Agent-based systems for supply chain management

Fernando D. Mele, **Gonzalo Guillén-Gosálbez**, Antonio Espuna and

Luis Puigjaner

Department of Chemical Engineering

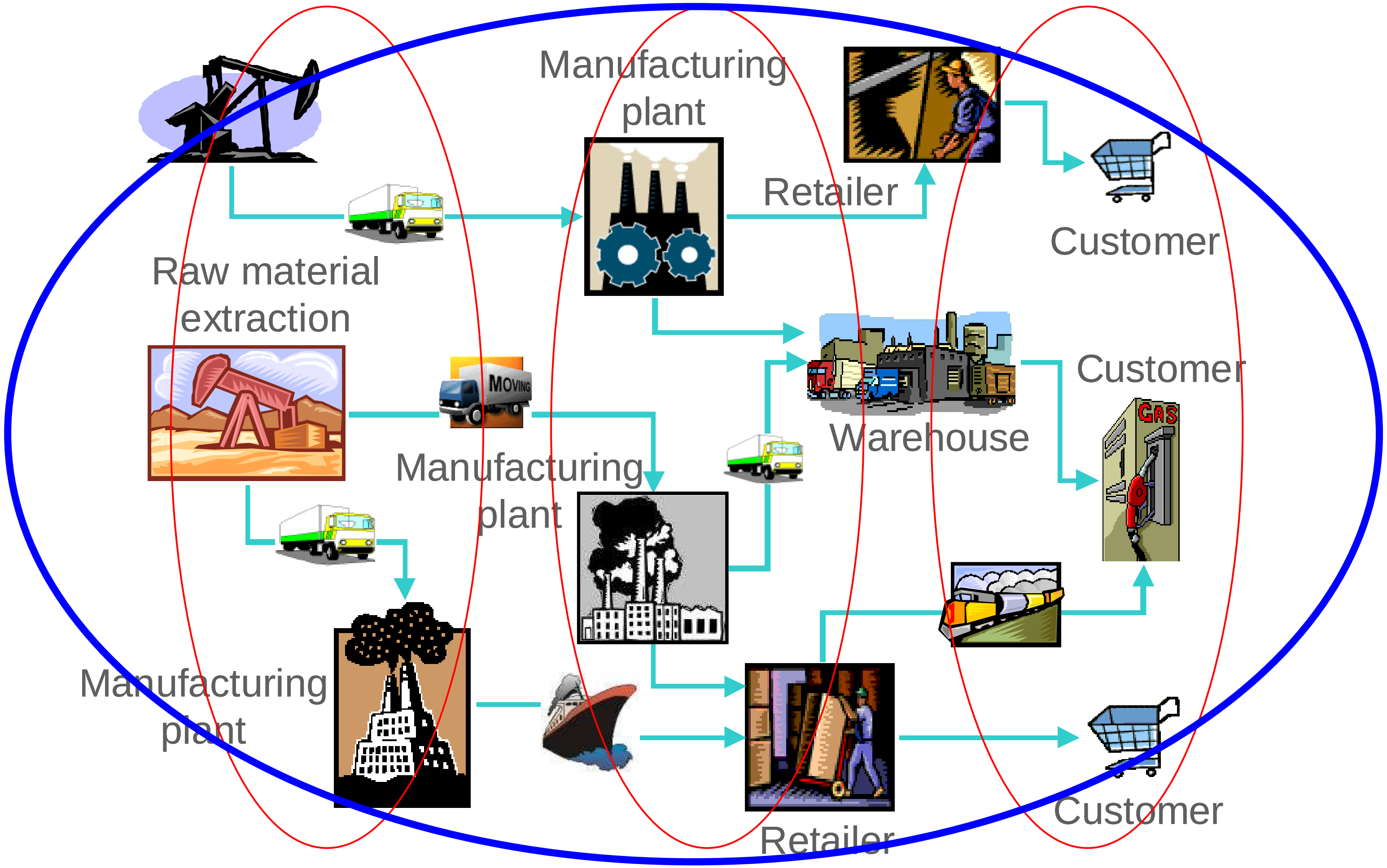
Polytechnic University of Catalonia, Barcelona, Spain

EWO Seminar, 11 December 2007

Outline

- Introduction
- Simulation models for SCM
- Multi-agent system for SCM
- Simulation-based optimization (Sim-Opt)
- Multi-objective Sim-Opt
- Mathematical programming vs Sim-Opt
- Conclusions

Supply chain management



Supply Chain

A SC can be defined as a network of business entities who work together in an effort to acquire raw materials, transform these raw materials into intermediate and finished products, and distribute these final products to retailers (Simchi-Levi et al., 2000)

SCM: Trends and challenges

Dynamic considerations:

- Dynamic simulation, simulation/optimization approaches

Integrated approaches

- Horizontal integration (manufacturing, distribution, etc.)
- Vertical integration (different decision-making levels: strategic, tactical and operational))

Multi-objective optimization

- Different conflictive criteria (economic, environmental issues, etc.)
- Rigorous approaches (weighted-sum method, ε-constraint method, goal-programming method)
- Heuristic approaches (GA-based, SA-based, etc.)

Approaches for SCM

SCM models and tools

Transactional

- Enterprise resource planning systems (ERP)
- Material resource planning systems (MRP)
- Customer relationship management systems (CRM)
- . . .

Analytical

Normative or optimization approaches

- Deterministic math. prog.
- Stochastic math. prog.

(LP, MILP, NLP, MINLP)

Descriptive approaches

- Forecasting models
- Simulation models
- . . .

