Simulation of Operations & Logistic

Systems analysis though discrete events modelling

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The complicated reality…

≡ Improving one of the many aspects of a system can deteriorate some other…

Multiple packages

Multiple products

Changeovers

Limited footprint

Client orders

Maintenance times

Transportation mode

Equipment capacity

Materials availability

Equipment availability

Operators

Real throughput?
Best schedule?
Enough resources?

Deliver on time?
Within specs?
Reduce costs?
Scale up?

Then comes simulation

- Simulation is a computerized imitation of a system
  - Based on knowledge or assumptions about the behavior of the parts of that system
  - With the purpose of obtaining insight in the overall system behavior

- Simulation helps when:
  - System or changes to system do not exist yet
  - System is too complex for equations and spreadsheets
  - Field experimentation is too expensive or time consuming
  - Real-life testing is unsafe, dangerous or leads to disaster

Model ≠ real-life

≡ A model is not one-to-one representation of reality

- It's a purposeful and often radical abstraction of a real life system, which can be used to answer questions or solve problems
- It contains only those elements of reality that are needed to answer the question or solve the problem.

≡ Why simplifying reality?

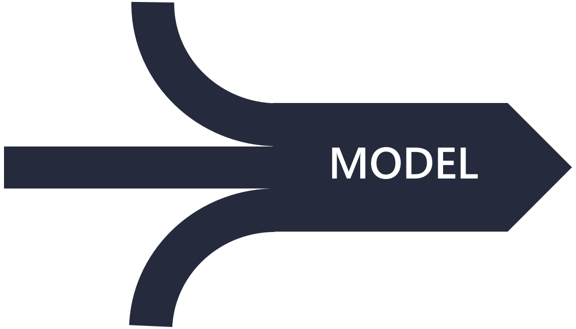
- To combine process expertise and operations management practical knowledge in a centralized decision tool
- To have faster and error-free calculations integrating system aspects
- To conveniently manipulate parameters and validate feasibility

Integrated global view on a process

Layouts, routes, dimensions, stationary and mobile equipment characteristics, technical data

DESIGN SPECIFICATIONS
engineering

HISTORICAL PROCESS DATA
data science
variability!



Cycle times, schedules, resources availability, logic, routing and operational constraints, reliability

OPERATIONS KNOWLEDGE
people

Outputs:

≡ Performance diagnosis
≡ Effective and ultimate throughput
≡ Equipment utilization rates
≡ Meaningful and custom statistics
≡ Trend and pie charts, histograms

Experimentation
Optimization

Trials and errors
for "free"!
No consequences!

Fact-based strategic insights

Engineering projects

- Design trade-offs and capacity assessment
- Sizing of fleets and equipment capacities
- Evaluation of risk and sensitivity

Conceptual model

Model with basic data

Enriched model, "what if" analysis

Update model with existing data

Troubleshooting with model

De-bottlenecking and fine tuning

Continuous improvement

- De-bottlenecking and scheduling of operations
- Maintenance planning and downtime reduction
- Assessment of effective and potential productivity

Ongoing operations

Expand or modernize with existing model

Different modelling flavours

Design sandbox

- ✓ Best estimator of expected assets
- ✓ System parameters TBD
- ✓ Resource counts TBD
- ✓ Layout and visuals TBD
- ✓ Purpose: determine the ideal system parameters (the design!)

Digital twin

- ✓ Virtual duplicate of existing assets
- ✓ Fine details on system parameters
- ✓ Calibrated with recent data
- ✓ Hi-Fi interactive 3D visuals (immersive VR if possible)
- ✓ Purpose: understand the deviance from the designed base conditions

The science under the hood

Some really hard work!

About event-based modelling

Model systems which change states at discrete points in time as a result of specific events

Examples of EVENTS

- Order/part arrivals
- Product movement
- Machine process start/finish
- Machine breakdown/repair

Examples of STATES

- Machines: idle, setup, processing, down
- Queues: empty, full
- Operators: on-shift, off-shift, utilized, idle
- Transports: travelling, loading, unloading

Simulation QUEUE and CLOCK

- Event execution & state updating trigger future events
- All events and cascading sub-events are put in a time-sorted queue
- The simulator jumps to the next timed event and executes it

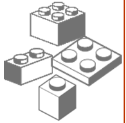
Typical model elements

- Simulation models capture all aspects of a production system to help analyzing and improving the global operational performance:
  - **Schedules** daily shifts, weekly production, planned maintenance
  - **Equipment** capacities, reliability, buffers, storage, conveying, piping
  - **Operators** activities duration, task coordination, procedures
  - **Maintenance** spare parts, work orders, repair times
  - **Transport** mode, traffic, speed, loading times, queuing at intersect.

Building blocks of complex systems

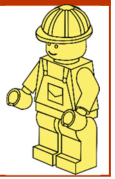
Most production systems and supply chains can be decomposed, modelled and optimized using these elements!

