Introduction to Supply Chain Simulation
Carnegie Mellon University

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Presenter Background
Ricki Ingalls

• Current Position
  ▫ Principal and Co-Founder, Diamond Head Associates Inc.
  ▫ Associate Professor, Oklahoma State University, School of Industrial Engineering and Management
  ▫ Former Site Director, Center for Engineering Logistics and Distribution (CELDi)

• Education

• Work Experience
  ▫ 30+ Years, including 16 years in industry and 14 years consulting after joining OSU.
My Partner at DHA
Randall Gibson

• Current Position
  ▫ Co-Founder and Managing Principal – Diamond Head Associates, Inc. – San Diego, CA

• Prior Experience
  ▫ 32 years in simulation industry as analyst, program manager, & business manager/simulation proponent - as founder of Automation Associates Inc. (Acquired in 2005 by TranSystems Corp.)
  ▫ Co-founder of two other high tech software companies
  ▫ 21+ years in real time process control, automation, and computer systems applications.

• Education
  ▫ M.E. – Elect. Engr./Comp. Sci. – University of California, Berkeley
  ▫ B.S. – Applied Physics; Psychology – Univ. of California, San Diego

Thinking about today

• I don’t know if I am here to referee the prize fight:
  ▫ *The Thrilla in Savannah: SUPPLY CHAIN OPTIMIZATION VS. SUPPLY CHAIN SIMULATION*

• Or if I am here to convince you to hire my star athlete:
  ▫ *I am the agent for SUPPLY CHAIN SIMULATION and he has some great skills that you need on your team.*

• Regardless, I am pretty sure someone is going to be offended.

• So, let’s get going...
Optimization is like AutoTrader

Simulation is like a test drive
The three swear words: Modeling, Optimization, and Simulation

- There are two words I never use in mixed company (academics and industry people) - Optimization and Simulation. I will use the word “Model,” but I have to be careful.
- Let’s say that you have a very dynamic supply chain that you want to analyze. What does your VP think when you tell him...
  - “I am going to model your supply chain.”
  - “I am going to optimize your supply chain.”
  - “I am going to simulate your supply chain.”

What these words mean

<table>
<thead>
<tr>
<th></th>
<th>Your VP</th>
<th>The Academic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>MRP and/or Excel</td>
<td>Any mathematical or logical formulation</td>
</tr>
<tr>
<td><strong>Optimize</strong></td>
<td>An efficient system in spite of real world problems</td>
<td>The best alternative of all mathematical formulations</td>
</tr>
<tr>
<td><strong>Simulate</strong></td>
<td>An MRP simulation</td>
<td>A detailed computer model that mimics the real system</td>
</tr>
</tbody>
</table>
Now that somebody is offended...
What we want to accomplish today

- Take an overview of different modeling techniques that are used and discuss their pros and cons.
- Work through a small example to emphasize the pros and cons.
- Discuss real supply chain simulation issues and why simulation is a good approach.

What are the two most important questions in any project?

- What question(s) are you trying to answer?
- What constitutes a good answer?
What question(s) are you trying to answer?

- The answer to this question should be:
  - Comprehensive. It can be a sentence or two.
  - Defines the boundaries of the problem and the key outputs to be analyzed.

- This question
  - Focuses the project on the real problem
  - Avoids scope creep
  - Should start every presentation on this project

An example

- This project will analyze the supply chain of all server products currently produced in Europe for consumption in the Asia-Pacific region and analyze the alternative of moving the production of those products to Singapore. Which of these two alternatives increases customer on-time delivery and corporate profits?
What constitutes a good answer?

- How is this different from “the question you are trying to answer?”
  - This answer to this question helps you understand the organizational issues involved.
  - You never put the answer in a Powerpoint presentation
- Some things in the answer
  - Due Date
  - It has to comprehend the “burr under the saddle” or “what is keeping the VP awake at night”
  - The VP has to be able to understand the basics of the process

A Supply Chain Example

PROBLEM STATEMENT:
The following supply chain has three possible ways to deliver products FINAL1 and FINAL2 to the customer CUST. All sites are eligible to be closed down, unless there is a minimum production value given.

ASSUMPTIONS:
1. Time is not considered in the model
2. There are two final products (FINAL1 and FINAL2) and three raw materials (RAW 1, RAW 3, and RAW 4)
3. Minimum must be calculated
4. Costs on the arcs are the transportation costs per unit shipped. All transportation lanes are assumed to have infinite capacity.
5. All capacities are joint if more than one product is handled at the facility.
Example 1: What are the two most important questions?

- What question(s) are you trying to answer?
  - Can we characterize our total supply chain costs and structure?
- What constitutes a good answer?
  - Any answer is good because the management does not understand where supply chain costs are occurring.