Analytical approaches for SCM

Planning-based approaches

Operations research optimization models

centralized approaches with global information sharing

LP, MILP, NLP, MINLP
Deterministic / stochastic math. programming

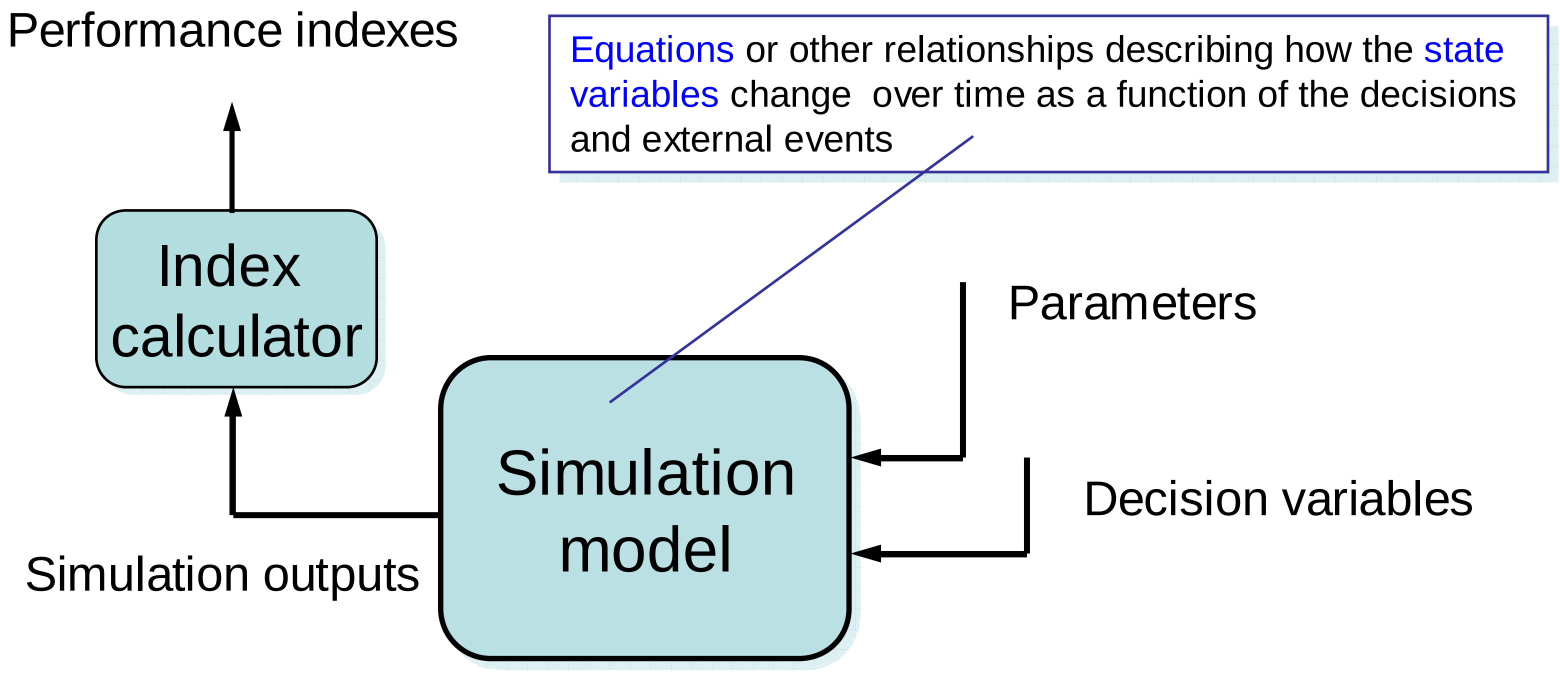
Demand-driven approaches

Discrete event-based simulation

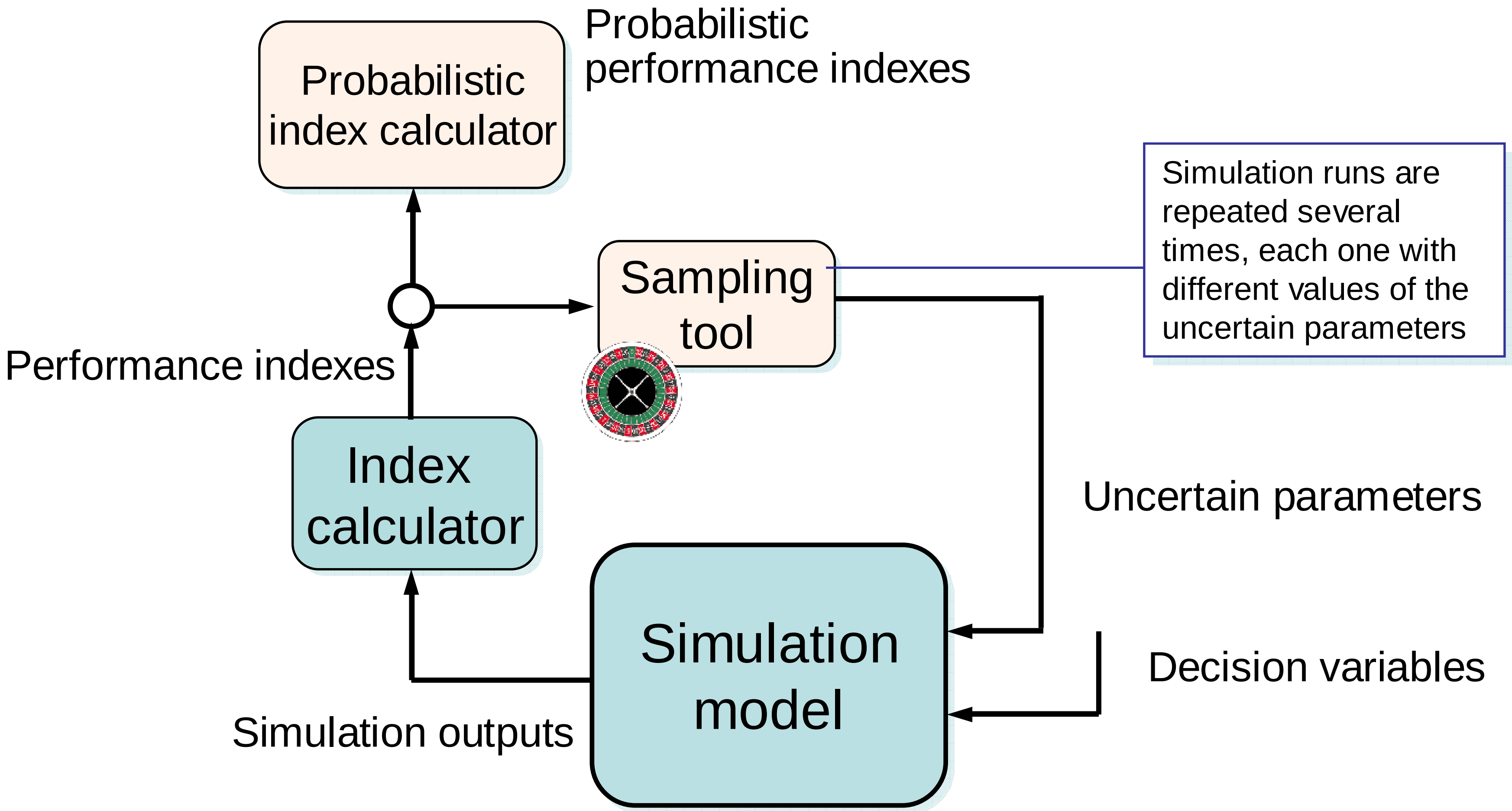
Deterministic / stochastic simulation

centralized or decentralized approaches, variable degree of information sharing

Deterministic simulation

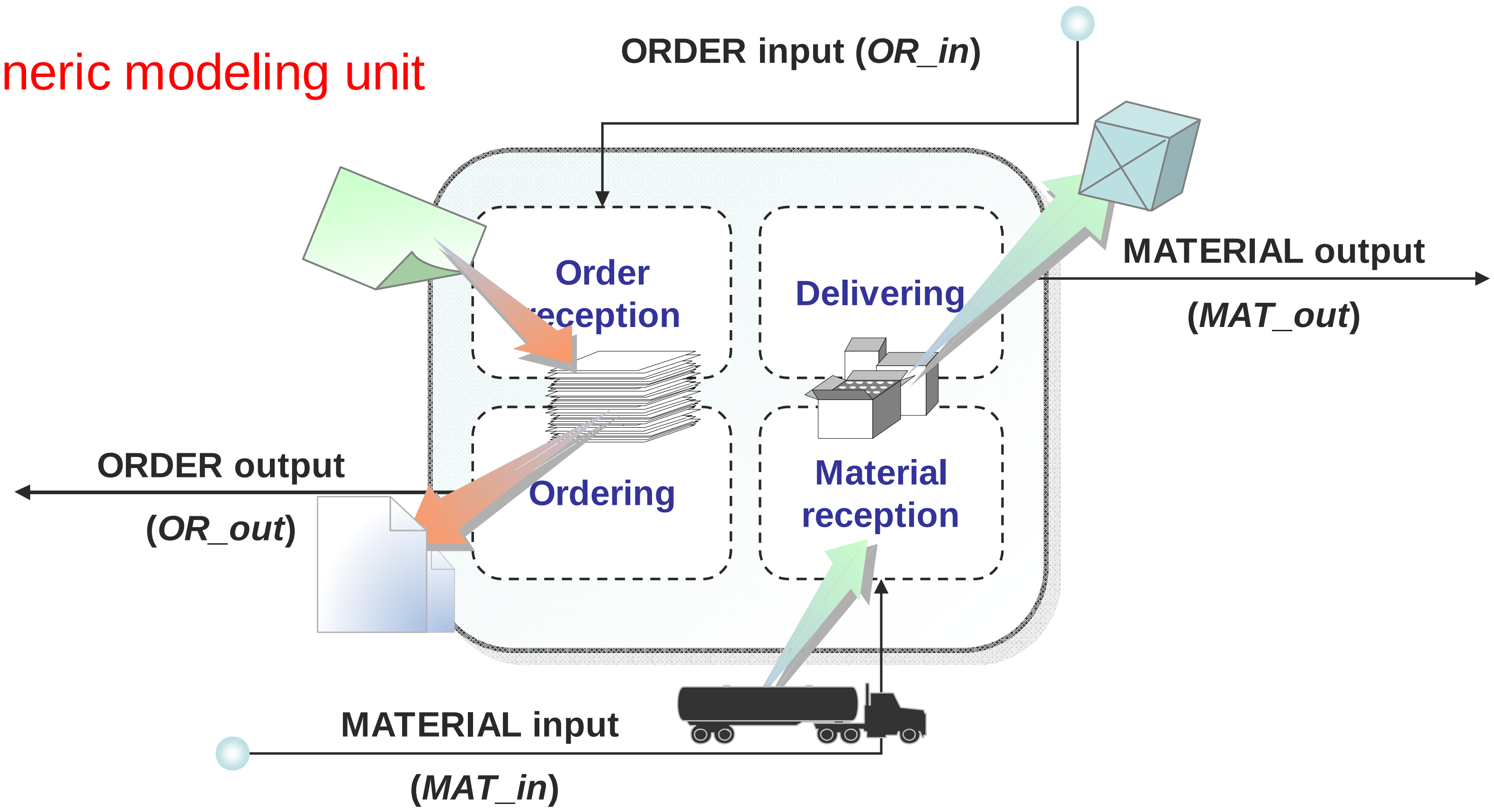


Stochastic simulation

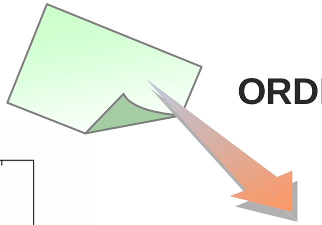


Modeling principles: generic modeling unit for SCM

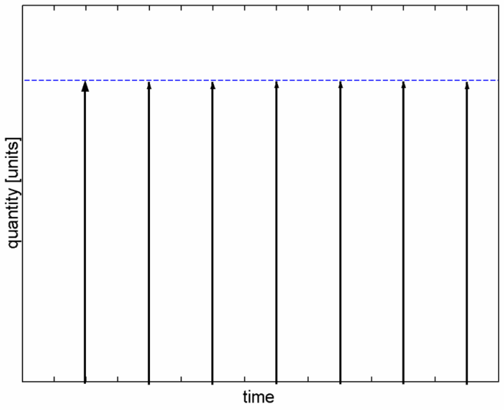
Generic modeling unit



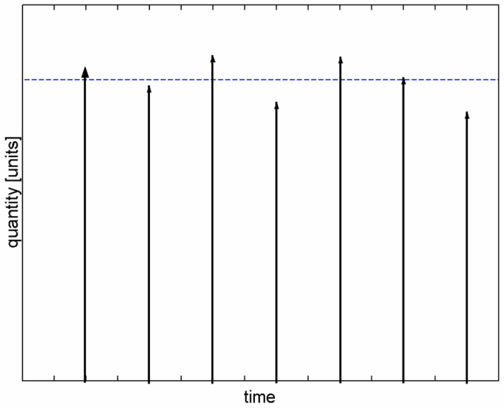
Demand model: orders placed by customers



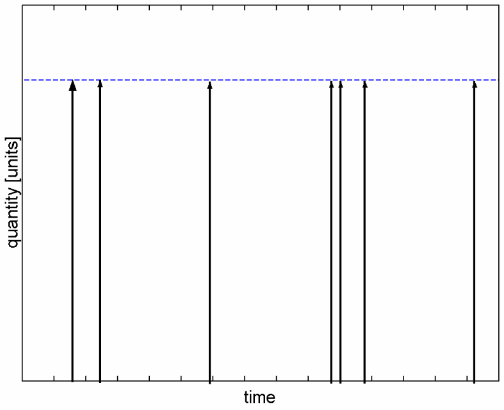
ORDER input (*OR_in*)

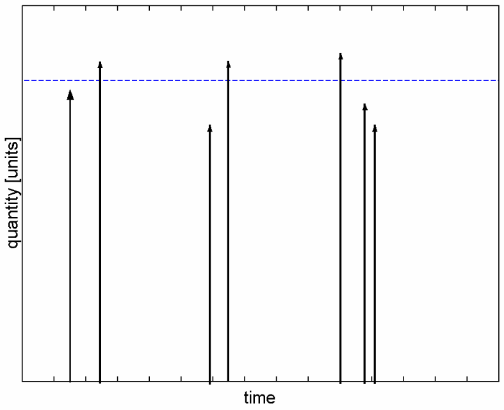


Uniform quantities and times



Variable quantities and uniform times





Quantities:

Normal distribution

Times:

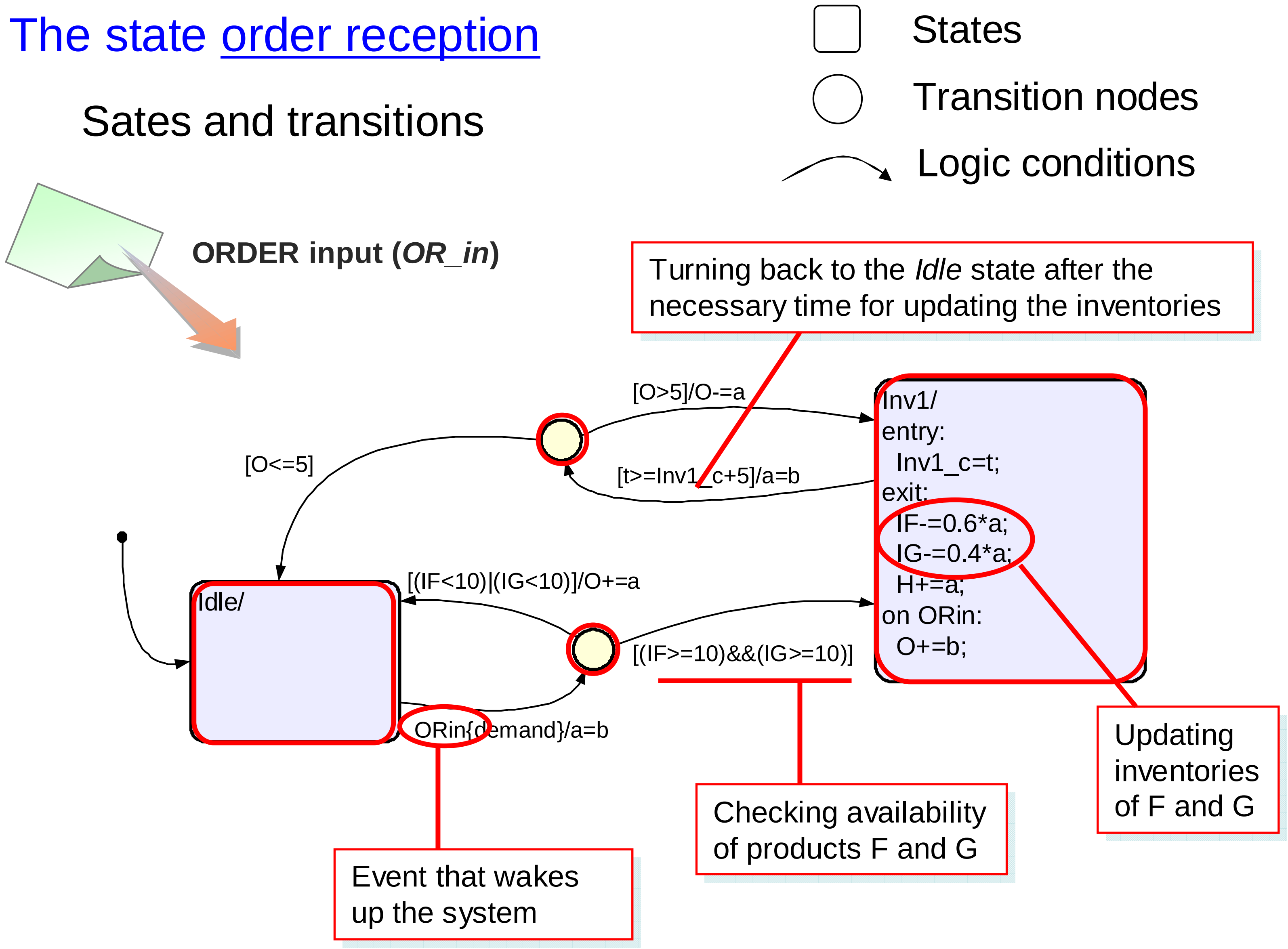
Poisson distribution

Uniform quantities and variable times

Variable quantities and times

The state order reception

Sates and transitions



Inventory model (state ordering)

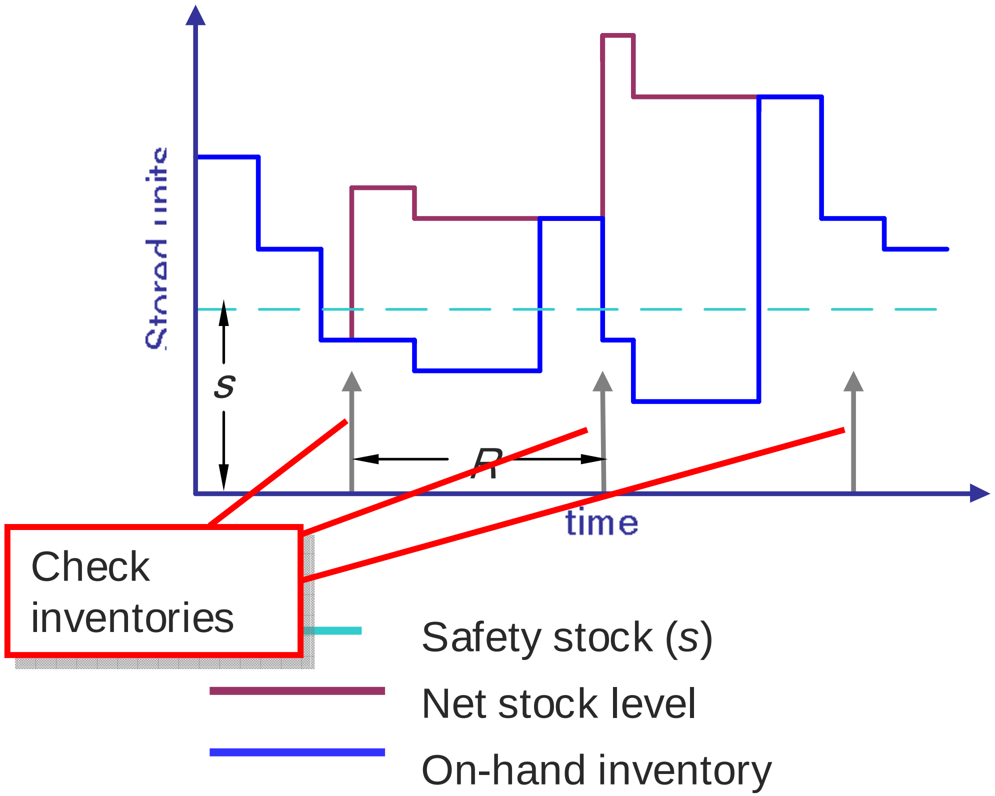
Inventory control policies

ORDER output

(*OR_out*)

- Continuous
  - (s, k) System
  - (s, Q) System
  - (R, S) System
- Periodic
  - (R, S) System
  - (R, s, S) System
  - (R, s, k) System

$$u = k(s - Inv)$$



Discrete event-based simulation

Performance measures: Key Performance Indicators (KPIs)

$$\mathcal{F}(\eta) = E[f(\eta, \omega)]$$

decision variables

expected value

scenario

Economic: *Total SC profit*

$$Profit = R - C$$

$$R = \sum_t \sum_{j \in Prod} \sum_i Q_{ijt} \cdot price_{ij}$$

$$C = TrnC + InvC + PrdC$$

Social: *Customer satisfaction*

$$MDSat \leq \frac{\sum_{pkt} Sales_{pkts}}{\sum_{pkt} Dem_{pkts}} \qquad \forall\, t > 1, s$$

Environmental: *Greenhouse effect impact*

$$GHE = \sum_e GWP_e \cdot m_e$$

Software agents

> An **agent** is an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives.
>
> *Wooldridge and Jennings, 1995*

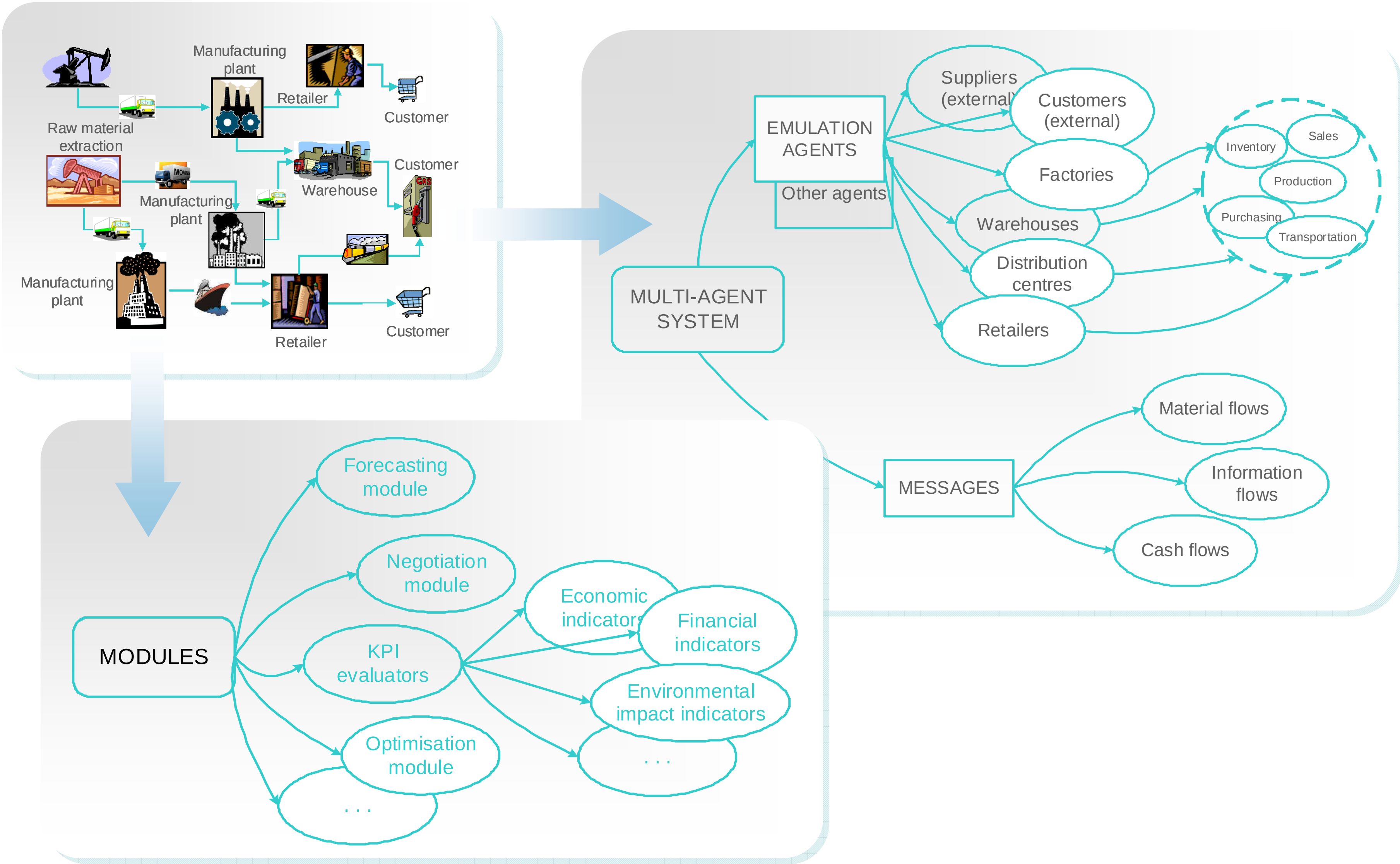
Autonomy: it should have some control over its actions and should work without human intervention.

