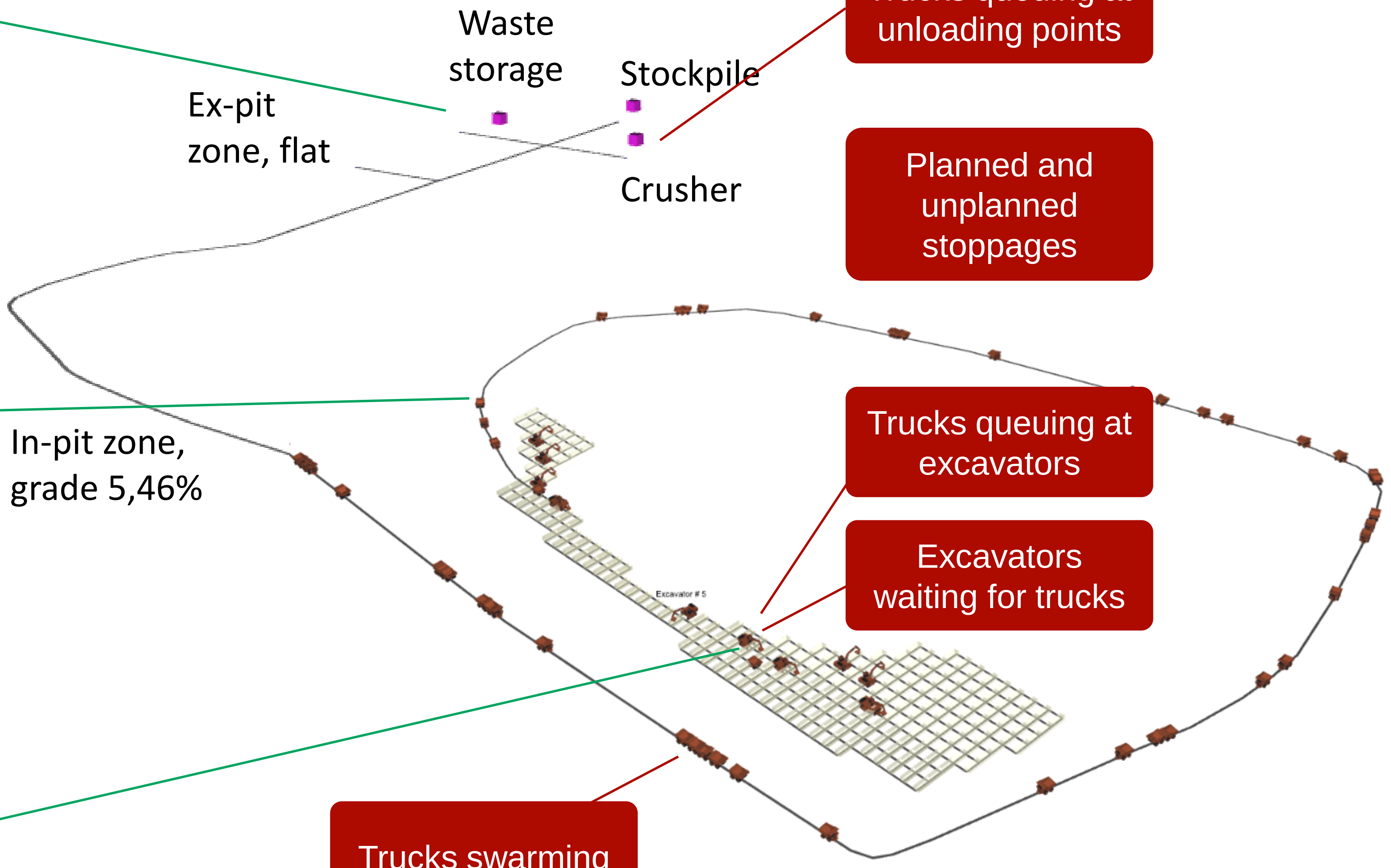
- \+ Uniform speed → no swarming
- \+ Less human factors delays
- \- More excavators
- \- More congestion
- \- Expenses for autonomous equipment

