The Use of Simulation for Bulk Cargo Terminal Planning and Design

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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**

Stockpile
Berth
BerthPoint
Reclaimer
BargeUnloader
ShipLoader
BTConveyor
SPConveyor
SurgeBin
Feeder
Stacker
StackerReclaimer

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
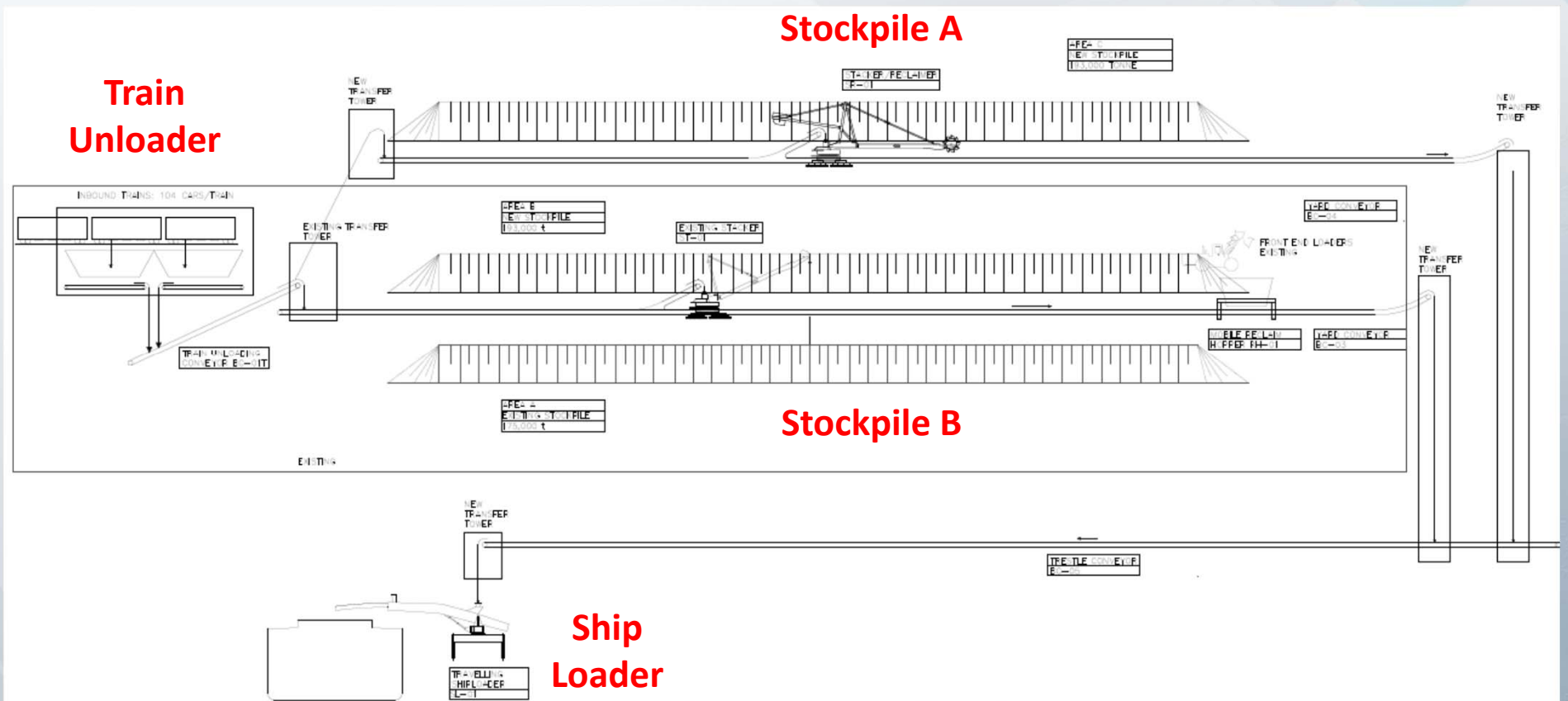
Ship Driven

- **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)**

Number of days late in relation to ETA	-4 to -2	-2 to 0	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12
Frequency	4%	15%	19%	20%	17%	12%	9%	20%

- **Train may arrive earlier than Ship ETA**

Number of days earlier in relation to Ship's ETA	% of the number trains assigned to ship
From -5 to 0	50%
From -10 to -5	25%
From -15 to -10	25%

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Key Inputs – Stockpile Distribution

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

	Stockpile Area				Total
	A	B	C	D	(tonnes)
Scenario 1	175,000	175,000			350,000
Scenario 2	175,000	193,000	193,000		561,000
Scenario 3	175,000	175,000	207,000	207,000	764,000

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Key Inputs – Ship Delays

Shiploading Activities		All Ship Types
Approach & Mooring	(h/ship)	2.0
Pre-Loading Clearance	(h/ship)	2.0
Ship Loading Delays		
Hatch Changes	(h/ship)	1.5
Intermediary Draft Checks	(h/ship)	1.0
Miscellaneous (shift changes, etc)	(h/ship)	1.5
Post-Loading	(h/ship)	2.0
Departure and Clearance of Channel	(h/ship)	2.0

- Ships loaded based on First-in-First-Serve rules.
- Direct loading has priority.

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Key Inputs – Train Delays

Train Unloading Activities	Unit	Average Per Train
Pre-unloading delays	(minutes)	10
Bad order delays	(minutes)	10
Post-unloading delays	(minutes)	20

