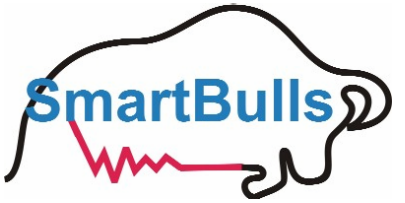

Controlling the Bullwhip Effect

- through Insight and/or Algorithms

Presentation at the ELO Seminar March 17, 2004

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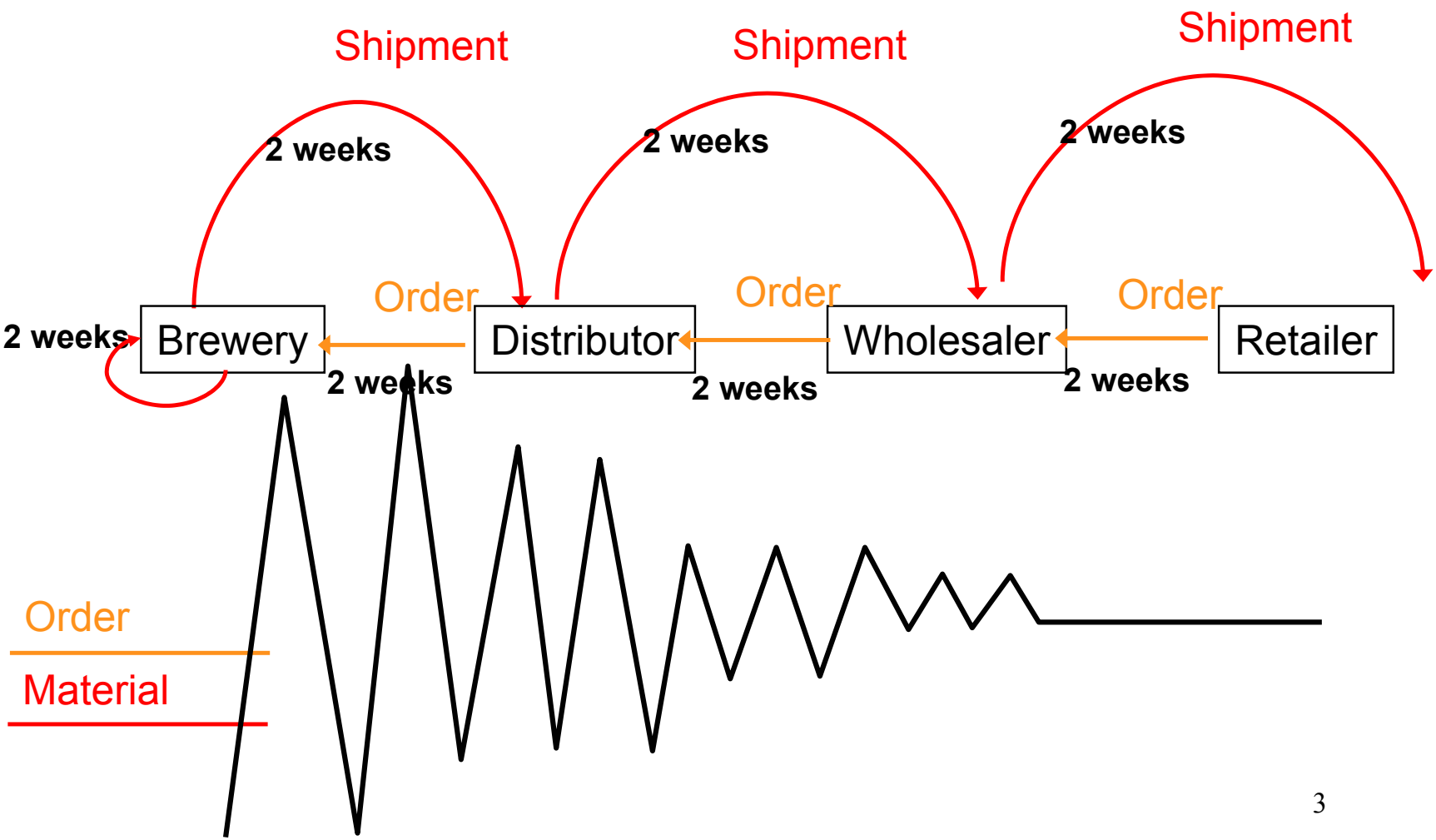
IAMSR / Åbo Akademi