3. Open Pit Mine Haulage System

Trucks unload the ore at one of destinations depending on grade

Trucks move the ore from pit to surface and return back to load

Excavators scoop the ore and load the trucks



Trucks queuing at unloading points

Planned and unplanned stoppages

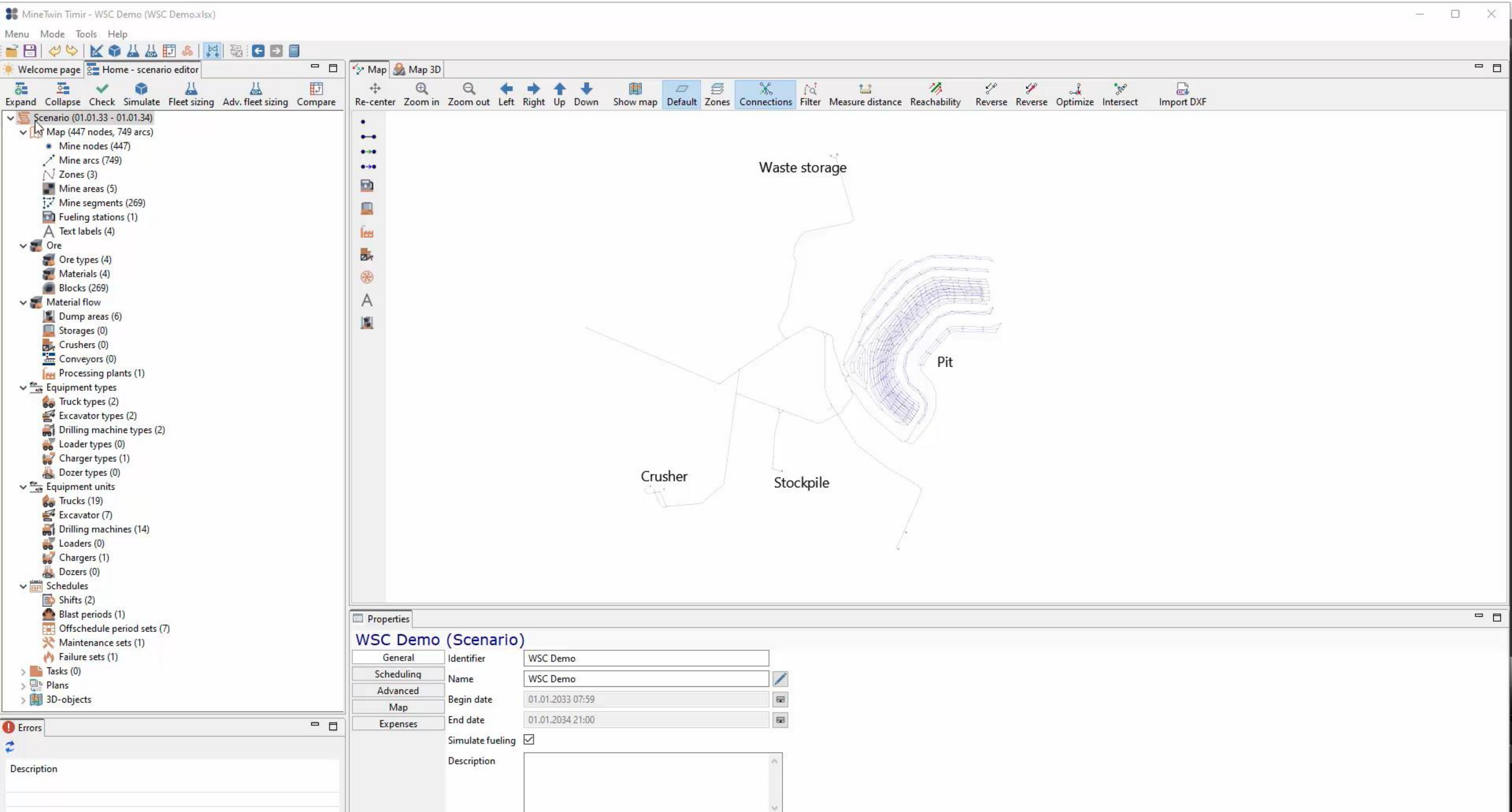
Trucks queuing at excavators

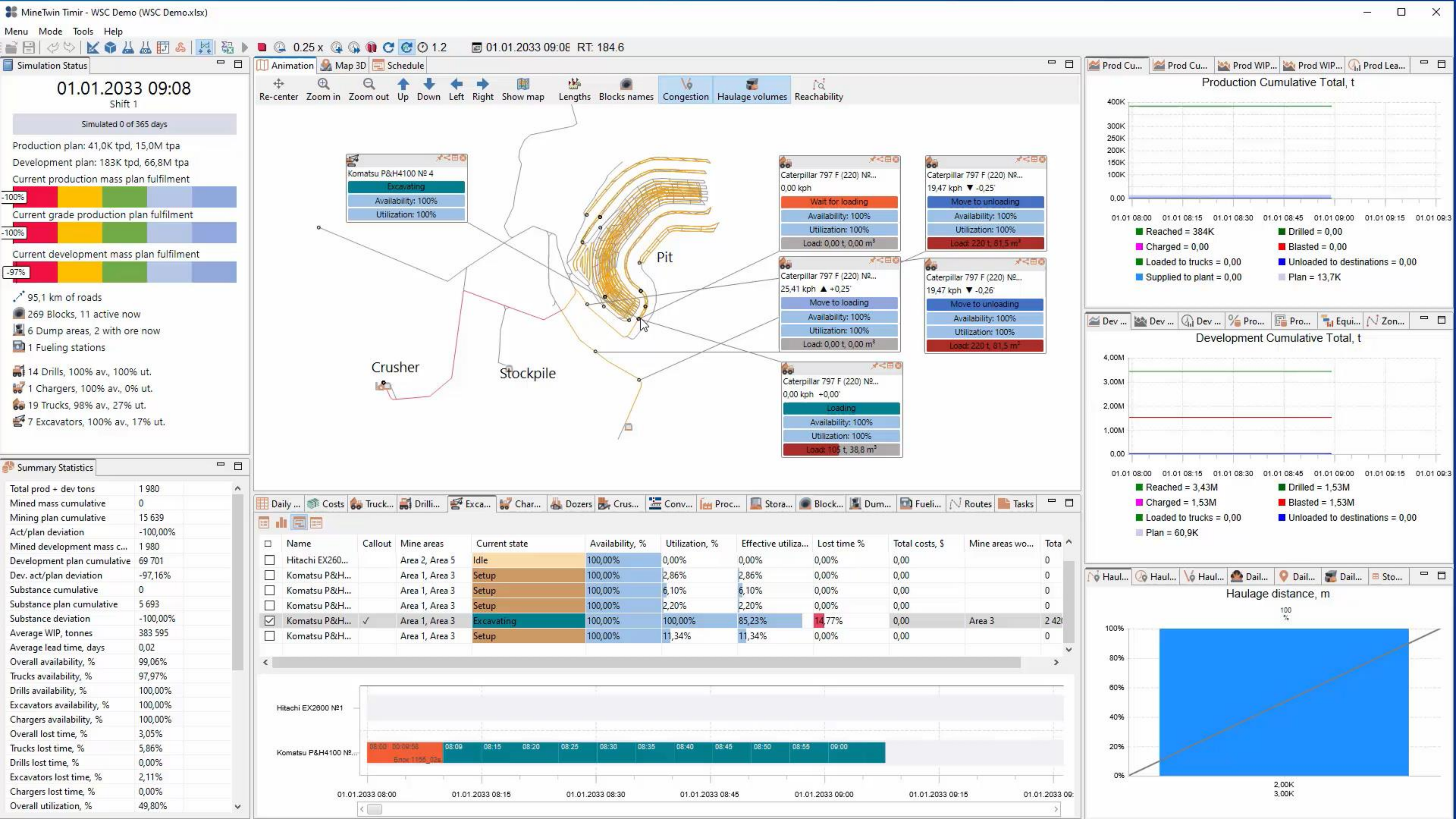
Excavators waiting for trucks

Trucks swarming