Social ability: it should be able to communicate with other agents and/or with human operators.

Reactivity: it should be able to react to changes in its environment.

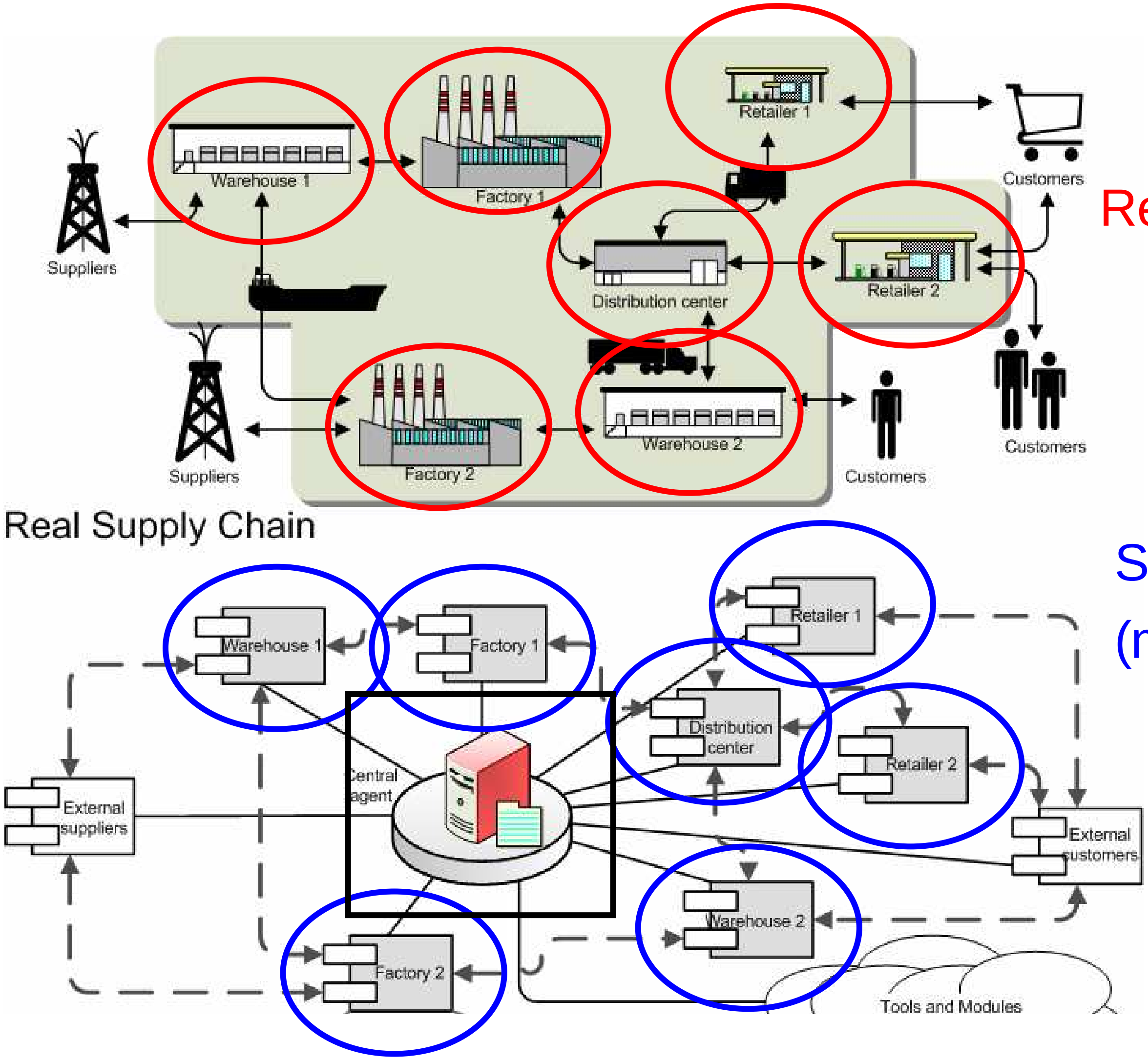
Pro-activeness: it should also be able to take initiative based on pre-specified goals.

Agent-based simulation model



Agent-based simulation model

Implementation of a multi-agent system



Real supply chain

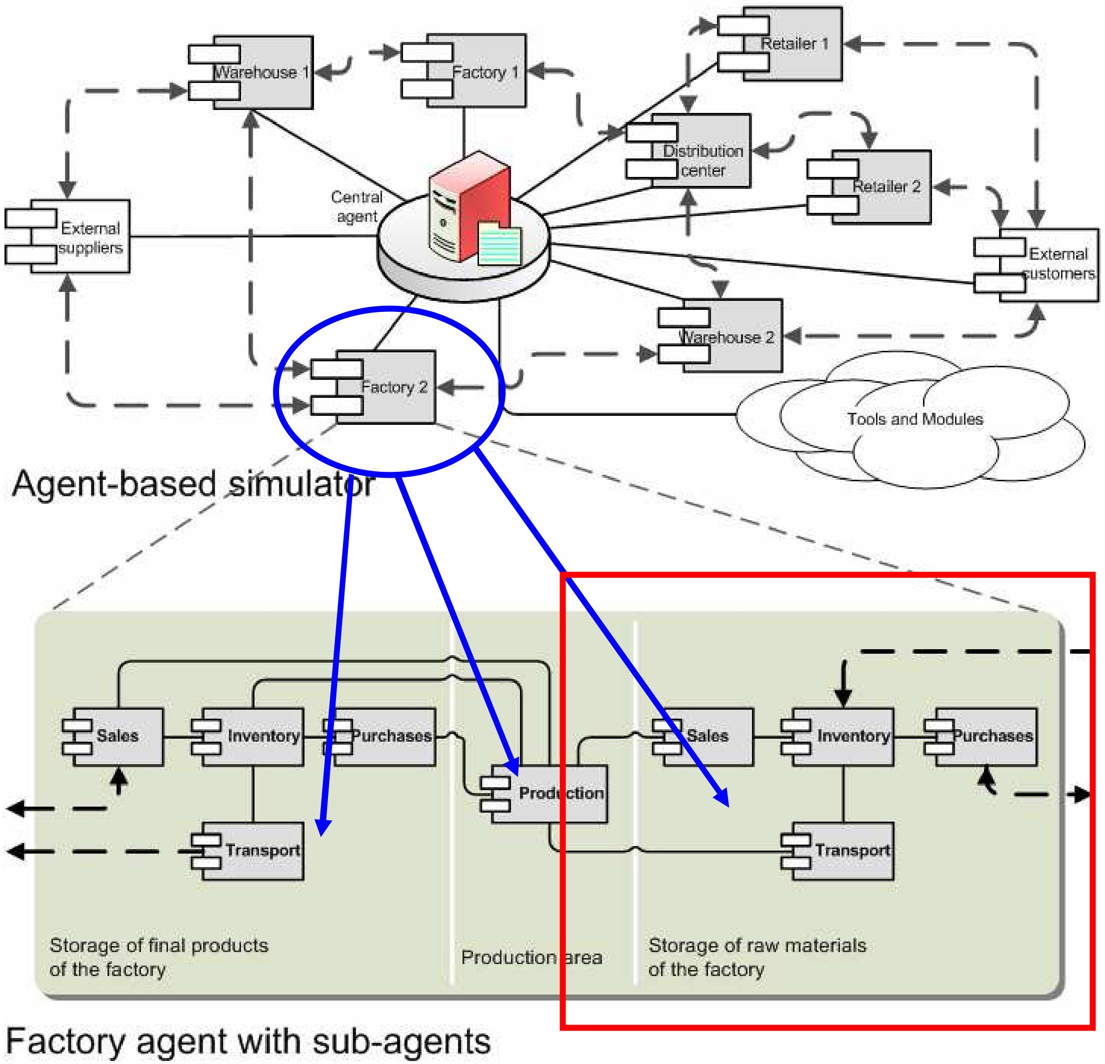
Simulation model (multi-agent system)

Central agent

- Exchanges messages
- Provides access to modules

Sub-agents

Implementation of a multi-agent system



Tasks

- Storage of raw materials
- Production
- Storage of final products

Sub-agents

- Sales
- Inventory
- Purchases
- Transport

Storage agent

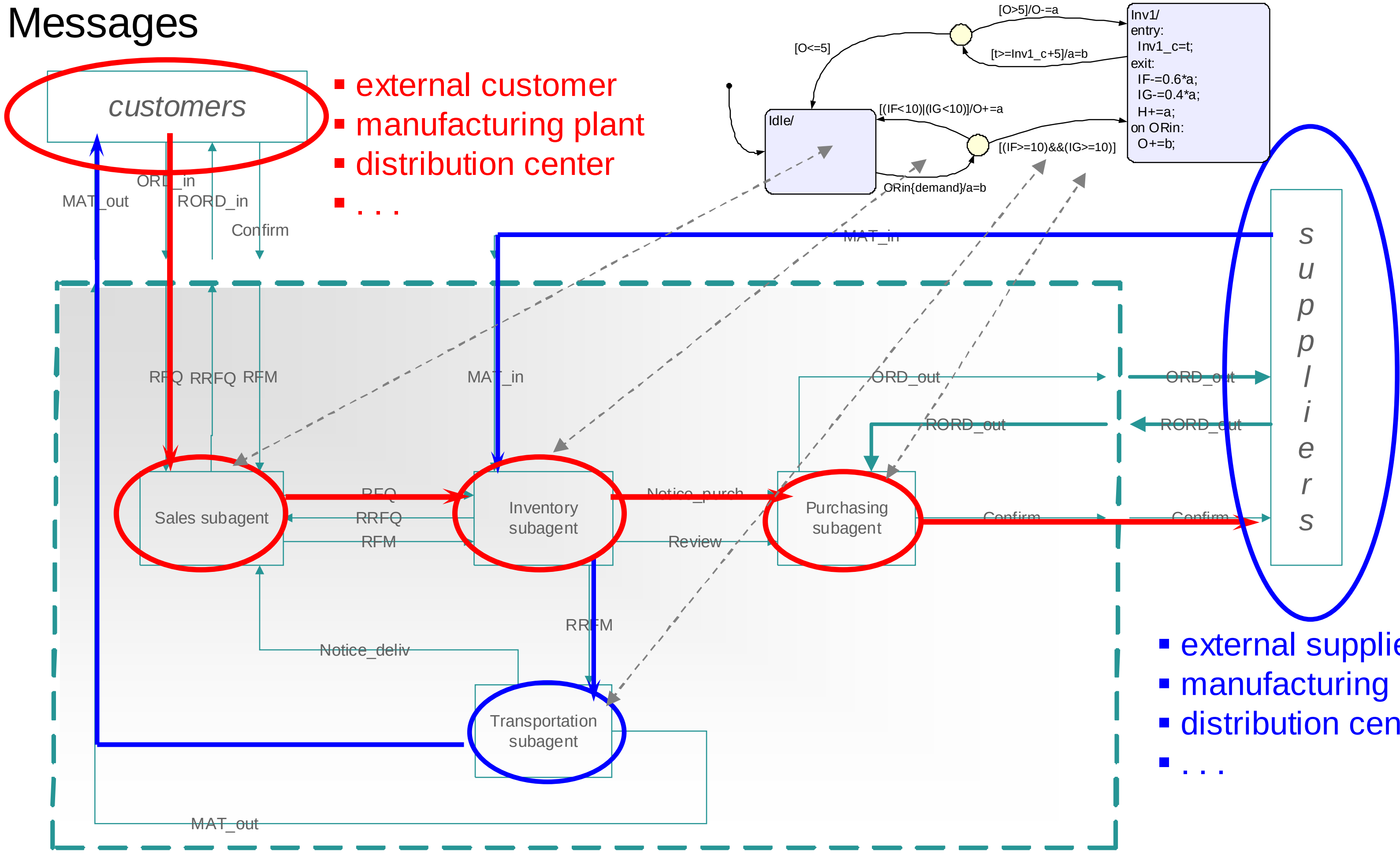
Plants (storage), warehouses, distribution centers and retailers

Storage agent

Subagents: Sales, Inventory, Purchasing and Transport

Messages

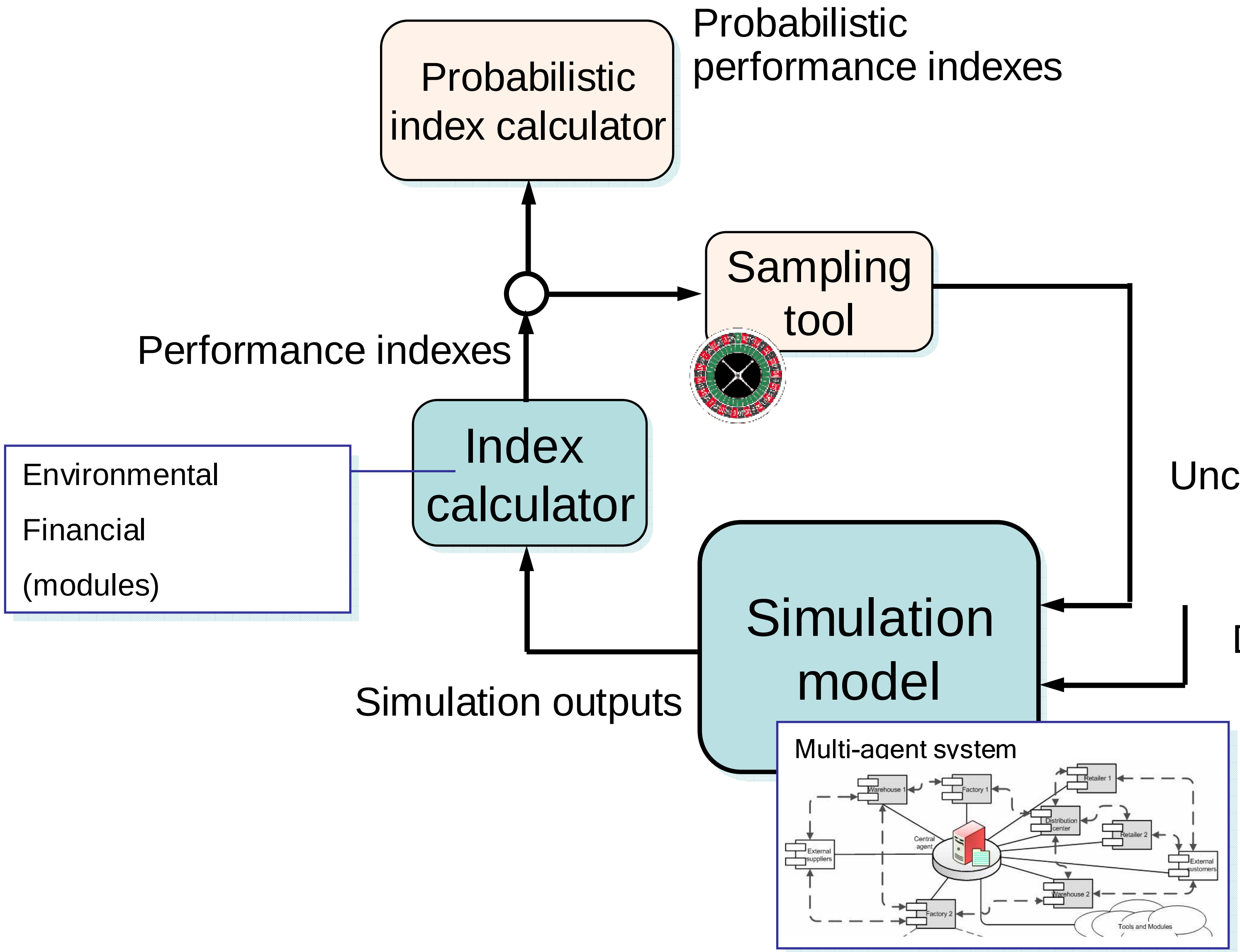
States and transitions



- external customer
- manufacturing plant
- distribution center
- . . .