Variability



- Probability distributions
- Delays and rates
- Uncertainty tolerances

Management



- Scheduler
- Dispatcher/regulator
- Assets tracking
- Performance monitoring

Delay

- Cycle time
- Time to failure
- Repair time

Rate

- Vehicle speed
- Bulk/liquid flow
- Items arrival

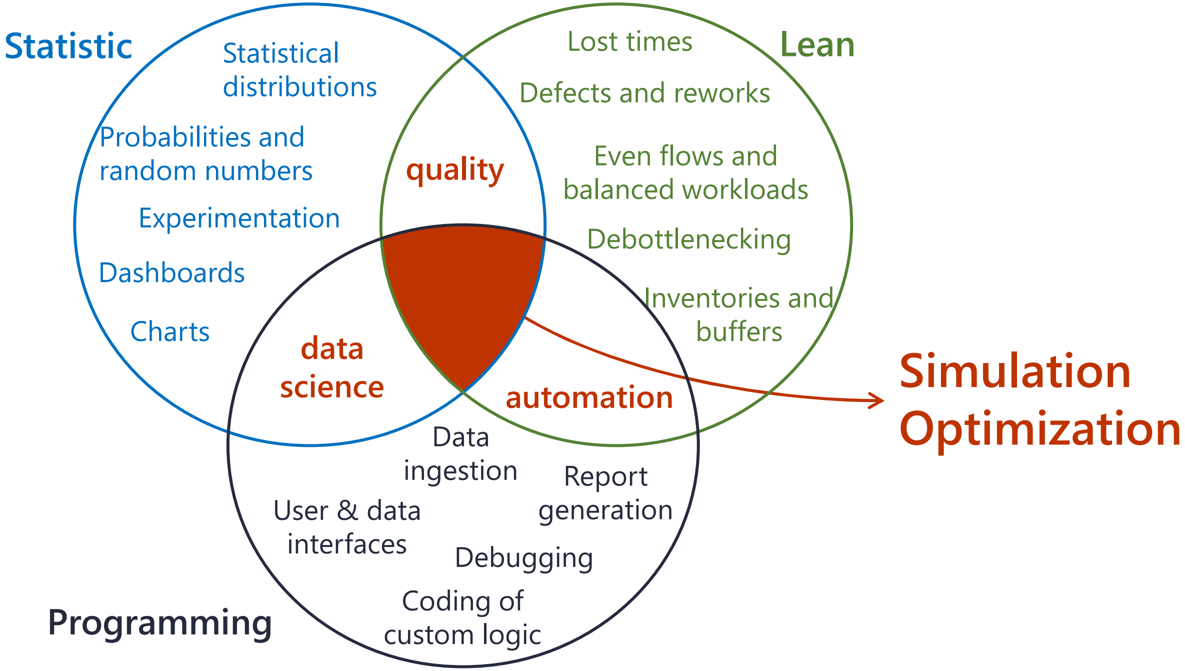
Wait

- Queue (FIFO)
- Stack (LIFO)
- Priority pick

Inventory

- Items storage
- Parts buffer
- Tank/silo

Required skills to build DES



Simulation modelling process

1| **DATA & INFO. COLLECTION**
- ≡ Discover assets and operations
- ≡ Obtain data and knowledge

2| **MODEL SPECIFICATION**
- ≡ Understand how system works
- ≡ Describe how it will be modelled

3| **MODEL DEVELOPMENT**
- ≡ Implement in simulation package
- ≡ Verify and validate model

We don't deliver simulation results.
We provide decision-ready facts!

4| **SYSTEM OPTIMIZATION**
- ≡ Test improvements
- ≡ Increase performance

Expertise and Examples

Some of the cool stuff we enjoyed doing!

Différence skills and expertise

≡ Mastering the fundamental concepts

- Probabilities and applied statistics - *capture intrinsic variability and randomness*
- Data structures and algorithms - *most efficient data storage and retrieval*
- Object-oriented programming - *modular and reusable coding*
- Modern data mining techniques - *connected databases and data visualization*

≡ Developing in general-purpose leading-edge platforms

- Built libraries for: traffic management, bulk/fluid material handling, fleet management, reliability analysis and maintenance planning
- Created reusable components for on-the-fly standardized outputs analysis (smart reports)
- Integrated optimization solvers and data mining engines to enhance models
- Connected simulation models to cloud platforms and virtual reality (VR) devices

Modern simulation software capabilities

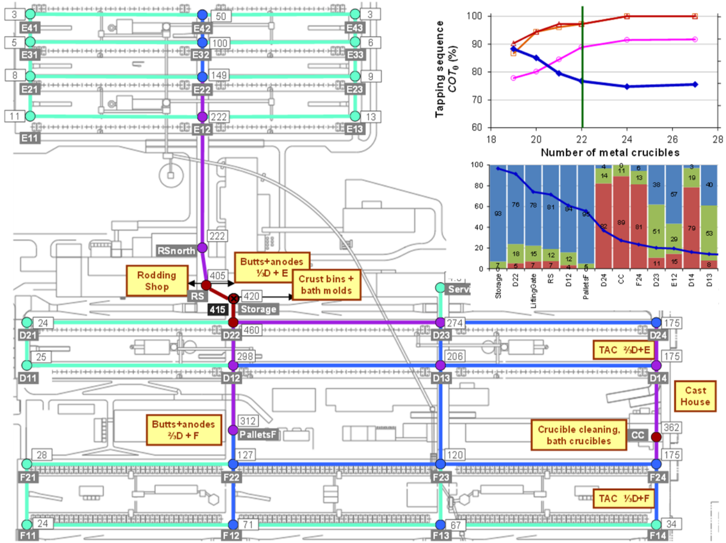
- Accurate and advanced 3D visualization
- Useful built-in object libraries
- Extensibility – plug external or build your own libraries
- Complete programming language – you want it, you make it!
- Visual runtime model checking and code debugging
- Database connectivity – Excel, JSON, local and cloud DB
- Multi-threading cross-platform high performance computing

