Closed Loop Supply Chains
Concept and Models

Jayendran Venkateswaran & D. Bijulal
Industrial Engineering & Operations Research
IIT Bombay

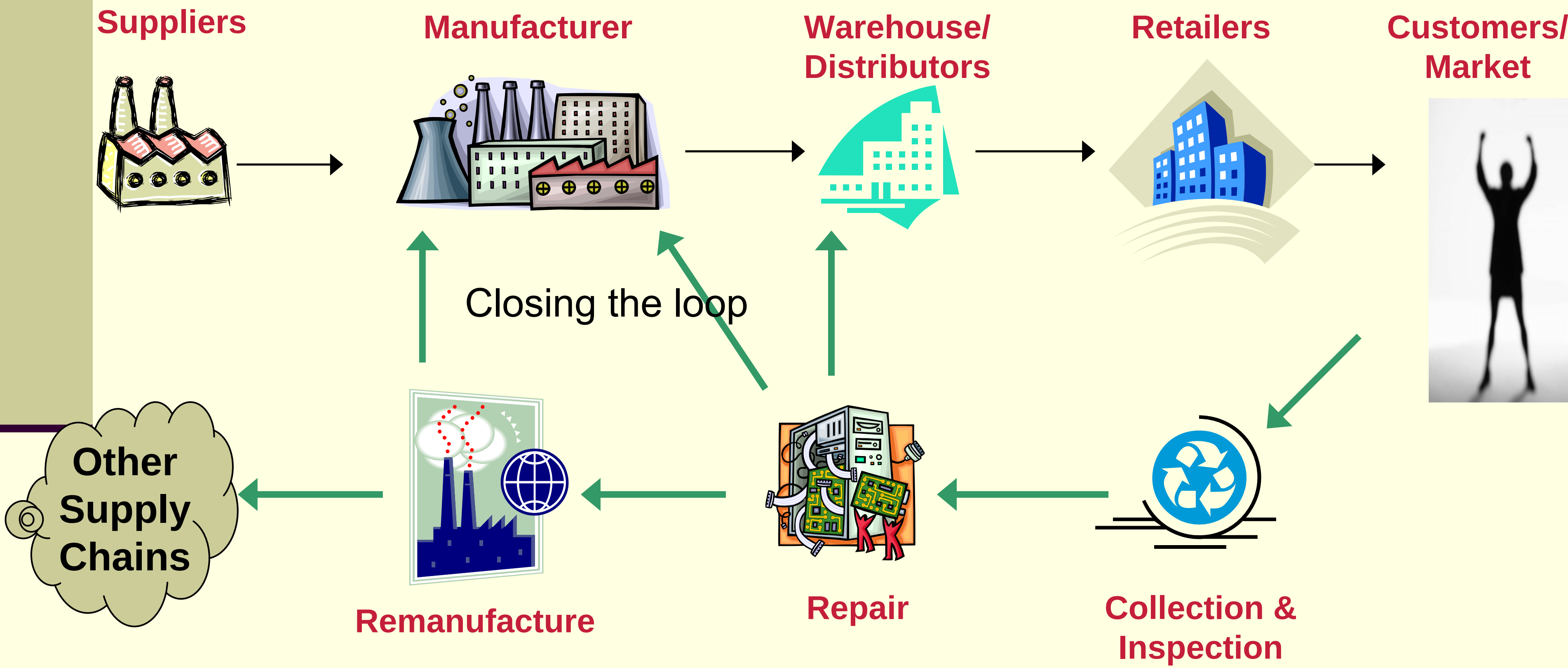
Symposium on "Optimization in Supply Chains"
27th October 2007

AGENDA

- Closed Loop Supply Chain (CLSC)
  - What is CLSC?
  - Research Issues
- Collection & Inspection aspect
  - Problem description
  - Models
  - Observations
- CLSC Production-inventory aspect
  - System dynamics model
  - Observations
- Conclusions

Closed Loop Supply Chain

- Holistic view of a combined forward supply chain & reverse supply chain



Why the interest in "closing-the-loop"?

- Legislative motivation
  - EU legislation on treatment of Waste from Electric and Electronic Equipment (WEEE)
    - End users must be able to return products.
    - Producers have to meet target levels of component, material and substance reuse and recycling.
    - Manufacturers must also finance the cost of collection, treatment, recovery, & environmentally sound disposal for all items returned.
- Environmental motivation
  - Enhance brand image → *Green Effect*
- Economic motivation
  - Engage in product recovery to reduce production costs!

Research Issues in CLSC

- Relatively new area of work
- Legal & environmental obligations *vs.* profit making
- Strategic Level Issues
  - Product design for *after-life*
  - Network structure
- Tactical level Issues
  - Managing the reverse logistics → Uncertainty in returns
  - Environmental impact → 'Green image' effect on demand
  - Pricing and market segregation
- Operational level Issues
  - Segregating returns into reuse, repair, remanufacturing and/or recycling
  - Scheduling common resources

Literature Review in CLSC (1)

- Krikke *et al*. (2003, IJPR) showed how concurrent product design & the process recovery options is rewarding
  - Considered economic costs & environmental impact
- Savaskan *et al*. (2004, Mgt Sc) studied different reverse channel settings:
  - (1) Direct collection (2) Collect via retailer, (3) 3rd party
- Salema *et al.* (2007, EJOR) presents a general network design model with multi-products, capacity limits, uncertain demand/ return
- Biehl *et al.* (2007, C&OR) designed reverse logistic network for US carpet industry to reduce landfill
  - Uncertain returns, collection points, forecasting type

Literature Review in CLSC (2)

- Zikopoulos *et al*. (2007, EJOR) shows high quality returns improves CLSC system profitability

- Toktay *et al.* (2003) forecast future returns as probability distributions
  - Used for decison on collections to minimize CLSC costs

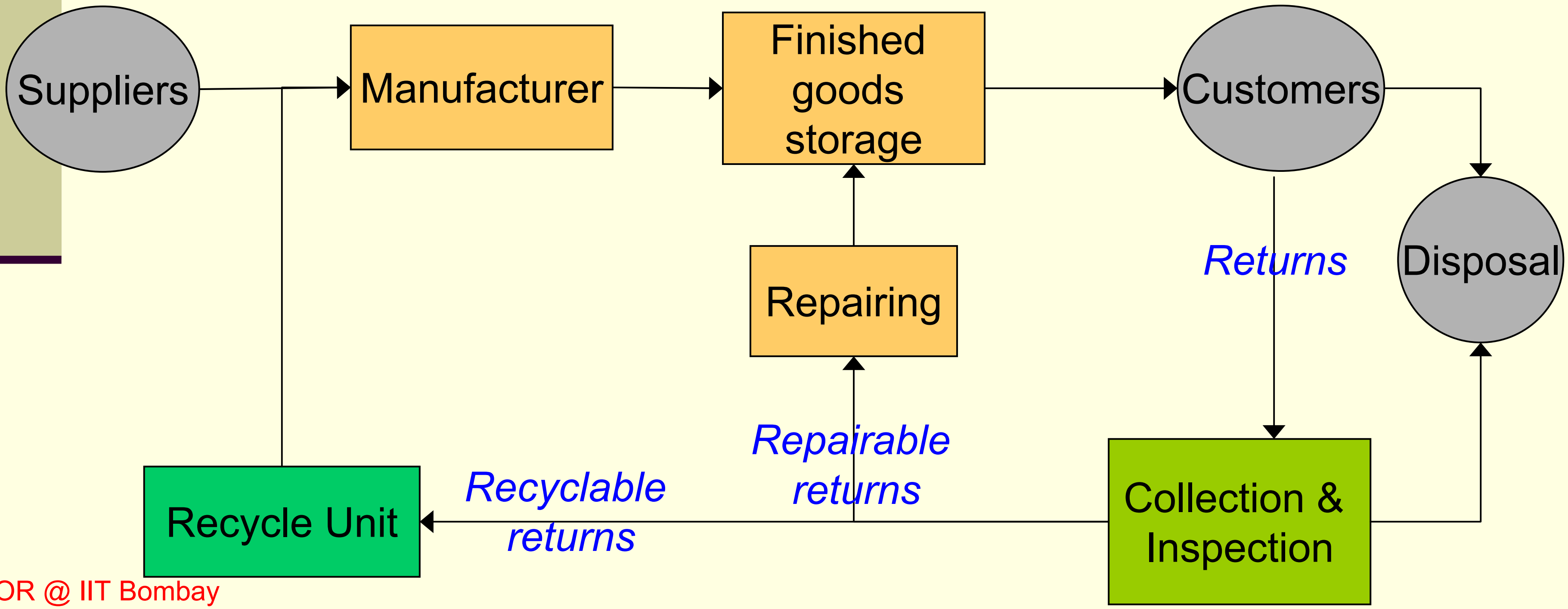
- Georgiadis & Vlachos (2007, EJOR) examined the impact of environmental issues on long-term behavior of single product SC with returns.
  - ‘Green image’ effect on demand, obligation due to legislation, capacity effects on CLSC profits