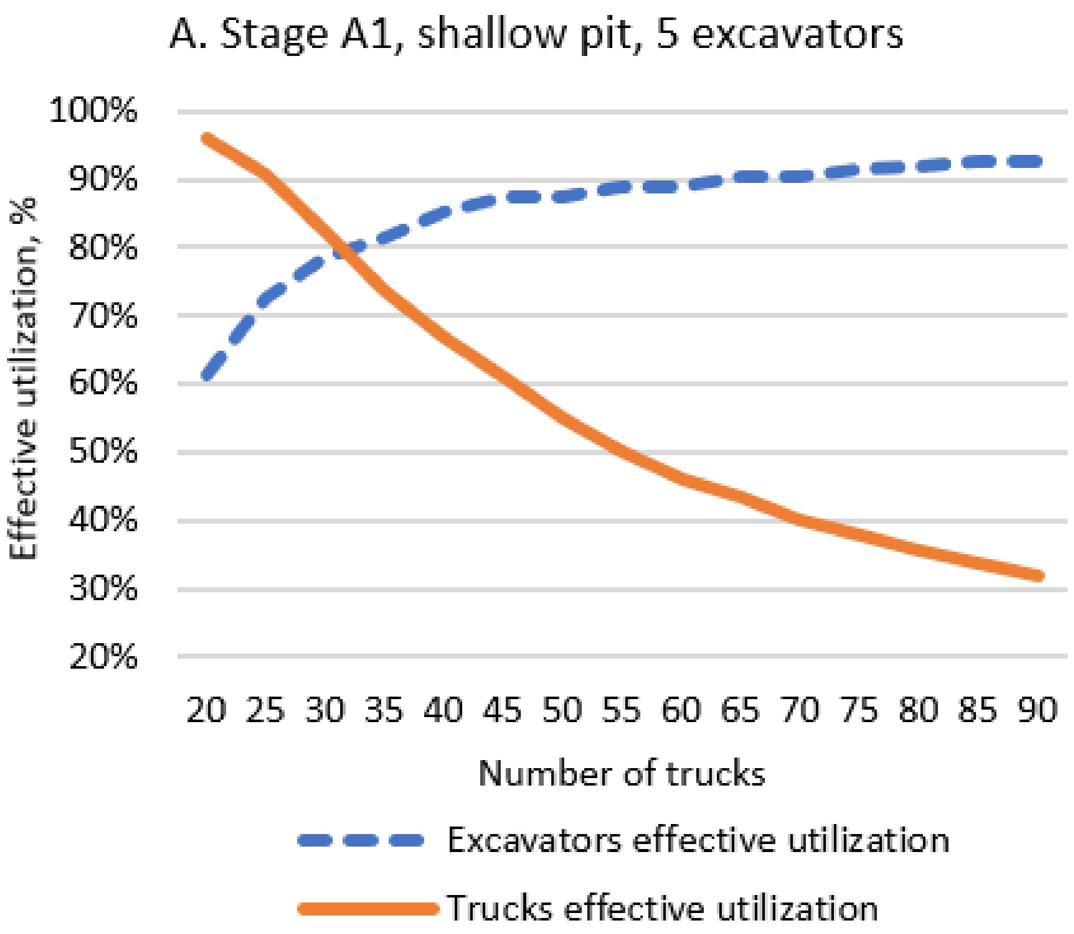
Simulation Study Design

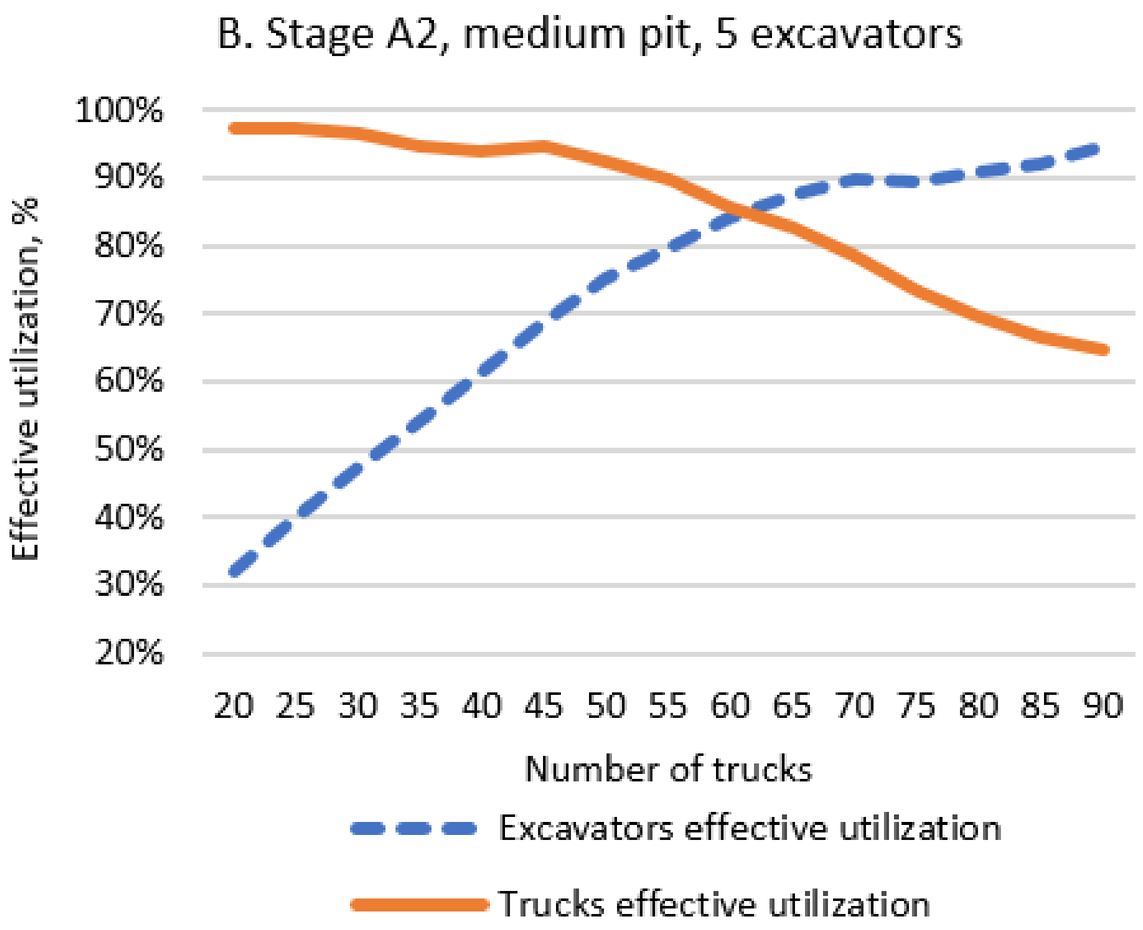
1. Took a sample ore body with drill-and-blast open pit mining technology
   - North American setting
   - Simple resource model – copper
   - 3 destinations – stockpile, crusher, waste storage
2. Considered 3 stages of mining
   - Shallow pit, 20-68 meters deep
   - Medium pit, 116-196 meters deep
   - Deep pit, 244-324 meters deep
3. For every stage, fixed the haulage rate (tons moved per day)
   - Haulage rate was calculated in Geovia Whittle software
4. Ran 924 experiments in MineTwin to calculate the required number of trucks and excavators
   - 4 fleet types (100t, 40t) x (manned, autonomous)
   - 3 stages
   - Varied number of trucks and excavators for every fleet type and stage
5. Calculated NPV for each option externally in Excel