- external supplier
- manufacturing plant
- distribution center
- . . .

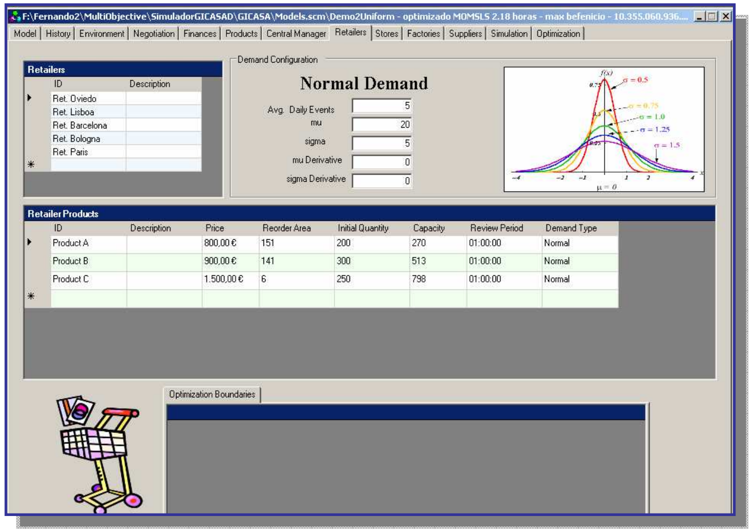
Stochastic simulation

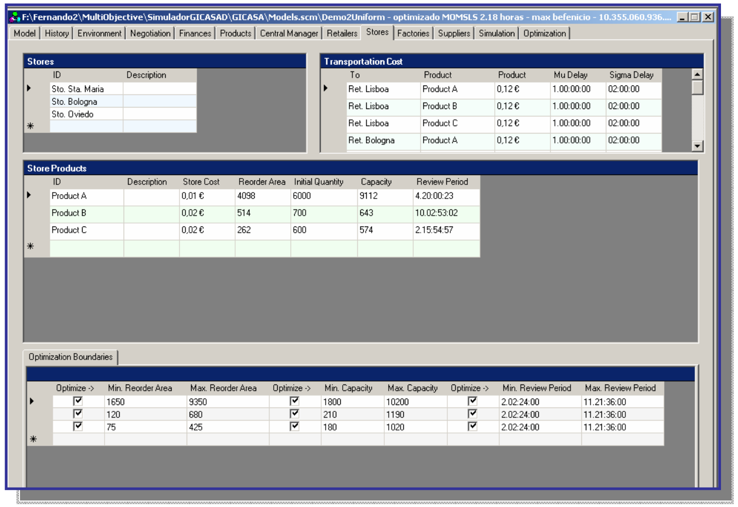


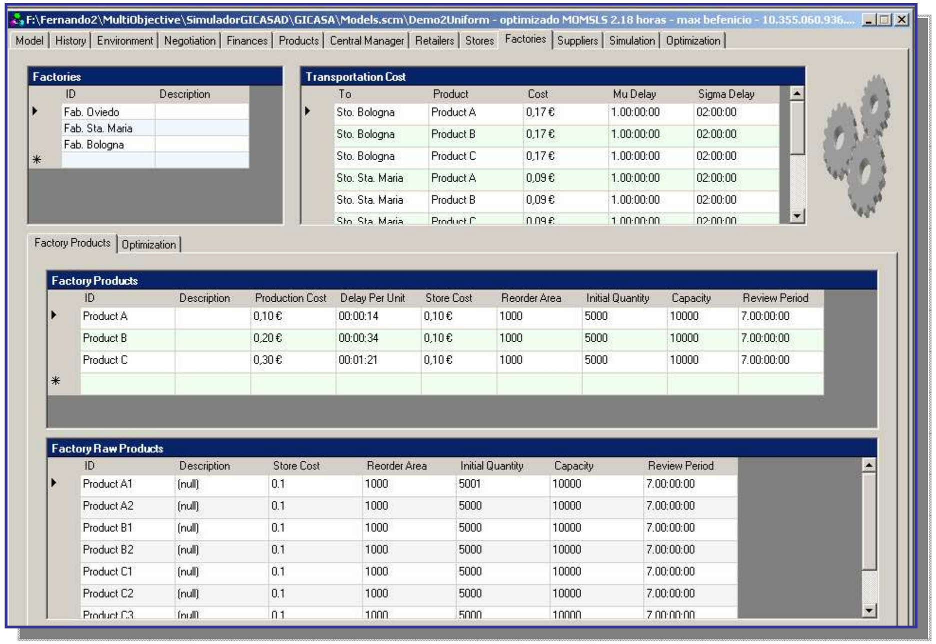
Software implementation

Retailers, warehouses and plants

- C#, *.NET* of *Microsoft* ®
- SC model: *XML files*

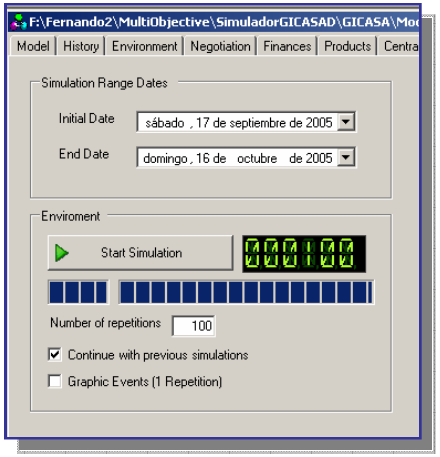


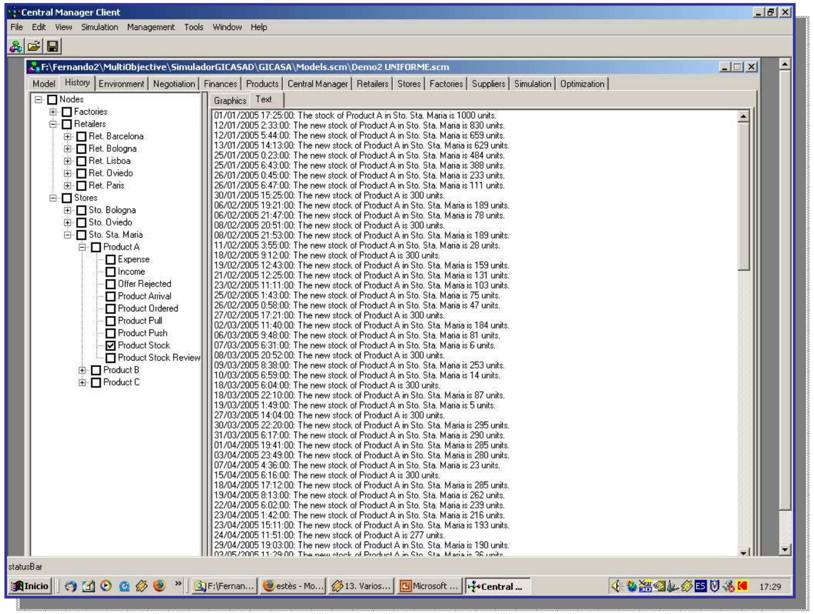


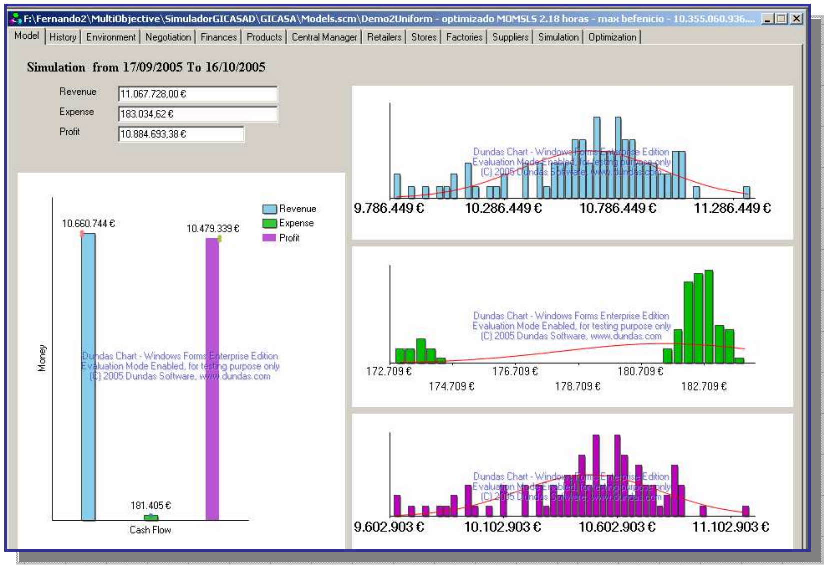


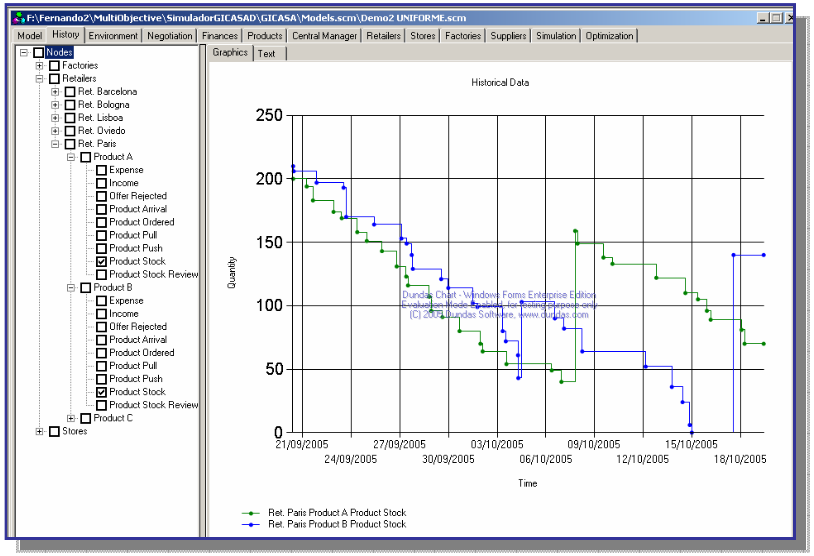
Software implementation

Simulation outcome



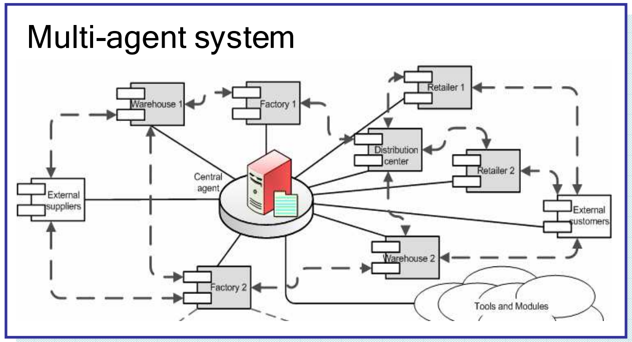






Framework for dynamic simulation of SCs

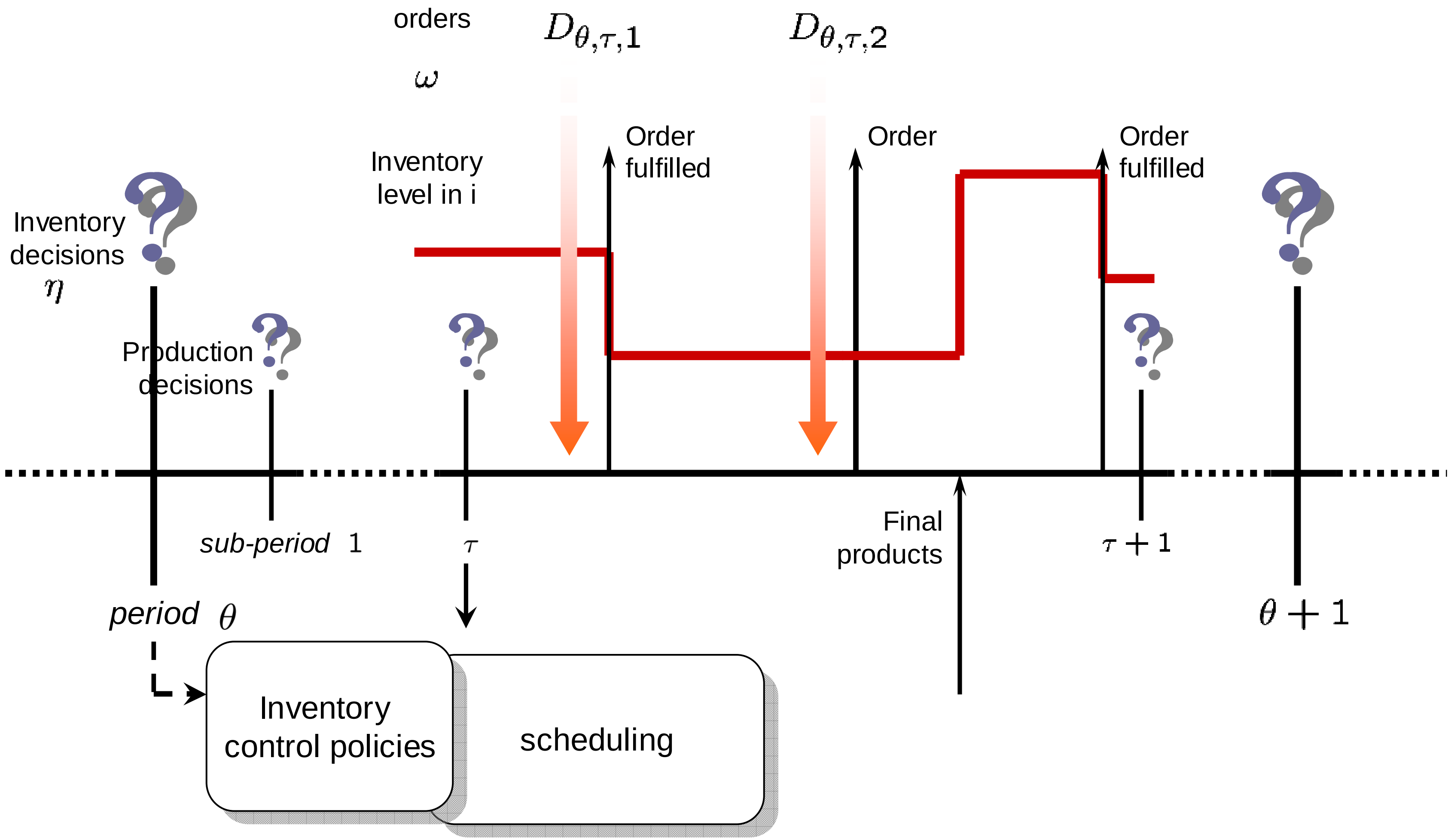
- Very few approaches in the literature for the CPI industry (Goodwin y col., 1997, Fox y col., 2000, Swaminathan y col., 1998, Julka y col., 2002
- Centralized or decentralized decision-making
- Different production, storage and transportation policies
- Connection with different modules:
    - Demand forecast
    - Planning, scheduling, etc.
- Flexibility