Problems looked into

- Modeling of Collection & Inspection Unit
  - Consideration of quantity & quality of returns
  - Explicit ‘Use Life’ of products
  - Total CLSC costs
- Modeling of production-inventory ordering dynamics considering product returns

Description of CLSC

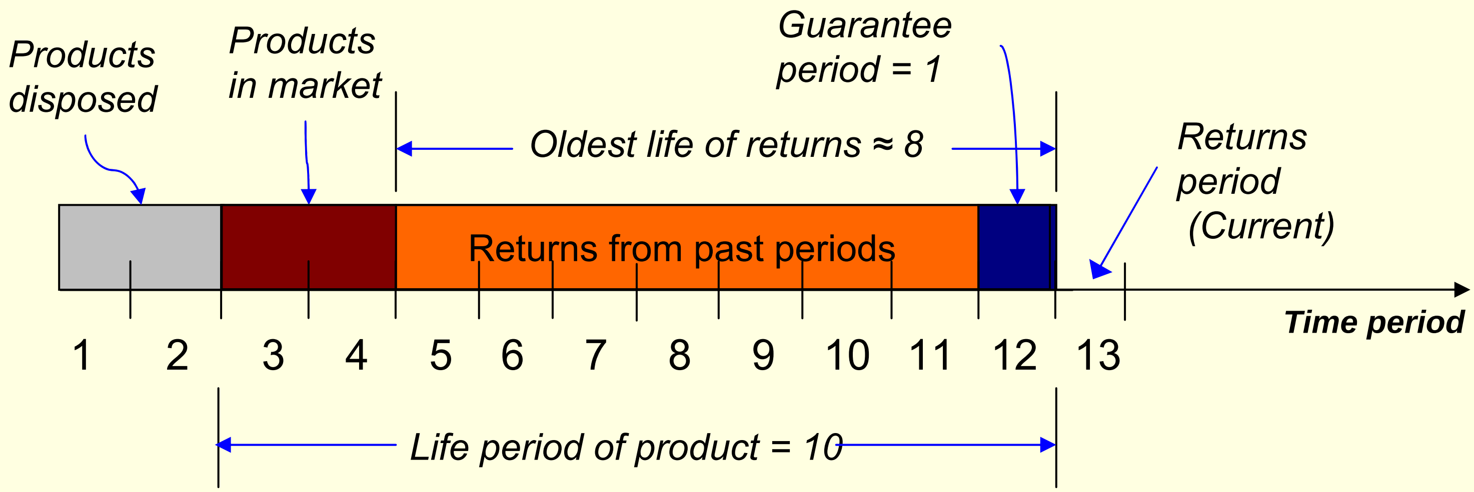
- Single product with stochastic delays; (Make to stock)
- Returns only from goods sold
- Sold goods have a maximum life period after which they are disposed.
- Goods transferred at end of period; transport time ignored
- Repaired products are as good as new



Model of C & I unit

- Key issue: Capturing Quantity & Quality of products returned
  - Quantity – amount returned in a period
  - Quality – suitability of returns for repairs, recycling or disposal.

- Definition of life periods:

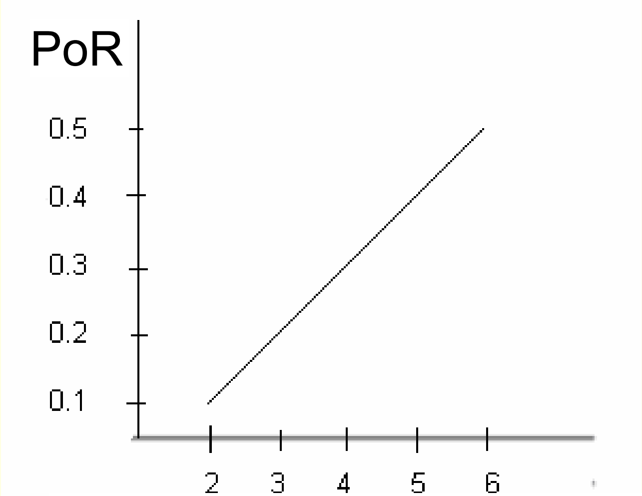


C & I – Quantity of Returns

- *Total Returns in period =*

  $\sum_{\text{(collection periods)}}$ (*probability of returns from a past period * pool available for return in that period*)

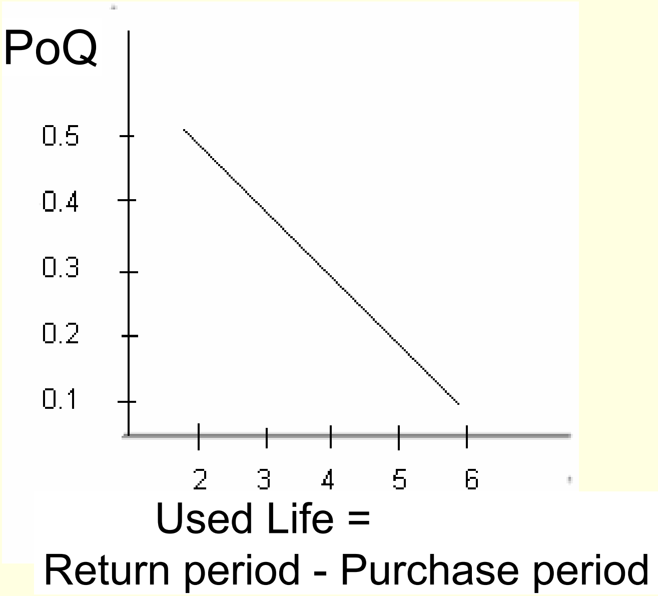
- Probability of returns (PoR) modeled as a curve varying with respect to <u>used life</u> of product