MineTwin Timir - WSC Demo (WSC Demo.xlsx)
Menu
Mode
Tools
Help
Welcome page
Home - scenario editor
Expand
Collapse
Check
Simulate
Fleet sizing
Adv. fleet sizing
Compare
Scenario (01.01.33 - 01.01.34)
Map (447 nodes, 749 arcs)
Mine nodes (447)
Mine arcs (749)
Zones (3)
Mine areas (5)
Mine segments (269)
Fueling stations (1)
Text labels (4)
Ore
Ore types (4)
Materials (4)
Blocks (269)
Material flow
Dump areas (6)
Storages (0)
Crushers (0)
Conveyors (0)
Processing plants (1)
Equipment types
Truck types (2)
Excavator types (2)
Drilling machine types (2)
Loader types (0)
Charger types (1)
Dozer types (0)
Equipment units
Trucks (19)
Excavator (7)
Drilling machines (14)
Loaders (0)
Chargers (1)
Dozers (0)
Schedules
Shifts (2)
Blast periods (1)
Offschedule period sets (7)
Maintenance sets (1)
Failure sets (1)
Tasks (0)
Plans
3D-objects
Errors
Description
Map
Map 3D
Re-center
Zoom in
Zoom out
Left
Right
Up
Down
Show map
Default
Zones
Connections
Filter
Measure distance
Reachability
Reverse
Reverse
Optimize
Intersect
Import DXF
Waste storage
Pit
Crusher
Stockpile
Properties
WSC Demo (Scenario)
General
Scheduling
Advanced
Map
Expenses
Identifier
WSC Demo
Name
WSC Demo
Begin date
01.01.2033 07:59
End date
01.01.2034 21:00
Simulate fueling
Description