We answer that question with a spreadsheet model

- Take all of the information in the problem and put it in a spreadsheet.
- Manipulate allocations to reflect a management strategy.
- For Example:
  - We want to keep the DC active, so 50% of all products will go from the DC to the customer.
  - The remaining 50% are split between the 2 manufacturing sites
  - The DC receives products from evenly from both manufacturing sites
  - The manufacturing sites receive RAW 1 from the closest supplier
Example 2: What are the two most important questions?

- What question(s) are you trying to answer?
  - Can we determine the supply chain structure that costs the least amount of money?
- What constitutes a good answer?
  - The management believes that our supply chain is inefficient and costs can be cut if we get the right suppliers and redeploy product in the supply chain.
We answer that question with an optimization model

- Give the model a superset of the supply chain
  - All of the possible locations
  - All of the possible transportation routes
  - All of the necessary capacities
  - All of the necessary costs, including site opening/closing costs.
- Allow the model to choose the “best” supply chain based one or more of the following:
  - Cost
  - Profit
  - Time

Our optimization solution
Example 3: What are the two most important questions?

• What question(s) are you trying to answer?
  ◦ We are carrying several weeks of inventory in the supply chain. Do we need that much inventory? How will decreasing inventory affect customer satisfaction?

• What constitutes a good answer?
  ◦ We need to drop more costs by dropping inventory while not hurting customer satisfaction.

That question needs a simulation model

• Now that we have the structure of the supply chain, we need to answer some important questions:
  ◦ What is my customer satisfaction?
  ◦ How do lead times affect my product delivery?
  ◦ What if my demand exceeds my capacity on a given day?
  ◦ Is my inventory policy really working?

• We will run 30 different 1-year models with different random demand to determine how the system performs.
2 Alternatives

• First, evaluate our current business scenario.
• Second, evaluate dropping finished good inventories from two weeks to two days.

Alternative 1 Data Inputs

• Because the simulation is more realistic and mimics the real system, we need more input data:
  ◦ Revenue is $1500/unit (expected $37.5M)
  ◦ Daily Demand is random that averages 15000/365 units per day for FINAL 1 and 10000/365 units per day for FINAL 2.
  ◦ Finished Good Inventory at the DC: 2 weeks
  ◦ Production Cycle Time in Manufacturing: 3 days.
  ◦ Raw Material Inventory at Manufacturing Sites: 2 weeks
  ◦ Transportation Times: Varies based on the source and the destination.
  ◦ Capacities: Daily Capacities are Site Capacities/365.
Alternative 1 Outputs

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$37.2M</td>
<td>$35.8M</td>
<td>$39.1M</td>
</tr>
<tr>
<td>Costs</td>
<td>$33.1M</td>
<td>$31.9M</td>
<td>$34.5M</td>
</tr>
<tr>
<td>Profit</td>
<td>$4.16M</td>
<td>$3.89M</td>
<td>$4.52M</td>
</tr>
<tr>
<td>Inventory Value</td>
<td>$2.72M</td>
<td>$2.71M</td>
<td>$2.74M</td>
</tr>
<tr>
<td>ICC</td>
<td>$1.36M</td>
<td>$1.36M</td>
<td>$1.37M</td>
</tr>
<tr>
<td>Profit w ICC</td>
<td>$2.80M</td>
<td>$2.53M</td>
<td>$3.16M</td>
</tr>
<tr>
<td>Missed Revenue</td>
<td>$181K</td>
<td>$15.0K</td>
<td>$330K</td>
</tr>
<tr>
<td>Missed Demand 1</td>
<td>0.27%</td>
<td>0.00%</td>
<td>0.66%</td>
</tr>
<tr>
<td>Missed Demand 2</td>
<td>0.80%</td>
<td>0.02%</td>
<td>1.74%</td>
</tr>
</tbody>
</table>

Alternative 2 Data Changes

- It is obvious that we are carrying a lot of inventory (approximately 13.6 financial turns/year) and meeting the customer demand.
- We have been tasked by management to increase inventory turns at least 18. Let’s run a scenario were the finished good and raw material inventories are cut to 2 days and see what we get.
### Alternative 2 Outputs