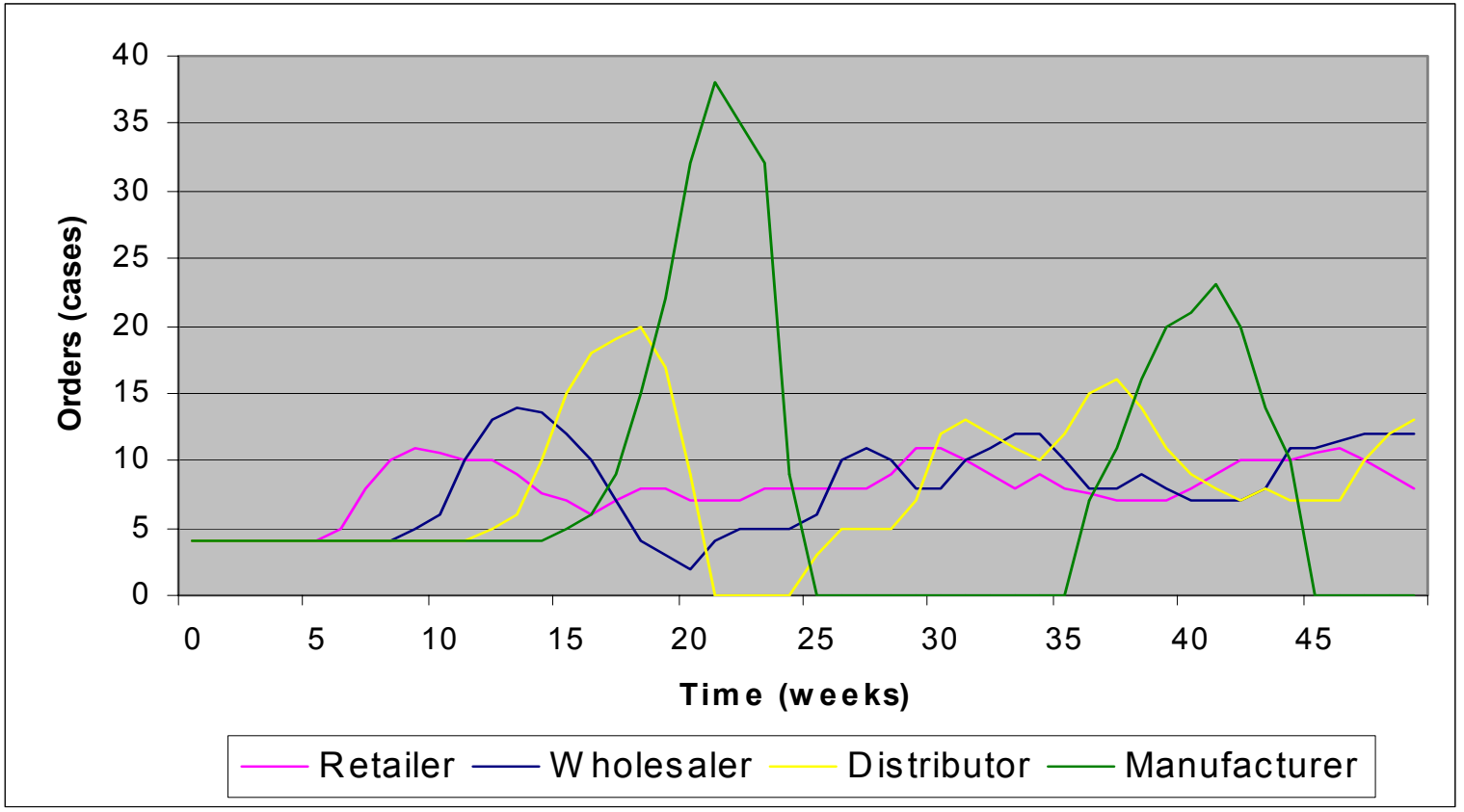
The Beer Game

- The Beer Game [MIT] has been played for many years
- Its purpose is to show the supply chain dynamics in a simulated real life environment
- Played by
  - Managers in management workshops
  - Students in business schools throughout the world
- The participants act as a player in a beer distribution chain
- The initial demand is stable and in equilibrium, then a change is introduced

