The Use of Simulation for Bulk Cargo Terminal Planning and Design
What is Simulation

• Simulation is the imitation of real system
  – Based on knowledge and assumptions of system
  – To obtain insights in the behavior of system

• Discrete event simulation
  – Used to model systems which change state at discrete points in time as a result of specific events

• Simulation model
  – A computer numerical model purposed built to mimic real world system behaviors and to answer specific questions
Why Simulation

- Increasing trend of requested use for decision making
- Analysis
  - Study system behavior without building real system
  - Analytic tools or spreadsheet is limited
  - Allowing dynamic behaviors and sophisticated system to be studied
- Visualization and animation
  - For better communication and presentation
- Cheaper & easier than before
  - Availability of cost effective hardware & software
  - Faster and reliable model building
Tool We Use

- **FlexTerm**
- Include FlexSim engine
  - *General purpose discrete event simulation software*
- Extended to container terminal and bulk terminal simulation
- Embedded objects such as train or barge unloaders, ship loaders, conveyors, stockpiles etc. for fast model building
- C++ or FlexScript for customization
How to Do It

- Drag-and-Drop objects into model space
- Make connections between objects to define material flow according to Process Flow Diagram (PFM)
- Define source and sink logic for material growth and erosion
  - *Product distribution*
  - *Barge, train, and ship logic*
  - *Inventory driven or ship driven*
- Define mixing rules, direct-loading and stockpile logic
- Define other delay events such as break-downs and weather
- Typically run 10 years with 1 min time interval
Typical Simulation Outputs

• Typical outputs include:
  – Throughput finished
  – Stockpile contents, average and maximum
  – Unloading and loading rate, net and gross
  – Equipment utilization
  – Berth occupancy
  – Berth time, port time, and waiting time for ship, train, and barge
Case Study – Bulk Terminal

- A bulk terminal delivering coal by train and exporting by ships
  - Train unloader, conveyor, stacker, mobile hopper, stacker-reclaimer, ship loader, surge bin
- Analyzing expansion to more than double its capacity
- Various proposed expansion layouts
  - Different stockpile configurations
  - Different equipment for stacking/reclaiming
- Goal of simulation
  - Verify if the proposed layouts meet the handling throughput capacity
  - Identify system bottlenecks
Simulation Methodology

• Define simulation model specification and discuss with client
  – Verify what will be in the model and what outputs are expected

• Build base case model
  – Usually a relatively simpler model with less variables
  – Verified with experts and calibrated with available data

• Multiple simulation productive runs to collect statistics
  – Each run being sufficiently long to get stable results

• Extend base model to study various scenarios and perform sensitivity analysis
System Process Flow Diagram

- Stockpile A
- Stockpile B
- Train Unloader
- Ship Loader
Ship Driven

• **Ship arrival**
  – *Ship’s ETA is scheduled to match target throughput.*
    – For example for 15 Mt/year, turn a ship every 2.04 days
  – *Ship arrives at terminal according to its NOR (notice of arrival)*
    – Ship’s NOR = Ship’s ETA + Ship Arrival Delay
    – For example, ship arrival delay can be 10 days later than ETA

• **Train arrival**
  – *Coal trains are designated to arrive at the terminal to satisfy the ship’s demand based on product inventory available at terminal’s stockyard*
  – *Train arrival time at terminal based on an arrival distribution relative to ship’s ETA*
    – For example train arrival can be 5 days earlier than ship’s ETA
Key Inputs – Ship and Train Arrival

- Ship may arrive earlier or later than ship’s Estimated Time of arrival (ETA)

<table>
<thead>
<tr>
<th>Number of days late in relation to ETA</th>
<th>-4 to -2</th>
<th>-2 to 0</th>
<th>0 to 2</th>
<th>2 to 4</th>
<th>4 to 6</th>
<th>6 to 8</th>
<th>8 to 10</th>
<th>10 to 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>4%</td>
<td>15%</td>
<td>19%</td>
<td>20%</td>
<td>17%</td>
<td>12%</td>
<td>9%</td>
<td>20%</td>
</tr>
</tbody>
</table>