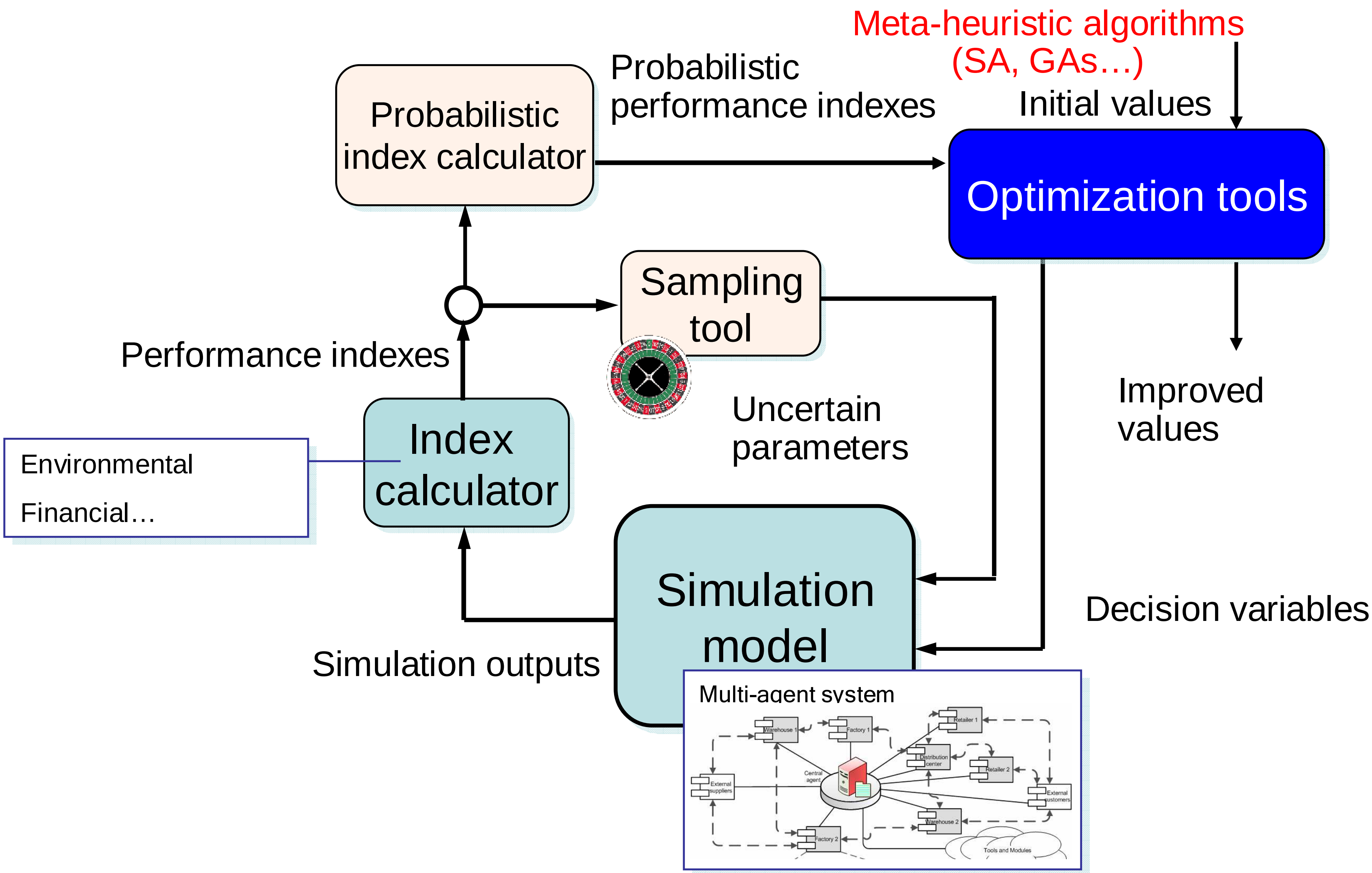
Lack of optimization capabilities!!

Simulation-based optimization

Decision-making under uncertainty

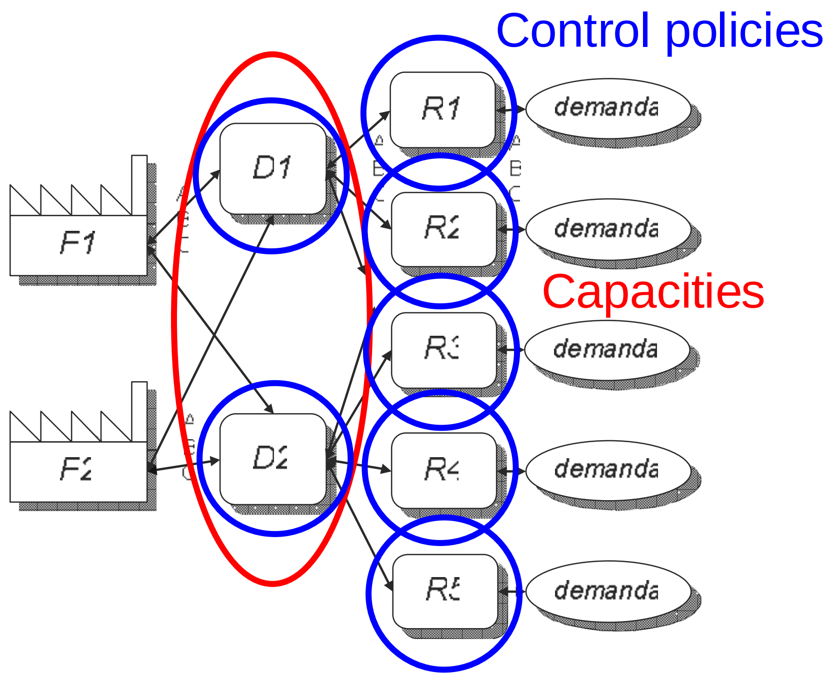


Sim-Opt architecture

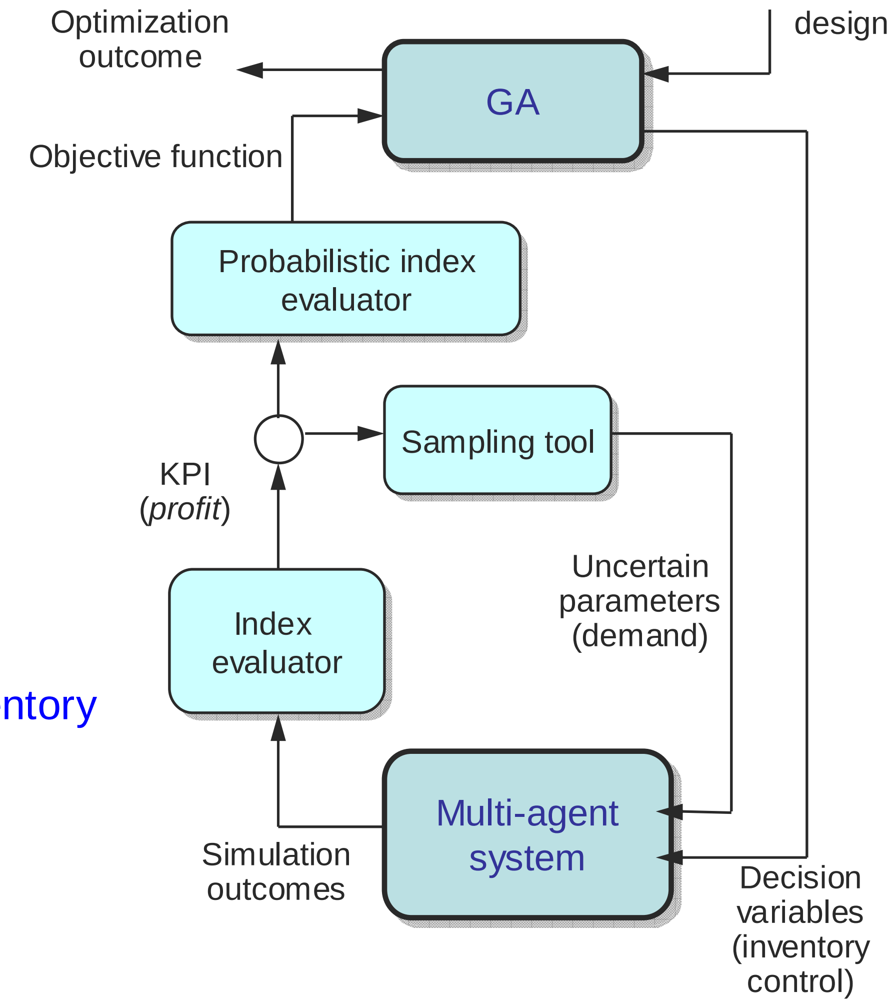


Case study Sim-Opt

SC design problem

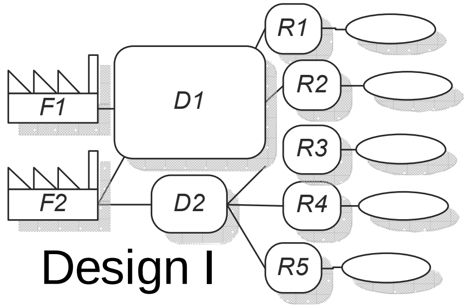


- Strategic-Tactical levels (capacities and inventory control policies)
- Uncertain demand (time and amount)
- System (*R*, *s*, *S*) for distribution centers
- System (*s*, *S*) for retailers
- Maximize expected profit

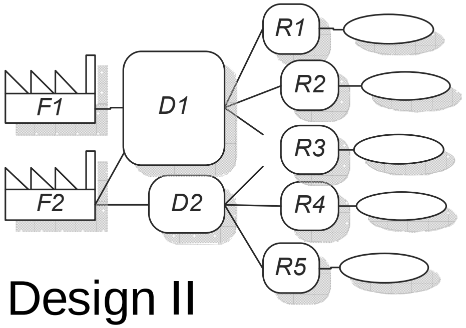


Results

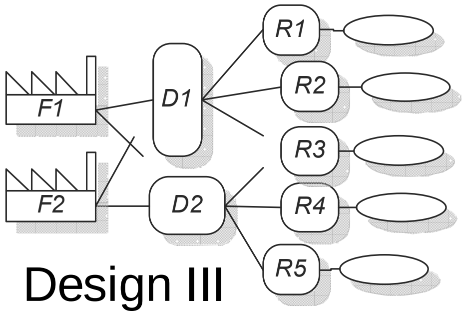
Entity	Distribution center D1			Distribution center D2		
Product	A	B	C	A	B	C
Design I	8,000	8,000	8,000	8,000	8,000	8,000
Design II	8,000	0	8,000	8,000	8,000	8,000
Design III	8,000	0	0	8,000	8,000	8,000
Design IV	2,000	2,000	2,000	8,000	8,000	8,000
Design V	2,000	0	2,000	8,000	8,000	8,000