The Beer Supply Chain

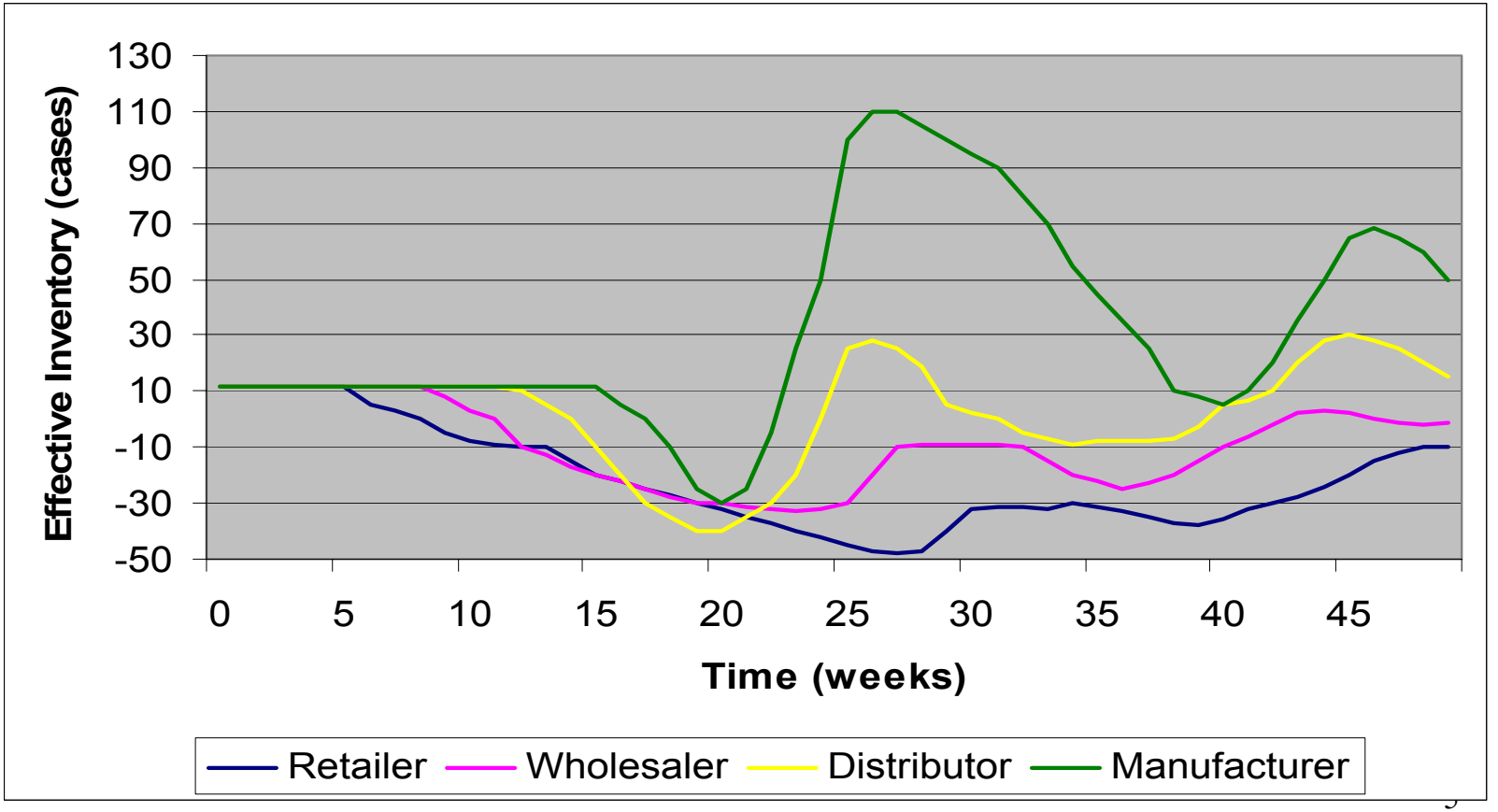


Orders for Beer: Base Case



Source: Van Ackere et al, 1993.

Orders for Beer: Base Case



The Bullwhip Effect in the Beer Game is Caused by...

- ... players making fully rational decisions...
- ... based on local information only...
- ... missing information on the whole supply chain.
- … worrying about the fate of other actors in the supply chain could change the outcome

What Causes this Bullwhip Effect?

- Demand forecast updating
  - no visibility of end demand in the supply chain
  - multiple forecasts in the supply chain
- Long lead times
- Rationing and shortage gaming
  - When short of supply actors in the chain order over their actual needs to satisfy their demand; need to consider the actions of others as well
- Order batching
  - Due to Full Truck Load, Full Ship Load, etc economics and high order costs, players batch small orders into one large order
- Price fluctuations
  - High-low pricing: when price is low demand is high and vice versa

Common Wisdom

- Generally there is much to gain with efficient Supply Chain Management and the elimination of the Bullwhip effect
- SAP, Oracle, Baan, Accenture, Bearing Point, I2 ... ...
- Different scenarios for the possible savings
  - Glosuch experienced a 46 % reduction in inventory
  - Another estimate states, that eliminating the bullwhip effect could increase product profitability by 30 to 40 per cent!
  - Will free up working capital
- Not only inventory reductions, but decrease in production overtime, rush orders
- Increased customer satisfaction, reduced lead times ...

