Independent Verification & Validation of Integrated Supply-Chain Network Simulation and Optimization Models

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Outline

- Project Description
  - Supply-chain systems
  - Project objectives
  - Expected outcomes
- Supply-chain system simulation specification
  - Multi-chain component simulation
  - Strategic planner
  - Knowledge interchange broker
- Validation phases
- Conclusion and future work

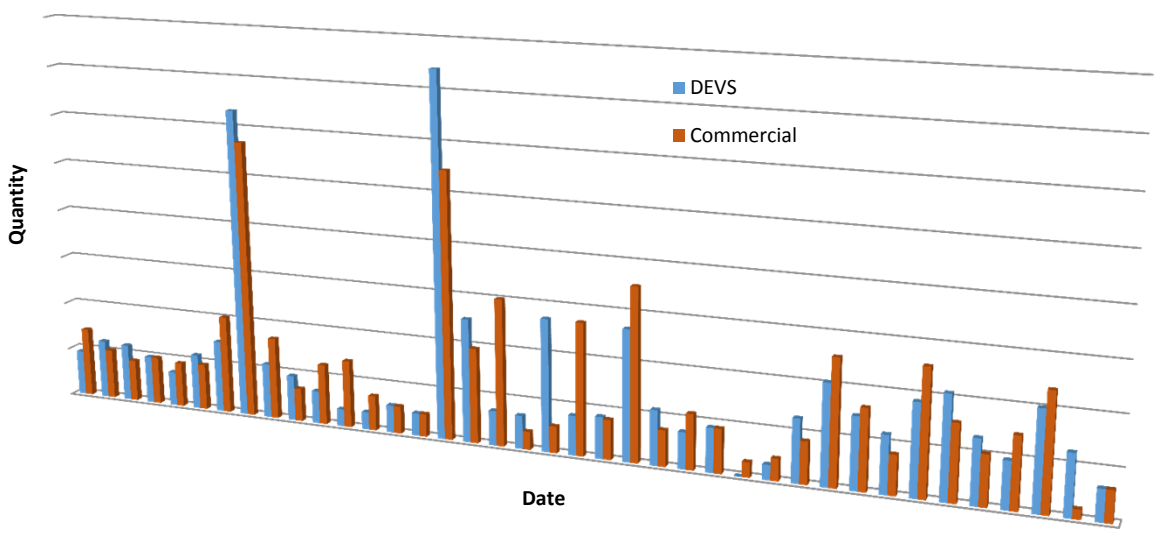
Project Overview

GOAL – Validation and verification of supply-chain network simulation using a flexible, scalable simulation environment for interacting processes/logistics and decision plans that enables development and evaluation of existing/proposed supply-chain systems

OUTCOMES – *1)* V&V for Intel's Discrete Event Simulation (DES) of production lines; *2)* Impact of modeling theory on creditability of integrated DES, Linear Programming (LP) decision plans, and Knowledge Interchange Broker (KIB) simulations.

Outcomes and Data Analysis

- Comparison between commercial and DEVS simulation results
  - This is reported in by-product by-site format
- Results may differ (up to a certain limit)
  - Considering the variability and stocahsticity of models
  - Different design perspectives
  - Various optimum solutions (integral points) in the LP model



- Both outputs can be compared with the plan (strategic planner expectation)
  - DEVS can perfectly match the expectation (will be shown in the validation section)
  - Commercial simulation cannot yet match the plan (although the simulation models are validated separately before)

Supply Chain System

Raw Material

Supplier

Manufacturing

Warehouse (storage)

Consumers

A system of inventories, processes, warehouses, and transportation mechanisms involved in producing and moving a product from raw material to finished goods and from production facilities to end customers

Supply Chain Simulation Issues & Considerations

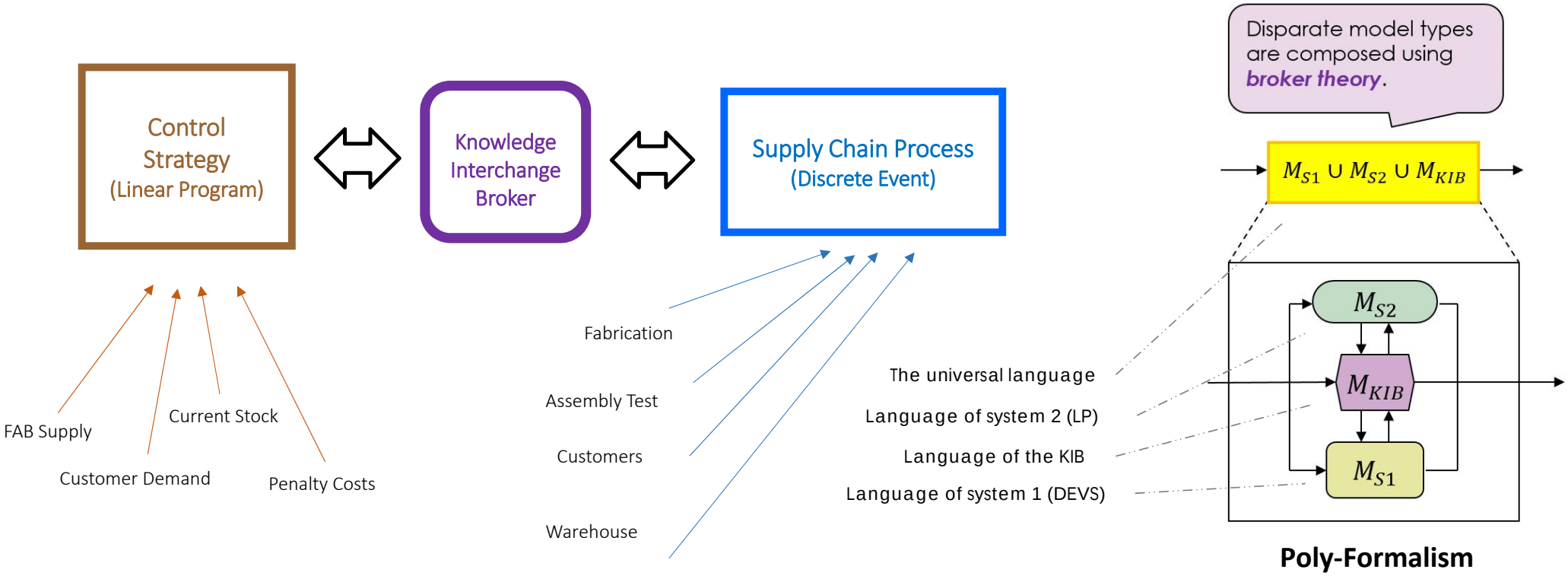
Stochasticity: production times and shipping times are inherently stochastic

Scale: the size of the optimization problem radically grows as the number of facilities, products, and transportation routes approach actual scales and complexity