MineTwin Timir - WSC Demo (WSC Demo.xlsx)
Menu Mode Tools Help
0.25 x
1.2
01.01.2033 09:08 RT: 184.6
Simulation Status
01.01.2033 09:08
Shift 1
Simulated 0 of 365 days
Production plan: 41,0K tpd, 15,0M tpa
Development plan: 183K tpd, 66,8M tpa
Current production mass plan fulfilment
-100%
Current grade production plan fulfilment
-100%
Current development mass plan fulfilment
-97%
95,1 km of roads
269 Blocks, 11 active now
6 Dump areas, 2 with ore now
1 Fueling stations
14 Drills, 100% av., 100% ut.
1 Chargers, 100% av., 0% ut.
19 Trucks, 98% av., 27% ut.
7 Excavators, 100% av., 17% ut.
Summary Statistics
Total prod + dev tons 1 980
Mined mass cumulative 0
Mining plan cumulative 15 639
Act/plan deviation -100,00%
Mined development mass c... 1 980
Development plan cumulative 69 701
Dev. act/plan deviation -97,16%
Substance cumulative 0
Substance plan cumulative 5 693
Substance deviation -100,00%
Average WIP, tonnes 383 595
Average lead time, days 0,02
Overall availability, % 99,06%
Trucks availability, % 97,97%
Drills availability, % 100,00%
Excavators availability, % 100,00%
Chargers availability, % 100,00%
Overall lost time, % 3,05%
Trucks lost time, % 5,86%
Drills lost time, % 0,00%
Excavators lost time, % 2,11%
Chargers lost time, % 0,00%
Overall utilization, % 49,80%
Animation Map 3D Schedule
Re-center Zoom in Zoom out Up Down Left Right Show map Lengths Blocks names Congestion Haulage volumes Reachability
Komatsu P&H4100 № 4
Excavating
Availability: 100%
Utilization: 100%
Caterpillar 797 F (220) №...
0,00 kph
Wait for loading
Availability: 100%
Utilization: 100%
Load: 0,00 t, 0,00 m³
Caterpillar 797 F (220) №...
19,47 kph ▼ -0,25'
Move to unloading
Availability: 100%
Utilization: 100%
Load: 220 t, 81,5 m³
Caterpillar 797 F (220) №...
25,41 kph ▲ +0,25'
Move to loading
Availability: 100%
Utilization: 100%
Load: 0,00 t, 0,00 m³
Caterpillar 797 F (220) №...
19,47 kph ▼ -0,26'
Move to unloading
Availability: 100%
Utilization: 100%
Load: 220 t, 81,5 m³
Caterpillar 797 F (220) №...
0,00 kph +0,00'
Loading
Availability: 100%
Utilization: 100%
Load: 105 t, 38,8 m³
Pit
Crusher
Stockpile
Daily ... Costs Truck... Drilli... Exca... Char... Dozers Crus... Conv... Proc... Stora... Block... Dum... Fueli... Routes Tasks
Name | Callout | Mine areas | Current state | Availability, % | Utilization, % | Effective utiliza... | Lost time % | Total costs, $ | Mine areas wo... | Tota
Hitachi EX260... | | Area 2, Area 5 | Idle | 100,00% | 0,00% | 0,00% | 0,00% | 0,00 | | 0
Komatsu P&H... | | Area 1, Area 3 | Setup | 100,00% | 2,86% | 2,86% | 0,00% | 0,00 | | 0
Komatsu P&H... | | Area 1, Area 3 | Setup | 100,00% | 6,10% | 6,10% | 0,00% | 0,00 | | 0
Komatsu P&H... | | Area 1, Area 3 | Setup | 100,00% | 2,20% | 2,20% | 0,00% | 0,00 | | 0
Komatsu P&H... | ✓ | Area 1, Area 3 | Excavating | 100,00% | 100,00% | 85,23% | 14,77% | 0,00 | Area 3 | 2 42
Komatsu P&H... | | Area 1, Area 3 | Setup | 100,00% | 11,34% | 11,34% | 0,00% | 0,00 | | 0
Hitachi EX2600 №1
Komatsu P&H4100 №...
08:09 08:15 08:20 08:25 08:30 08:35 08:40 08:45 08:50 08:55 09:00
01.01.2033 08:00 01.01.2033 08:15 01.01.2033 08:30 01.01.2033 08:45 01.01.2033 09:00 01.01.2033 09:15
Prod Cu... Prod Cu... Prod WIP... Prod WIP... Prod Lea...
Production Cumulative Total, t
400K 300K 250K 200K 150K 100K 0,00
01.01 08:00 01.01 08:15 01.01 08:30 01.01 08:45 01.01 09:00 01.01 09:15
Reached = 384K
Drilled = 0,00
Charged = 0,00
Blasted = 0,00
Loaded to trucks = 0,00
Unloaded to destinations = 0,00
Supplied to plant = 0,00
Plan = 13,7K
Dev ... Dev ... Dev ... Pro... Pro... Equi... Zon...
Development Cumulative Total, t
4,00M 3,00M 2,00M 1,00M 0,00
01.01 08:00 01.01 08:15 01.01 08:30 01.01 08:45 01.01 09:00 01.01 09:15
Reached = 3,43M
Drilled = 1,53M
Charged = 1,53M
Blasted = 1,53M
Loaded to trucks = 0,00
Unloaded to destinations = 0,00
Plan = 60,9K
Haul... Haul... Haul... Dail... Dail... Dail... Sto...
Haulage distance, m
100 %
100% 80% 60% 40% 20% 0%
2,00K
3,00K

6. Optimal Fleet Composition Changes Analysis





All plots and charts are for 40t autonomous trucks

7. In Deeper Pits, The System Gets More Truck-Constrained

Shallow pit, 20m

Trucks effective utilization + excavators' effective utilization

Number of excavators \ Number of trucks	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
2	137%	124%	120%	117%	118%	113%	111%	110%	111%	109%	109%	109%	109%	107%	107%
3	160%	145%	135%	130%	129%	123%	119%	119%	118%	116%	116%	114%	111%	112%	111%
4	180%	168%	157%	149%	141%	136%	132%	129%	125%	125%	123%	117%	119%	117%	117%
5	171%	176%	169%	157%	151%	143%	138%	136%	131%	130%	127%	125%	122%	120%	120%
6	160%	171%	178%	169%	161%	153%	148%	145%	140%	135%	134%	131%	130%	126%	126%
7	153%	164%	172%	180%	172%	166%	160%	154%	147%	145%	140%	139%	135%	133%	132%
8	145%	157%	166%	172%	181%	173%	169%	162%	156%	153%	148%	145%	141%	138%	136%
9	141%	151%	160%	169%	173%	180%	175%	170%	164%	161%	156%	152%	148%	145%	142%
10	137%	146%	155%	163%	170%	173%	180%	175%	174%	168%	164%	159%	155%	151%	147%