- Trains unloaded based on First-in-First-Serve rules.
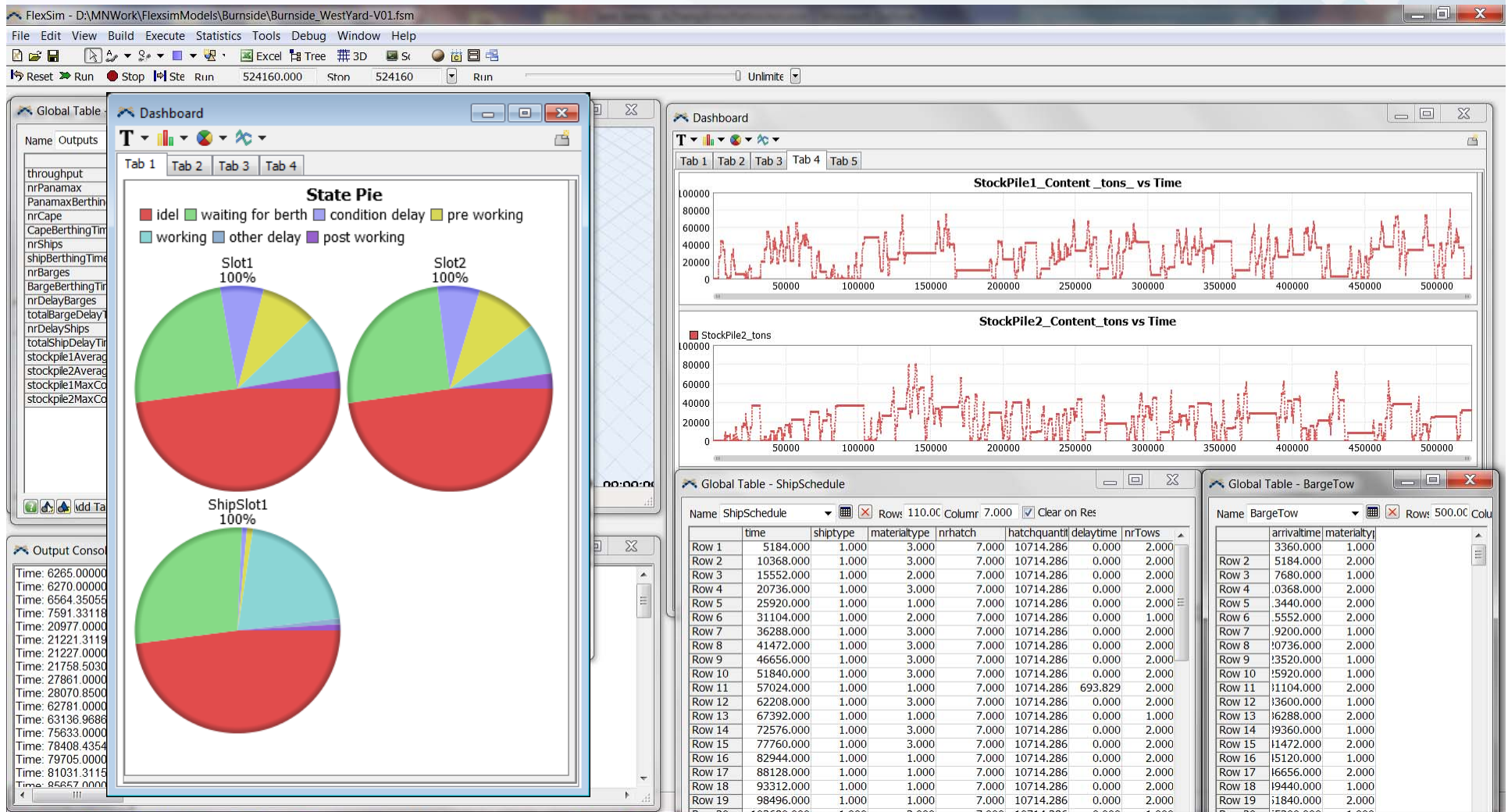- Trains selected to match direct loading product

Key Inputs – Equipment Rate

Equipment Type	TAG	Peak Rate (tph)	Net Rate (tph)	Availability (%)
Train Unloader	TU	3000	2500	90%
Stacker	ST-01	3000	n/a	95%
Shiploader	SL-01	8000	n/a	95%
Mobile Reclaim Hopper	RH-01	3000	2500	95%
Stacker-Reclaimer	SR-01	7800	4200	95%

Simulation Run Screen

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.**
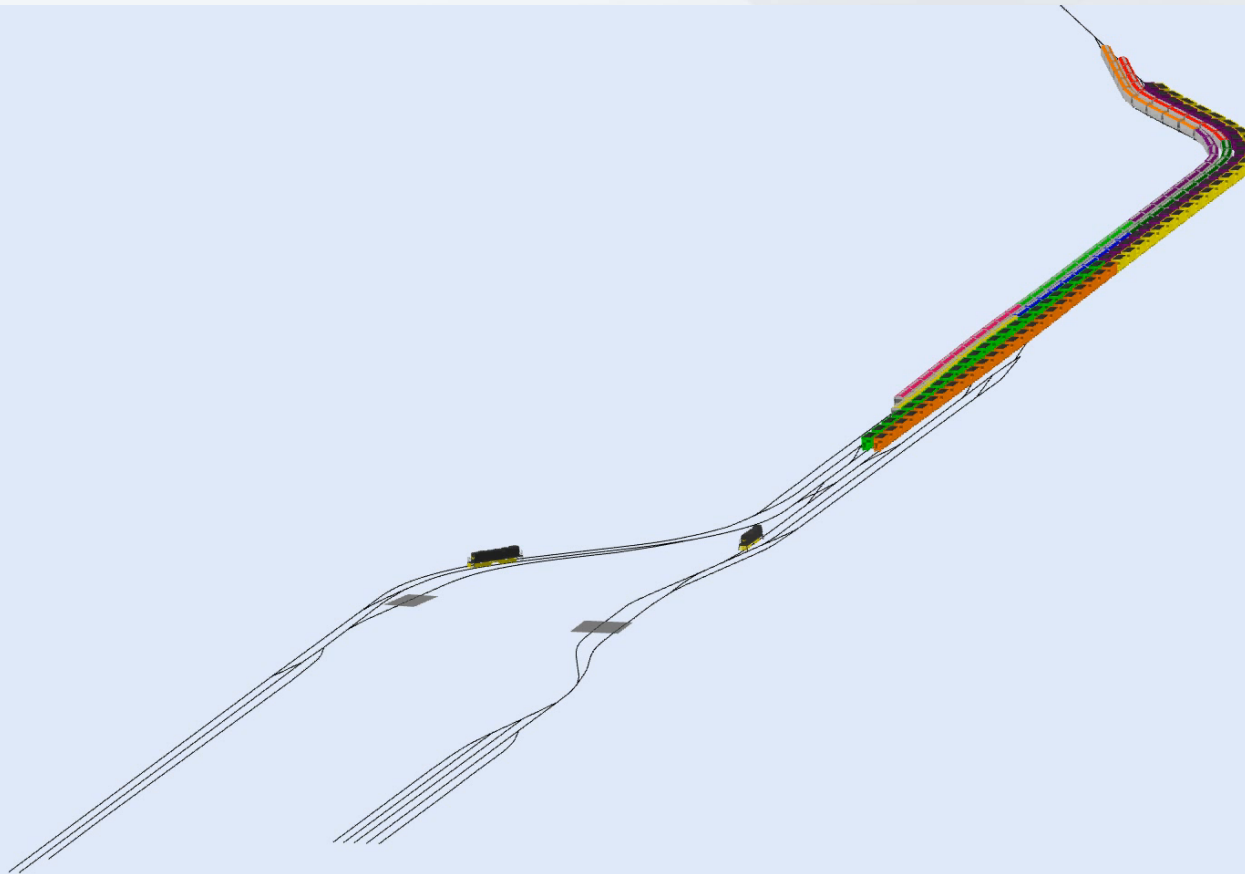
Model Outputs