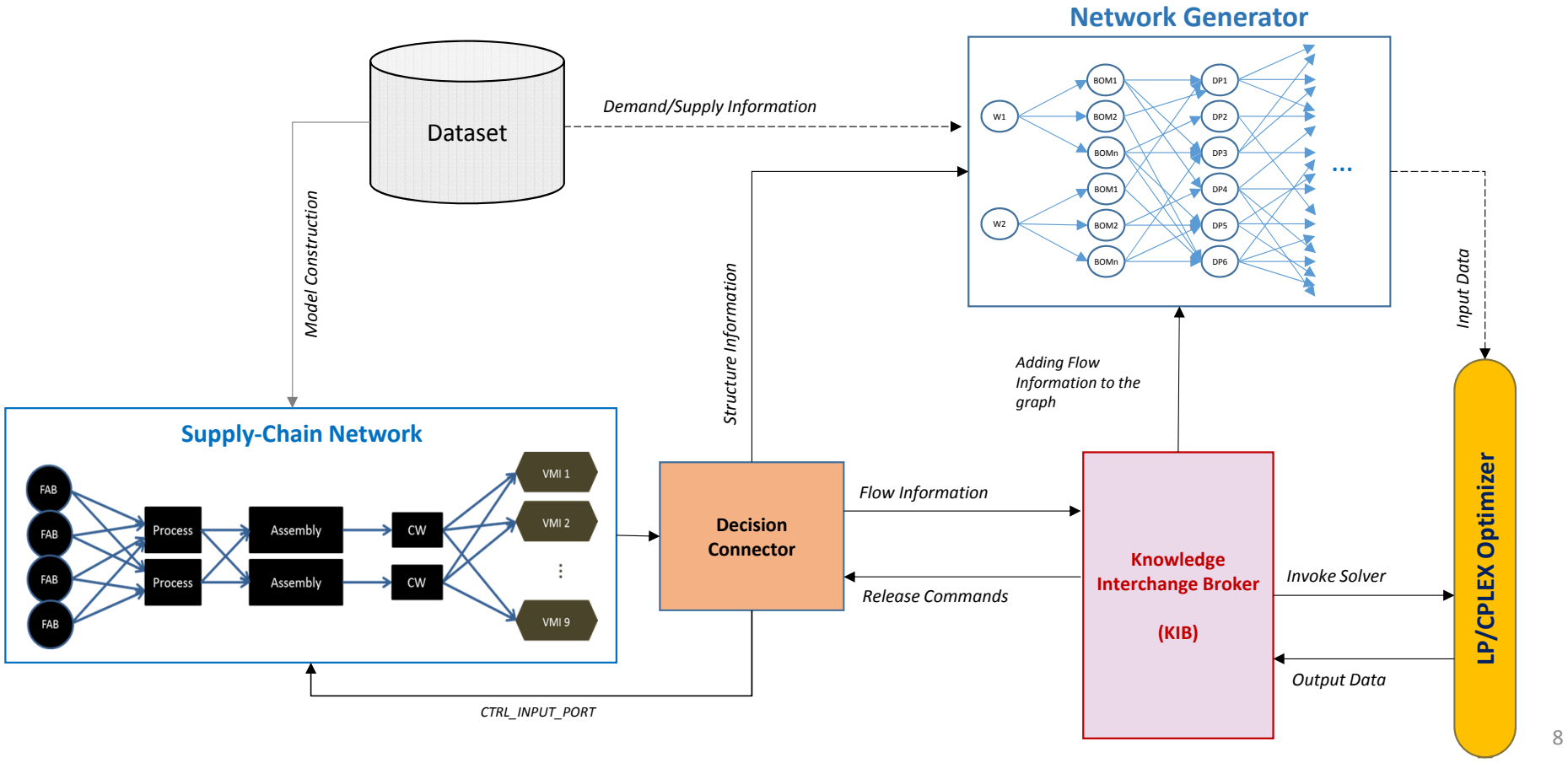
Abstraction: accurate processes/logistics model specifications are necessary to develop credible simulations; interactions between simulation and optimization models must be separately modeled as in KIB to have flexible, integrated DES and LP simulation models

Impact: credibility of decision plans depends on credible simulation as well as credible interaction models.

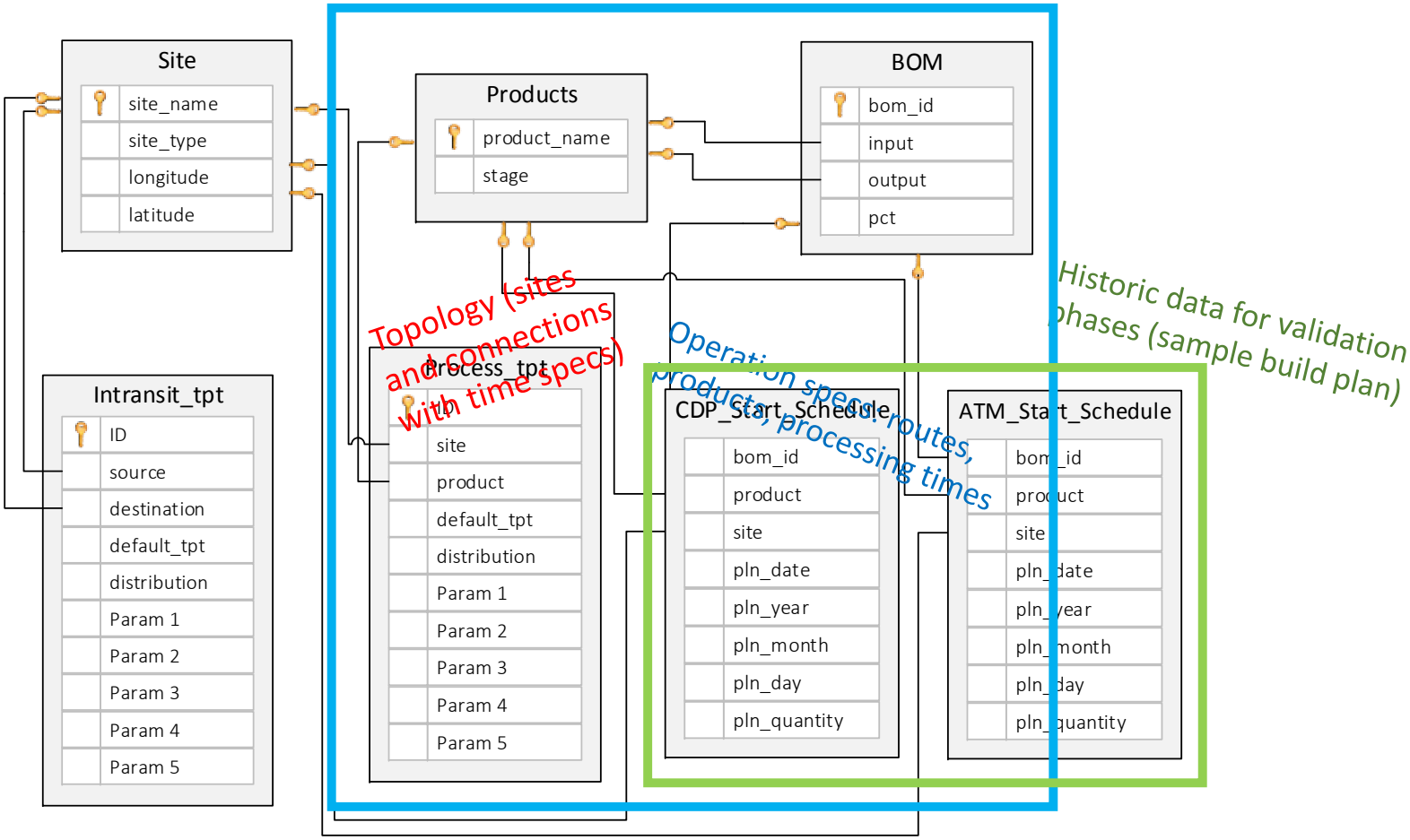
A View of an Integrated Supply-Chain Simulation System