Reached target haulage rate

Exceeded target haulage rate

Medium pit, 196m

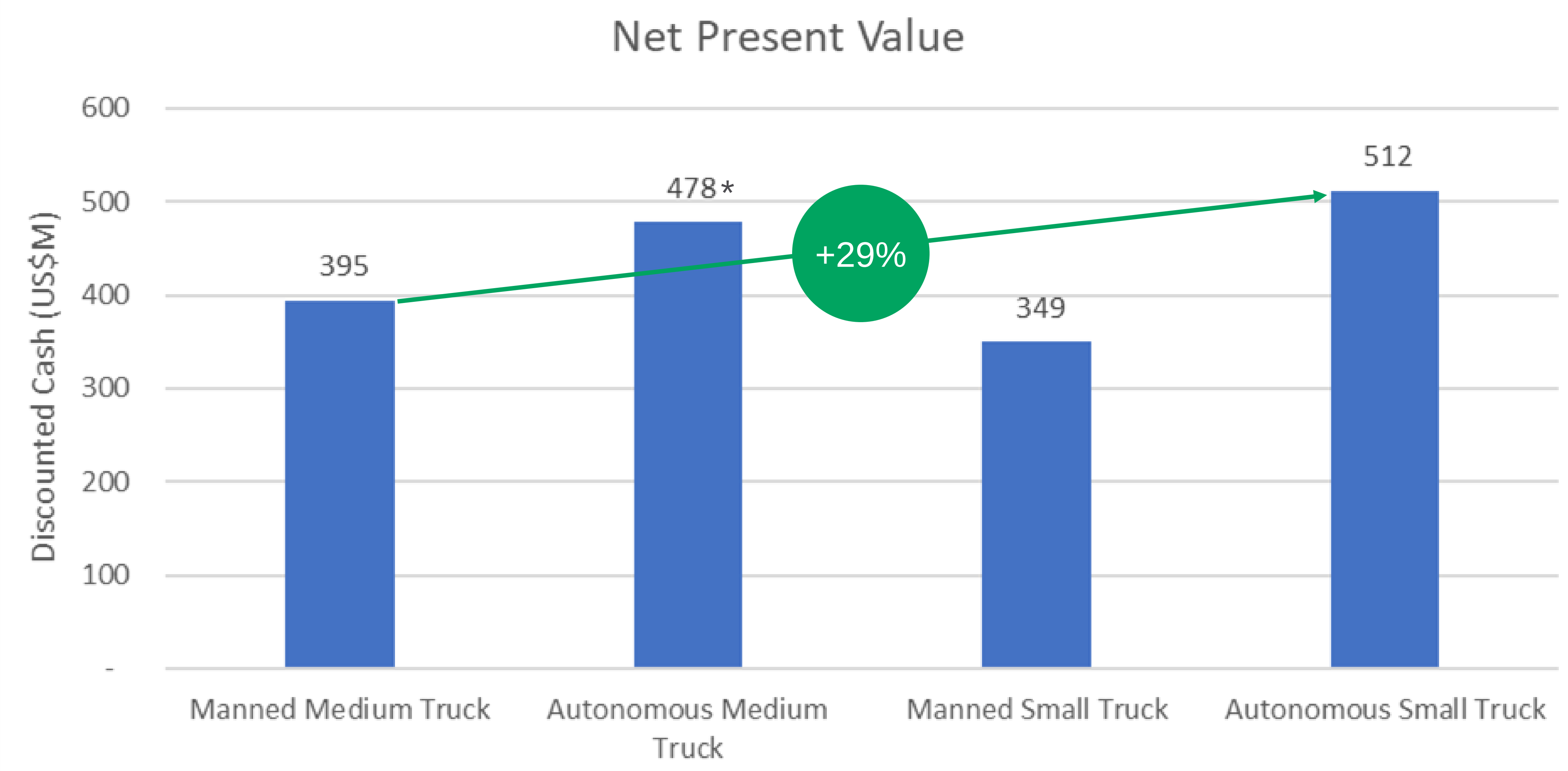
Trucks effective utilization + excavators' effective utilization