Experience in various sectors

- Surface and underground mining operations
- Underground mine life-of-mine plan development
- Ore concentrators and processing plants
- Smelters and casthouses production scheduling
- Materials handling logistic and haulage
- Mine-to-ocean supply chains and logistics
- Rail and road network logistics and transportation
- Mobile equipment maintenance shops
- Airport baggage handling systems
- Industrial greenhouses
- Food, beverage and packaging facilities
- Tissue paper converting and packaging lines
- Ports: bulk/liquid material terminals and containers

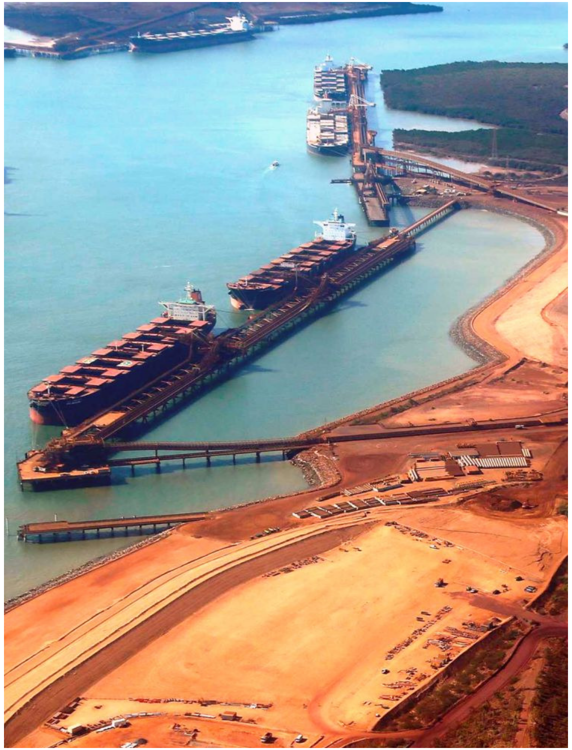
Aluminum smelter modernization

- Focus on scheduled pot tending activities and resulting traffic throughout the smelter
  - Represent crucial resources coordination
  - Model interferences between pedestrians, vehicles and overhead cranes
- Development of feasible pot tending activity schedules and overtime reduction
  - Analysis of alternative crane configuration
  - Evaluation of delivery routes options
- Reduced CAPEX by rationalizing vehicle fleet sizes and number of containers
  - Rectified insufficient storage area sizes
  - Identified areas with worker safety issues
  - Popular colored traffic map!



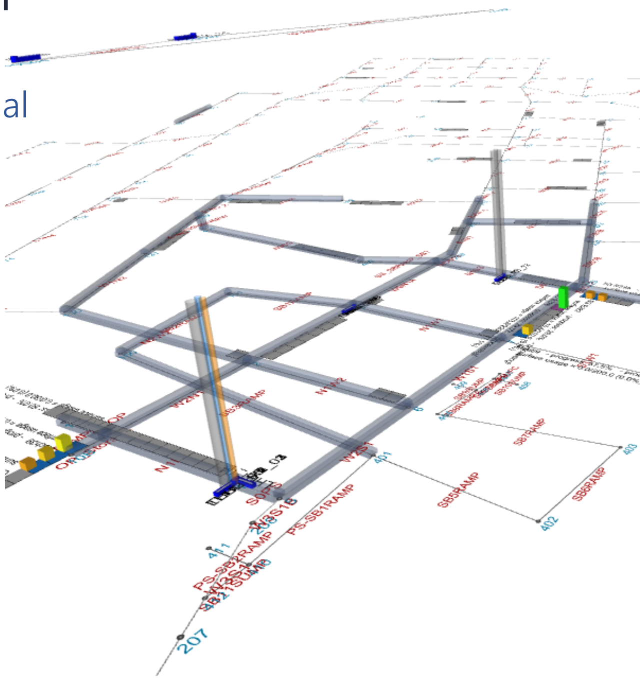
Iron ore port debottlenecking

- Focus on: ore from the mine with trains, on-site storage and conveying, ship loading and trans-shipment activities
  - Account for adverse weather and tide
  - Model calibrated and validated with data
- Operations & logistics improvements:
  - Debottlenecking of current operations (5.3 Mtpa when expecting 8 Mtpa) + train fleet optimization
  - Development of the roadmap to 20 Mtpa
- Study outcomes:
  - Identified a bonus 16% throughput with same assets but more efficient operational strategy
  - One year after, the Client asked for model update and roadmap to 35 Mtpa



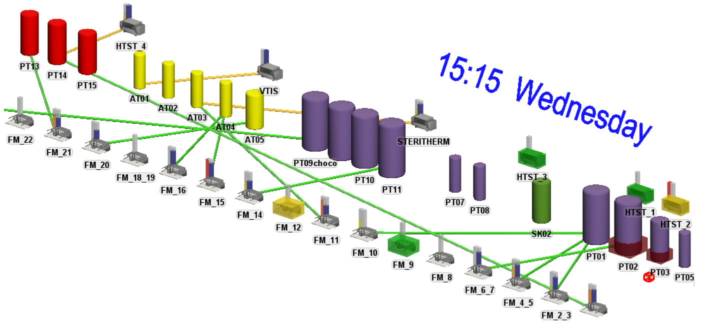
Material & equipment shaft logistics

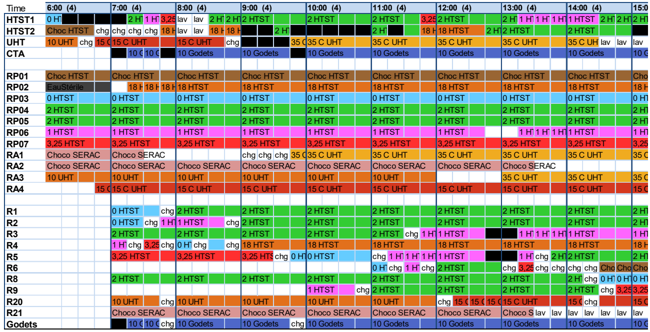
- Focus on: lowering mobile equipment, construction supplies and development material
  - Model material handling activities from surface laydowns to final destination in underground drifts and warehouses
  - Capture time-dependent underground space limitations restrictions
  - Manage underground traffic interferences and priorities
- "What-if" simulator:
  - Needed to quickly adjust to logistic schedule in constant evolution
- Study outcomes:
  - Verified the feasibility of the logistics plan
  - Triggered significant amount of changes to ensure on-time execution of the plan
  - Highlighted complex interactions causing delays