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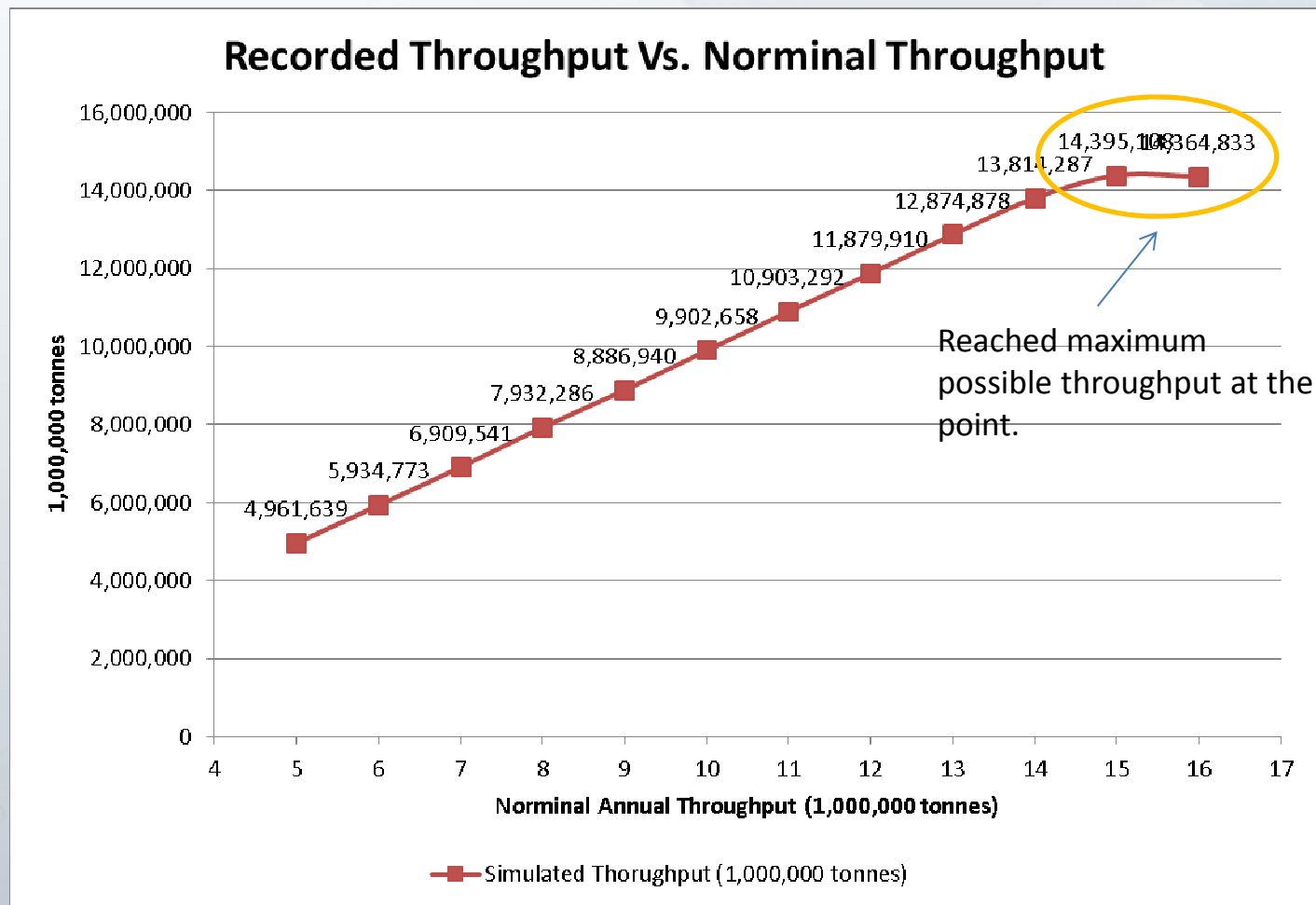
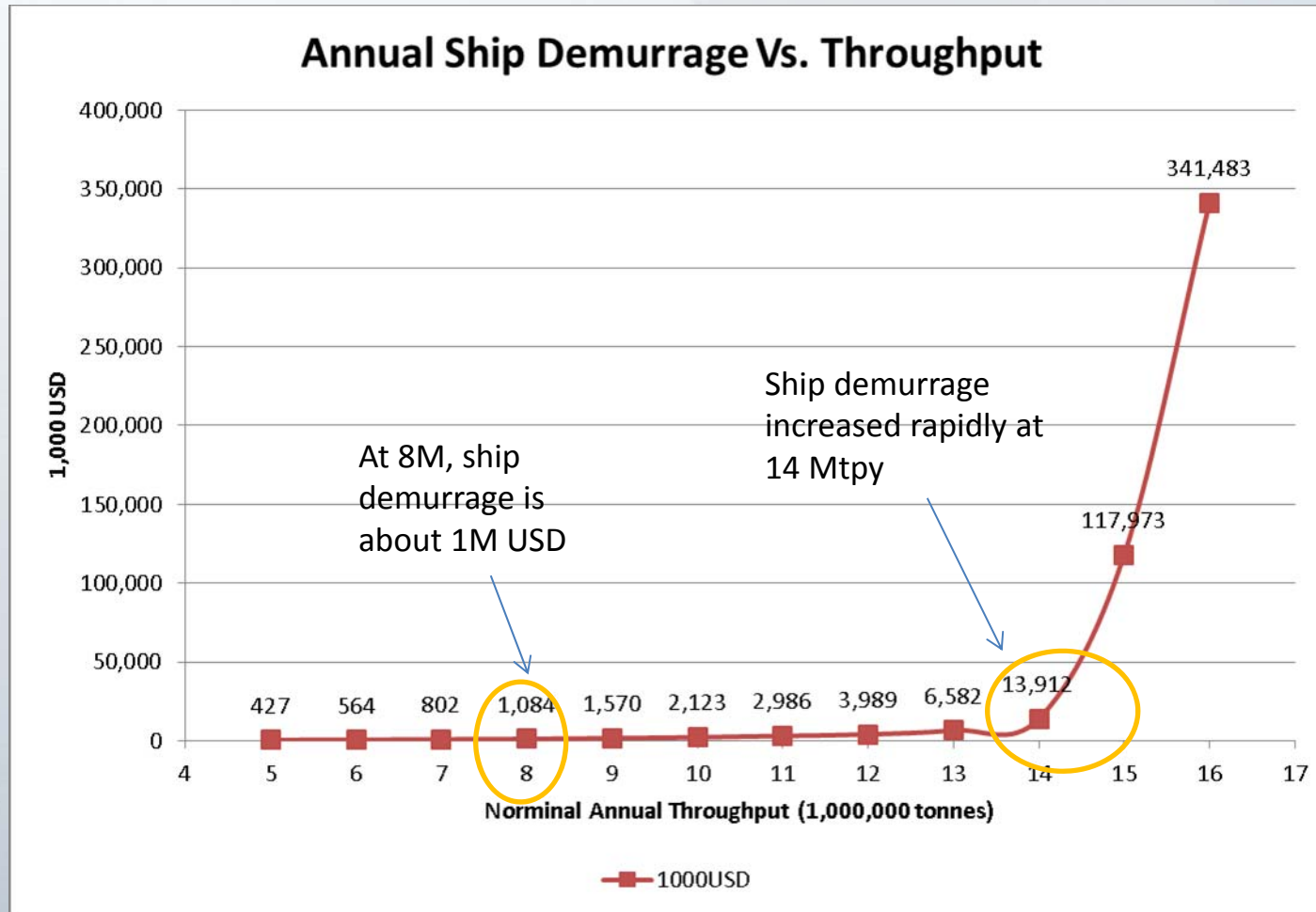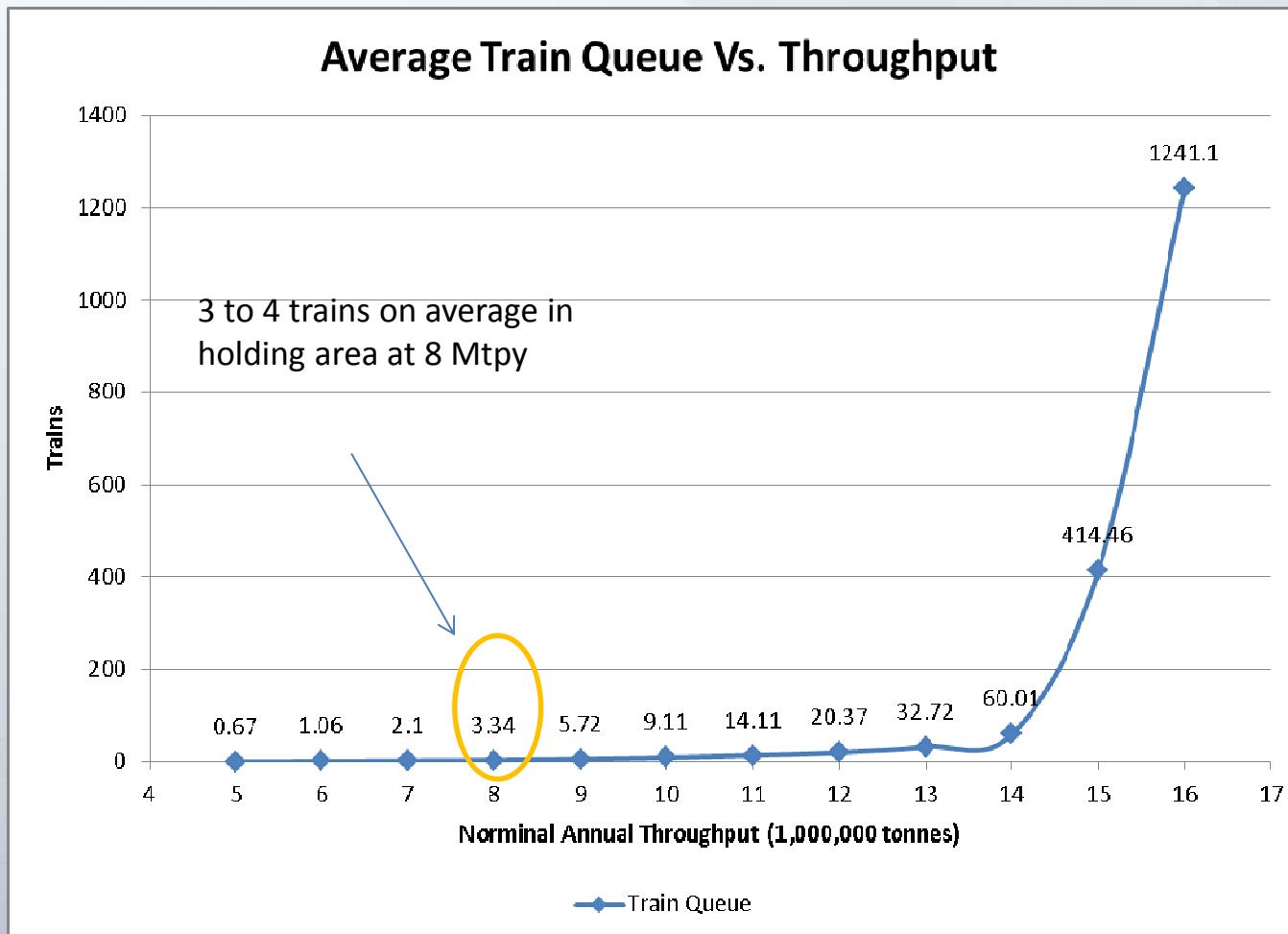# Bulk Terminal FlexTerm Simulation Model
Rail Component