Some Insights for Controlling the Bullwhip

- Information sharing
  - The benefits increase when moving upstream
  - Eliminate intermediaries
  - VMI / DMI / CPFR
  - Harmonize the use of forecasts
- Lead time reduction
  - Elimination of information delay
  - Eliminate intermediaries
  - JIT
  - Quick Responses

Some Insights for Controlling the Bullwhip

- Eliminate shortage gaming
  - Allocate scarce capacity according to past sales
  - Imaginary shortage - elimination with information sharing
  - Stricter cancellation policies
- Smaller batches – balanced ordering
  - More frequent and smaller orders
  - Third party logistics provider to ensure full truck-load
  - New performance metrics to avoid quarterly hassle

Some Insights for Controlling the Bullwhip

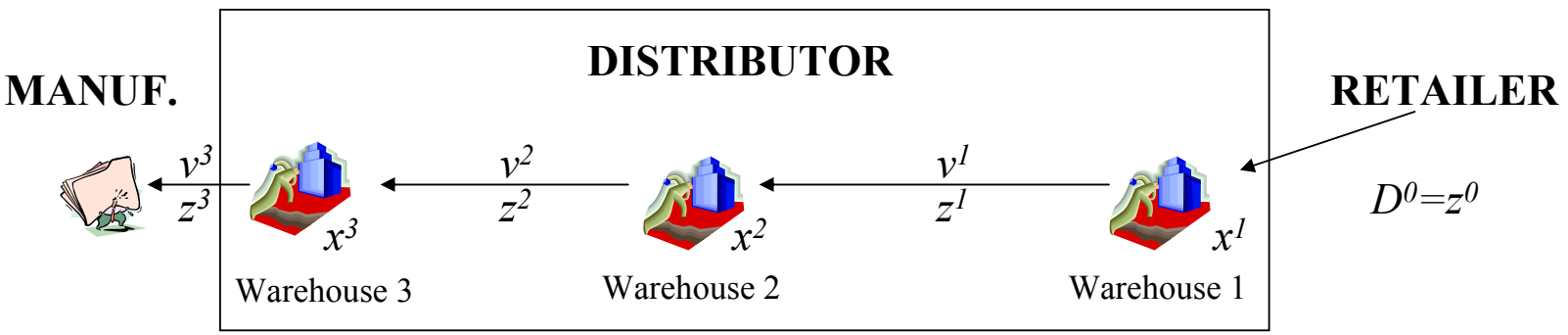
- Stable prices
  - Long term contracts with customers
  - Every Day Low Cost
  - Case Duracell
    - 90 % during short term promotions 32 weeks a year
    - New stable prices robbed the retailers of the reason to forward buy
  - Every Day Low Price
  - Using ABC-analysis supports stable pricing according to Lee et al. (1997)
  - More effective advertising

Some Insights for Controlling the Bullwhip

- **CPFR** (Collaboration Planning Forecasting and Replenishment)
  - More flexible than VMI (Vendor Managed Inventory)
  - Defines the role of each player in the supply chain
  - Can give practical suggestions for appropriate actions
  - Removal of Supply-Process Constraints
    - “By extending the retailers’ order cycle and thus making it consistent with the manufacturing cycle, production could move to a "make-to-order" process for some products. This removes the need to hold a significant amount of finished goods inventory in the value chain and improves customer service, which produces dramatic benefits. “

Some Algorithms

- Procter & Gamble and Wal-Mart discussed ways of improving inventory of diapers
  - Continuous replenishment without ordering
  - Key issues: Collaboration, trust, senior management support



D is the demand — x is the inventory level

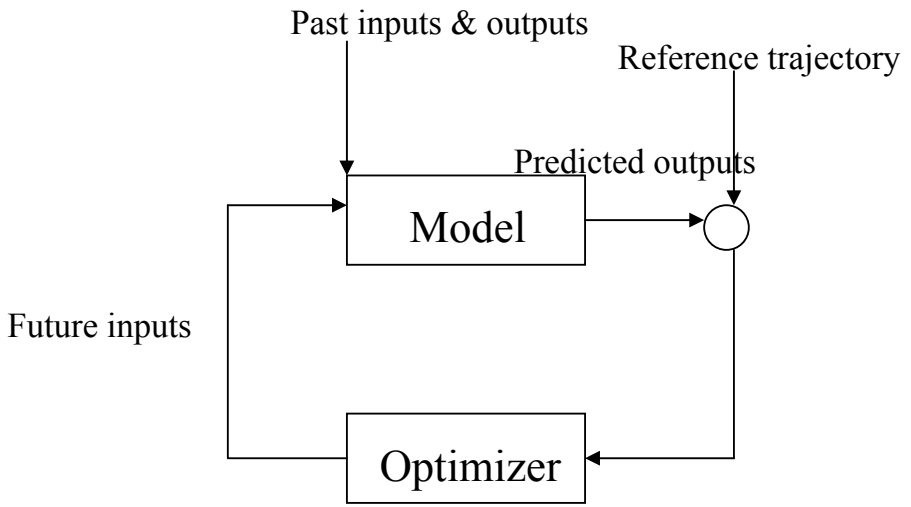
v is the lead time — z is the order quantity