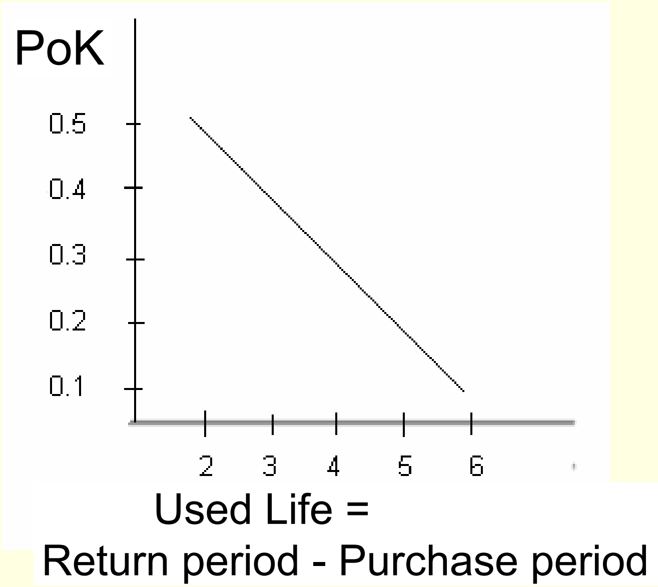


Used Life =
Return period - Purchase period

C & I Quality of Returns

- From the quantity returned, the proportion sent for repairs, recycling and disposal
  - Probability of returns repairable (PoQ)
  - Probability of returns recyclable (PoK)
  - Probability of returns disposed = 1 – PoQ - PoK
- Depends on the used life of product





Rest of the supply chain

- From C&I unit returns are pushed to Repair unit and Recycle unit, at end of each period
- From Repair unit repaired goods are pushed to finished goods storage, at end of each period
- From Recycle unit recycled goods are pushed to shop floor, at end of each period
- Shop floor orders (Demand – Recycle qty – raw material inventory) with supplier, at end of each period
  - Instantaneous supply
- Demand at the start of period

Costs in the CLSC

Forward SC

- Production cost → 50 / unit
- Cost of raw material from suppliers → 100 / unit
- Inventory storage cost → 300 / unit
- Shortage cost for unmet demand → 500 / unit
- Raw material storage cost → 30 / unit

Reverse SC

- Inspection cost → 10 / unit
- Repair cost → 100 / unit
- Recycling cost → 95 / unit

- Disposal cost → 50 / unit

Simulation Model – Material flow

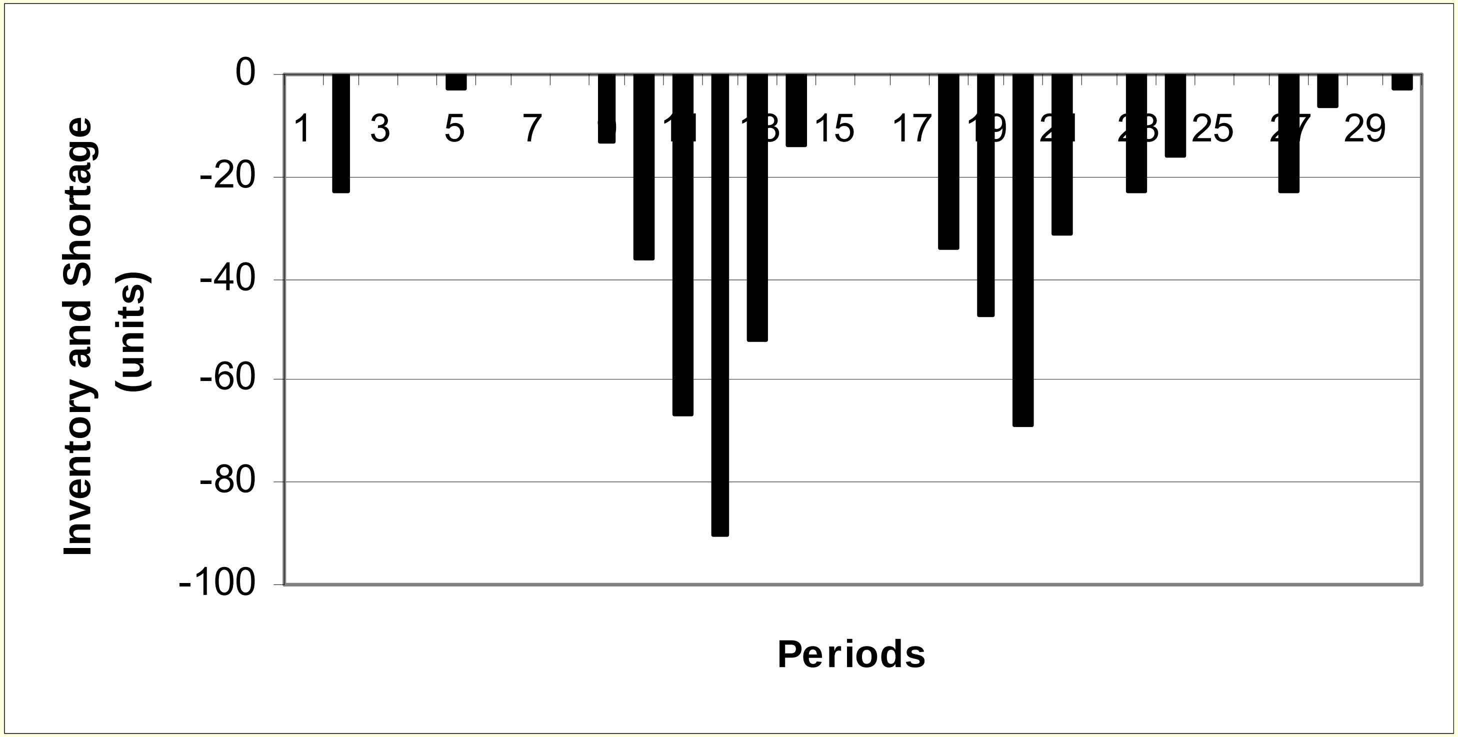
- Modeled using Arena™.
- Shop floor with stochastic delays (time/part)
- Inspection, Recycling, Repairing stochastic delays (time/part)
- Deterministic demand per period
- Run length = 30 periods

- Verification of model
  - With zero Demand
  - Collection with fixed "max used life" returns

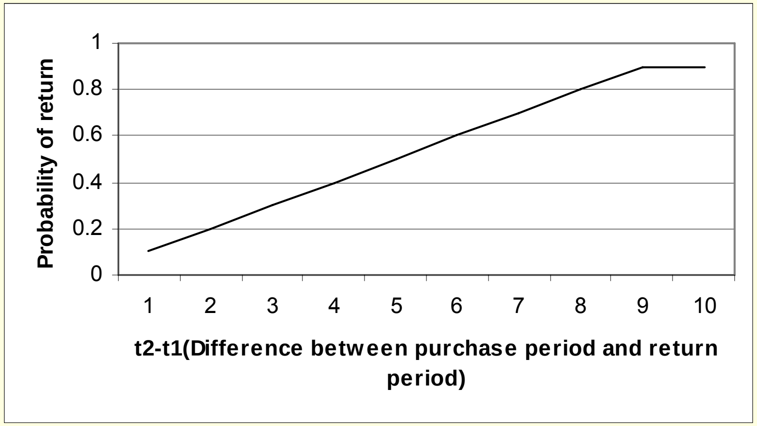
Experiments

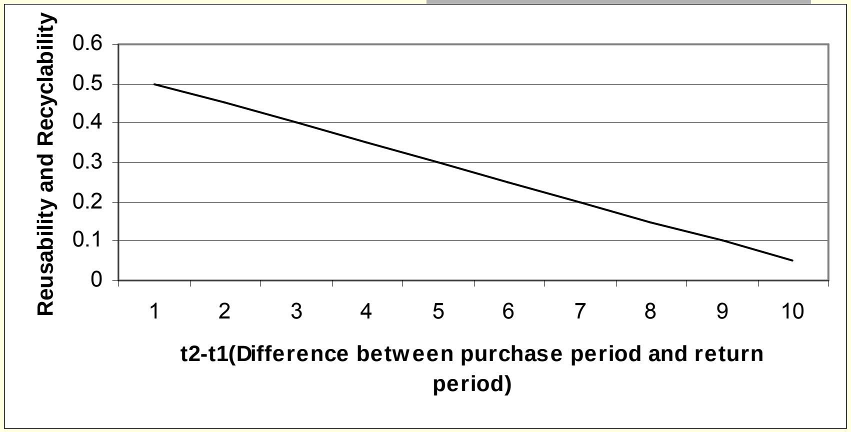
- Maximum life period = 10
- Base case (No collections)
- Total Cost = Rs. 733350

Sold goods have a maximum life period after which they are disposed.