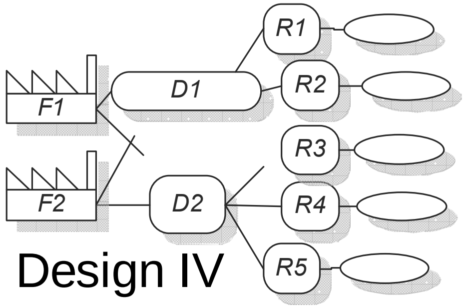
Design I



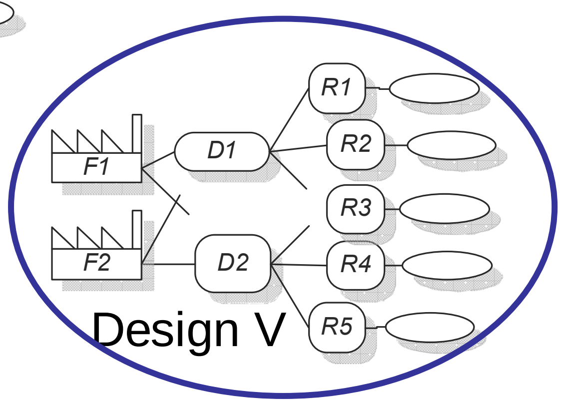
Design II



Design III



Design IV

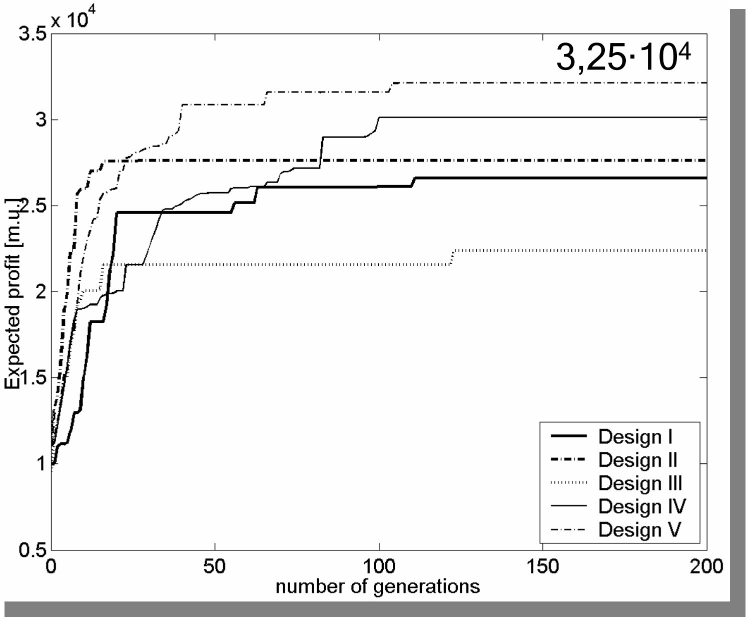


Design V

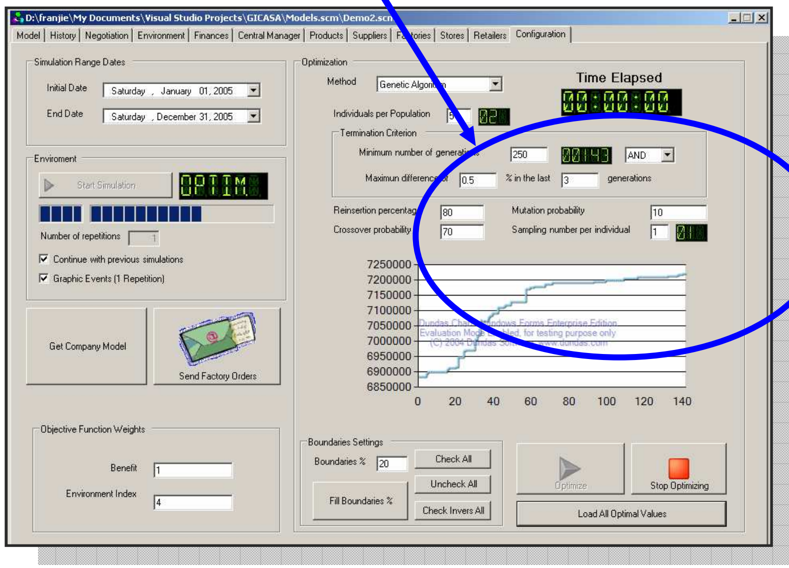
Case study Sim-Opt

Results

Entity	Distribution center D1			Distribution center D2		
Product	A	B	C	A	B	C
Design I	8,000	8,000	8,000	8,000	8,000	8,000
Design II	8,000	0	8,000	8,000	8,000	8,000
Design III	8,000	0	0	8,000	8,000	8,000
Design IV	2,000	2,000	2,000	8,000	8,000	8,000
Design V	2,000	0	2,000	8,000	8,000	8,000

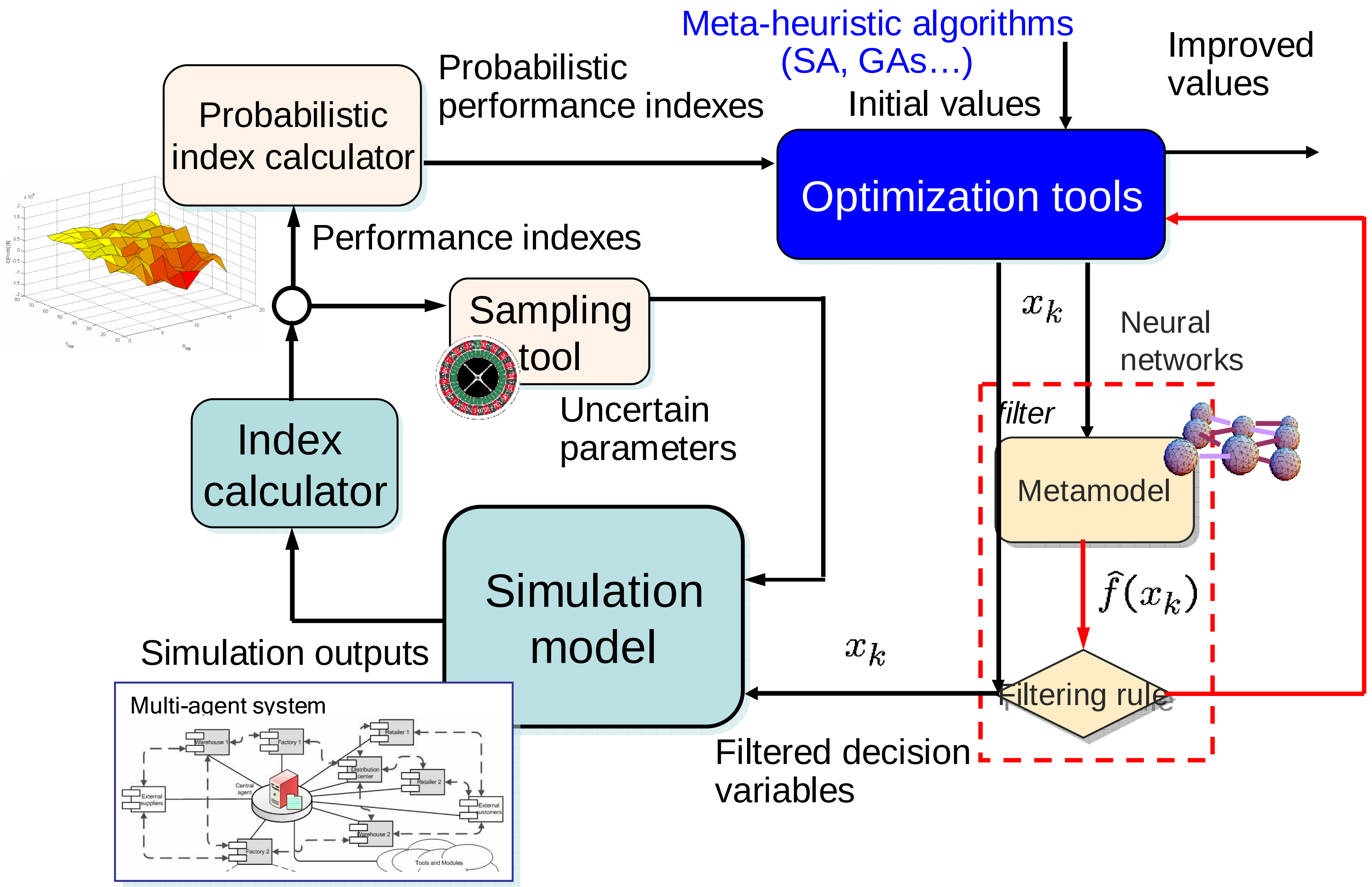


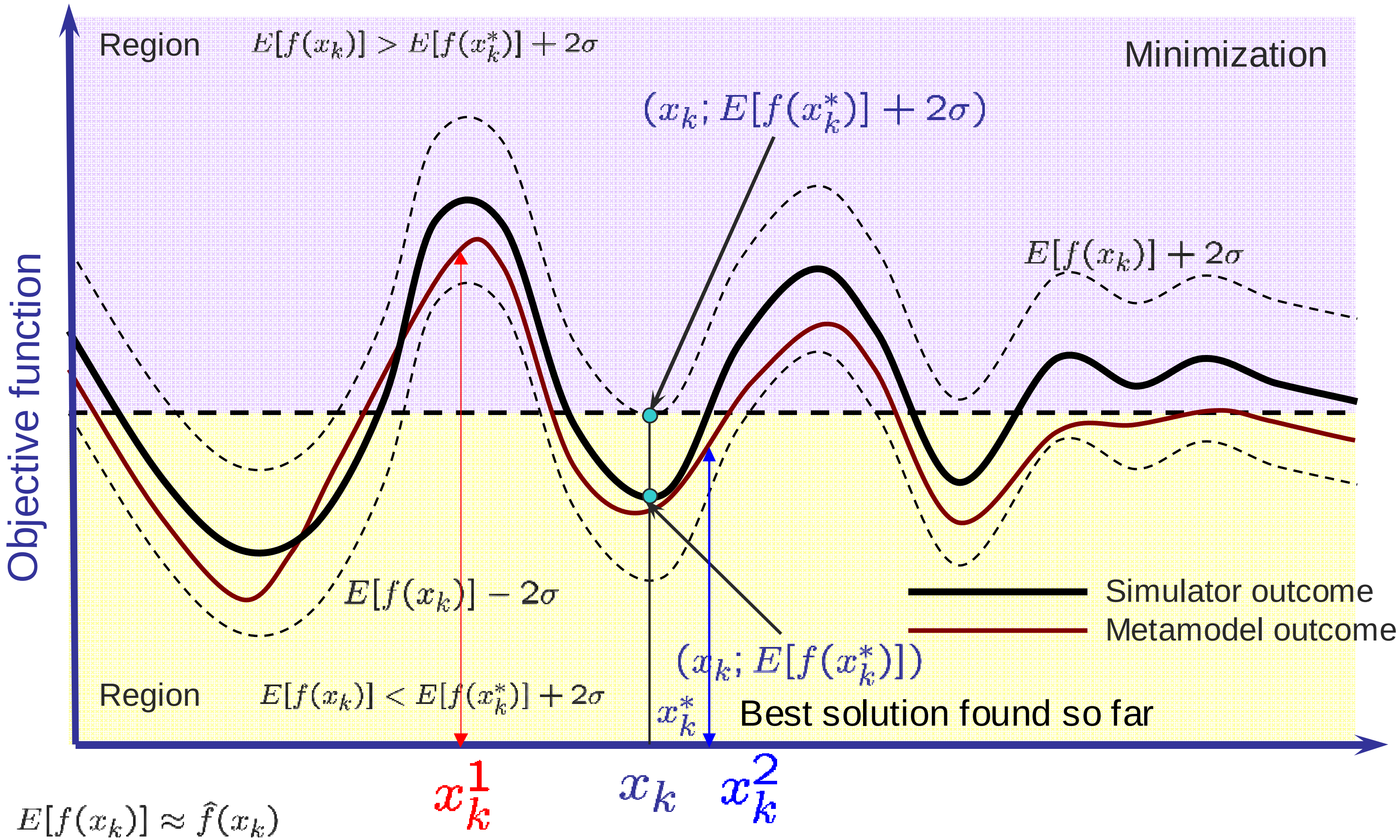
Tuning parameters



Large CPU times!!

Sim-Opt architecture





$E[f(x_k)] \approx \hat{f}(x_k)$

IF $\hat{f}(x_k) > E[f(x_k^*)] + \zeta$, $\zeta = 2\sigma_{f(x_k)}$, THEN DISCARD x_k

Sim-Opt architecture

Tuning parameters

Genetic algorithm parameters

$MaxGen$	Maximum number of generations
N	Population size
Ns	Number of Monte Carlo samples
Px	Probability of cross-over
Pm	Probability of mutation

Metamodel

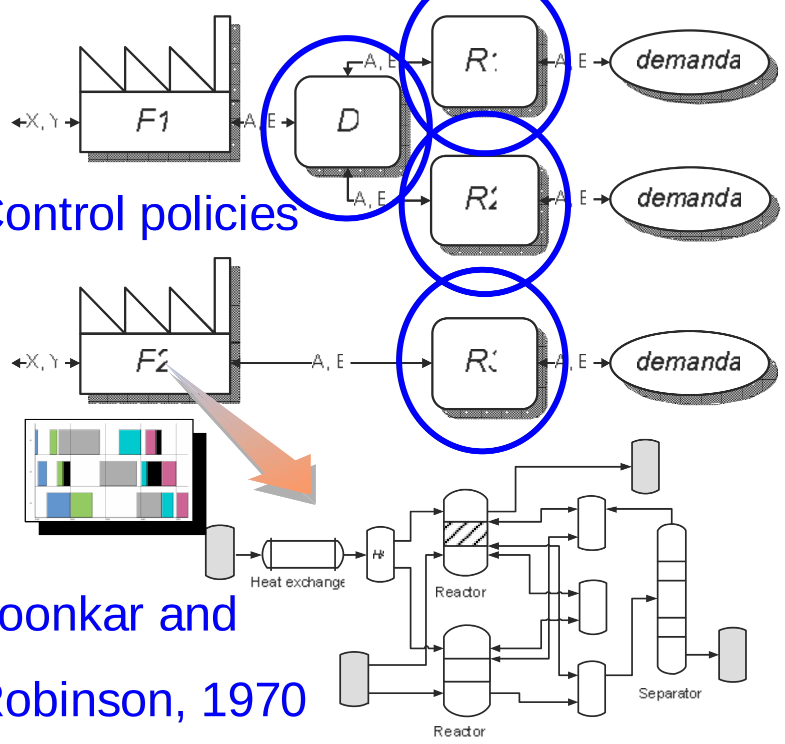
ζ	Maximum tolerance
ϕ	Frequency of metamodel training

