## Agent-based systems for supply chain management

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- 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)

#### Introduction



# 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.)

















# **Stochastic simulation**





### Modeling principles: generic modeling unit for SCM



# Demand model: orders placed by customers

time



ORDER input (*OR\_in*)

Quantities: Normal distribution Times:

Poisson distribution

#### Uniform quantities and variable times Variable quantities and times

time



Simulation models for SCM

Inventory model (state ordering) Inventory control policies

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



### Performance measures: Key Performance Indicators (KPIs)



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

Environmental: *Greenhouse effect impact* 

$$GHE = \sum_{e} GWP_e \cdot m_e$$





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.





Multi-agent system for SCM

# Agent-based simulation model







### 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

States and transitions



#### •••• •••• UPC

# **Stochastic simulation**



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# Software implementation



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• SC model: XML files

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Bit         Description         Production         Control         Review Period           Product         0.10 €         00.0014         0.10 €         1000         5000         10000         7.00.00.00           Product A         0.10 €         00.0014         0.10 €         1000         5000         10000         7.00.00.00           Product B         0.20 €         00.0121         0.10 €         1000         5000         10000         7.00.00.00           *         0         0.20 €         00.0121         0.10 €         1000         5000         10000         7.00.00.00           *         0         0.00 €         00.0121         0.10 €         1000         5000         10000         7.00.00.00           *         0         0.00 €         00.0121         0.10 €         1000         5000         10000         7.00.00.00           *         0         0.00 €         5001         10000         7.00.00.00         7.00.00.00           *         0.1         1000         5000         10000         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00         7.00.00.00 <td></td> <td></td> <td></td> <td></td> <td>Sto Sta Maria</td> <td>Product C</td> <td>0.09.6</td> <td></td> <td>1.00-00-00</td> <td>02-00-</td> <td>nn 🖃</td> <td></td>					Sto Sta Maria	Product C	0.09.6		1.00-00-00	02-00-	nn 🖃	
Product L         0.30 e         00001/21         0.10 e         1000         5000         10000         20000/00           Factory Raw Products         ID         Description         Store Cost         Reorder Area         Initial Quantity         Capacity         Review Period           Product A1         (null)         0.1         1000         5000         10000         7.00.00.00           Product B1         (null)         0.1         1000         5000         10000         7.00.00.00           Product B1         (null)         0.1         1000         5000         10000         7.00.00.00           Product B2         (null)         0.1         1000         5000         10000         7.00.00.00           Product B2         (null)         0.1         1000         5000         10000         7.00.00.00				The second se		10.2016	3 6 6 8 8	50		10000	7 CULCULOC	
Focdor B         0.20 C         0.000 SH         0,10 C         1000         5000         10000         7.00.00,00           *         0.30 C         0.00.121         0,10 C         1000         5000         10000         7.00.00,00           *         0.00 C         0.00.121         0,10 C         1000         5000         10000         7.00.00,00           *         1D         Description         Store Cost         Reorder Area         Initial Quarkity         Capacity         Review Period           *         Product A1         (null)         0.1         1000         5000         10000         7.00.00.00           Product B2         (null)         0.1         1000         5000         10000         7.00.00.00           Product B1         (null)         0.1         1000         5000         10000         7.00.00.00           Product C1         (null)         0.1         1000         5000         10000         7.00.00.00	*	Product A		0,10€	00:00:14	0,10€	1000	500	0	10000	7.00:00:00	
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Factory Raw Products         ID         Description         Store Cost         Reorder Area         Initial Quantity         Capacity         Review Period           Product A1         [rull]         0.1         1000         5001         10000         7.00.00.00           Product A2         [rull]         0.1         1000         5000         10000         7.00.00.00           Product B2         [rull]         0.1         1000         5000         10000         7.00.00.00           Product B2         [rull]         0.1         1000         5000         10000         7.00.00.00           Product B2         [rull]         0.1         1000         5000         10000         7.00.00.00	*	Product B Product C		0,20€ 0,30€	00:01:21	0,10€	1000	500	0	10000	7.00:00:00	
Factory Rew Products           ID         Description         Store Cost         Reorder Area         Initial Quantity         Capacity         Review Period           Product A1         [rull]         0.1         1000         5001         10000         7.00.00.00           Product A2         [rull]         0.1         1000         5000         10000         7.00.00.00           Product B1         [rull]         0.1         1000         5000         10000         7.00.00.00           Product B2         [rull]         0.1         1000         5000         10000         7.00.00.00           Product C1         [rull]         0.1         1000         5000         10000         7.00.00.00	*	Product B Product C		0,20€ 0,30€	00:00:34	0,10€	1000	500	0	10000	7.00:00:00	
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### Simulation outcome



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ile	Edit View Simulation Management Tool	s Window Help	
-			
	F:\Fernando2\MultiObjective\Simula	dorGICASAD\GICASA\Models.scm\Demo2UNIF0RME.scm	×
	Model History Environment Negotiation	Finances   Products   Central Manager   Retailers   Stores   Factories   Suppliers   Simulation   Optimizat	ion
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		2204/2005 14:200: The new stock of Product A in Sto. Sta. Maria is 216 units: 2204/2005 11:100. The new stock of Product A in Sto. Sta. Maria is 133 units. 24/04/2005 11:51:00. The new stock of Product A in Sto. Sta. Maria in 130 units: 12/04/2005 19:03:00. The new stock of Product A in Sto. Sta. Maria in 130 units: 12/04/2005 19:00. The new stock of Product A in Sto. Sta. Maria in 30 units:	
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#### Multi-agent system for SCM