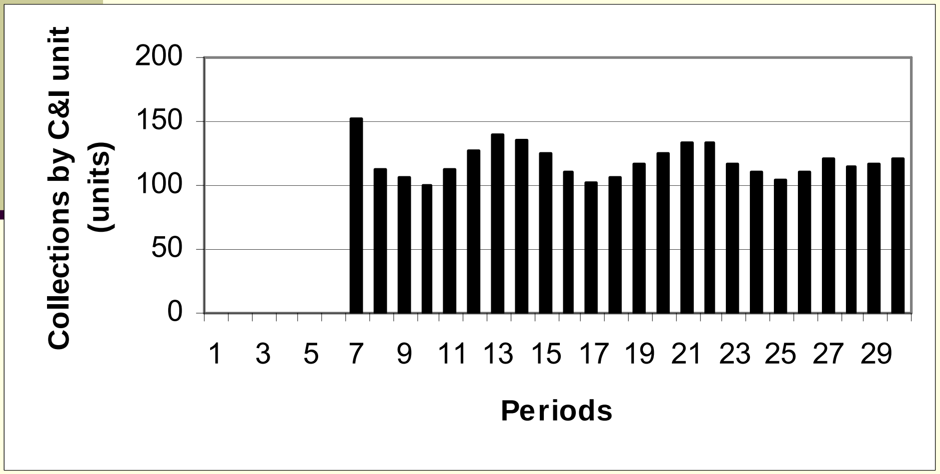


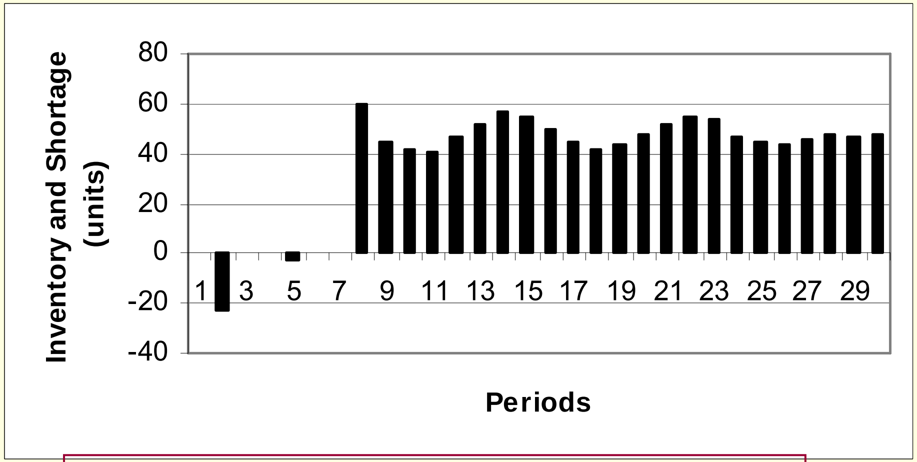
Experiments – Fixed ‘max used life’





- Max used life = 4; Collection starts in 7th period
- Collection happens in all periods





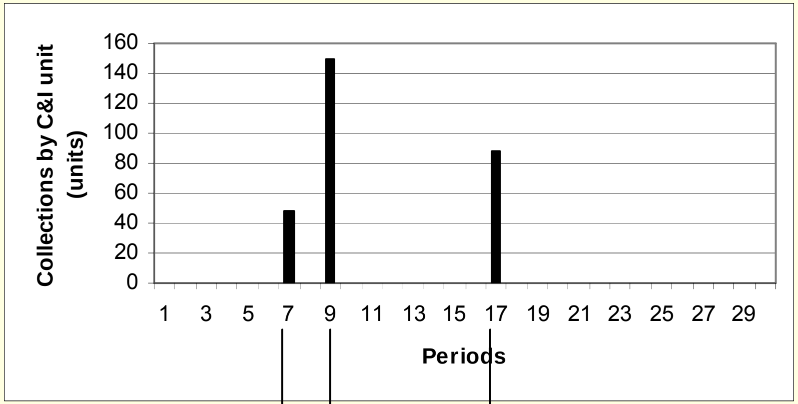
Total cost = 1281932

Experiments – Collection in few periods

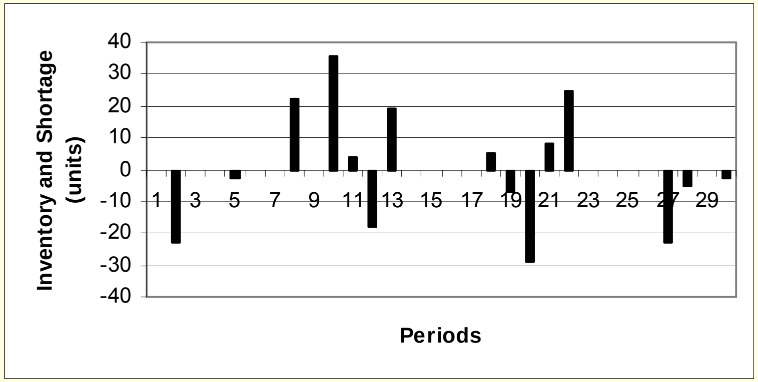
- Decision variables:
  - Which periods are returns collected?
  - What should be the *max used life* for that period?
- Given
  - Probability of returns
  - Probability of returns repairable, recyclable
  - Demand pattern
- Simulation-Optimization using OptQuest™

Experiments – Collection in few periods

- Results of simulation-optimization



Max used life 2 4 3



Total cost = 593543

- Comparing with Base Case
  - Collections just before expected shortage most beneficial

Designed Experiments

- Factors and levels
  - Probability of returns: Linear, Convex, Concave
  - Probability of Reuse and Recycle: Varying slope
  - Maximum life period: 6, 10, 15, 20 periods
- For each combination, best periods to collect in were determined
- Key observations from results
  - Number of periods collections allowed: 2 ~ 4
  - Max used life: 2~7
  - Collections around period 9 and 17 (to counter shortages)

Observations & Conclusions

- Collections in few periods may provide more benefits than collections every period
- Shape of probability of returns not significant
- Low repairability + recyclability → more disposal, higher cost

- Several assumptions & sensitivity of parameters needs to be verified
- Need to test with a more realistic scenario with landfill restrictions, multiple players, demand/ returns forecasting
- Can the idea be extended to time promotional events such as ‘buy-back’ schemes?