Number of excavators \ Number of trucks	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
2	180%	169%	160%	152%	145%	140%	137%	133%	130%	128%	126%	124%	123%	121%	120%
3	161%	176%	182%	178%	167%	160%	154%	149%	145%	142%	139%	137%	134%	133%	131%
4	146%	157%	166%	177%	183%	178%	173%	165%	161%	157%	153%	150%	146%	143%	141%
5	137%	146%	155%	162%	171%	178%	182%	178%	176%	169%	165%	162%	158%	154%	151%
6	131%	139%	144%	154%	162%	166%	176%	179%	181%	180%	176%	171%	166%	165%	162%
7	127%	133%	140%	147%	153%	160%	167%	172%	174%	178%	183%	180%	178%	174%	170%
8	123%	130%	135%	141%	146%	152%	158%	162%	169%	175%	178%	181%	180%	183%	181%
9	121%	126%	131%	136%	142%	146%	151%	157%	161%	164%	169%	175%	178%	181%	183%
10	119%	124%	128%	132%	137%	142%	146%	152%	156%	160%	165%	167%	172%	176%	180%

Reached target haulage rate

Exceeded target haulage rate

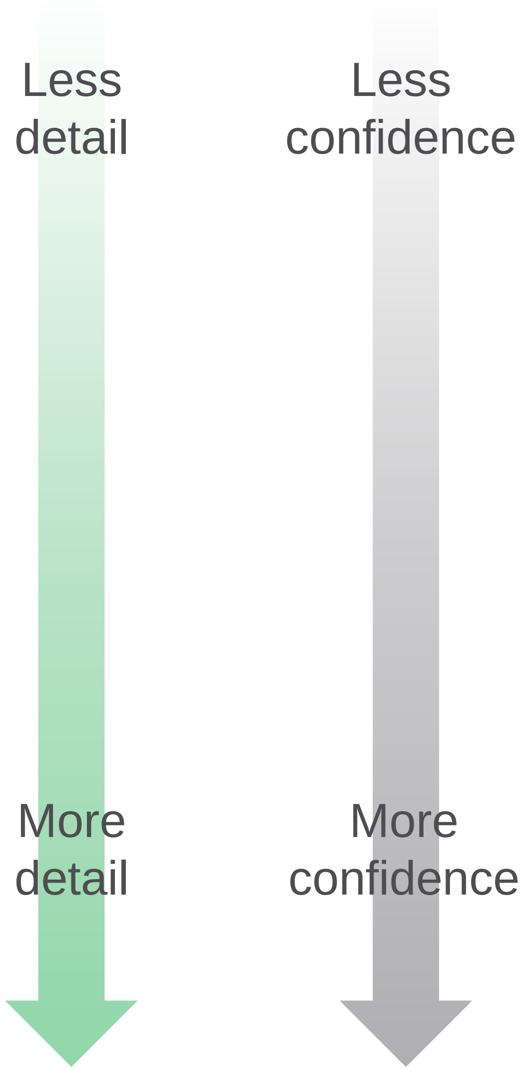
8. Autonomous 40-ton Trucks Improved The Mine's NPV by 29% Compared to Human-driven 100-ton Trucks



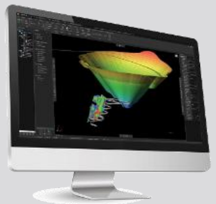
* Used standard vendor price for converting CAT-777E (Medium) trucks to autonomous

9. Decision Support Approaches Mining

- Static calculations (e.g. Excel)
  - Average distances, durations, load sizes, etc.
  - No time factor
- Semi-dynamic calculations
  - Excavation front movement
  - Approximate trucks-to-shovels allocation
  - Does not consider drilling, blasting, and excavators relocation
- Full-scale simulation
  - Considers queuing in front of excavators and dumping points
  - Simulates daily allocation of trucks by excavators
  - Simulates drilling, blasting, and excavators relocation
  - Simulates the impact of both planned and unplanned stoppages
  - Simulates blending and maintaining constant ROM grades

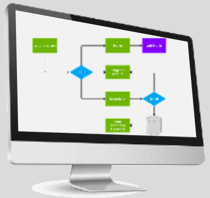


10. Advantages of Platform-Based Domain-Specific Tools Like MineTwin



Industry standard haulage simulation tools

MineTwin



General purpose simulation tools

Standard mining processes, objects, and reports

Library of standard equipment types and models

Geometric and geological data import from industry standard formats

Scheduling and coordination logic customizable with code

Ability to add custom objects and processes

Thank you

For more details visit our website www.mine-twin.com

Visit Whittle Consulting website for the complete report here: https://latestnews.whittleconsulting.com.au/whittle-consulting-pronto-case-study

MINE TWIN

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MINE TWIN

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