System Architecture

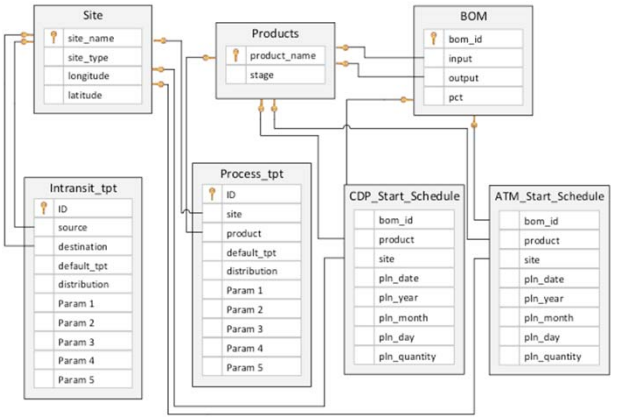


Partial View of the Dataset

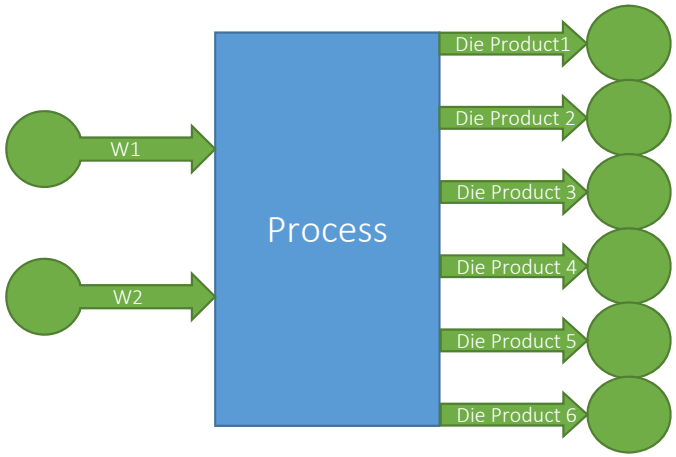


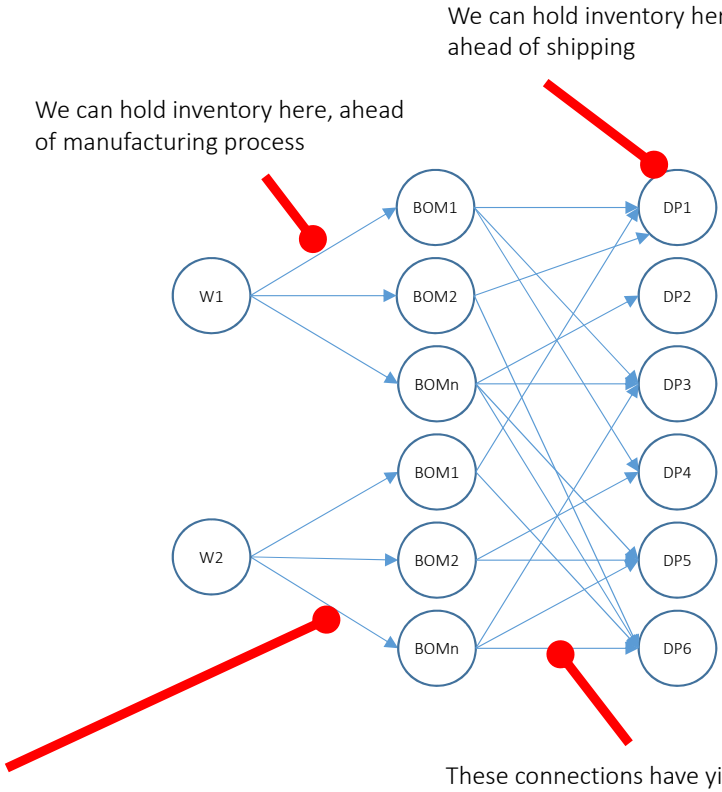
Dataset Content - DES

- Information coming from the dataset
  - Shipping times
  - Initial inventory
  - Demand at VMIs and CWs (for a full year; X)
  - Processing times (X different configurations)
  - Sites (X)
  - Shipping elements (X)
  - Products (X kinds)
  - Processing configurations (X individual routes)
- The model resulting from these record contains:
  - 620 atomic/coupled models
  - 1000+ couplings
  - …



LP Model



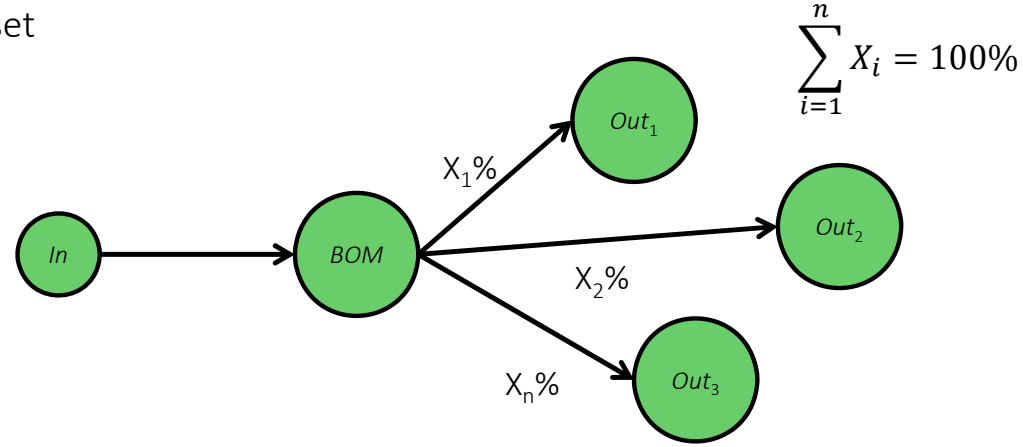


These connections have specified lead times (TPT)
Throughput time are supplied by the simulation model