Some Algorithms

- Model Predictive Control [MPC] has been used in different applications [Kaj-Mikael Björk]
  - Recently Perea-Lopez et al (2003) wrote a paper in managing the supply-chain with a MILP-dynamic model
  - In the context of bullwhip-effect
    - Analytical proofs are hard to derive
    - Simulation models can demonstrate how the supply chain acts
    - The models can be much more detailed than with the approach of Lee et al (1997) (and many more)
    - Could be used as real replenishment rules and control systems for a supply chain
  - Good models (to cure the bullwhip effect) could probably be developed into distribution systems for the participants

Some Algorithms

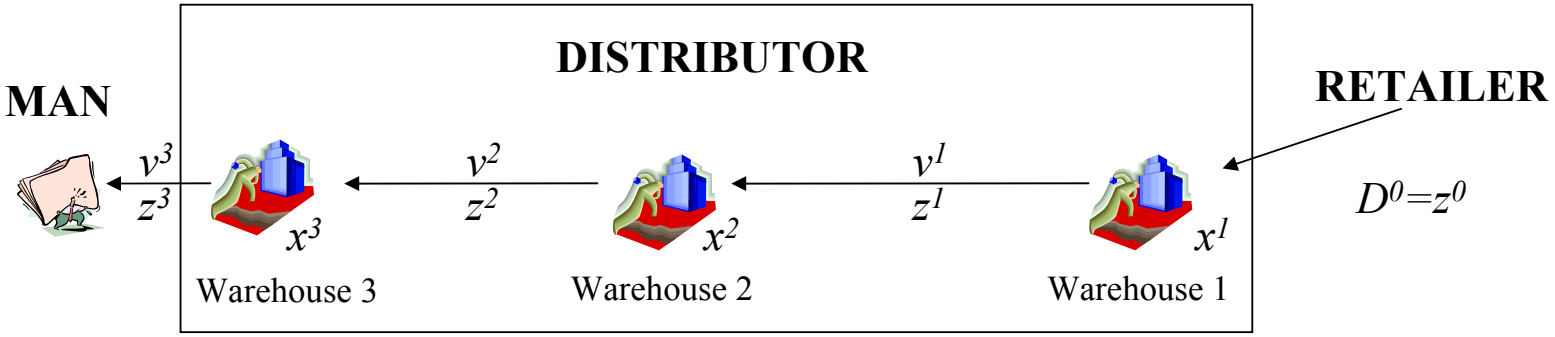
- The basics
  - Rolling horizon
  - Optimization of predicted outputs from future inputs
  - The demand is predicted according to the model $D_t = d + \rho D_{t-1} + u_t$
  - Only the next period's values are used from the optimizer



Some Algorithms

- Additional features
  - MPC is often used to follow a Reference trajectory
    - In this case the optimizer would most likely be a routine that minimizes the deviations from the predicted outputs and the reference trajectory
  - It is possible, however, to use more rigorous optimization models
    - In our case it would be to minimize the distribution costs for the Distributor
  - Demand prediction: $\boxed{D_{t+1} = d + \rho D_t}$
    - Note that is essential to find a good model for the demand
    - In this case a simple AR model have been used
    - More advanced models can be used if the demand patterns require so

Some Algorithms



D is the demand x is the inventory level z is the order quantity v is the lead time

The objective to minimize

$$\min_{z_i^1,z_i^2,z_i^3} -\sum_{t=1}^{T}\pi_1\cdot\min(0,x_t^1)-\sum_{t=1}^{T}\pi_2\cdot\min(0,x_t^2)-\sum_{t=1}^{T}\pi_3\cdot\min(0,x_t^3)$$
$$+\sum_{t=1}^{T}h_1\cdot\max(0,x_t^1)+\sum_{t=1}^{T}h_2\cdot\max(0,x_t^2)+\sum_{t=1}^{T}h_3\cdot\max(0,x_t^3)$$
$$+\sum_{t=1}^{T}c_1\cdot z_t^1+\sum_{t=1}^{T}c_2\cdot z_t^2+\sum_{t=1}^{T}c_3\cdot z_t^3$$

Some Algorithms

Minimization needs additional formulas to ensure inventory feasibility...