- Train may arrive earlier than Ship ETA

<table>
<thead>
<tr>
<th>Number of days earlier in relation to Ship’s ETA</th>
<th>% of the number trains assigned to ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>From -5 to 0</td>
<td>50%</td>
</tr>
<tr>
<td>From -10 to -5</td>
<td>25%</td>
</tr>
<tr>
<td>From -15 to -10</td>
<td>25%</td>
</tr>
</tbody>
</table>
Key Inputs – Stockpile Distribution

- **Stockpiles:**
  - *Divided into areas for each product type*
  - *Stacking and reclaiming from one area, then the next area in progression*

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>175,000</td>
<td>175,000</td>
<td></td>
<td></td>
<td>350,000</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>175,000</td>
<td>193,000</td>
<td>193,000</td>
<td></td>
<td>561,000</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>175,000</td>
<td>175,000</td>
<td>207,000</td>
<td>207,000</td>
<td>764,000</td>
</tr>
</tbody>
</table>
## Key Inputs – Ship Delays

<table>
<thead>
<tr>
<th>Shiploading Activities</th>
<th>All Ship Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach &amp; Mooring</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Pre-Loading Clearance</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Ship Loading Delays</td>
<td></td>
</tr>
<tr>
<td>Hatch Changes</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Intermediary Draft Checks</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Miscellaneous (shift changes, etc)</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Post-Loading</td>
<td>(h/ship)</td>
</tr>
<tr>
<td>Departure and Clearance of Channel</td>
<td>(h/ship)</td>
</tr>
</tbody>
</table>

- Ships loaded based on First-in-First-Serve rules.
- Direct loading has priority.
Key Inputs – Train Delays

<table>
<thead>
<tr>
<th>Train Unloading Activities</th>
<th>Unit</th>
<th>Average Per Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-unloading delays</td>
<td>(minutes)</td>
<td>10</td>
</tr>
<tr>
<td>Bad order delays</td>
<td>(minutes)</td>
<td>10</td>
</tr>
<tr>
<td>Post-unloading delays</td>
<td>(minutes)</td>
<td>20</td>
</tr>
</tbody>
</table>

- Trains unloaded based on First-in-First-Serve rules.
- Trains selected to match direct loading product
## Key Inputs – Equipment Rate

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>TAG</th>
<th>Peak Rate (tph)</th>
<th>Net Rate (tph)</th>
<th>Availability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train Unloader</td>
<td>TU</td>
<td>3000</td>
<td>2500</td>
<td>90%</td>
</tr>
<tr>
<td>Stacker</td>
<td>ST-01</td>
<td>3000</td>
<td>n/a</td>
<td>95%</td>
</tr>
<tr>
<td>Shiploader</td>
<td>SL-01</td>
<td>8000</td>
<td>n/a</td>
<td>95%</td>
</tr>
<tr>
<td>Mobile Reclalm Hopper</td>
<td>RH-01</td>
<td>3000</td>
<td>2500</td>
<td>95%</td>
</tr>
<tr>
<td>Stacker-Reclamer</td>
<td>SR-01</td>
<td>7800</td>
<td>4200</td>
<td>95%</td>
</tr>
</tbody>
</table>
During simulation, tables and charts are displayed that allow for visual inspection and tracking of results.
Key Performance Indicators

• Train Queuing - considered unacceptable when cars cannot return to the mine with sufficient time to load.
• Vessel queuing - considered unacceptable when demurrage costs exceed the profit margins unless there are strategic reasons
• Receiving commitment – of 90% with one dumper is acceptable, slightly higher with multiples or on a monthly basis
• Shipping commitment - 75% with a single berth and 80% with multiples or a standby berth are generally accepted for annual averages, monthly levels can be higher.
Model Outputs

- Terminal Throughput
- Demurrage
- Train Queue
- Berth Commitment
- Direct Loading Rate
- Stockpile Content
- Equipment Utilization
- Stockpile State Probabilities
- Berth Time Probabilities
Bulk Terminal FlexTerm Simulation Model
Rail Component
Outputs - Throughput