These connections have yields specified to represent the BOM split

Loading Data from Simulation

- Coming from CTRL_OUTPUT_PORT (Separate initialization from run-time sim exec.)
  - BoH information for inventories and processes (provides data for LP)
- Data generated inside Decision Connector
  - Flow information
    - Demand: based on records in the dataset
    - Supply: FAB's output
  - Structure information
    - Shipping
    - BOM
    - …



Commercial DES Simulator

- Systems are constructed using pre-specified components:
  - Queues
  - Servers
  - Links
  - …
- No mathematical basis
- Uses object-oriented software concepts and methods
- Java utility classes as data structures and Java methods for receiving/processing/sending actions
- Graphical visualization of the simulation

DEVS-Suite Simulator

- Constructed using Parallel DEVS formalism

$$\langle X, S, Y, \delta_{ext}, \delta_{int}, \delta_{con}, \lambda, ta \rangle$$

$$\langle X, Y, M, EIC, EOC, IC \rangle$$

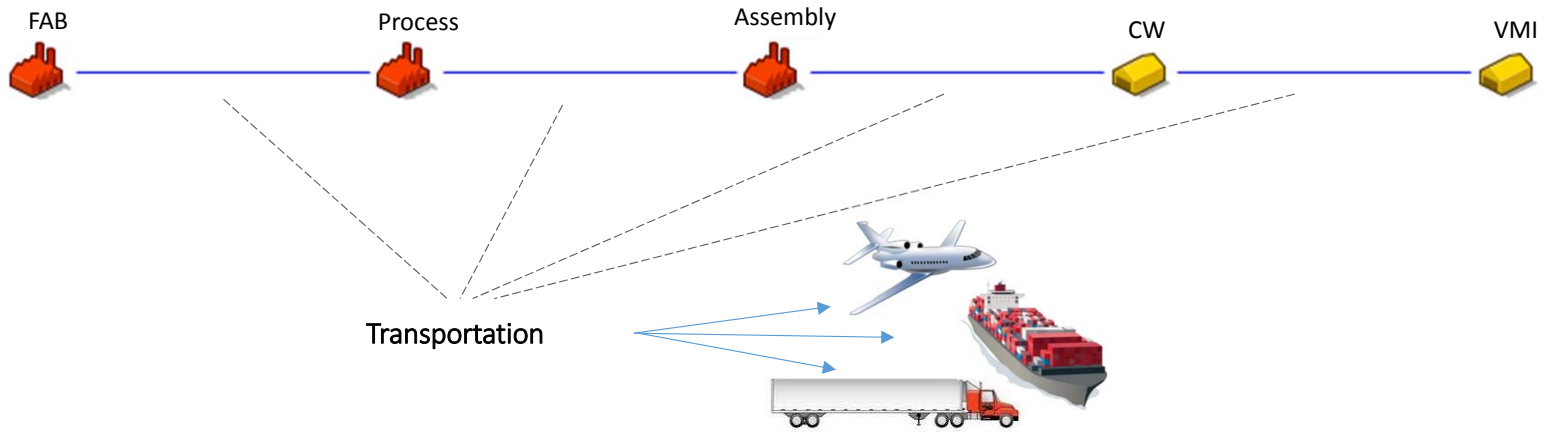
- Atomic and coupled models follow strict modularity; hierarchically models are closed under coupling
- Java methods for receiving/processing/sending messages:
  - External transition function
  - Output function
  - Internal transition function
- Graphical visualization of the simulation

Comparison of Commercial and DEVS-Suite Simulators

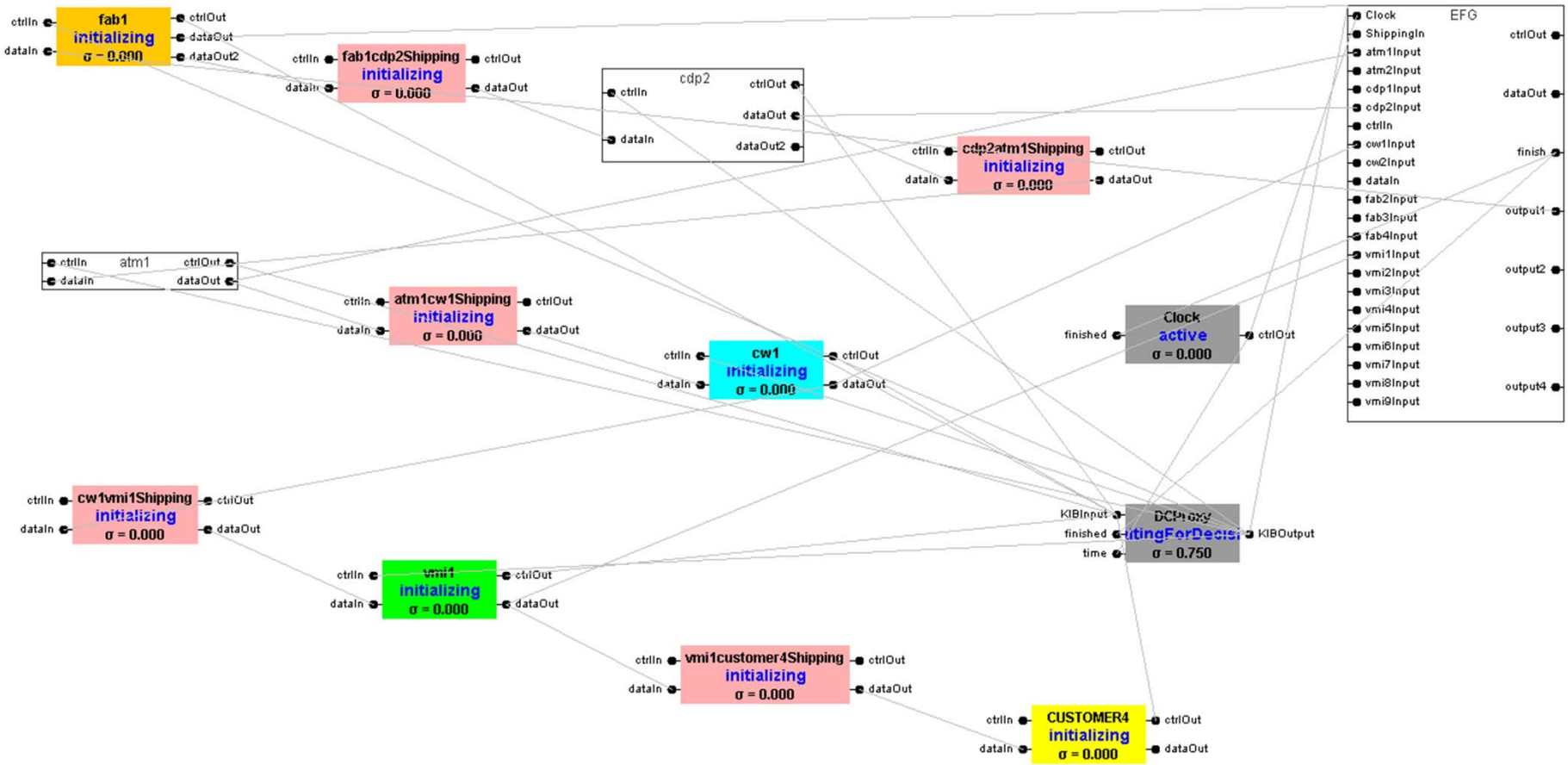
- DEVS-Suite has a theoretical foundation
- Both DEVS-Suite and the commercial simulator follow object-orientation design and implementation.
- There is one-to-one relationship between formal models and their implementation in DEVS-Suite
- Both simulators are capable of other kinds of simulation (such as agent-based) in addition to DES (however not used for this project)
- Fast and easy modeling of small systems in the commercial simulator
- DEVS-Suite is open-source; commercial simulator is not