Simulation-aided dairy plant expansion

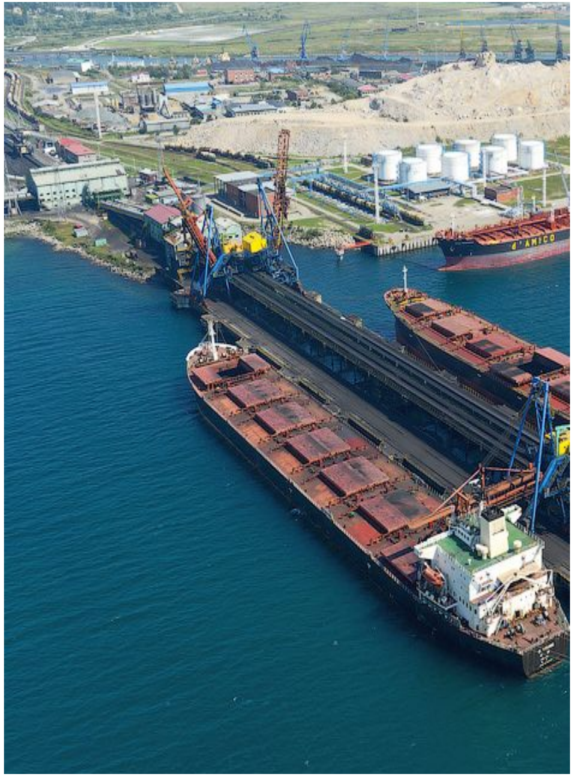
- Focus on milk pasteurizing, temporary holding and filling processes
    - Model equipment cleaning, changeover and routing based on product specifications
    - Generate and execute a weekly schedule based on customer demands
- Developed a feasible weekly schedule and optimized it by reducing waiting times
    - Support experts during trade-off analyzes
    - Provide training to the Client
- Discovered unused production capacity with actual equipment
    - Eliminated over-design in expanded plant
    - Drastic increase in study iteration speed





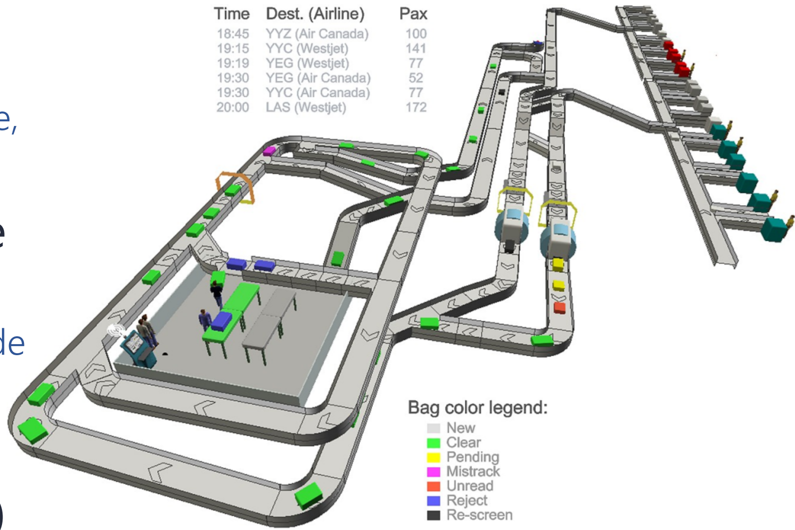
Mine-to-ocean supply chain

- Focus on: bauxite multi-modal transport from mine to ocean, and cargo & fuel from ocean to mine
  - Model truck haulage in open pits, railways operations, shiploading and navigation to open water
  - Consider material handling equipment, stockpiling, and tide constraint
- Supply chain design:
  - Calculation of overall throughput, mobile resources utilization rate, berth occupancy and round trip times
  - Optimization of truck and train fleets size
- Study outcomes:
  - Verified the feasibility of the logistics plan
  - Risk assessment for production margins
  - Evaluated mine trucks requirement and incremental throughput



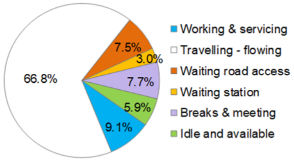
Simulation of baggage handling system

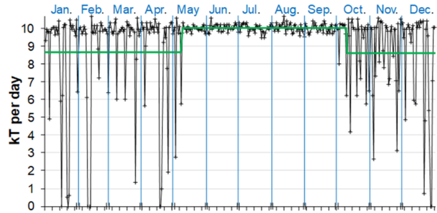
- Focus on conveyor network performance for the next 10 years
  - Model bags flow triggered by flights schedule and passenger arrival rate
  - Calculate system throughput, machine utilization rate, passenger and bag staytime
- Validated performance for expected volume and determined maximal bag throughput
  - Evaluate system response under selected failure mode scenarios
- Identified a merge point design flaw that limited to 630 bph (instead of 900 bph)
  - Optimized routing logic to prevent unexpected gridlock during peak periods