Recorded Throughput Vs. Normal Throughput

Reached maximum possible throughput at the point.
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Outputs - Demurrage

Annual Ship Demurrage Vs. Throughput

At 8M, ship demurrage is about 1M USD

Ship demurrage increased rapidly at 14 Mtpy

At 14 Mtpy, demurrage is approximately 117,973 USD

At 16 Mtpy, demurrage is approximately 341,483 USD

Ship demurrage increased at a rate of 14 Mtpy
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Outputs - Train Queue

Average Train Queue Vs. Throughput

3 to 4 trains on average in holding area at 8 Mtpy
Outputs - Berth Commitment

Berth Commitment - A measure of the overall total berth usage. Includes berth occupancy, minimum time between ships at berth, weather downtime and maintenance.
At this point, direct loading cannot increase anymore, as almost all trains are direct loaded. In general stacking only takes place during ship delays and reclaiming only takes place during train delays, except when equipment is breakdown. This is an indication that the train station is the bottleneck.
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Outputs - Stockpile Content

Averge Stockpile Content Vs. Throughput

- Stockpile A is approaching capacity
- Stockpile B is approaching capacity
- Stockpile B has sufficient capacity

Stockpile A: Capacity
Stockpile B: Capacity
Outputs - Equipment Utilization

![Graph showing Equipment Utilization Vs. Throughput](image-url)
Outputs – Stockpile Tracking

Tracking - First Year

Day

1,000 tonnes

Ships/Trains

AreaA (1000 tonne)  AreaB (1000 tonne)  Ship Queue Content  Train Queue Content
Outputs – Stockpile State Probabilities

Stockpile Areas A & B

- Area A Probability
- Area B Probability
- Area A Cumulative Probability
- Area B Cumulative Probability

Content (1,000 tonnes)

Probabilities:
- Stockpile A & B Capacity
  - 0% (0-25)
  - 1% (25-50)
  - 4% (50-75)
  - 9% (75-100)
  - 17% (100-125)
  - 81% (125-150)
  - 100% (150-175)
Outputs – Berth Time Probabilities

![Ship Berthing Time Probability Graph](image-url)

- Handysize and Handymax
  - 74.7%
  - 75.8%
- Panamax
  - 46.1%
- Capesize
  - 0.1%

The Use of Simulation for Bulk Cargo Terminal Planning and Design
Conclusions

• Theoretical maximum throughput for the terminal was identified through simulation experiments
• Practical throughput capacity can be identified by examining KPIs such as ship and train queues, demurrage, and equipment utilization
• Through simulation experiments and sensitivity analysis, bottleneck of operation (stockpile, ship loader, train unloader, holding area etc.) can be identified as well as their impact to the operation
Conclusions

• Queue contents, demurrage, direct loading percentage etc. can be obtained with confidence through dynamic simulation

• Some interesting findings:
  – Non-linear relationship between demurrage and throughput
  – Non-linear relationship between equipment utilization and throughput
  – Direct loading does not always result in an increase to loading rate (because no time for stacking)
  – Three peaks of ship berth time probability for various ship types
Thank You
Bull Pen
Key Terminology

• **Net loading time:**
  – *Total time between the start of loading and the completion of loading during which product is flowing into the ship.*

• **Gross loading time:**
  – *Total time between the start of loading and completion of loading.*
  – *Gross Loading Time = Net Loading + Ship delays + Blockages + Shiploader breakdowns*
Key Terminology

• **Ship Delays:**
  – *These include approaching and mooring, pre-loading clearance, intermediate draft surveys, hatch changes, shift changes, paper work, on board delays, departure and clearance of channel etc.*

• **Berth time or occupancy**
  – *Total time or percentage that ships occupy the berth;*

• **Total time in port**
  – *Berth time plus waiting time*
  – *Used to calculate demurrage*
Key Terminology

• Demurrage
  – Number of days exceeding the allowed days of laytime to finish loading a ship
  – Usually negotiated between operator and shipper
  – Certain rule used to convert demurrage to monetary cost

• Similarly for unloading barge and trains, demurrage or detention cost may incur