Validation (1)

- Phase 1: Single-chain validation
  - A single chain model were designed to test simulation models
  - Simulation models for facilities and shipping components were tested with pulse and slope signals from a devised dataset
  - We expected to see the same patterns in product actual output log (DEVS and commercial simulation)
  - All processing and shipping times were set as deterministic

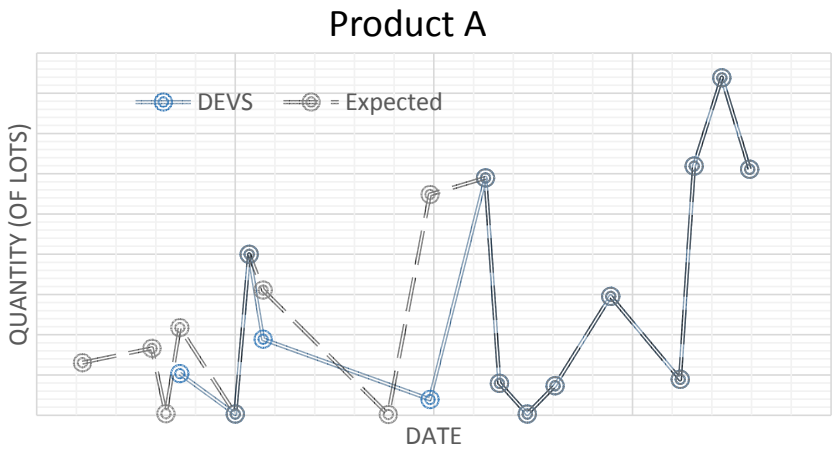


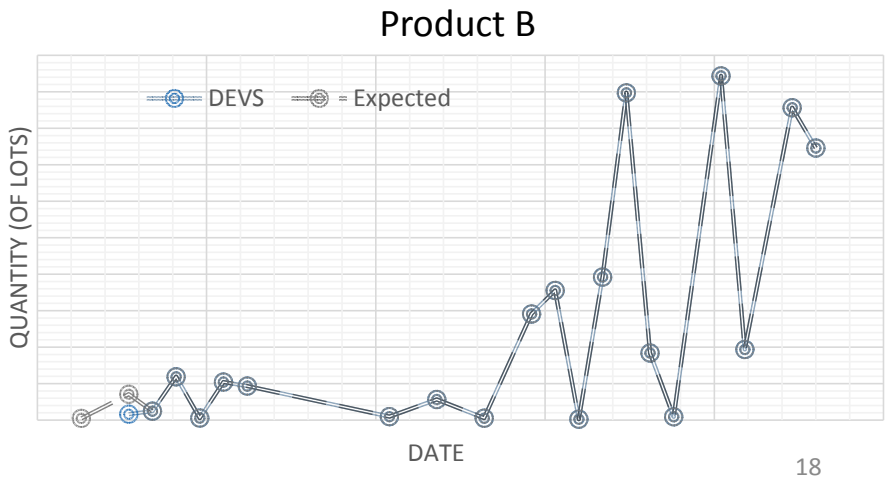
Phase 1 in DEVS-Suite



Validation (2)

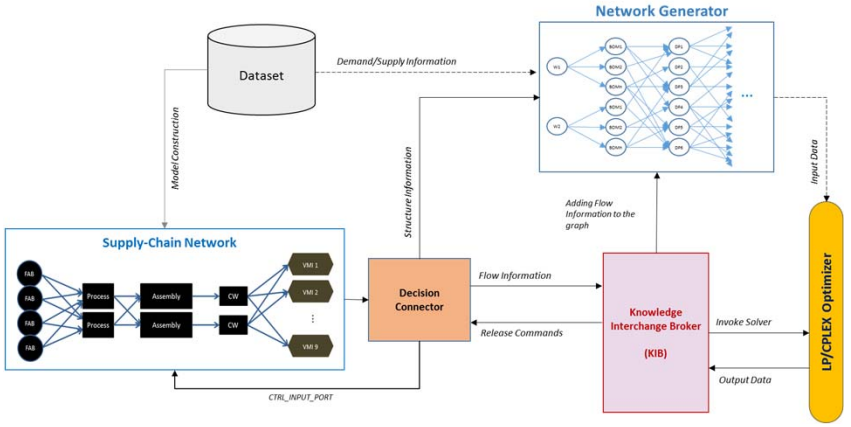
- Phase 2: Historic data validation
  - We expected to see a rough consistency between the actual output and historic delivery
  - It phases out LP and KIB validation
  - Plots are generated in a by-product by-site basis
  - Stochasticity is imported from the dataset for processing/shipping times





Validation (3)

- The complete model with KIB, LP, and simulation models
  - KIB is validated by comparing results between KIB-based simulation and non-KIB-based ones
  - The totality of the simulation is validated (system-wide validation) by comparing actual output log with the expected ones
  - By-product by-site plots are created as a result of this simulation
  - The complete model with
    - 620 atomic/coupled models
    - 1,000+ couplings
    - X data record (demand, routes, …)
    - Stochastic processing/waiting times
    - X set of products (X kinds)
    - …