Optimization of mine-to-mill road transport

- Focus on haulage and delivery activities triggering movements along a 75 km road
  - Model traffic constraints and delays, and vehicles priorities and interferences
  - Calculate haulage cycle times, utilization rates, daily and yearly throughput
- Determination of optimal truck fleet size
  - Calculation of effective average truck speed
  - Sensitivity analysis on key design values
  - Evaluation of hot seating strategy benefits
- Reduced fleet size by 25% by choosing trucks 15% slower with a 50% larger payload
  - Identified a bottleneck: truck waiting time for loading at the stockpile





Simulation of seed-to-harvest operations

≡ Focus on plants flow across the system, from seeding to harvesting processes

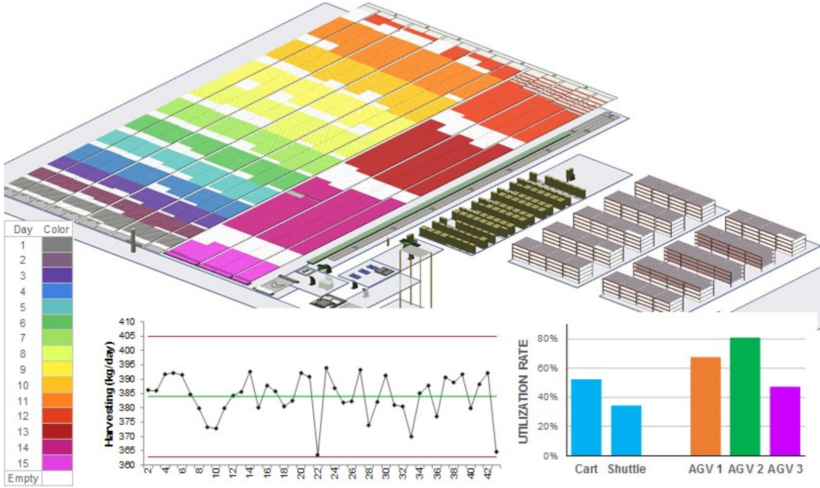
- Model scheduled activities, and interactions between conveyors and mobile resources
- Calculate throughput, containers requirement, utilization rates, run lengths

≡ Evaluate performance of different layouts, AGV paths and vehicle speeds

- Confirm storage capacities, conveyor lengths and number of mobile resources
- Verify on-time completion of activities

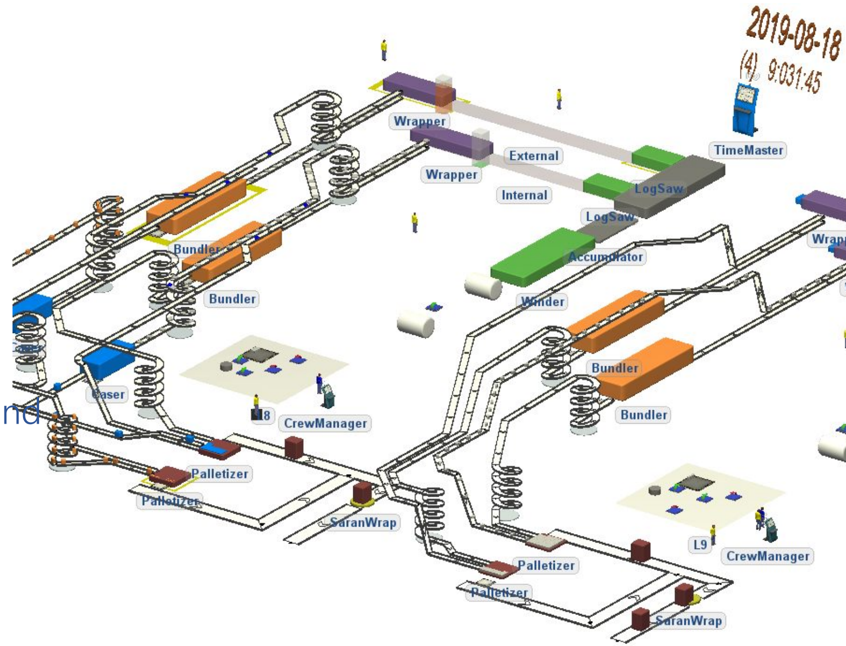
≡ Identified a bottleneck: germination rooms did not have sufficient space

- Increased AGVs speed and modified their paths to eliminate waiting times for transport



Increasing tissue paper converting OEE

- Simulation of the tissue converting and packaging process
  - Inclusion of stationary and mobile equipment, conveyors, accumulators, etc.
  - Deep use of reliability data to predict failures and process stops
  - Modelling of operators duties, daily cleaning, changeovers and failure responses
- Global system understanding
  - Investigation of “actual” performance to understand the key drivers
  - Test of alternative operation modes
  - Test of potential improvements before they are implemented on the lines
- OEE increased by 12%… (≈ 12M$/year savings)