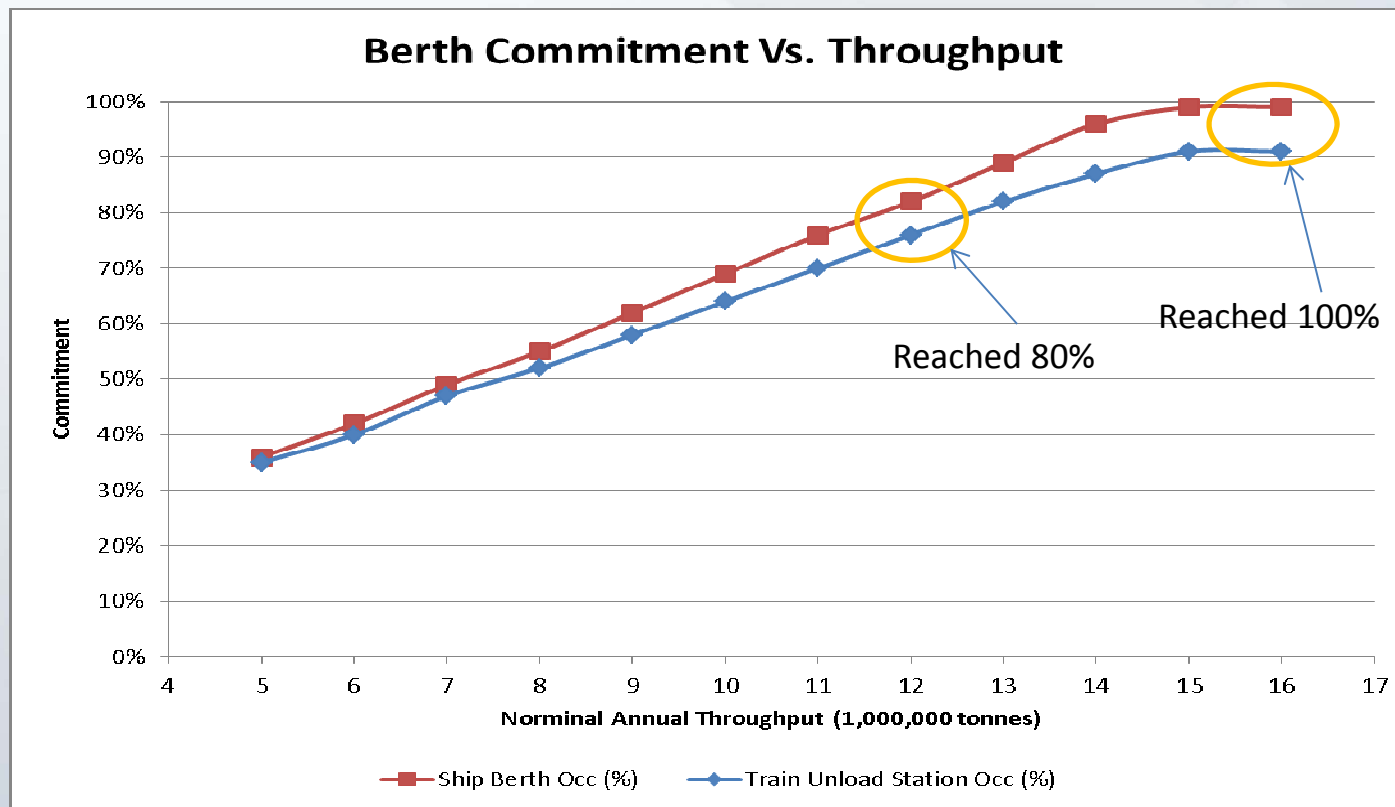Day 1, 01:40:00

Outputs - Throughput

Outputs - Demurrage

Annual Ship Demurrage Vs. Throughput

At 8M, ship demurrage is about 1M USD

Ship demurrage increased rapidly at 14 Mtpy

Data points: 427, 564, 802, 1,084, 1,570, 2,123, 2,986, 3,989, 6,582, 13,912, 117,973, 341,483

Y-axis: 1,000 USD

X-axis: Norminal Annual Throughput (1,000,000 tonnes)

Legend: 1000USD

Outputs - Train Queue

Outputs - Berth Commitment

Berth Commitment Vs. Throughput

Reached 100%

Reached 80%

Ship Berth Occ (%) — Train Unload Station Occ (%)