Optimization under the constraints...

$$\begin{aligned} x^1_{i+v1} &= x^1_{i+v1-1} - D_{i+v1} + z^1_i \quad ,\vee i \in [1,2,...,T] \\ x^2_{i+v2} &= x^2_{i+v2-1} - z^1_{i+v2} + z^2_i \quad ,\vee i \in [1,2,...,T] \\ x^3_{i+v3} &= x^3_{i+v3-1} - z^2_{i+v3} + z^3_i \quad ,\vee i \in [1,2,...,T] \end{aligned}$$

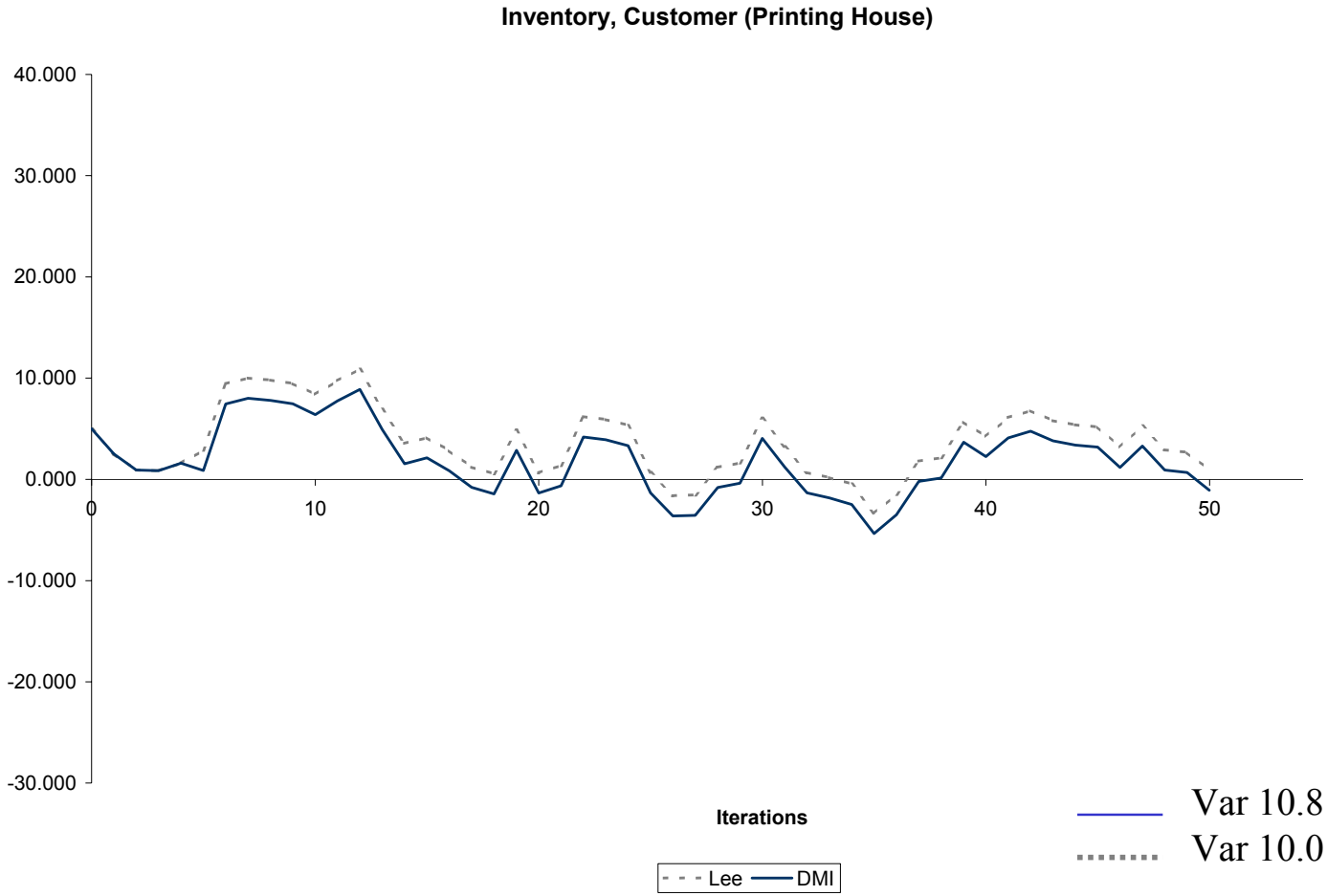
Note that some states (i<v1, for instance are predetermined from the orders and inventory placed before time 1 (events that have already happened cannot be manipulated)

Some Algorithms

- Using the MPC-approach with the proposed supply chain may decrease the bullwhip effect
  - Compared to the case, where all individual participants in the SC would optimize their own inventory (Lee et al, 1997)
  - The proposed solution would probably decrease overall inventory (with 15-35 % ?)
- An example problem is solved for comparison
  - Assumes instant order handling up-streams
  - Backlogging
  - The demand follows the formula $\boxed{D_t = d + \rho D_{t-1} + u_t}$
  - Lead times are more than 1
  - Penalty shortage costs are more than unit holding costs