Strategic planning of a port terminal

≡ Modelling of the mine-to-ocean chain

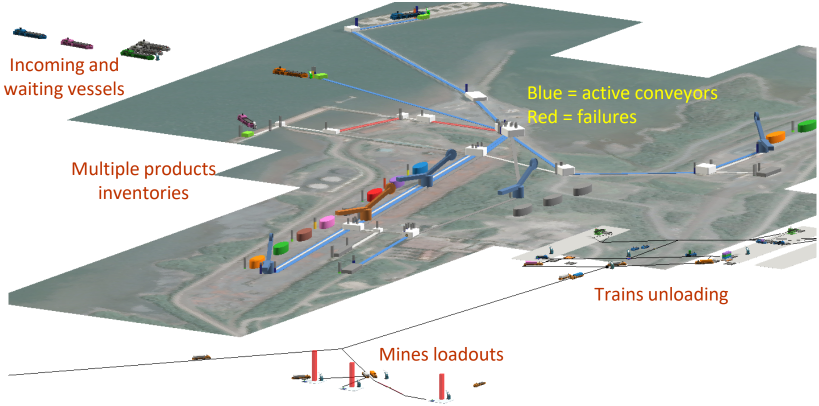
- Train loading and travel to the port
- Handling and dumping of train segments
- By-grade ore stockpiling and conveying
- Shiploading process and marine operations

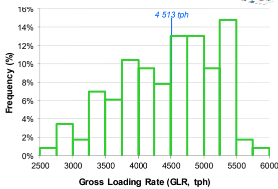
≡ Considered real-life complexity

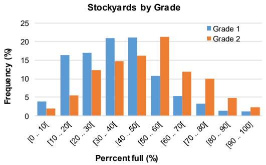
- Included variability from historical data
- Tested several operating modes and strategies
- Verified the feasibility of the proposed design.

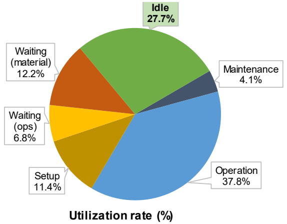
≡ Study outcomes

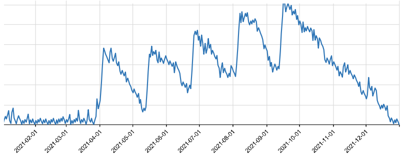
- Several diverging points of view now aligned: a clear engineering project was defined
- Anticipated high berth utilization rate could be addressed to avoid excessive demurrage costs
- Maximized Gross Loading Rate
- Consensus is made between all stakeholders







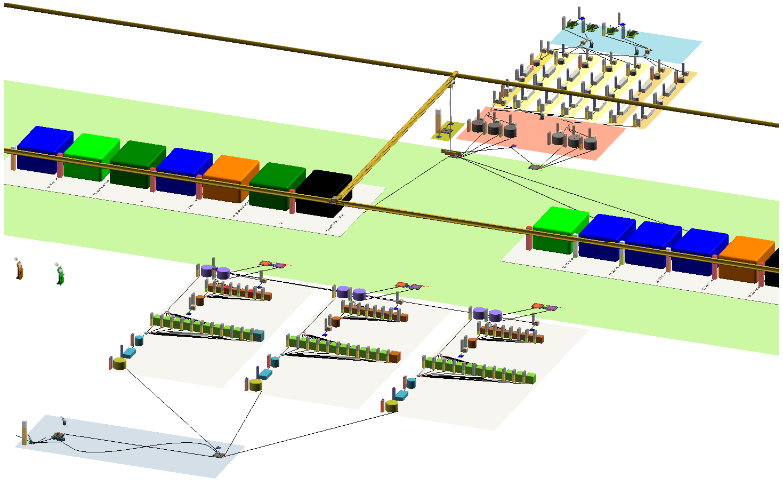




Validation of a concentration complex

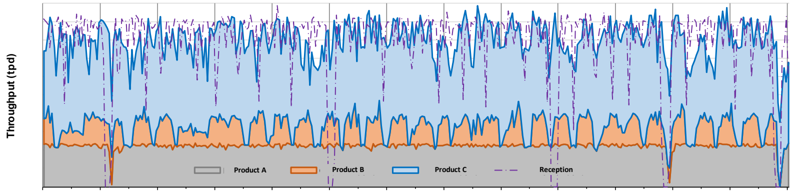
≡ Modelling of a 3-in-1 mineral concentration complex

- From truck loadout at the mine to the shipping of finished products bags
- Includes: parallel processing lines, overhead cranes operations, products changeover, and traceability/purity control logic
- Based on accurate discrete-rate mass balances



≡ Engineering validation & enhancement

- Initial purpose was to validate the design a ~ 1G$ capital investment: will it work???
- Maintenance plans and advanced modelling of unplanned stops had to be implemented
- Silos were resized: some needed larger capacities, some could be reduced
- Managed all the anti-contamination rules and resulting process and flow constraints



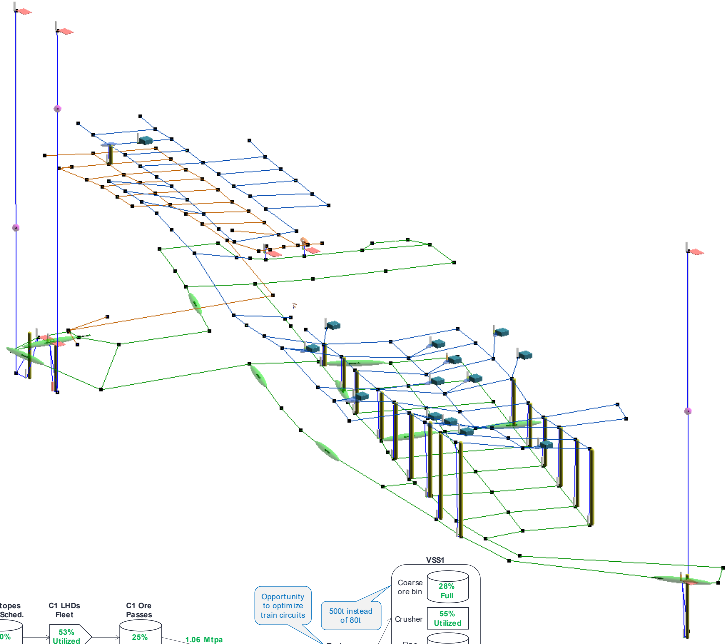
Optimization of an ore transportation system