Maximum number of simulations

$$\mathcal{N} = Ns \cdot N \cdot (Rep \cdot MaxGen + 1)$$

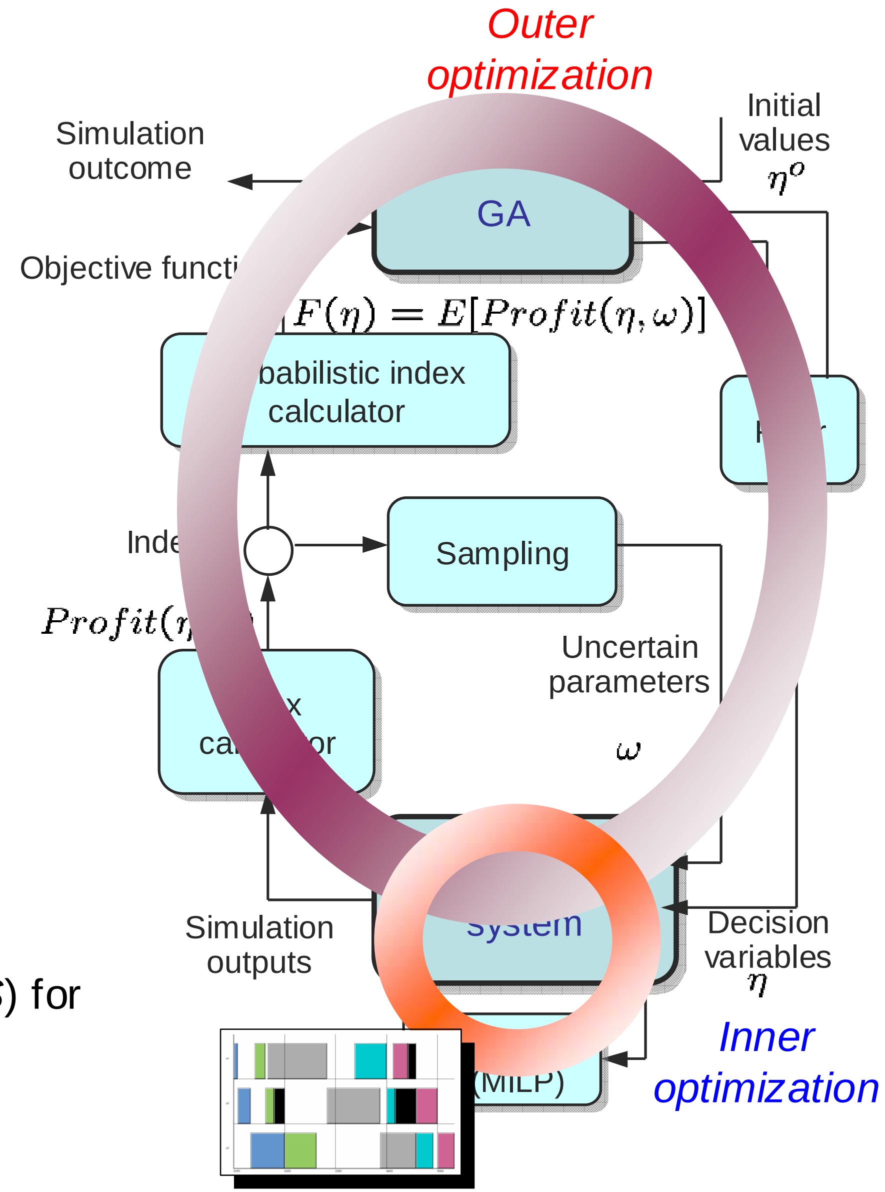
Case study

SC with embedded multi-product plants



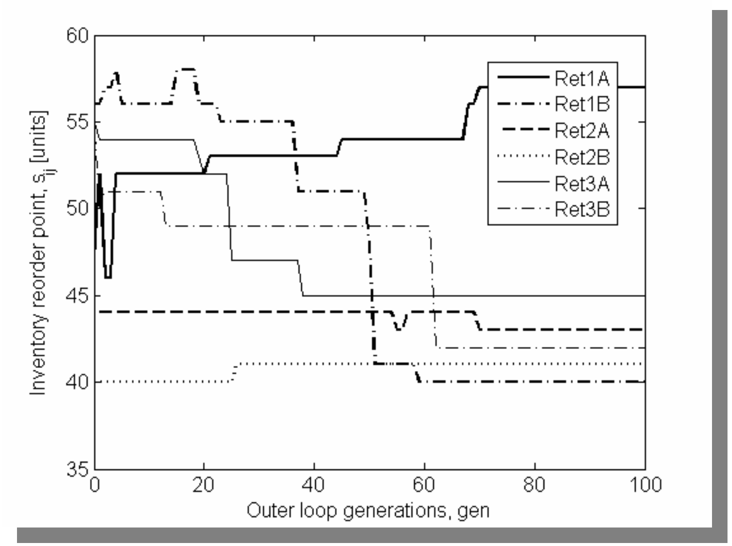
Control policies

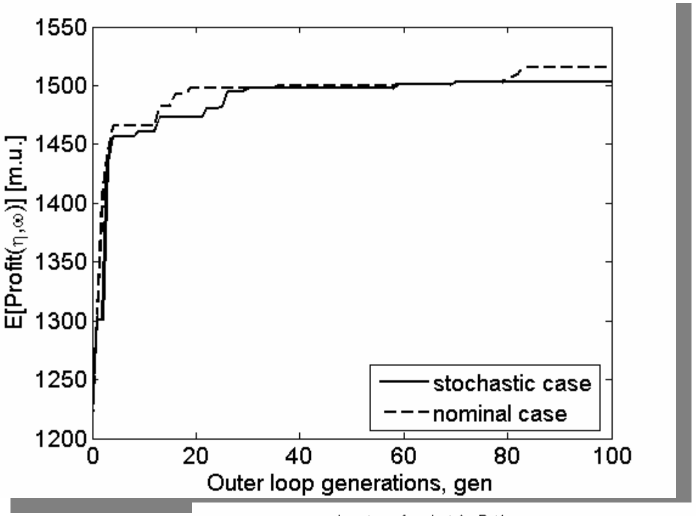
Loonkar and Robinson, 1970

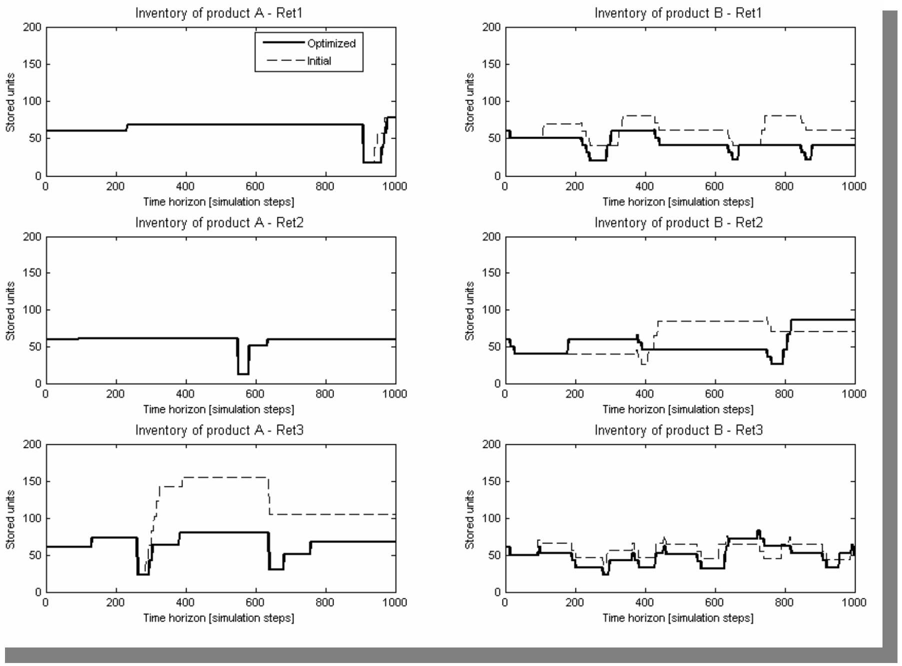


- Integration of tactical-operational levels
- Uncertain demand (quantity and amount)
- System (*R, s, S*) for distribution centers and (*s, S*) for retailers
- Maximize expected profit

Case study







Outer loop optimization

$MaxGen$ 100 generations

Ns 50 samples (scenarios)

$Time$ 10 s/run (total time 28 hours)

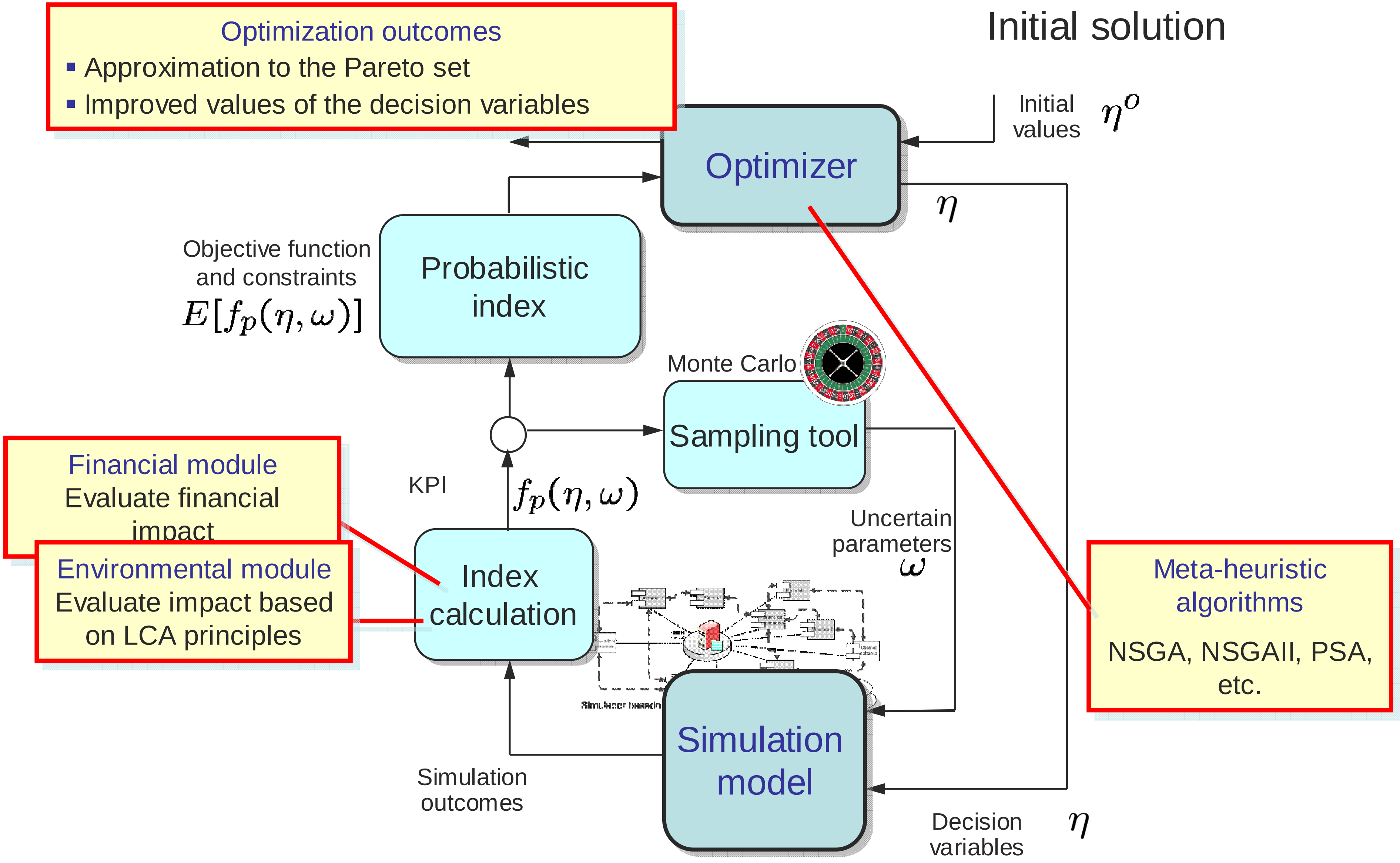
$\mathcal{N}$ $2{\cdot}10^4$ simulation runs

Inner optimization

0,1-1 seconds

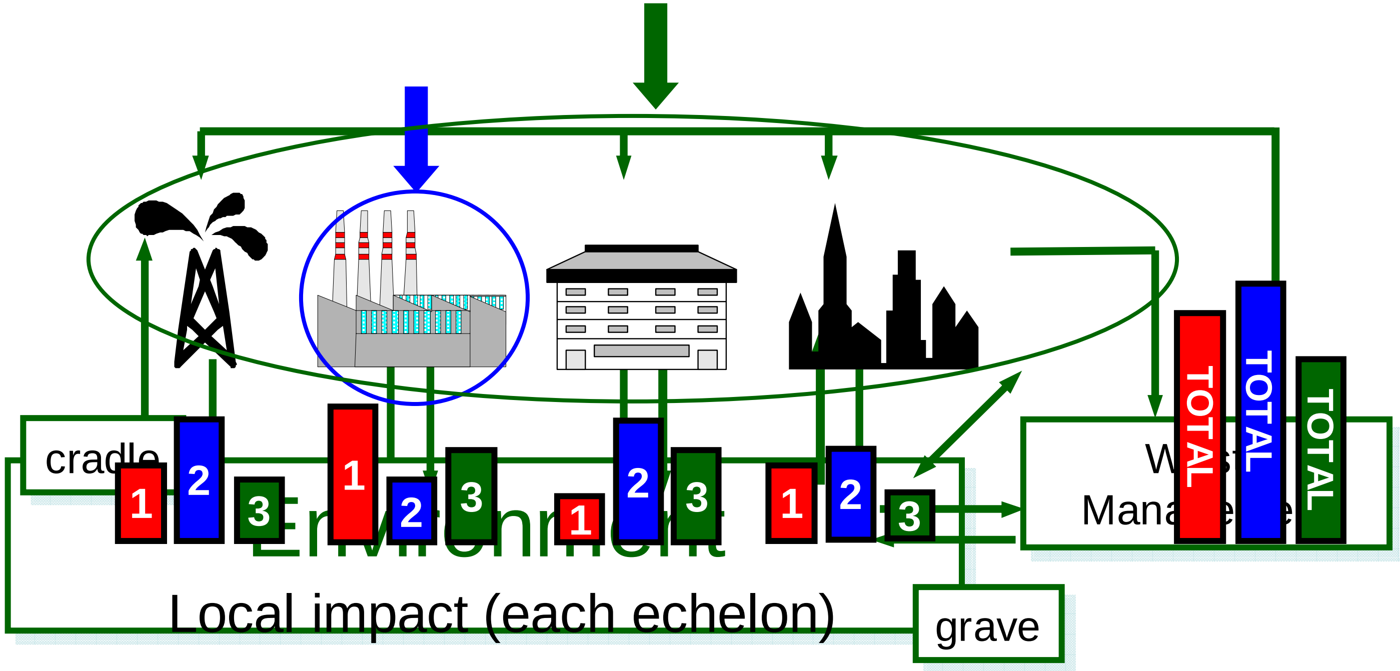
GAMS-CPLEX

Multi-objective Sim-Opt



Environmental concerns

Environmental issues in SCM



Total impact

(entire SC)

Life Cycle Assessment (LCA)

LCA

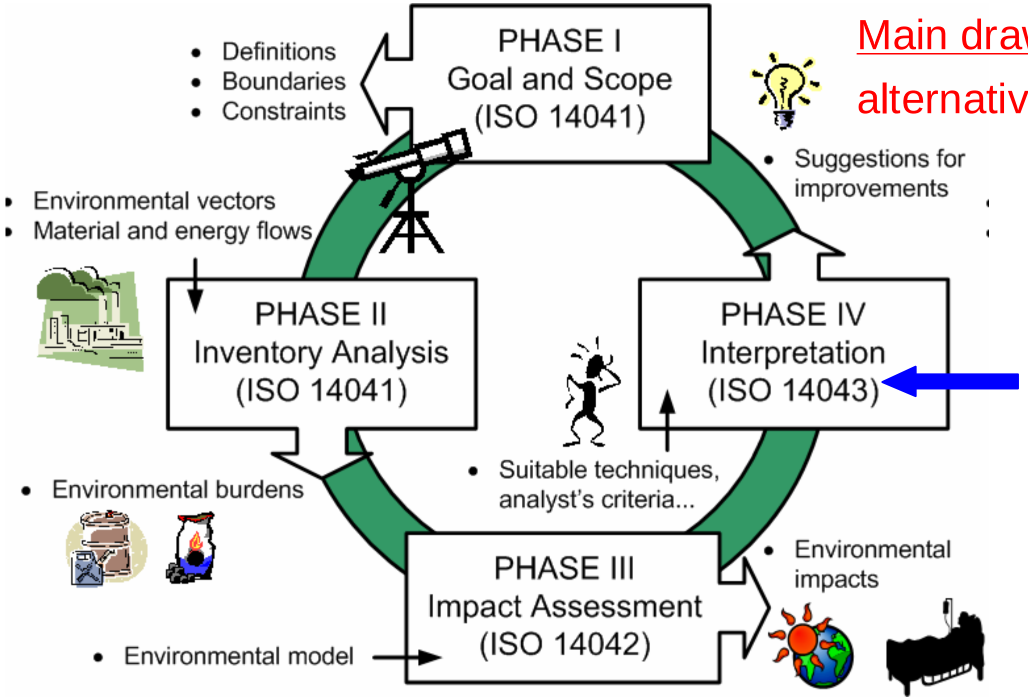
(ISO 14040 series on LCA)