PRODUCTION INVENTORY DYNAMICS

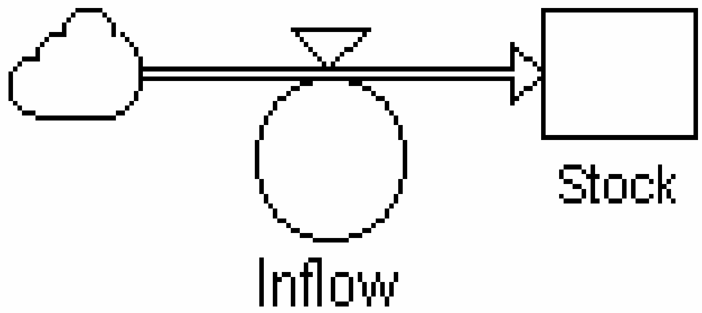
- Modeling of production-inventory ordering dynamics considering product returns
- System Dynamics tool is employed
- Single player model at aggregated level
  - Repairable returns feeds into end inventory
  - Recycled returns feeds into WIP

Modeling Basics: Stock & Flow diagram

- **Stocks or Level**: Accumulate over time
  - Characterizes the states of the system, provides inertia and memory, acts as a source of delay and create disequilibrium dynamics
- **Flow or Rate**: Causes Stocks to change over time
- **Information**: Helps define other instantaneous variables/ calculations

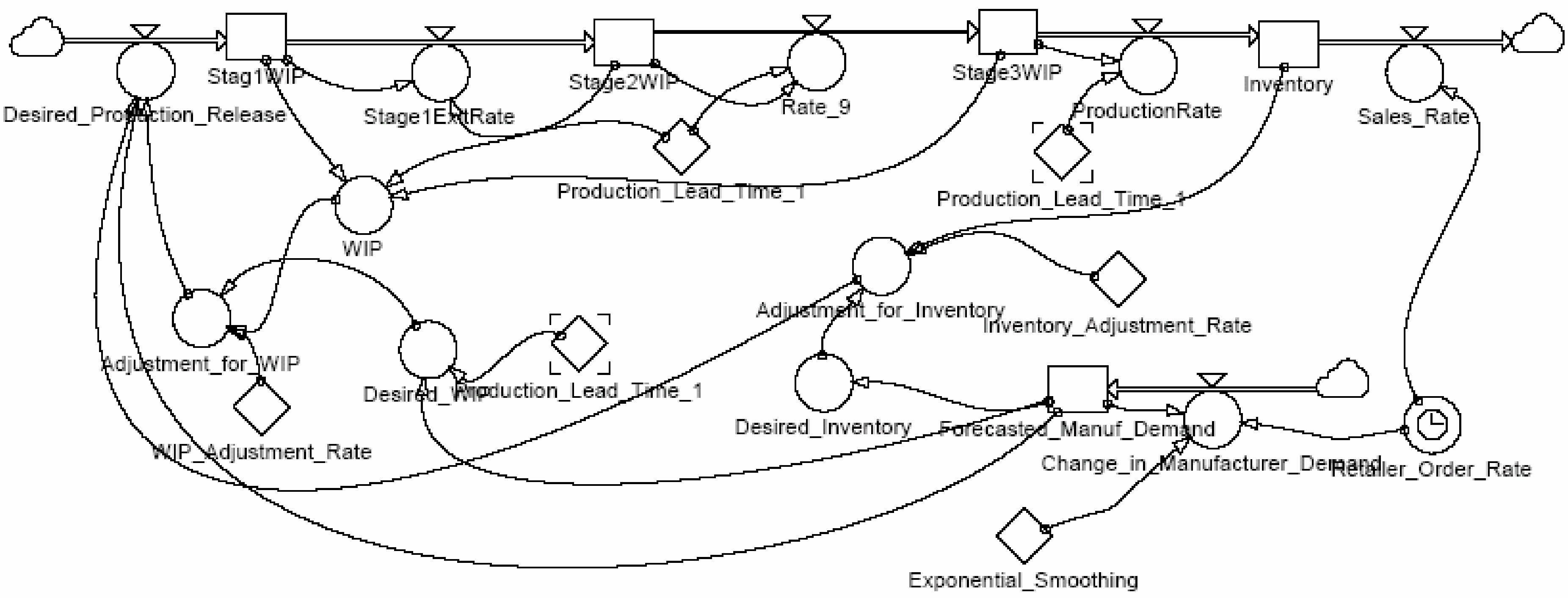
$$Stock(t) = Stock(0) + \int_0^t Inflow(\tau)d\tau - \int_0^t Outflow(\tau)d\tau$$

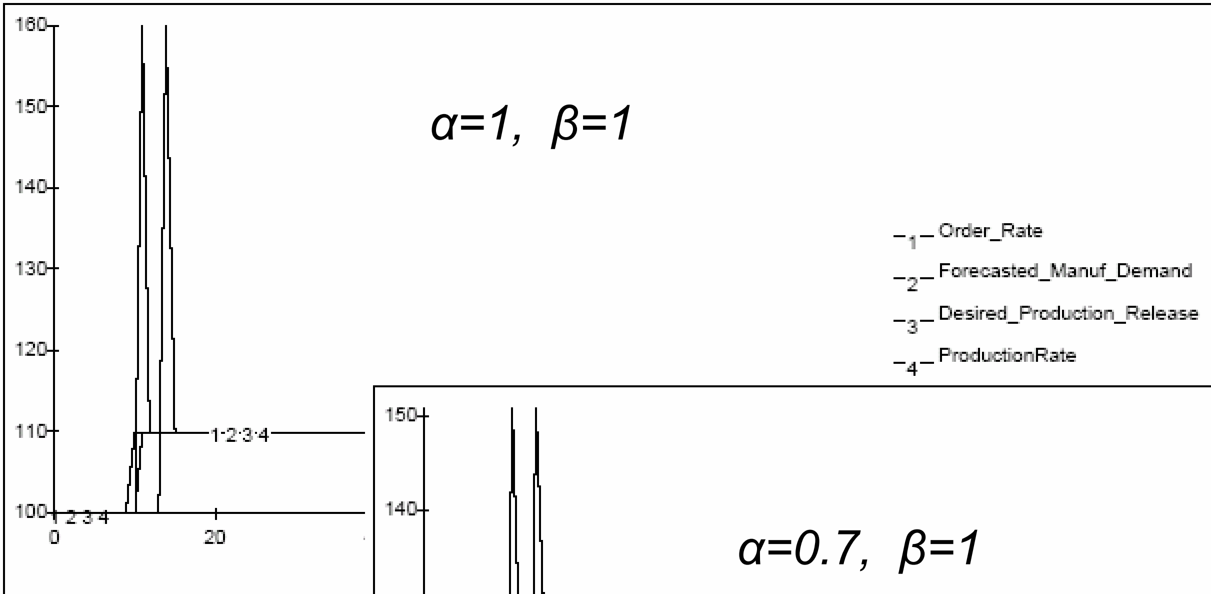
$$\frac{d}{dt}[Stock(t)] = Inflow(t) - Outflow(t)$$