Commitment

Norminal Annual Throughput (1,000,000 tonnes)
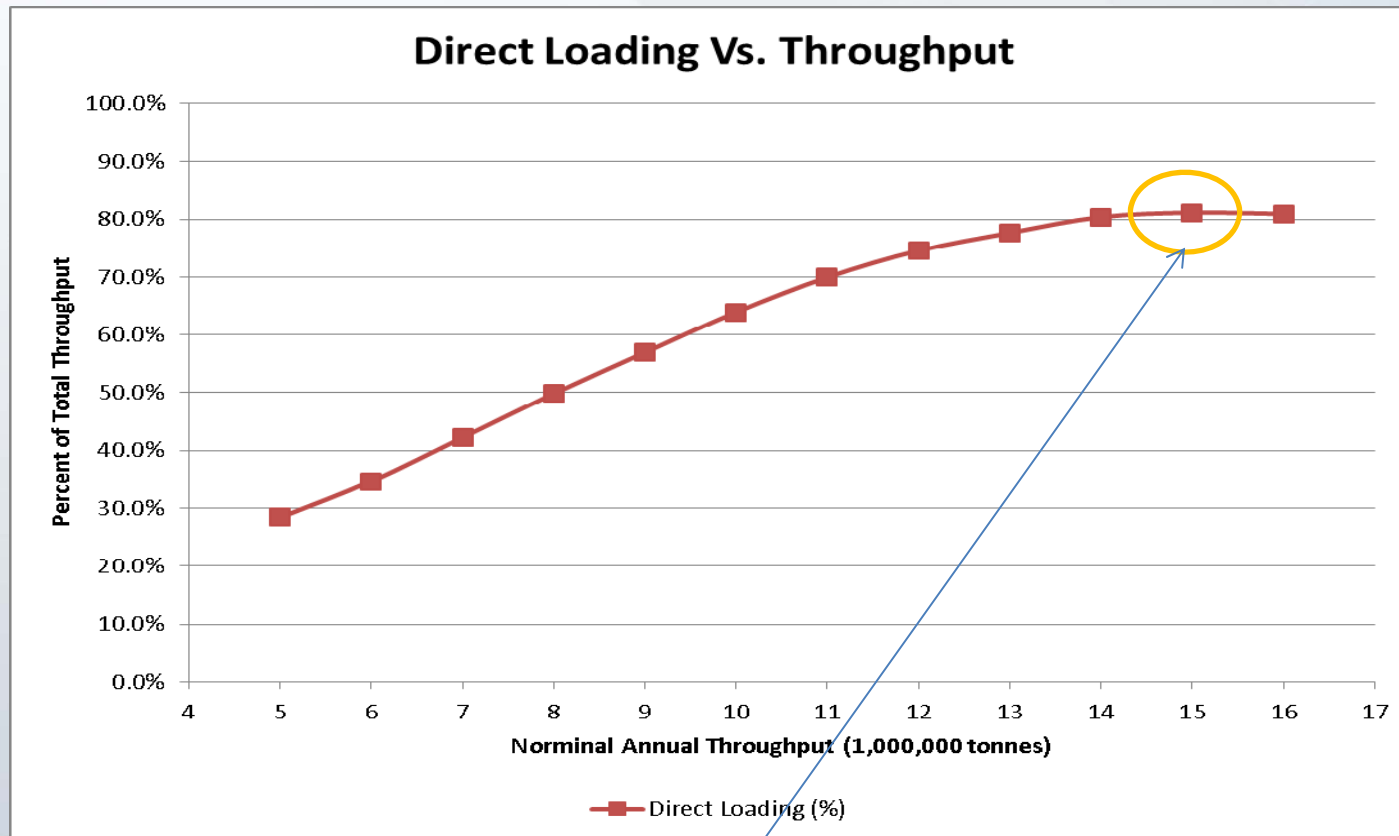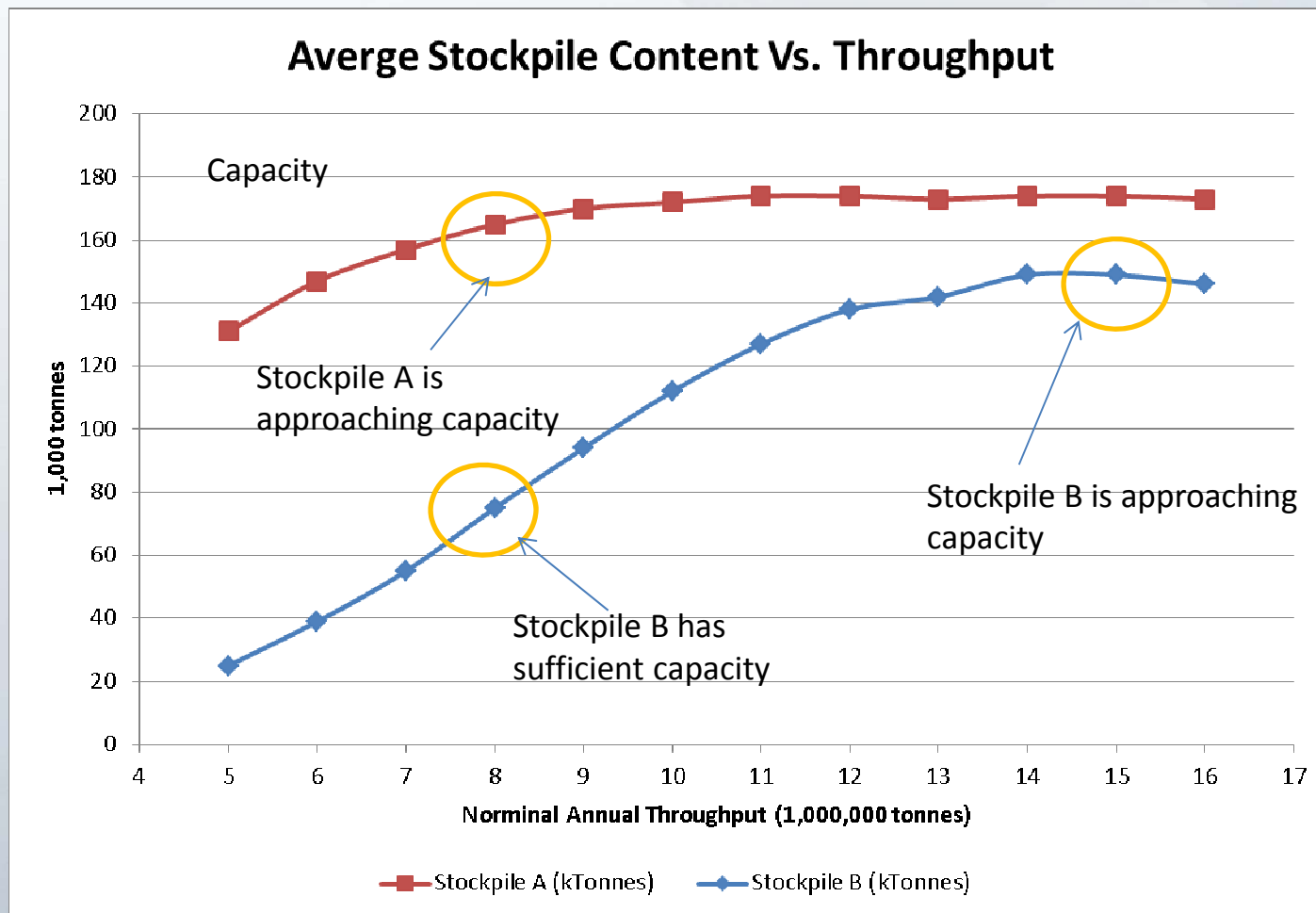
Berth Commitment - A measure of the overall total berth usage. Includes