Objective strategy to evaluate the environmental loads associated with a product, process or activity

by quantifying energy and materials used and waste released

to evaluate opportunities to do improvements

It includes the **ENTIRE LIFE CYCLE** of the product

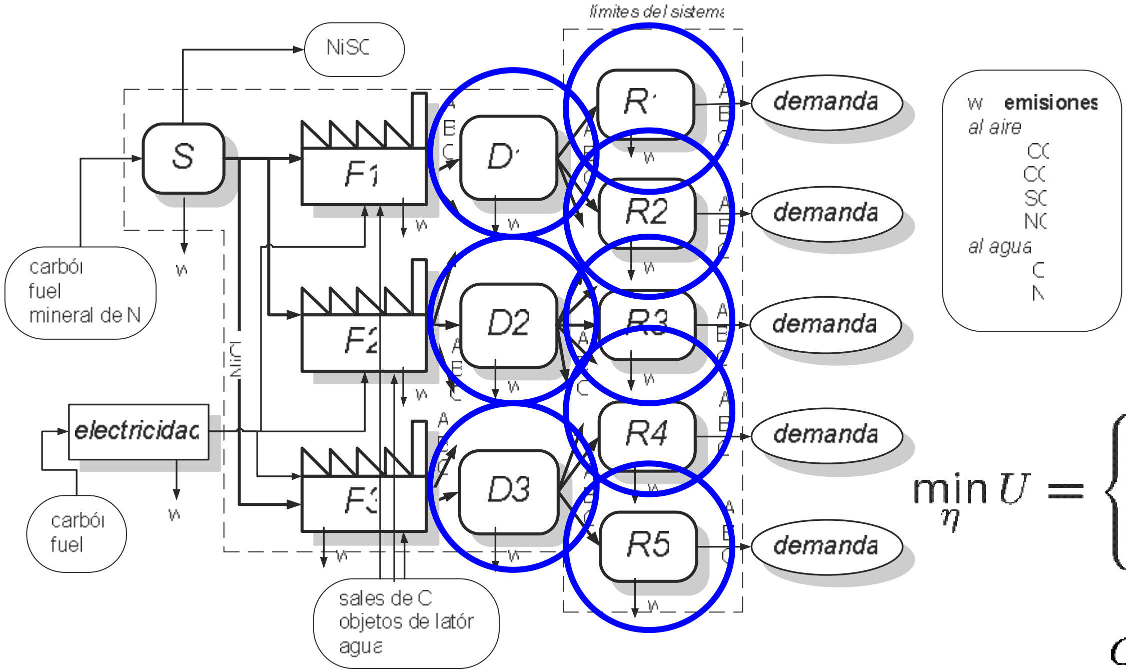


Main drawback: a systematic procedure to search alternatives for environmental improvements is lacking

Combine LCA with optimization tools (Azapagic et al., 1999, Hugo and Pistikopoulos, 2005)

Case study

Multi-objective tactical-operational SCM problem

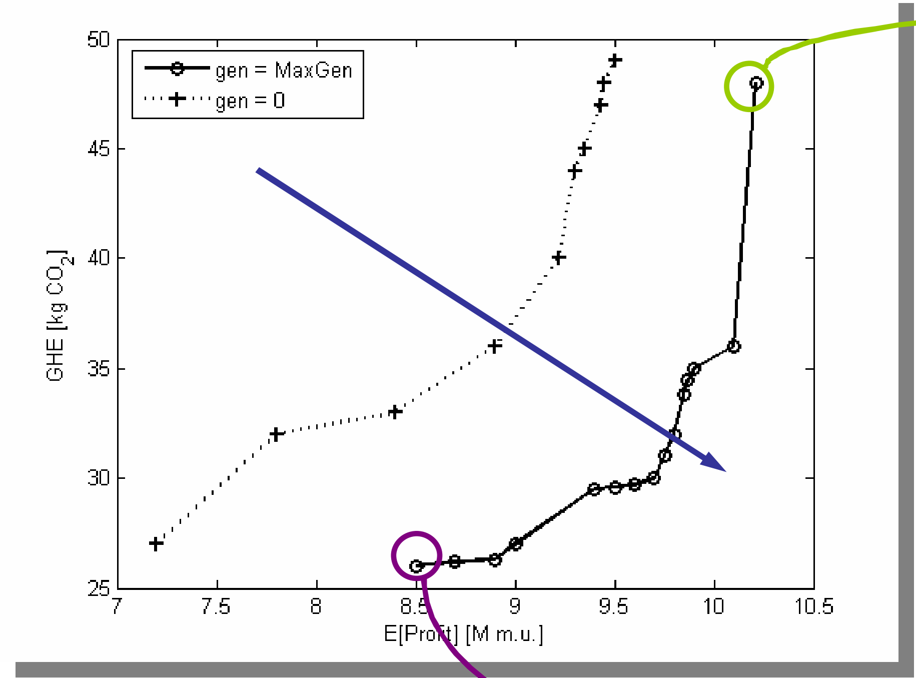


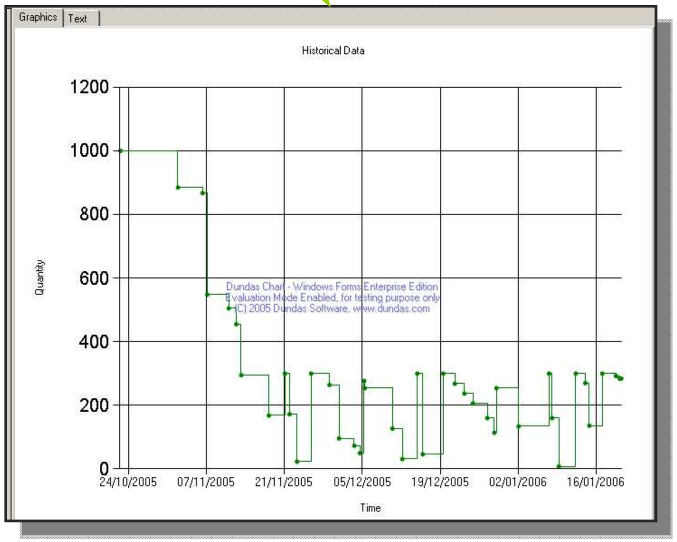
$$\min_{\eta} U = \left\{ \begin{array}{rcl} -\mathcal{F}_1(\eta) & = & -E[Profit(\eta,\omega)] \\ \mathcal{F}_2(\eta) & = & E[EnvIndex(\eta,\omega)] \\ \ldots & & \end{array} \right\}$$

$$GHE = \sum_e GWP_e \cdot m_e$$

$$m_e = \varphi_e^{\mathrm{P}} \cdot t^{\mathrm{P}} + \varphi_e^{\mathrm{I}} \cdot t^{\mathrm{I}} + \varphi_e^{\mathrm{T}} \cdot t^{\mathrm{T}}$$

- Uncertain demand (quantity and amount)
- System (*R*, *s*, *S*) for distribution centers and (*s*, *S*) for retailers
- Maximize expected profit
- Minimize expected contribution to global warming





Approximation to the Pareto set

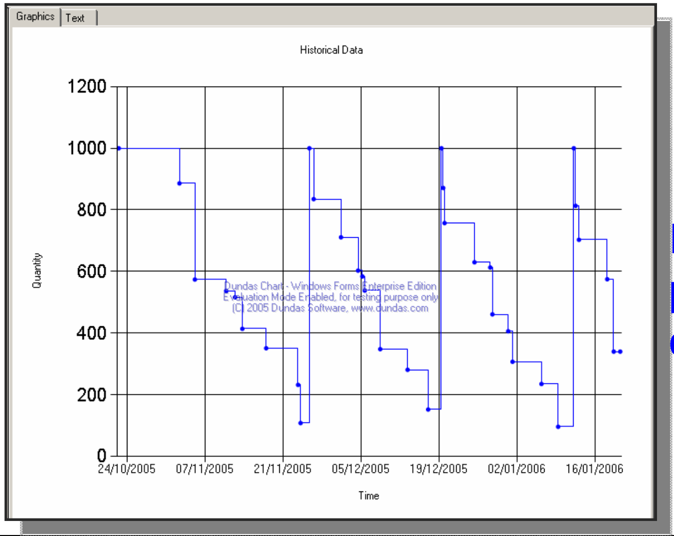
$MaxGen$ 100 generations

Ns 90 samples

$Time$ 10 s/simulation

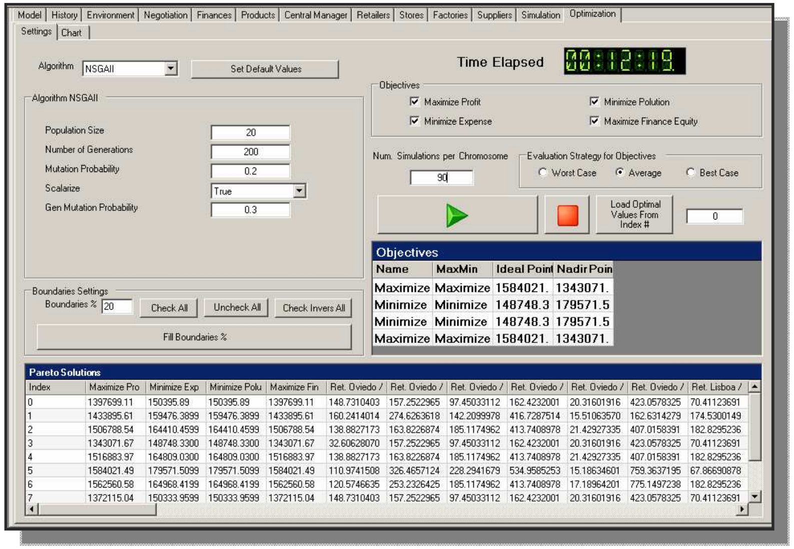
$\mathcal{N}$ $1{\cdot}10^5$ simulations

Total time 100 hours (NSGAII)

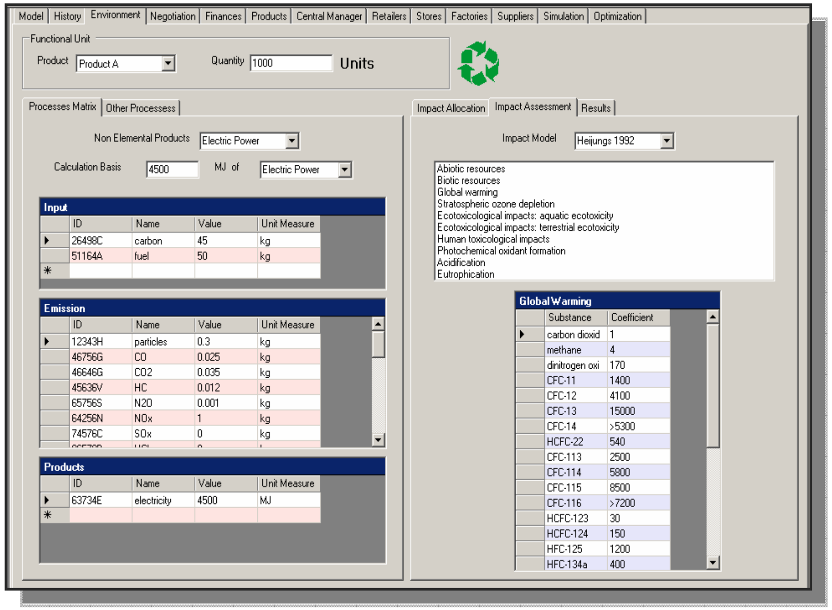


Inventory profiles of product B in distribution center *D1*

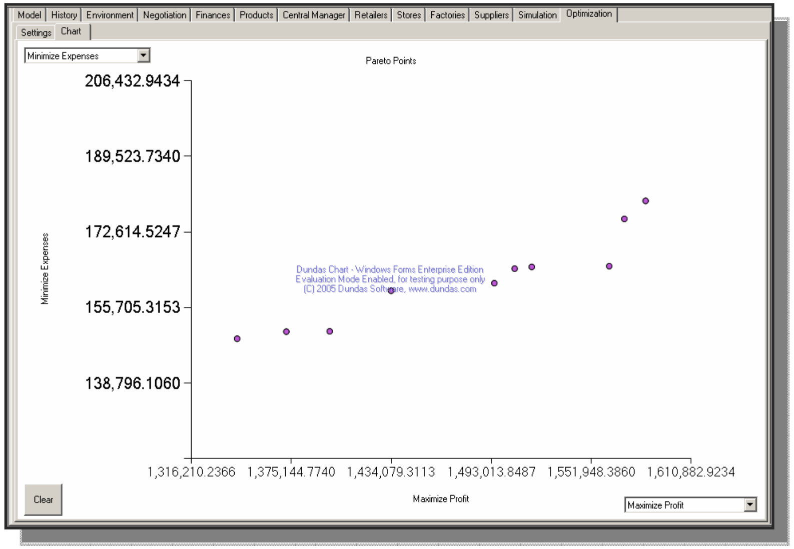
Case study



GA parameters



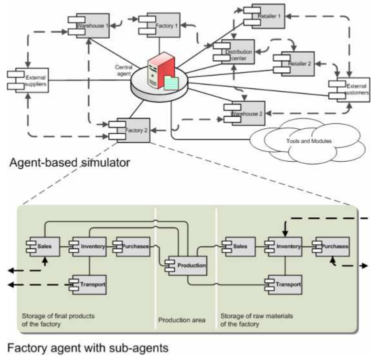
Graphical user interface of the Life Cycle Assessment module (LCA)



Graphical results

Formal comparison

Mathematical Programming vs Sim-Opt approach

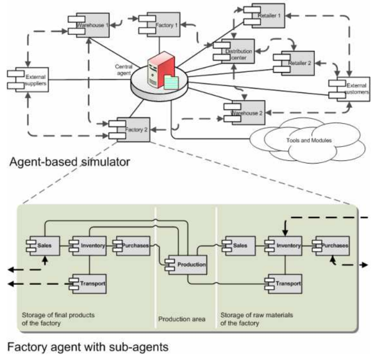


- Based on algebraic equations
- Steady state models
- Centralized system
- Simplifications
- Well established theory
- Available software (GAMS, AIMMS, etc.)
- Optimal solutions

- Based on logic rules (states and transitions).
- Captures the dynamics of the system
- Centralized/decentralized system
- Realistic SC representation
- Need to develop efficient optimization strategies
- Customized solution (generic programming languages: C++, C#, Java, Visual Basic, etc.)
- Optimality is not guaranteed

Practical guidelines

Mathematical Programming vs Sim-Opt approach



- Push systems (make-to-stock)
- Centralized system (global information sharing)
- Strategic/Tactical/Operational
- Solve well defined design/planning/scheduling problems
- Optimization skills (math. prog.)
- Available decomposition strategies
- Optimal or near-optimal solutions

- Pull systems (make-to-order)
- Decentralized system (partial sharing of information)
- Strategic/Tactical
- Provides insights: capture dynamics and delays in information flows
- Software development skills (C++, Java, etc.)
- Cannot avoid large CPU times
- Optimality is not guaranteed

Conclusions

- Multi-agent system for SCM
  - Decentralized SCs
  - Dynamics
  - Realistic industrial practices
- Sim-Opt framework to improve the SCM
- Use of meta-models to decrease CPU time
- Multi-objective optimization