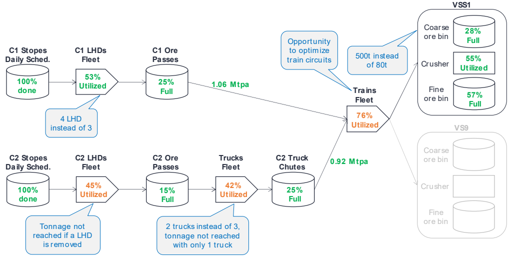
Underground haulage simulation

- Scheduled stopes production
- LHDs movements and ore passes management
- Trucks and trains operations with traffic and ventilation constraints
- Crushing, storage and hoisting to surface
- Colors to distinguish the different networks

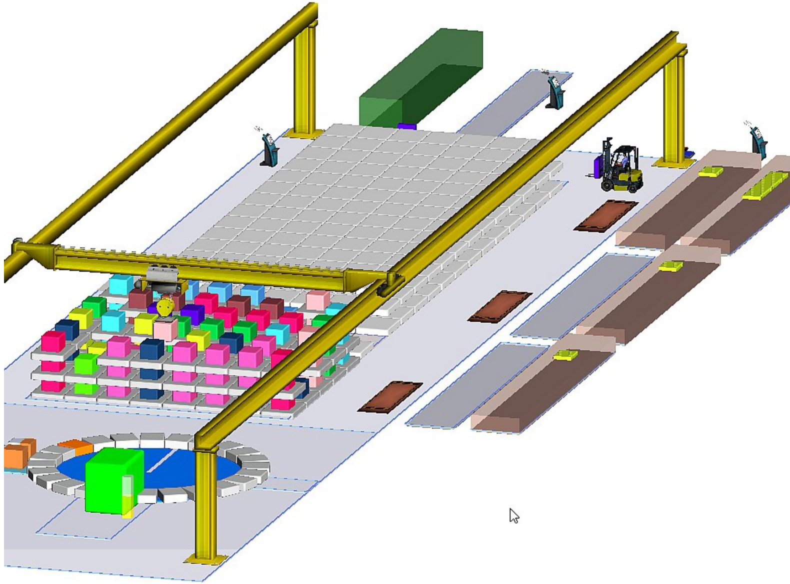
Findings and optimizations

- Valuable value chain view of the system to identify bottlenecks based on simulation results
- The crushers were located to lower levels to allow larger coarse ore bins (alleviating train congestion and hoisting during crew changes)
- All fleets sizes were optimized and several moments during the LOM
- Potential HSE issues identified near truck pads





Design of a casthouse expedition center



Modelling of casting and warehousing

- Metal arrival, casting wheel, reliability and defects
- Handling of storage racks and metal plates by the overhead crane
- Smart stacking optimized to reduce total time
- Staging and sorting by lots for trains and trucks

Considered real-life complexity

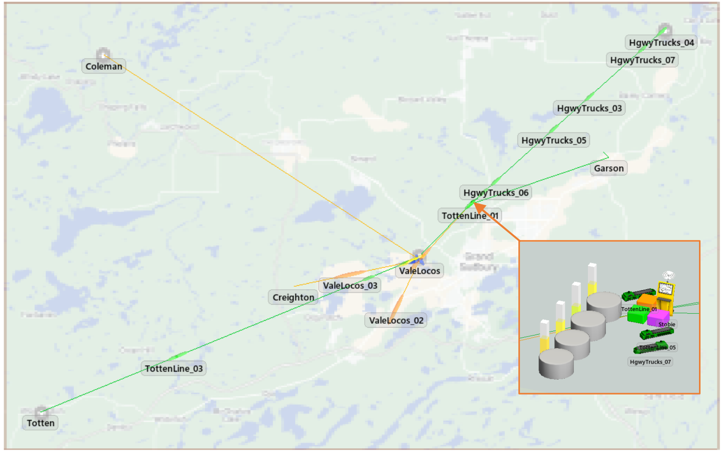
- Included a highly flexible shipping schedule
- Considered adverse weather impacts (freezing rain, snow storm, etc.) on logistics
- Reliability functions defined using historical data

Study outcomes

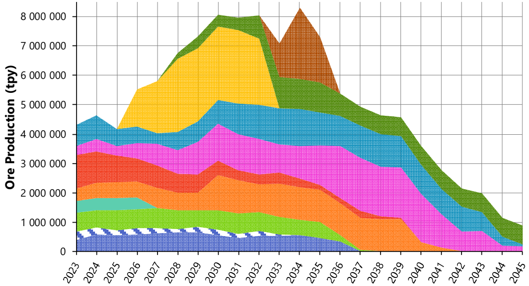
- Identified HSE issues to be mitigated
- Reduced the crane’s total daily travel distance
- Determined the economic lot size in the warehouse

Strategic planning of a transportation network

≡ Modelling of multi-modal mines-to-mills
- Daily ore arrival with variability and grades
- Loading, transit and unloading times
- Storage capacities and ore blending
- Multiple trucks and trains specifications/payloads
- Handling of railcars in yard with prioritization
- Optimal dispatching of shared resources