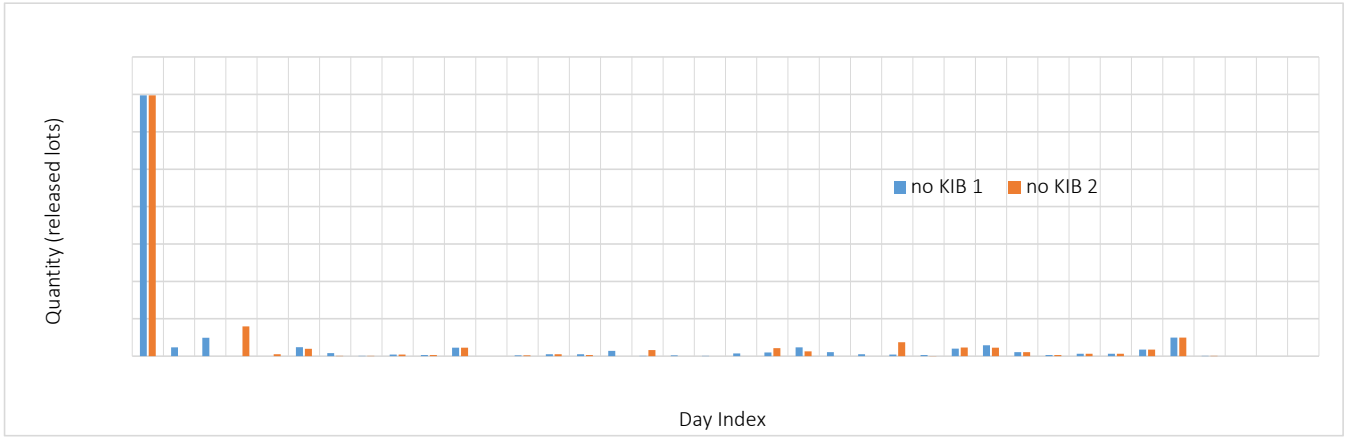


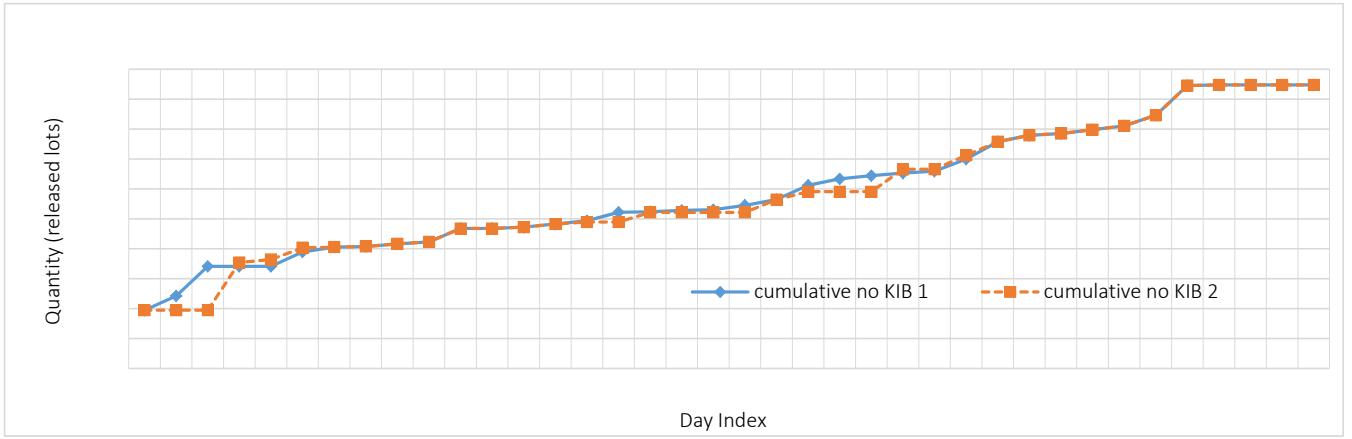
Validation Phases (summary)

	Stochastic proc. Times	Multi-chain model	Historic release commands	Database	LP	KIB	Input data
Phase 1 (single chain)				✓			Pulse and step functions
Phase 2 (historic data)	✓	✓	✓	✓			Network topology, processing times, initialization, and release commands from the dataset
Phase 3-1 (KIB validation)	✓	✓		✓	✓	✓	1. Network topology, processing times, and initialization from the dataset. 2. KIB transformations form configuration XML files
Phase 3-2 (System-wide)	✓	✓		✓	✓	✓	The output of the simulation against the expected output

Results (1) – no KIB

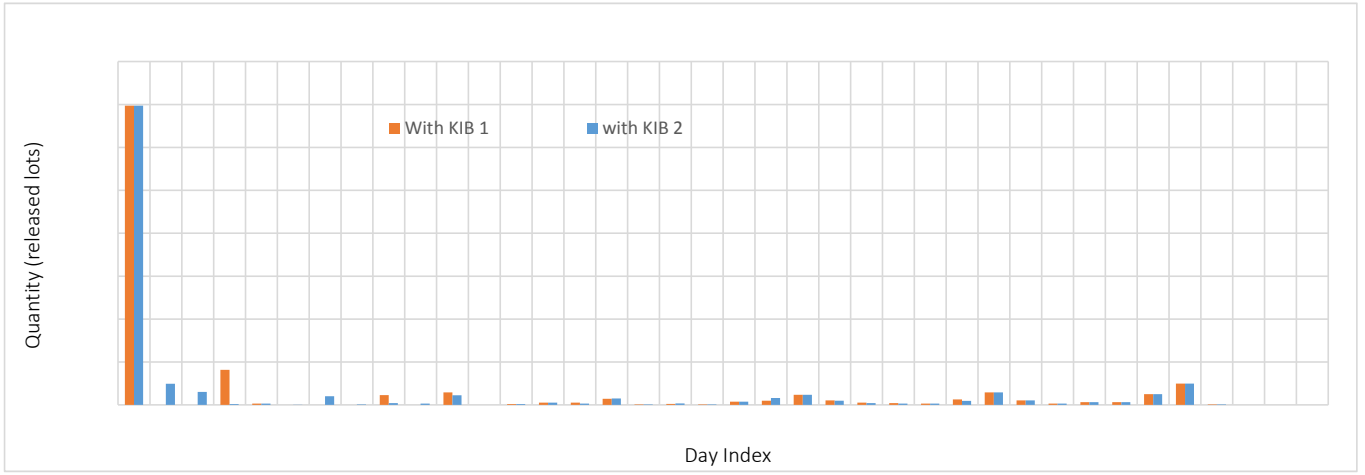
- All processing/shipping times were changed to deterministic times
- Two experiments without the KIB
- Expected to see reasonably close results (not identical)
  - Since LP is not under our control and multiple solutions may exist, two instances may have different results