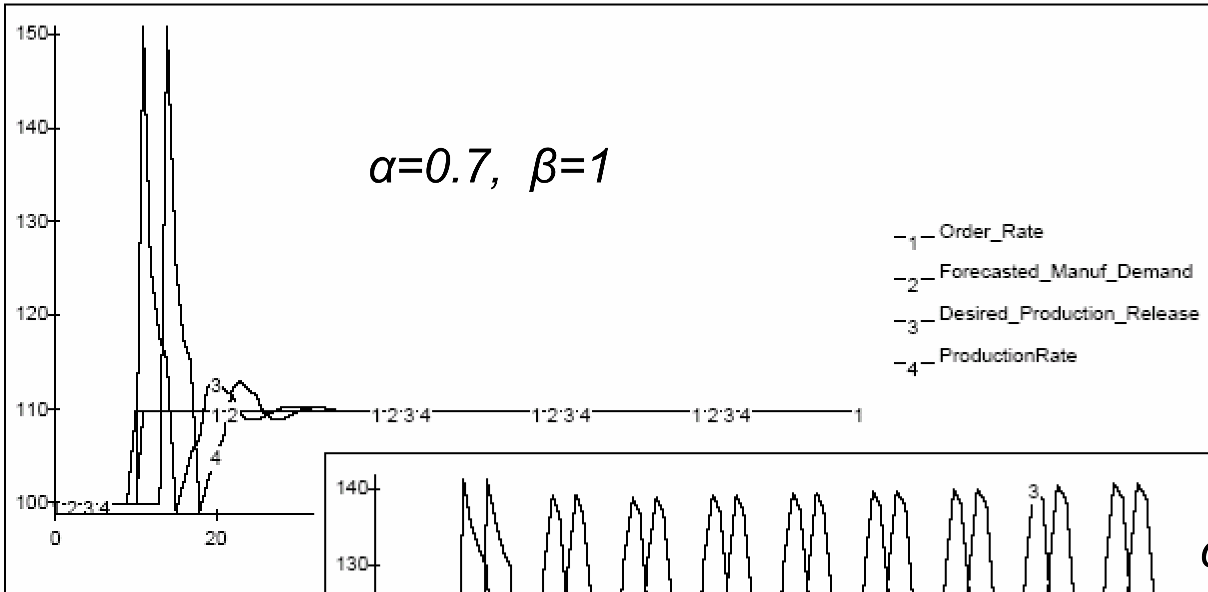


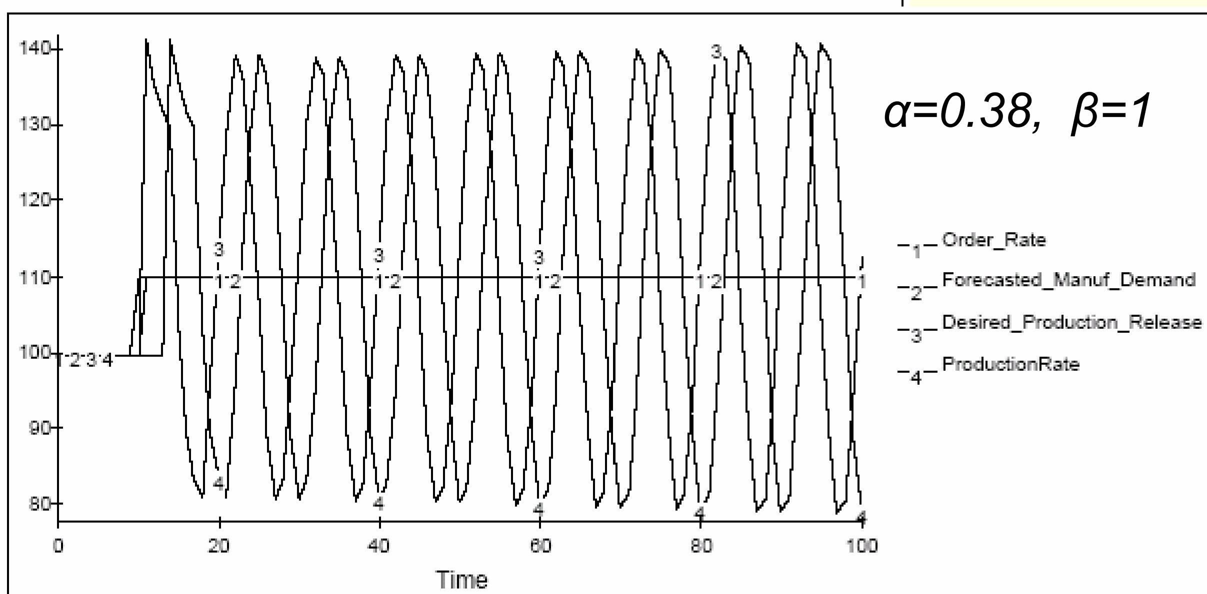
SD Model

- *Production_Release = Forecast + α(Desired_WIP – WIP) + β(Desired_INV - INV)*
- *Desired_WIP = Leadtime*Forecast*
- *Desired_INV = Forecast*

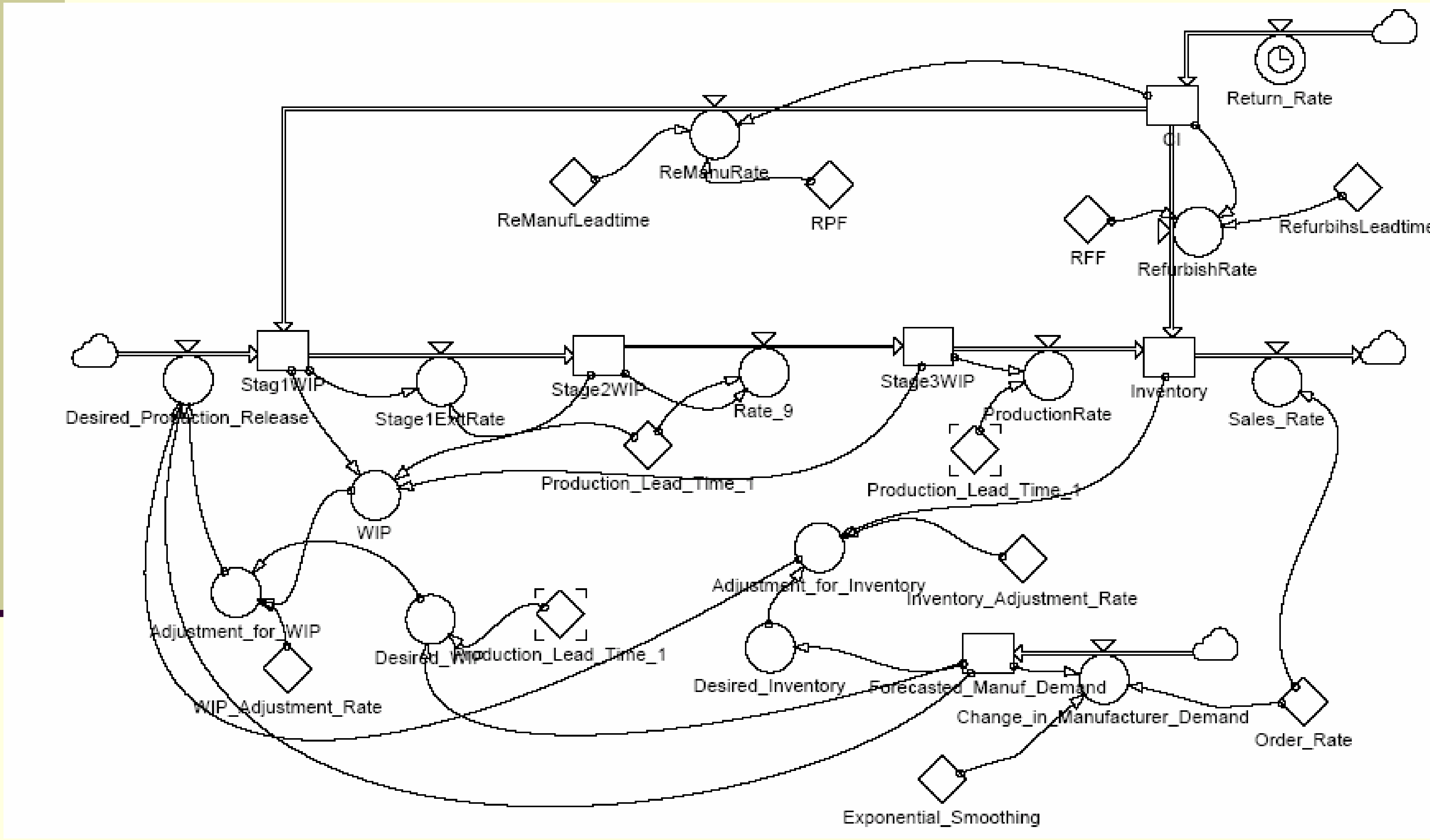



α=1, β=1
1 Order_Rate
2 Forecasted_Manuf_Demand
3 Desired_Production_Release
4 ProductionRate
160
150
140
130
120
110
100
0
20