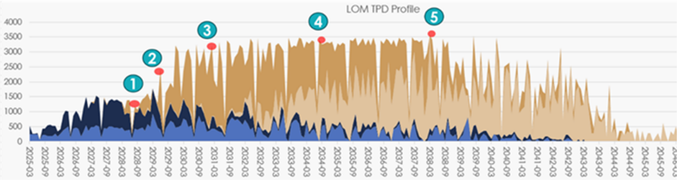
≡ Considered real-life complexity
- Allowed to configure any network including rehandling using the input files only
- Considered adverse seasonal impacts (freezing rain, snow storm, etc.) on logistics and cycle times

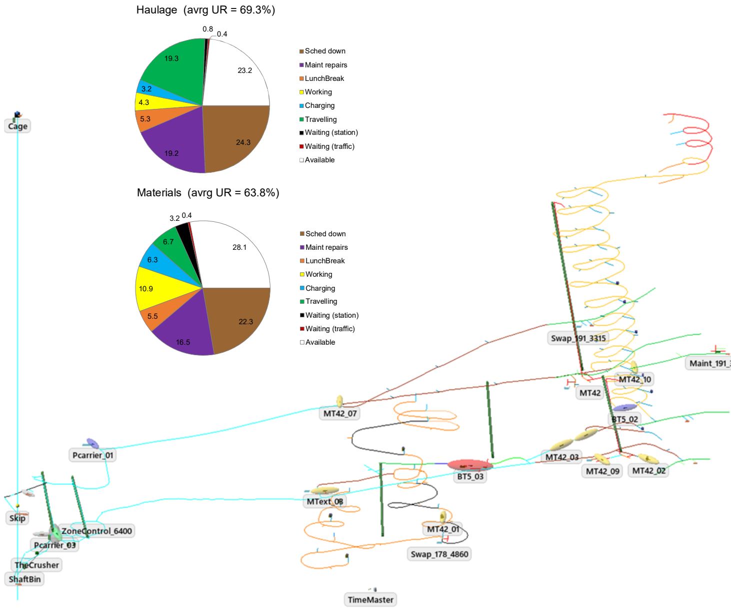


≡ Study outcomes
- Identified bottlenecks caused by ticketing booths, small loadout bins, inefficient truck types, etc.
- Optimized fleet sizes throughout the life-of-mine

Underground mine traffic and logistic

- Focus on haulage and delivery activities triggering truck movements on the ramps
  - Production and development heads to passes, then ore passes to crusher and hoisting
  - Model traffic constraints and delays, and vehicles priorities and interferences
  - Consider battery swapping and recharging cycles of electric vehicles
  - Calculate effective trucking times, haulage cycle times, utilization rates and throughput



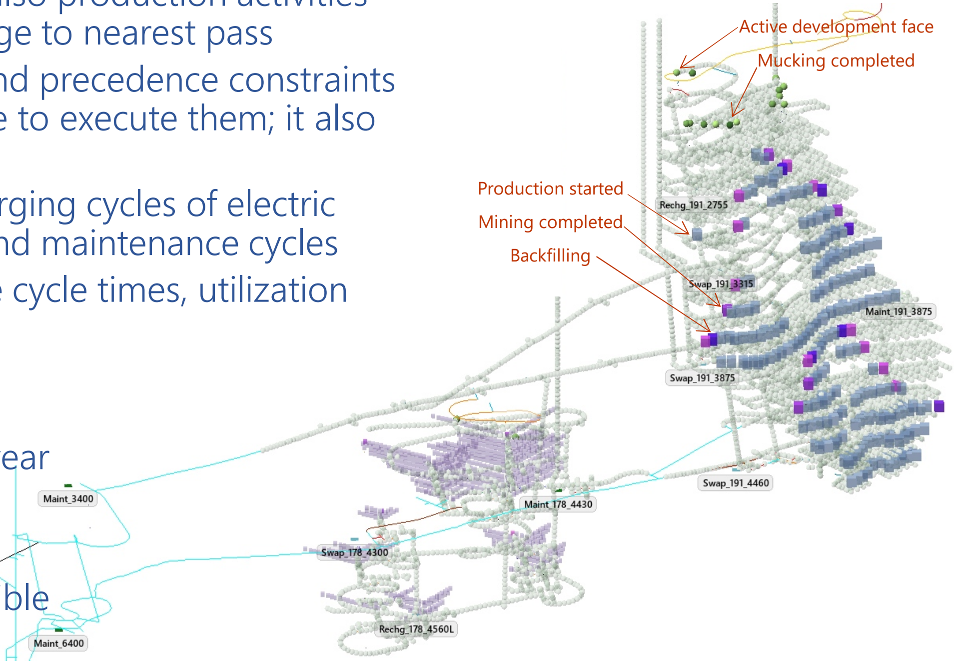


- Highlights
  - Determined optimal truck fleets size at various times
  - Captured the impacts of traffic congestion
  - Identified issues related to lack of storage at the crusher
  - Validated that the proposed LOMP is feasible

Mine development and production

≡ Focus on mine development and production schedules

- Modeling of crew-based development activities using shared mobile resources (drills, bolters, LHDs, etc.), and also production activities (cut-and-fill, longhole blasting) and haulage to nearest pass
- The model considered time-dependent and precedence constraints to trigger activities only when it is possible to execute them; it also incorporated time-varying fleet sizes
- It considered battery swapping and recharging cycles of electric vehicles, in addition to vehicle reliability and maintenance cycles
- Calculate effective trucking times, haulage cycle times, utilization rates, development and production rates



≡ Highlights

- Determined optimal fleets sizes for each year
- Determined the number of blasts per day
- Identified most sensitive parameters
- Validated that the proposed LOMP is feasible

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