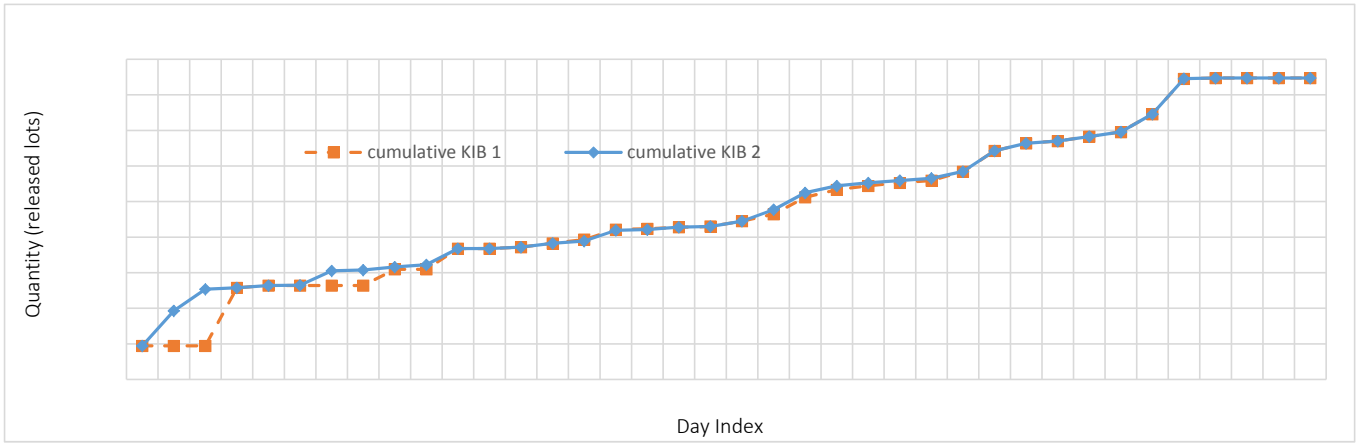




Results (2) – with KIB

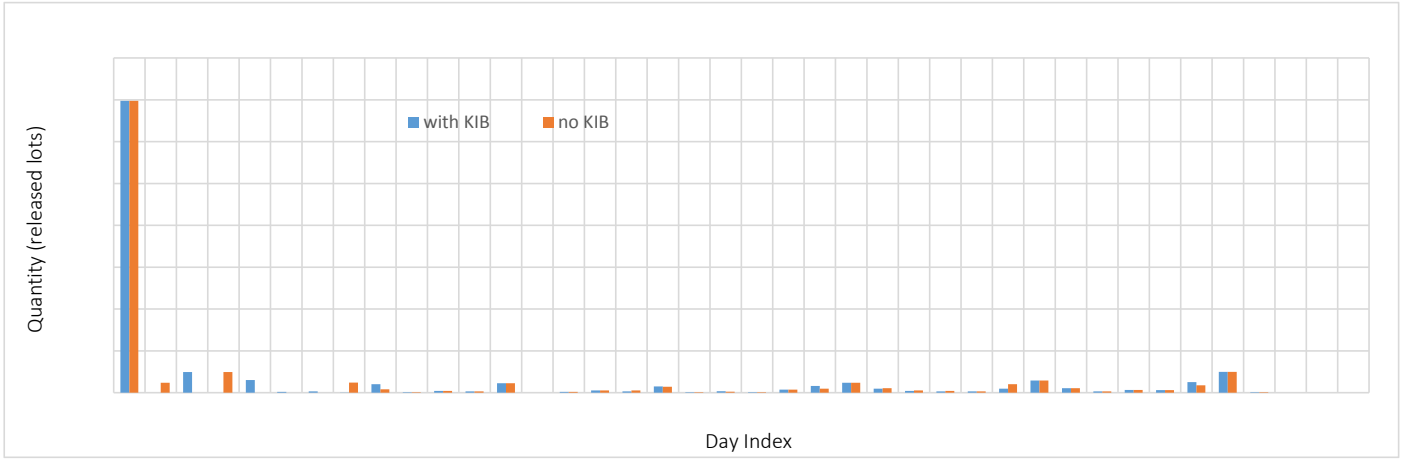
- All processing/shipping times were changed to deterministic times
- Expected to see reasonably close results (not identical)
  - Since LP is not under our control and multiple solutions may exist, two instances may have different results