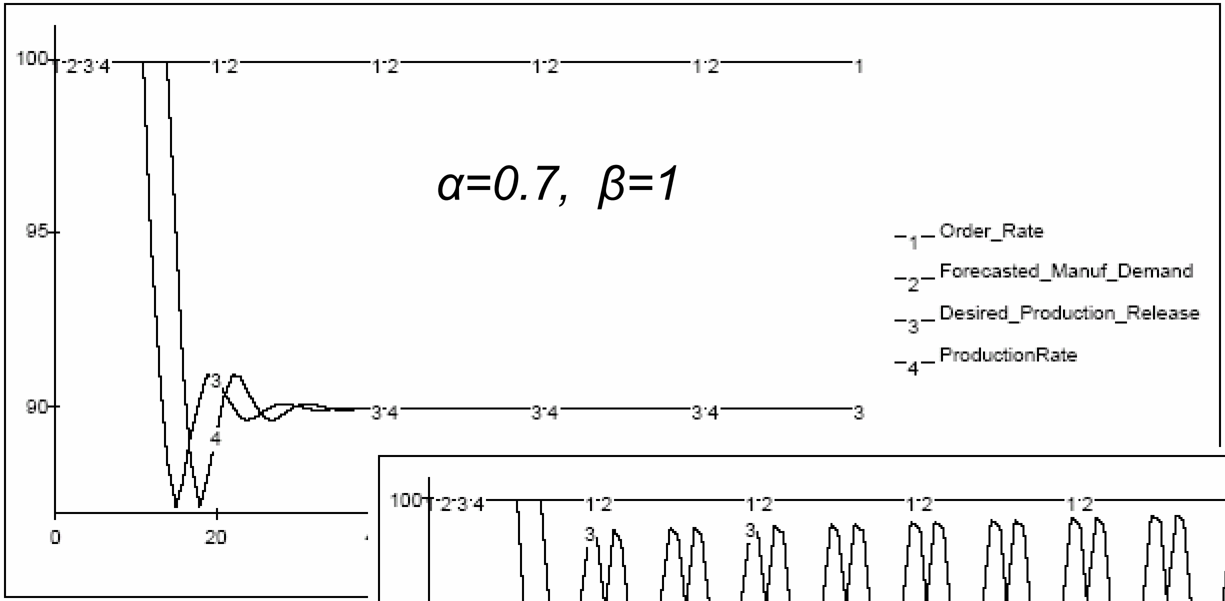

α=0.7, β=1
1 Order_Rate
2 Forecasted_Manuf_Demand
3 Desired_Production_Release
4 ProductionRate
150
140
130
120
110
100
0
20

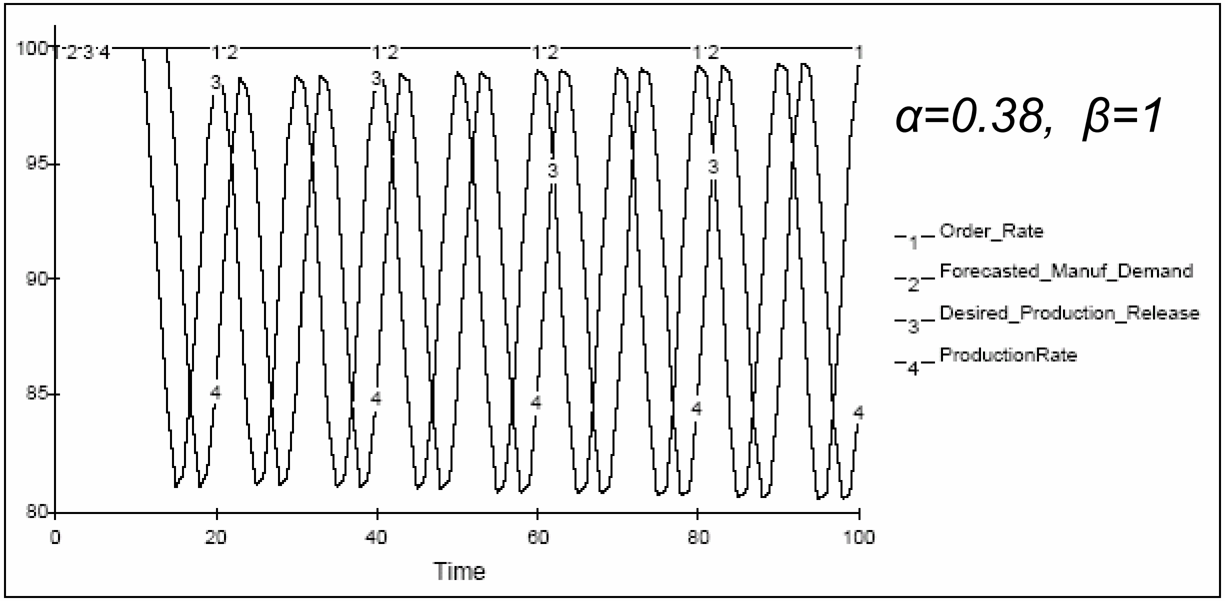

α=0.38, β=1
1 Order_Rate
2 Forecasted_Manuf_Demand
3 Desired_Production_Release
4 ProductionRate
140
130
120
110
100
90
80
0
20
40
60
80
100
Time