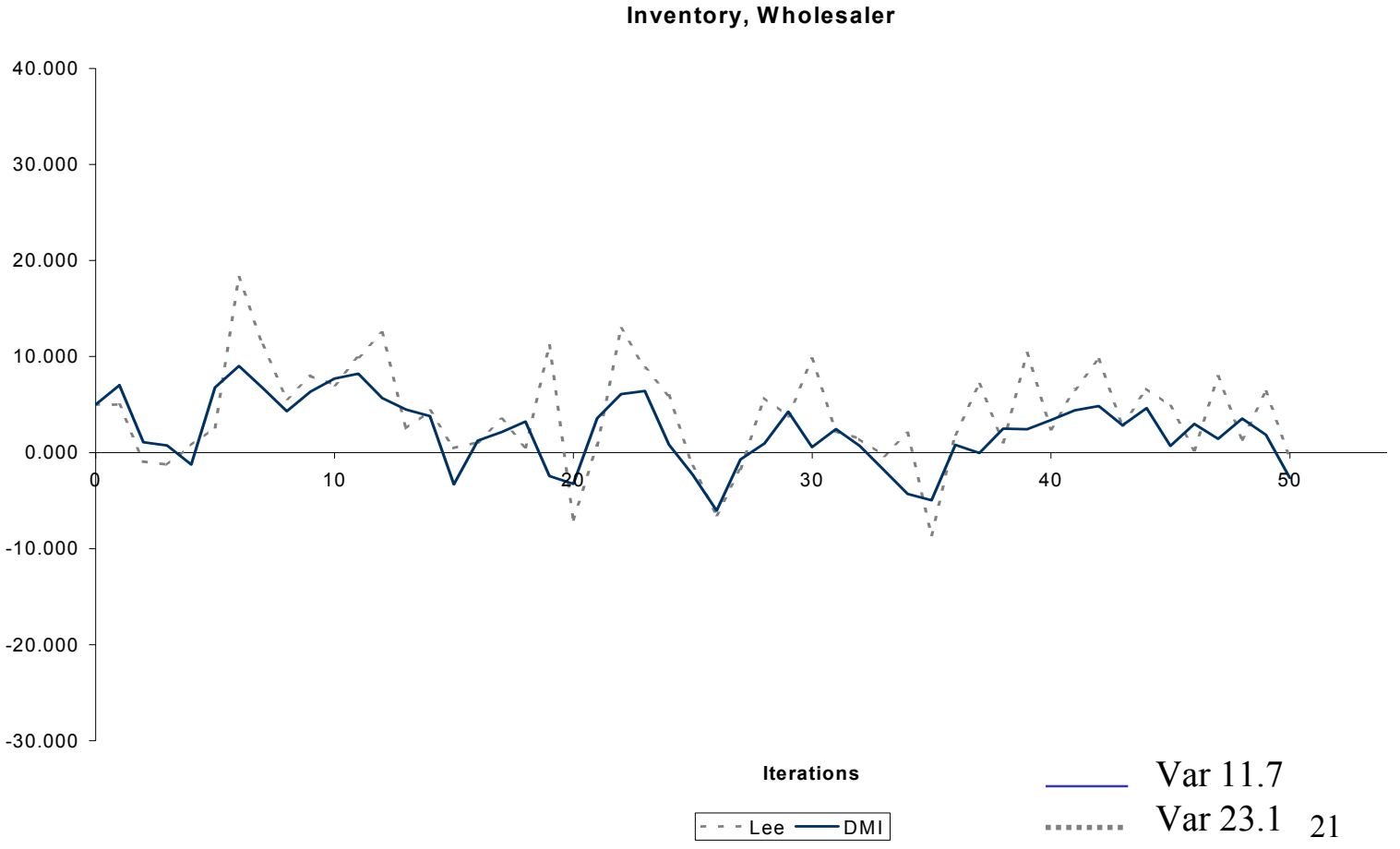
DMI – Theoretical Example (DSP)

Inventory levels at customer:
dashed line – old supply chain, solid line – new supply chain