berth occupancy, minimum time between ships at berth, weather downtime and maintenance

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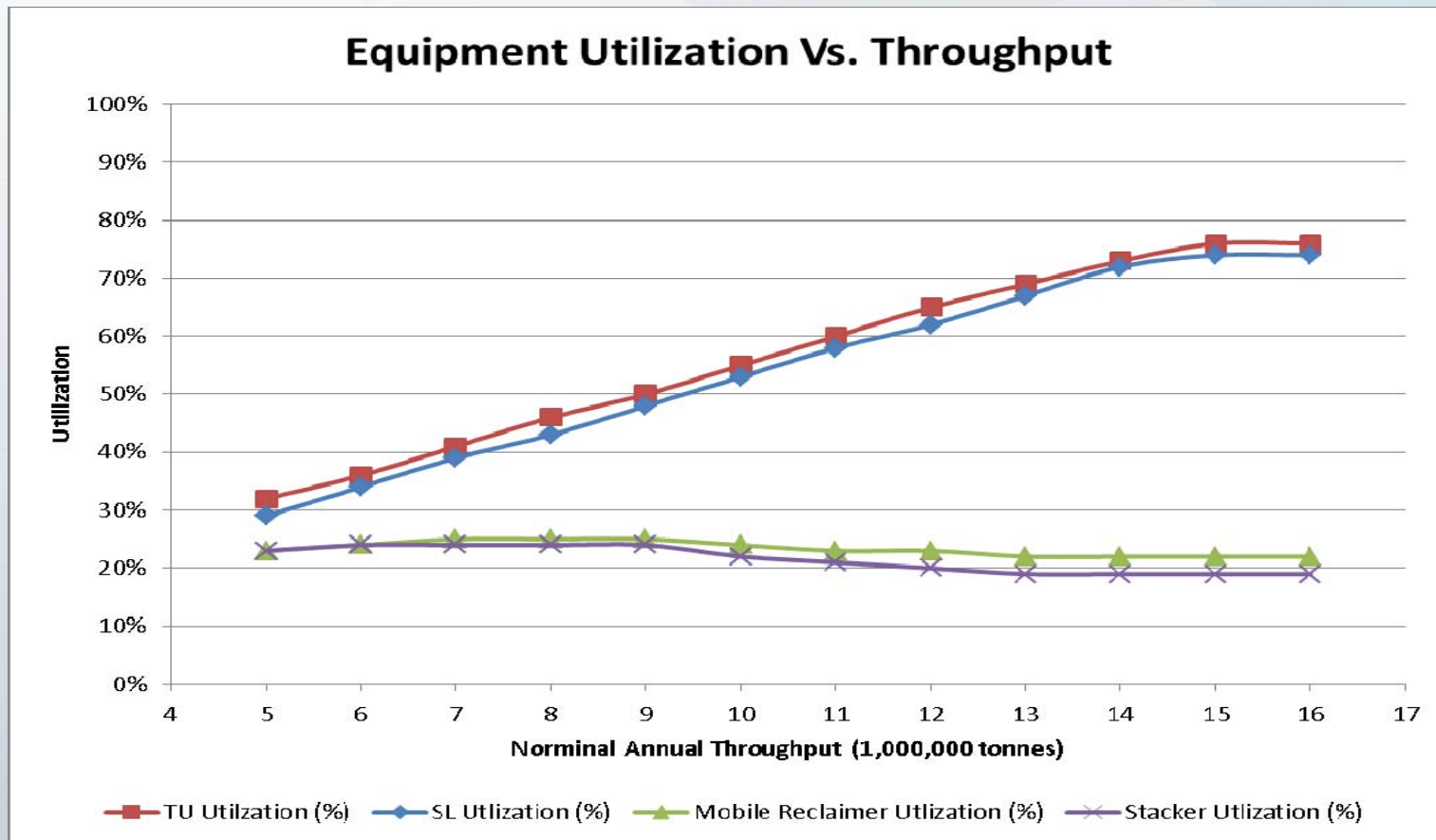# Outputs - Direct Loading Rate