# **Agent-based simulator**



### 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!!



### **Decision-making under uncertainty**



UPC









### SC design problem

UPC



- 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





# **Case study Sim-Opt**



### **Results**

F2

Entity	Distrib	ution ce	enter Di	Distrib	ution ce	enter D2
Product	Α	В	С	Α	В	С
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







# **Case study Sim-Opt**



### Results

Entity	Distrib	ution ce	enter D1	Distribution center D2			
Product	Α	В	С	Α	В	С	
Design I	8,000	8,000	8,000	8,000	8,000	8,000	
Design II	8,000	0	8,000	000,8	8,000	8,000	
Design III	8,000	0	0	000,8	8,000	8,000	
Design IV	2,000	2,000	2,000	000,8	8,000	8,000	
Design V	2,000	0	2,000	8,000	8,000	8,000	



### **Tuning parameters**



#### Large CPU times!!

















### **Tuning parameters**

#### Genetic algorithm parameters

Maximum number of generations
Population size
Number of Monte Carlo samples
Probability of cross-over
Probability of mutation

#### Metamodel

- $\zeta$  Maximum tolerance
- $\phi$  Frequency of metamodel training

#### Maximum number of simulations

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







- 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











# **Multi-objective Sim-Opt**







#### Environmental issues in SCM





# Life Cycle Assessment (LCA)



ULBRIGH





### Multi-objective tactical-operational SCM problem



- 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

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













Produ	ct Product A	•	Quantity	1000	Units	4					
ocess	es Matrix Other	Processess				Impact Alloc	cation II	npact Ass	essment Resul	ts	
	Non Elei	nental Product	s Electric Pov	ver 💌				Impact M	odel Heijun	gs 1992	-
Ci	alculation Basis	4500	MJ of	Electric Power	•	Abiotic Biotic I Global	resources resources	28			
Inpu	<i>k</i>					Stratos	spheric of	one deple	tion	a	
	ID	Name	Value	Unit Measure		Ecotor	xicologica xicologica	l impacts: l impacts:	aquatic ecotoxic terrestrial ecotox	sty initu	
F	26498C	carbon	45	kg		Humar	n toxicolo	gical impac	ts.	any .	
	51164A	fuel	50	kg		Photoc	chemical	oxidant for	mation		
*						Eutrop	cation hication				
Emi	ssion ID	Name	Value	Unit Measure				Glob	Substance	Coefficient	-
Þ	12343H	particles	0.3	kg				-	carbon dioxid	1	
	46756G	CO	0.025	kg					methane	4	
	100100	CO2	0.035	kg					dnitrogen oxi	1400	
	466460		0.010	line and the second sec					CEC 12	4100	
	45636V	HC	0.012	ĸg						41111	
	45636V 65756S	HC N20	0.0012	kg kg					050.12	15000	
	45636V 45636V 65756S 64256N	HC N20 N0x	0.001	kg kg					CFC-13 CFC-14	15000	
	45636V 65756S 64256N 74576C	HC N20 NOx SOx	0.001 1 0	kg kg kg	-				CFC-13 CFC-14 HCFC-22	15000 >5300 540	
	45636V 65756S 64256N 74576C	HC N20 N0x S0x	0.001	kg kg kg					CFC-12 CFC-13 CFC-14 HCFC-22 CFC-113	15000 >5300 540 2500	
Pro	465460 45636V 657565 64256N 74576C	HC N20 N0x S0x	0.001	kg kg kg	<u> </u>				CFC-12 CFC-13 CFC-14 HCFC-22 CFC-113 CFC-114	15000 >5300 540 2500 5800	
Pro	45536V 65756S 64256N 74576C occursor fucts	HC N20 N0x S0x Name	0.012 0.001 1 0 Value	kg kg kg Unit Measure					CFC-12 CFC-13 CFC-14 HCFC-22 CFC-113 CFC-114 CFC-115	15000 >5300 540 2500 5800 8500	
Pro	45636V 65756S 64256N 74576C 0005300 ducts ID 63734E	HC N20 N0x S0x Name electricity	0.012 0.001 1 0 Value 4500	kg kg kg Unit Measure MJ					CFC-13 CFC-14 HCFC-22 CFC-113 CFC-114 CFC-115 CFC-116	15000 >5300 540 2500 5800 8500 >7200	
Pro	4564613 45636V 65756S 64256N 74576C 0007300 fucts ID 63734E	HC N20 N0x S0x Name electricity	0.012 0.001 1 0 Value 4500	kg kg kg Unit Measure MJ					CFC-13 CFC-14 HCFC-22 CFC-113 CFC-114 CFC-115 CFC-116 HCFC-123	15000 >5300 540 2500 5800 8500 >7200 30	ľ
Pro	4564613 45636V 657565 64256N 74576C 055730 fucts ID 63734E	HC N20 N0x S0x Name electricity	0.012 0.001 1 0 2 Value 4500	kg kg kg Unit Measure MJ	<b></b>				CFC-13 CFC-14 HCFC-22 CFC-113 CFC-113 CFC-114 CFC-115 CFC-116 HCFC-123 HCFC-124	15000 >5300 540 2500 5800 8500 >7200 30 150	ľ

#### **GA** parameters



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

#### **Graphical results**

Multi-objective Sim-Opt

# **Formal comparison**



### Mathematical Programming vs Sim-Opt approach



- Based on algebraic equations
- Steady state models
- Centralized system
- Simplifications

- Well established theory
- 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
- Available software (GAMS, AIMMS, etc.) 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 Provides insights: capture dynamics and delays in 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
- information flows
  - Software development skills (C++, Java, etc.)
  - Cannot avoid large CPU times
  - Optimality is not guaranteed





- 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