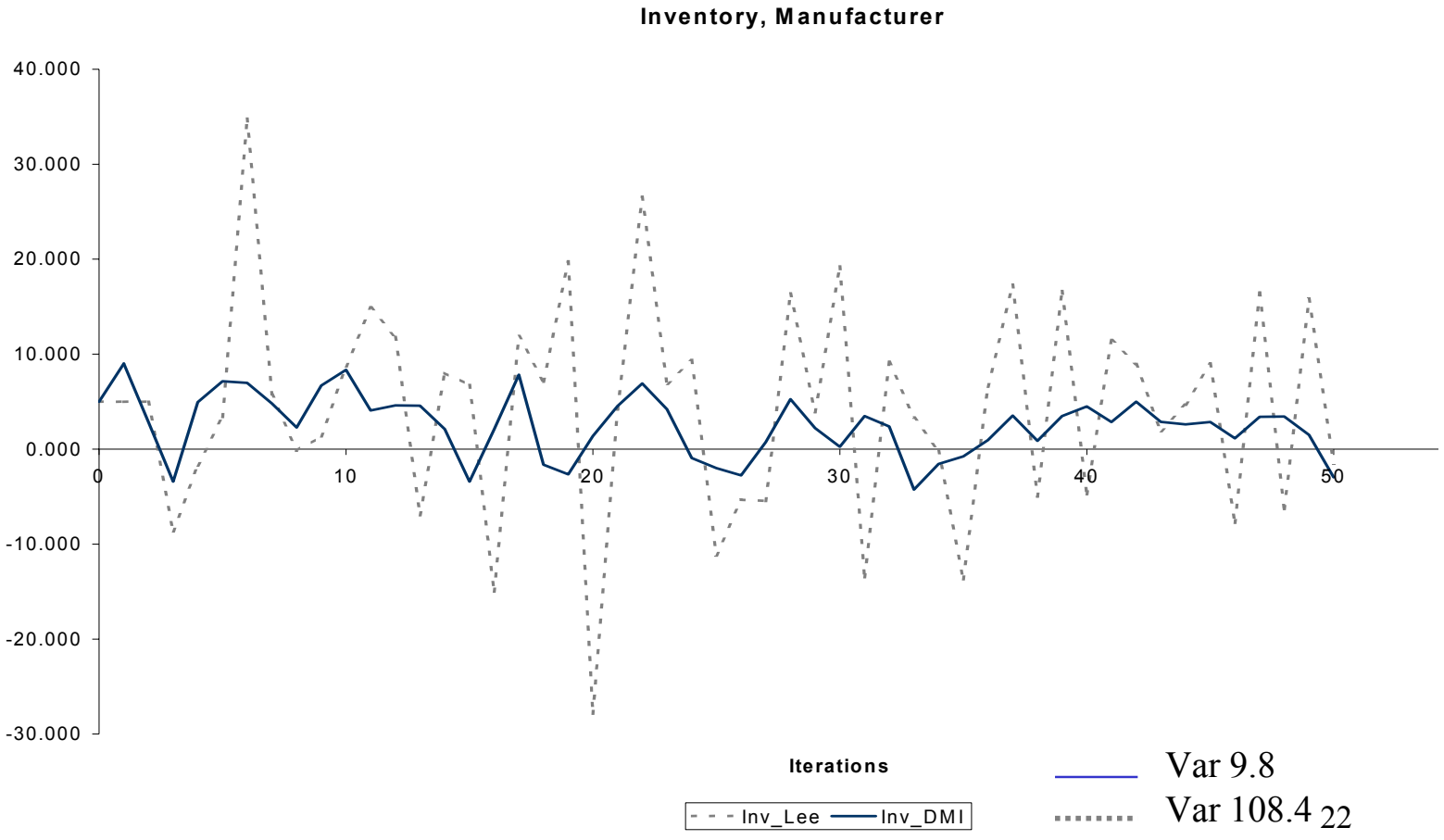
Wholesaler (DSP)

Inventory levels at wholesaler:
dashed line – old supply chain, solid line – new supply chain



Manufacturer (DSP)

Inventory levels at manufacturer:
dashed line – old supply chain, solid line – new supply chain



Comparison –Numbers

The old supply chain (each member optimizes their own operations, Lee et al, 1997)

	Retailer		Wholesaler		Manufacturer	
	Mean	**Var**	**Mean**	**Var**	**Mean**	**Var**
Demand	12.730	1.140	12.773	3.418	12.844	18.796
Opt ord	12.773	3.418	12.844	18.796	12.669	138.052
Inv	2.519	5.455	2.493	16.200	2.452	78.110

The new supply chain (MPC- model, where the distributor optimizes his operations)

	Retailer		Wholesaler		Manufacturer	
	Mean	**Var**	**Mean**	**Var**	**Mean**	**Var**
Demand	12.726	1.122	12.709	2.164	12.655	6.346
Opt ord	12.709	2.164	12.655	6.346	12.630	28.010
Inv	2.387	8.023	2.425	8.664	3.225	10.521

Smart Bulls Objectives

- Find better theoretical models
- Take care of uncertainty, imprecision with soft computing methods
- Then enhance, develop the models with soft computing
- Work with corporate partners to find better ways to use practical insight by building good ICT tools
- Then combine insight and theoretic models
- Partners: Amerpap, MetsäTissue, M-real, UPM Wisa Wood

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