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.
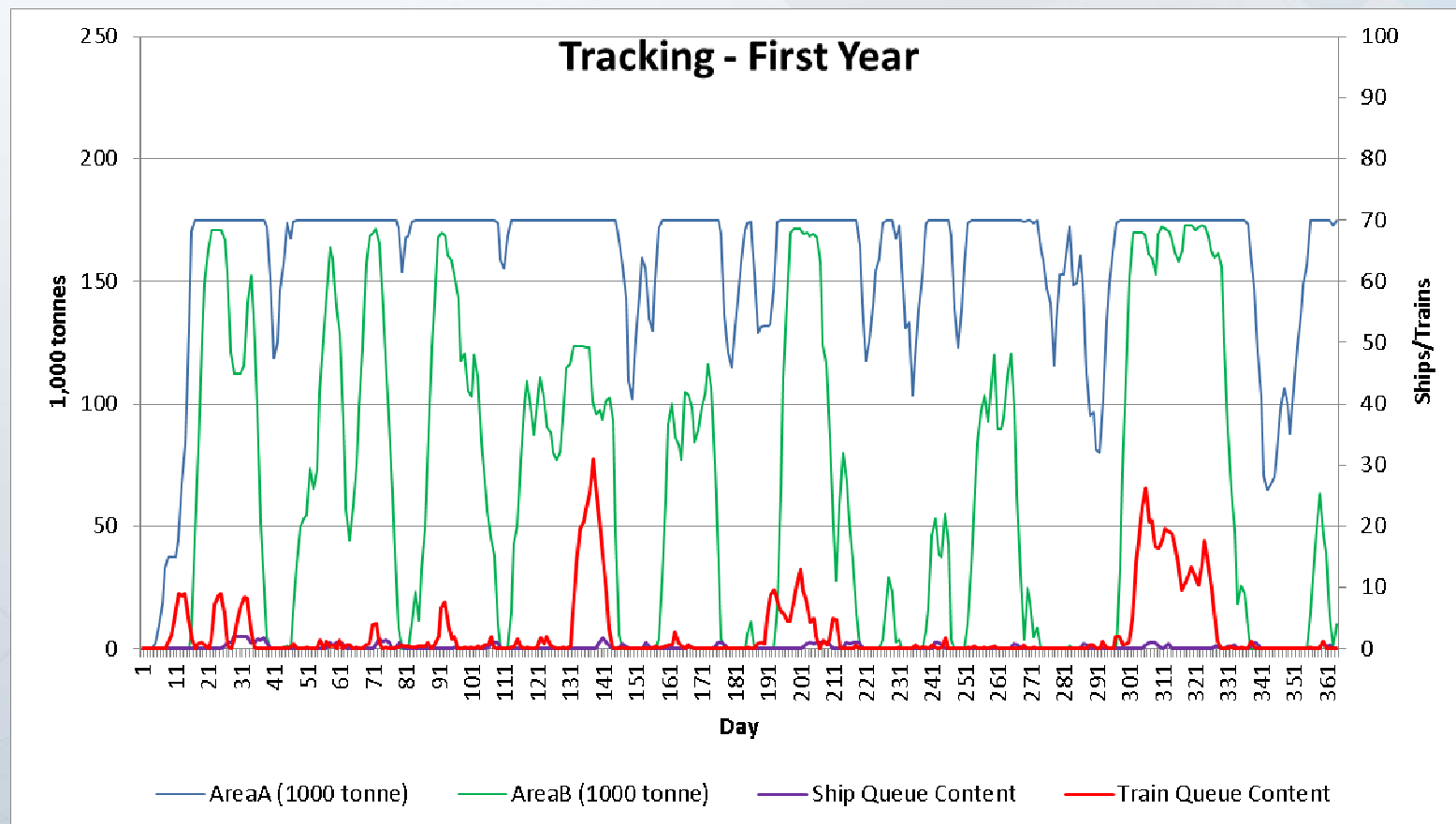
Outputs - Stockpile Content

Averge Stockpile Content Vs. Throughput

Capacity

Stockpile A is
approaching capacity

Stockpile B has
sufficient capacity

Stockpile B is approaching
capacity

1,000 tonnes

Norminal Annual Throughput (1,000,000 tonnes)

Stockpile A (kTonnes)   Stockpile B (kTonnes)