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>% Chng</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$36.2M</td>
<td>$35.2M</td>
<td>$37.1M</td>
<td>3.0%</td>
</tr>
<tr>
<td>Costs</td>
<td>$31.8M</td>
<td>$31.0M</td>
<td>$32.6M</td>
<td>3.8%</td>
</tr>
<tr>
<td>Profit</td>
<td>$4.32M</td>
<td>$4.07M</td>
<td>$4.62M</td>
<td>3.9%</td>
</tr>
<tr>
<td>Inventory Value</td>
<td>$1.71M</td>
<td>$1.68M</td>
<td>$1.74M</td>
<td>37.4%</td>
</tr>
<tr>
<td>ICC</td>
<td>$853K</td>
<td>$838K</td>
<td>$868K</td>
<td>37.4%</td>
</tr>
<tr>
<td>Profit w ICC</td>
<td>$3.47M</td>
<td>$3.22M</td>
<td>$3.77M</td>
<td>24.0%</td>
</tr>
<tr>
<td>Missed Revenue</td>
<td>$1.42M</td>
<td>$0.35M</td>
<td>$2.38M</td>
<td>682%</td>
</tr>
<tr>
<td>Missed Demand 1</td>
<td>3.30%</td>
<td>1.13%</td>
<td>5.95%</td>
<td>1100%</td>
</tr>
<tr>
<td>Missed Demand 2</td>
<td>4.39%</td>
<td>0.76%</td>
<td>9.05%</td>
<td>452%</td>
</tr>
</tbody>
</table>

### What can we say about the simulation?

- In this small example, we show that the answers are not straightforward. You can
  - Improve profitability
  - Meet inventory targets (21.7 turns vs. 13.6 turns)
  - Make more customers dissatisfied
  - Miss more revenue
- The simulation simply gives realistic alternatives to consider.
The type of analysis is based on the two most important questions

- What question(s) are you trying to answer?
  - If you need to pick the best from a multitude of static solutions, then you need to optimize.
  - If you need to evaluate dynamic conditions, such as customer satisfaction or varying customer demand, the you need to simulate.

- What constitutes a good answer?
  - Listen to what your managers are really saying. They will tell you what is keeping them up at night.

Business situations where optimization will not work.

You can get very offended now.
Optimization can’t handle demand forecast changes and forecast error

- No one variable effects the movement of material through a supply chain like demand forecast changes.
- If the demand forecast is up, the chain tries to produce more product in order to fill inventories up to their proper levels. This can mean overtime expenses, expediting charges, and other charges.
- If the demand forecast is down, then manufacturing sites go idle, materials already in inventory go obsolete, and costs already in the chain have to be absorbed.

Optimization can help manage downside risk for Wall Street

- 1. The company announces earnings and makes "forward looking statements".
- 2. Based on the "forward looking statements" and other information, the Wall Street analysts estimate the company’s earnings in the future, starting with the next quarter.
- 3. The stock price goes up (or down) based on the future earnings estimates.
- 4. The company announces the next quarter’s earnings.
  - 4.1. If the company does not meet the earnings estimates, the stock price plummets.
  - 4.2. If the company meets (or even exceeds) the earnings estimates, the stock stays stable.
- 5. Go to Step 2.
Simulation shows the effect of variance

Net Profit After Tax

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
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<tbody>
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</table>

There are some real business issue optimization can’t address

- Too complicated to optimize
  - Rule-based or prioritized schemes
- Variance, Variance, Variance
  - This is the primary reason for using simulation over optimization.
  - If variance is a key driver in your supply chain, an optimization will not capture the supply chain dynamics.
Back to that swear word – “optimization”

- Senior Management could care less about optimization
  - In a business sense, to *optimize* is to make something as good as you can, in spite of the variance.
- An optimal supply chain
  - Delivers product even if the demand forecast is dead wrong.
  - Operates at an acceptable cost regardless of machine breakdowns, labor shortages, and material shortages.
- To senior management, an optimal supply chain is not optimal at all. An optimal supply chain is robust.

How we have used supply chain simulation

- Analyze the company’s and/or their competitors’ supply chains.
- Find order-of-magnitude financial improvements and sustainable competitive advantages.
- Evaluate different, and possibly radical, supply chain ideas.
- Measure the supply chain impact on the corporate financial measurements, including Net Profit After Tax, ROIC, and EVA.
We identified big improvements with both optimization and simulation

• Optimization:
  ▫ In Canada, we restructured the supply chain and cut non-material costs by 18%.
  ▫ We integrated new acquisitions to best serve both the new combined customer base.

• Simulation:
  ▫ For the North American market, we showed increased profitability and significantly increased customer service (over 20% points) by moving certain supplier from Far East to North America.
  ▫ In Asia/Pacific region, we showed that high-end products should be produced locally to improve customer service and profitability.
  ▫ For one product group, we dropped inventory by over 65% and costs by over 20%.

In conclusion

• Optimization and simulation both have their place in analyzing supply chains
• Simulation shows its strength when the supply chain is very dynamic and has transient performance problems
• Simulating a supply can be very complex because a model must mimic several key business processes, including the basic MRP process, planning and scheduling, capital acquisition, labor policies, allocation of constrained resources, etc.
• If modeled correctly, a supply chain simulation can show ways to increase revenues, profitability, and service levels to the customer. This can translate into large financial advantages to the company.
I told you he had great skills. Are you ready to sign him?