SD Model – Adding returns



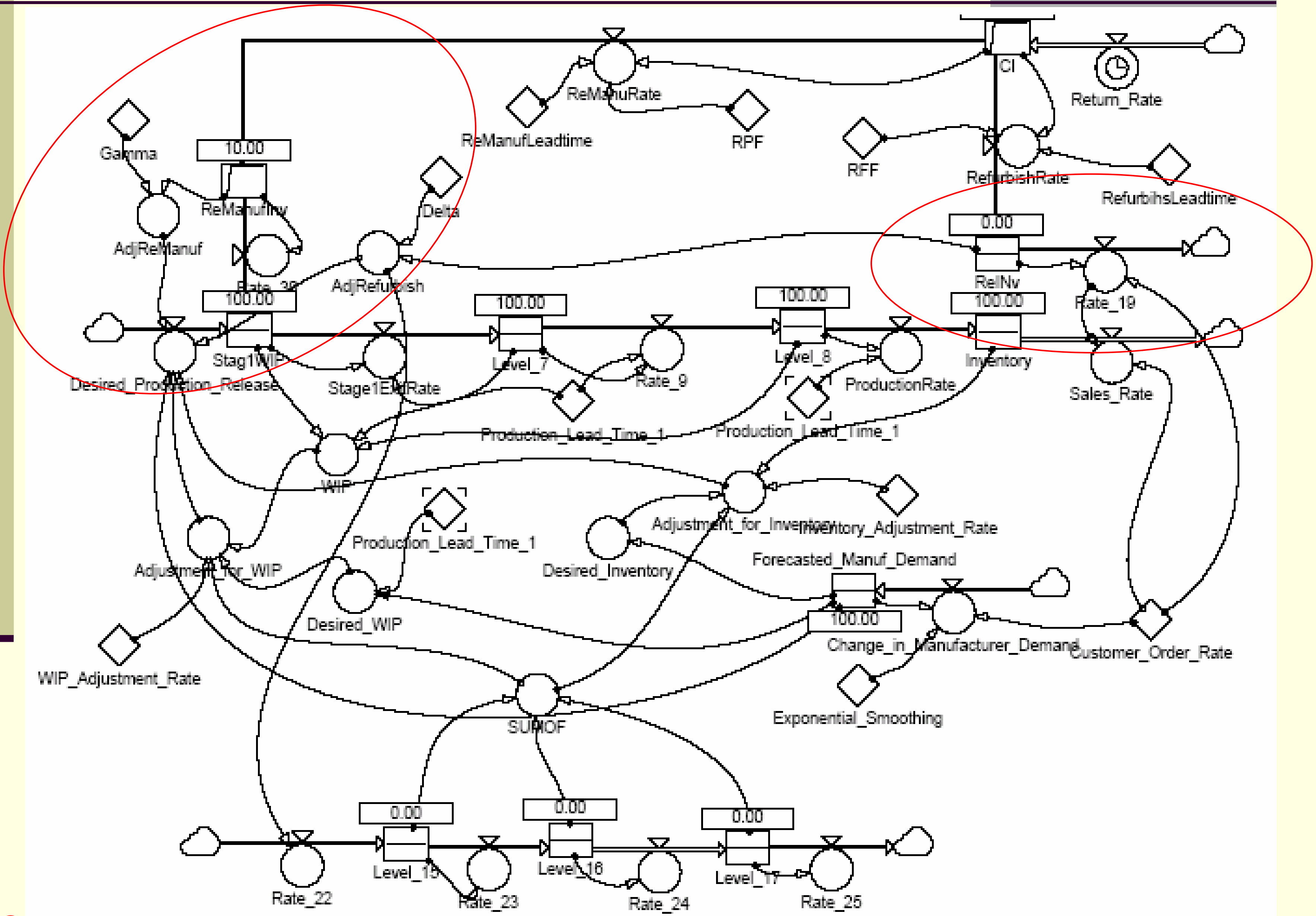
Results – Adding returns





Any thing different from earlier case? Any thing interesting?

SD Model with Returns - Improved



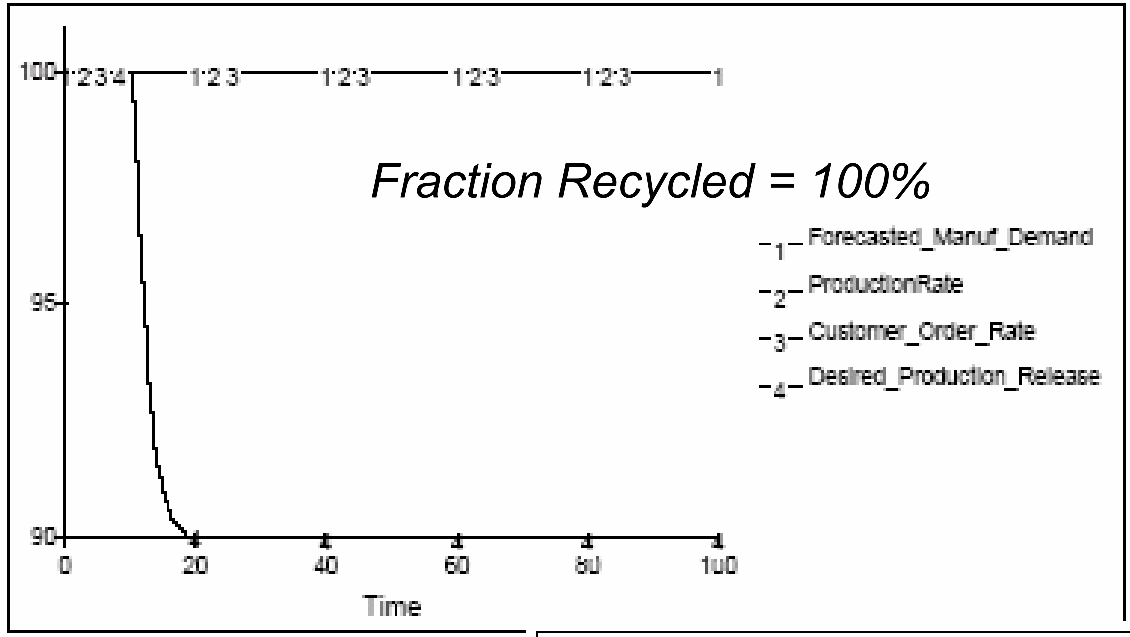
SD Model with Returns - Improved

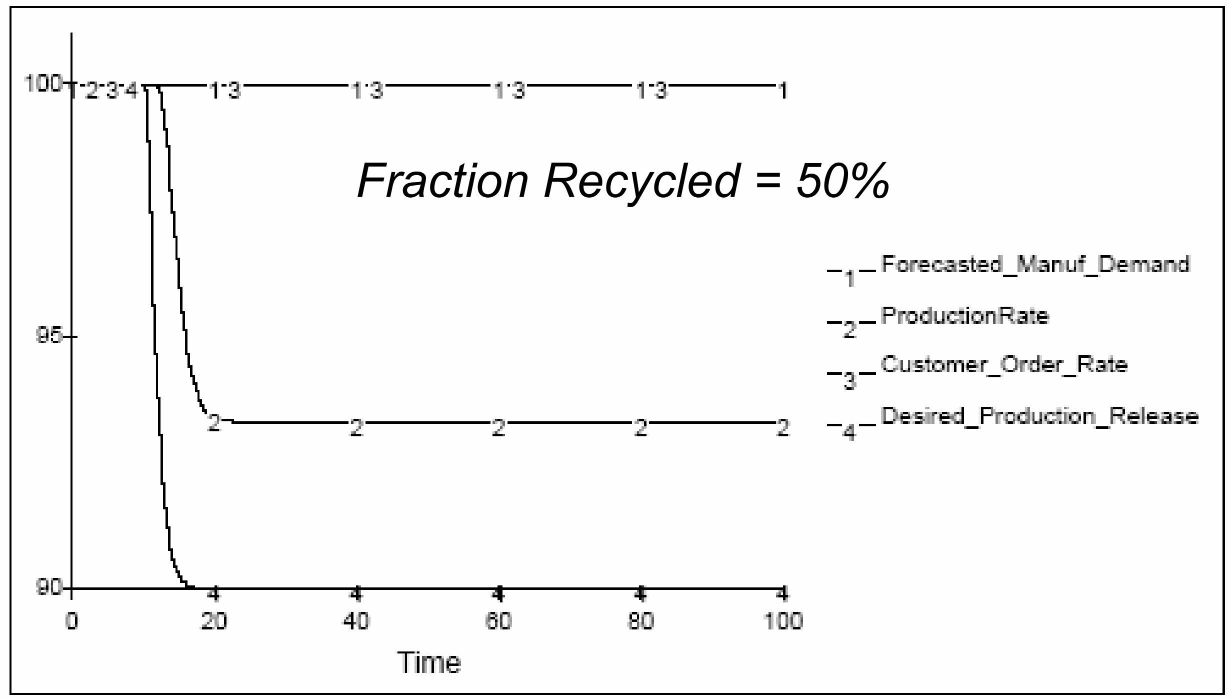
- *Production_Release = Forecast + α(Desired_WIP – WIP) + β(Desired_INV - INV) + γ(-RecycleINV) + δ(-RepairINV)*

- *Desired_WIP = Leadtime*Forecast - ReturnsWIP*

- *Desired_INV = Forecast + ReturnsWIP*

- *ReturnsWIP* → WIP reduction due to use of recycled raw materials





α=any value,
β=any value
δ = γ = 1

Conclusions

- Need to distinguish between returns and demand
  - Especially under steady demand scenario
- Danger of fluctuations in returns be misread as demand fluctuations
  - Leads to bullwhip effect!
- Questions
  - What happens in multiple echelon supply chains?
  - How to use returns information, esp. upstream members?
  - Can forecast of returns be included?
  - ‘Green image’ effect? etc