Outputs - Equipment Utilization

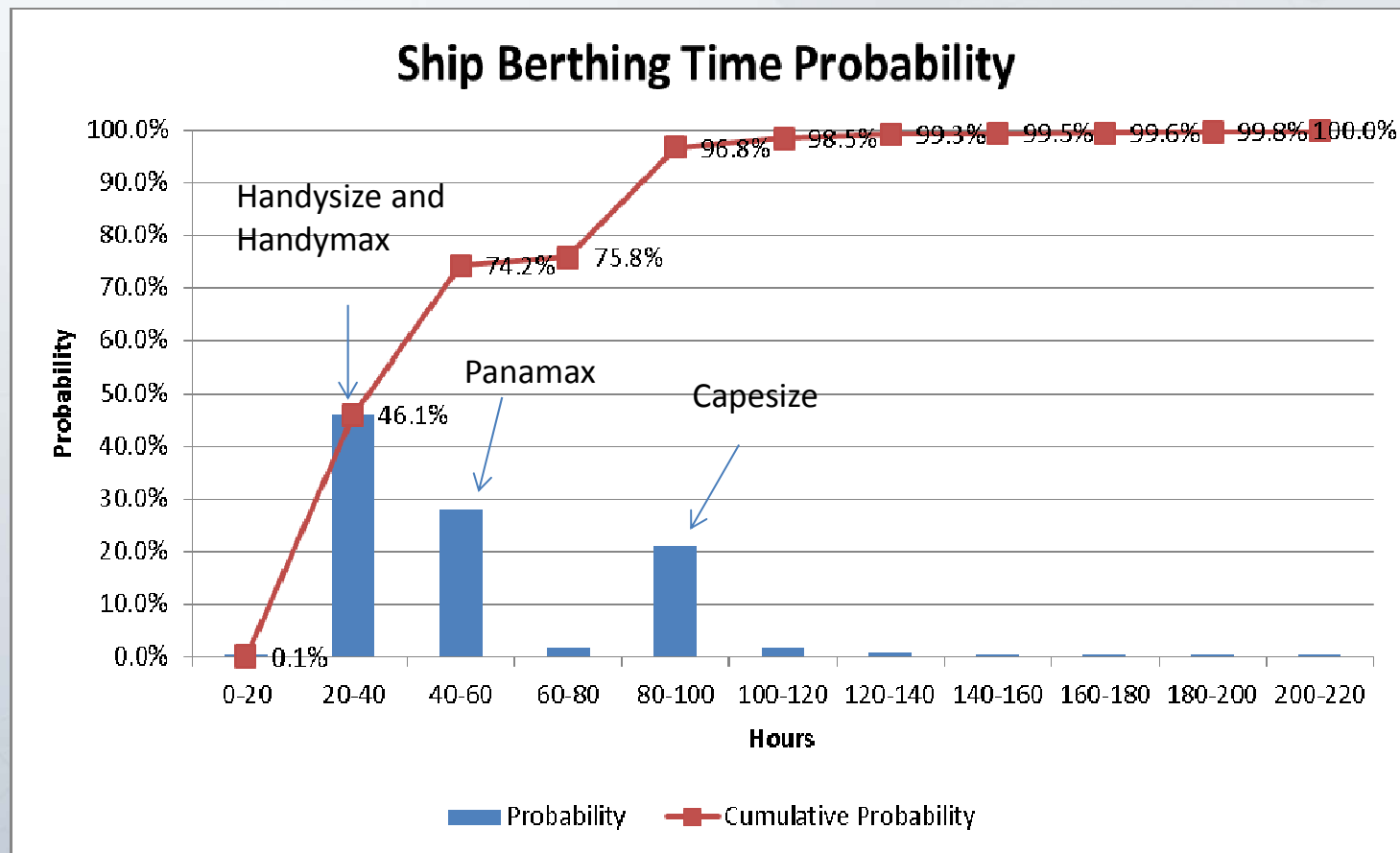Equipment Utilization Vs. Throughput

Outputs – Stockpile Tracking

Outputs – Stockpile State Probabilities
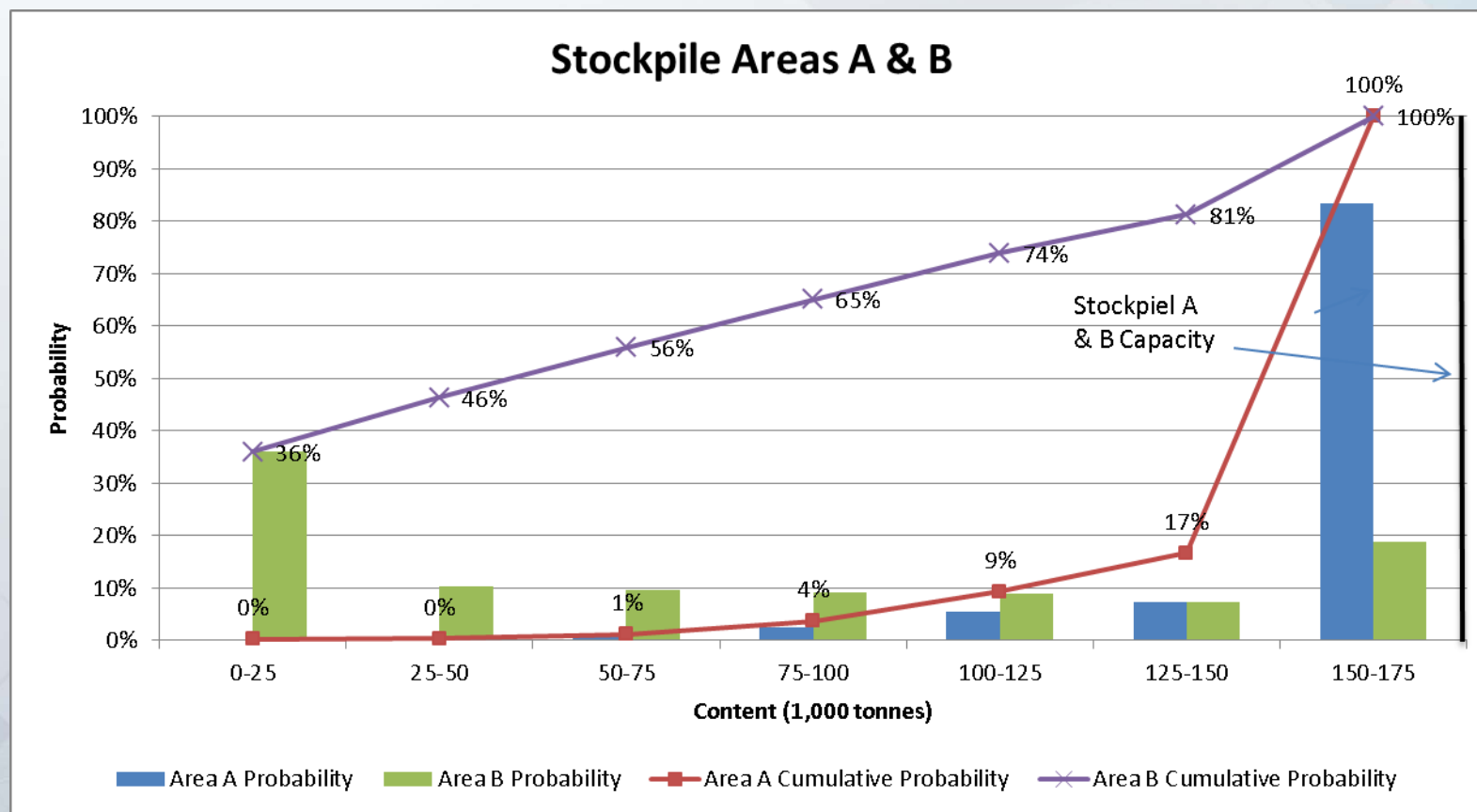
Outputs – Berth Time Probabilities

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*

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Thank You

Bull Pen

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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**