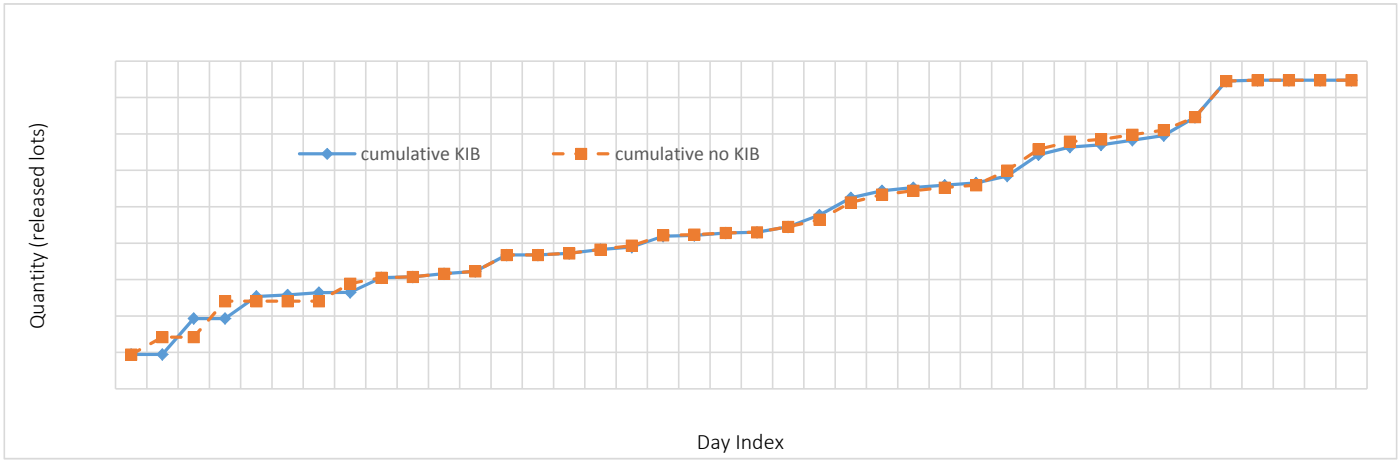




Results (3) – no KIB vs. with KIB

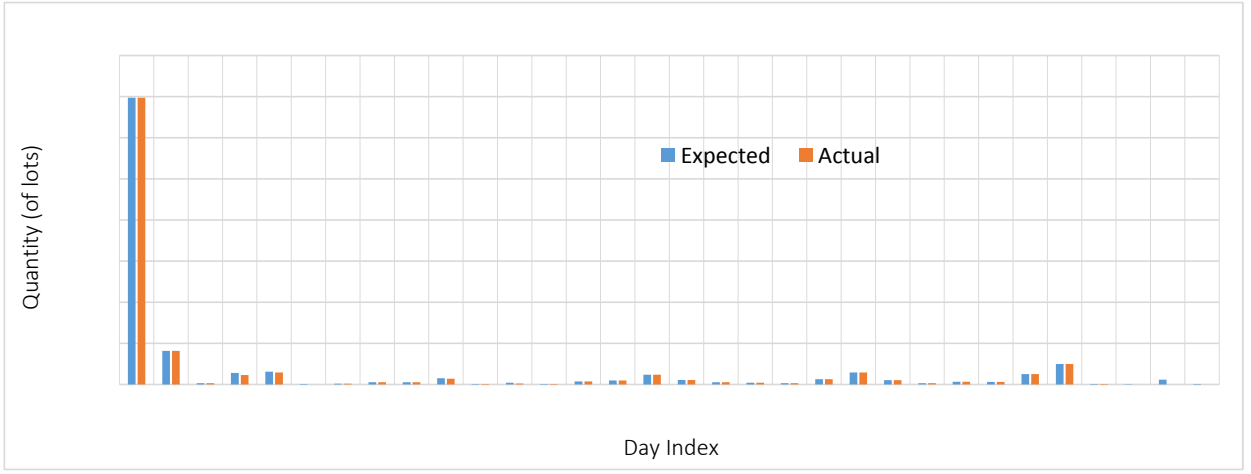
- One experiment with the KIB and the other without it
- Similar to the previous experiments, the results may have slight differences because of the unpredictability in the LP side

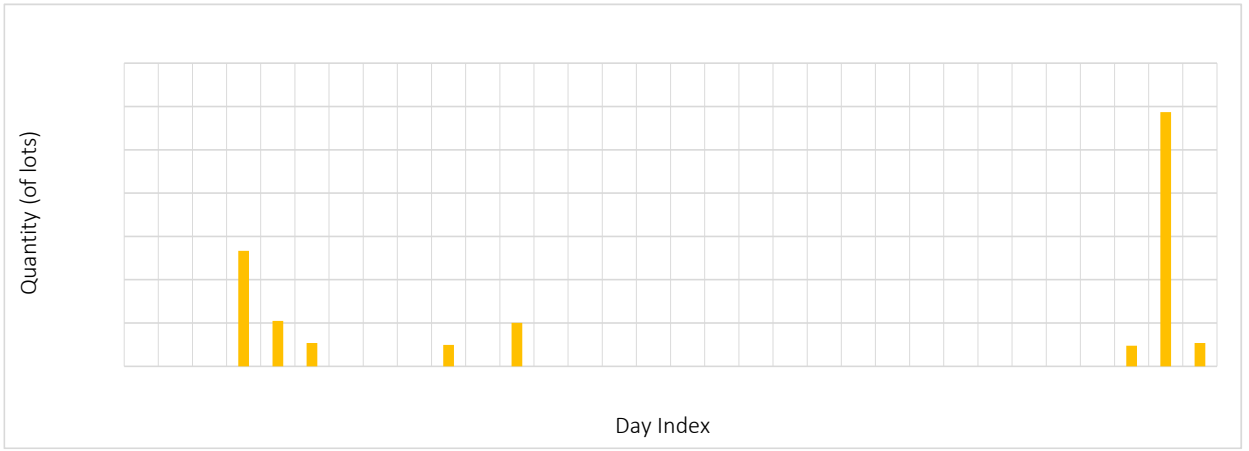




Results (4)

- System-wide validation:
  - The second plot is reporting the difference between the plan (LP results) and the actual outputs (reported in the first plot)
  - The threshold of acceptable difference is set by domain experts and based on the current state of the system

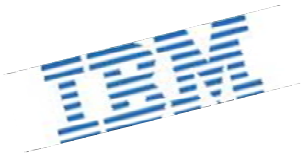




Simulation Platform Spec

- Software
  - Java 7 – 64bit
  - Windows 7 – 64bit
  - IBM ILOG CPLEX Optimization Studio 12.5
  - DEVS-Suite 2.1.0
  - Microsoft SQL Server 2012 Developer version
- Hardware
  - Intel Core 2 Duo – 2.9GHz
  - 8GB of physical memory (DDR3)

➢ Maximum memory usage: 5.8 GB



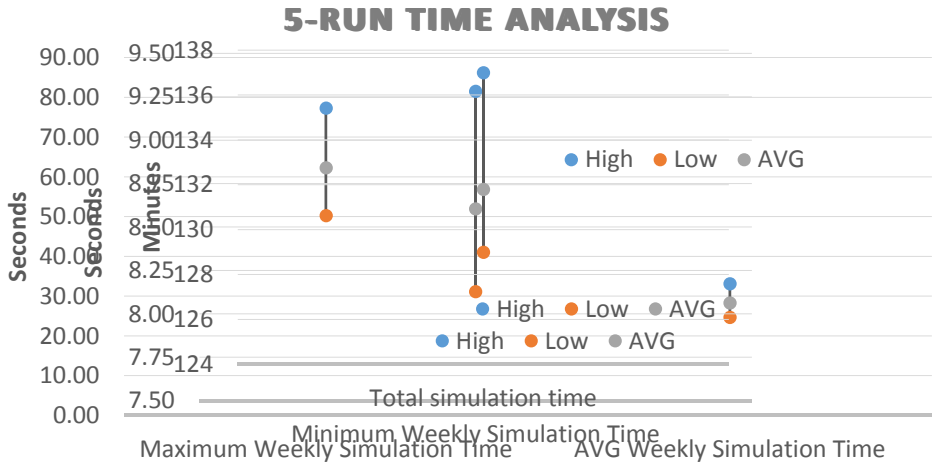

Performance Analysis

Minimum Simulation Time (for one week):	8.61 sec
Maximum Simulation Time (for one week):	62.29 sec
AVG Simulation Time (for one week):	28.30 sec
Total simulation time (59 weeks)	131.8 minutes

* Simulation time measures the duration of simulation for one week
* Each solves takes 114 seconds on average

Time Analysis

	High	Low	AVG
Minimum Weekly Simulation Time	9.28(s)	8.13(s)	8.61(s)
Maximum Weekly Simulation Time	77.28(s)	50.26(s)	62.29(s)
AVG Weekly Simulation Time	33.13(s)	24.69(s)	28.30(s)
Total 59-week simulation time	137(m)	129(m)	131.8(m)



Conclusion & Future Work

- Developed a simulation platform by integrating discrete event simulation, strategic control, and knowledge interchange broker
- Validated Intel's commercial simulation model
- Fed data for data analysis/mining team

❖ Future Work

- Simulating company-level operation
- Integration with tools where the simulation/optimization data can be mined for information aiding control and operation