Manufacturing – Is there a Role for Algebraic Modeling Systems?

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Practice of Mathematical Optimization
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GOR ABB

Agenda

- General Algebraic Modeling System
- Reel Production Model
- Corrugated Board Trim-loss Model
- Batching and Scheduling Model

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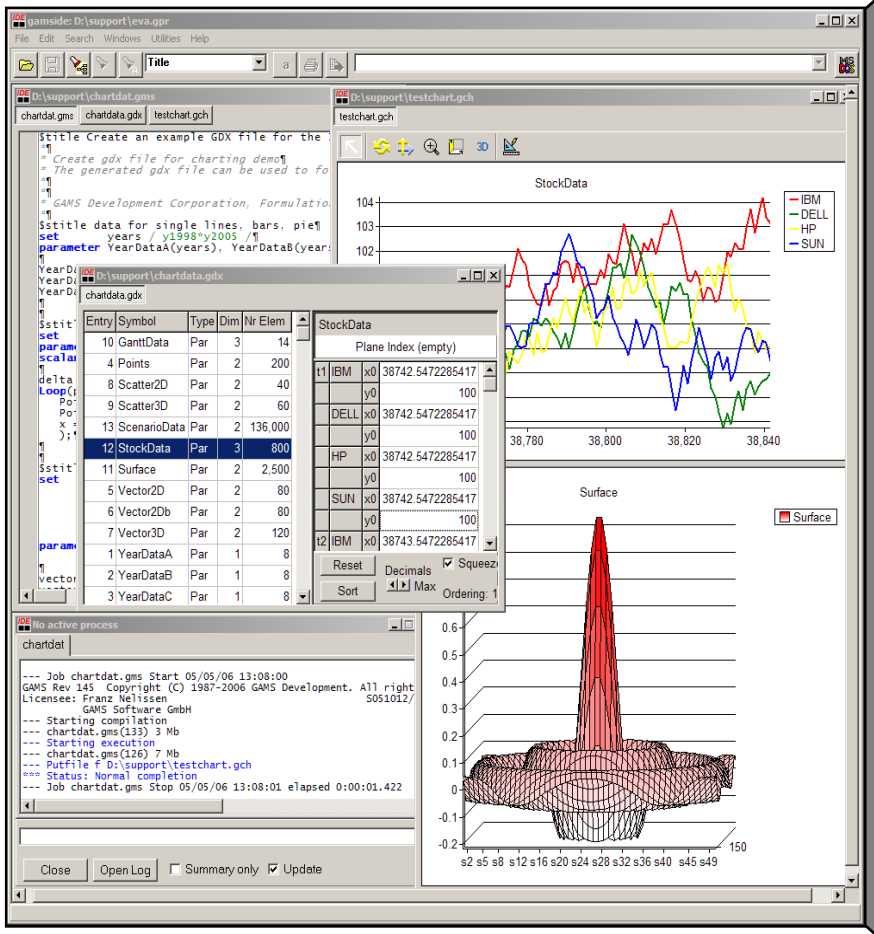
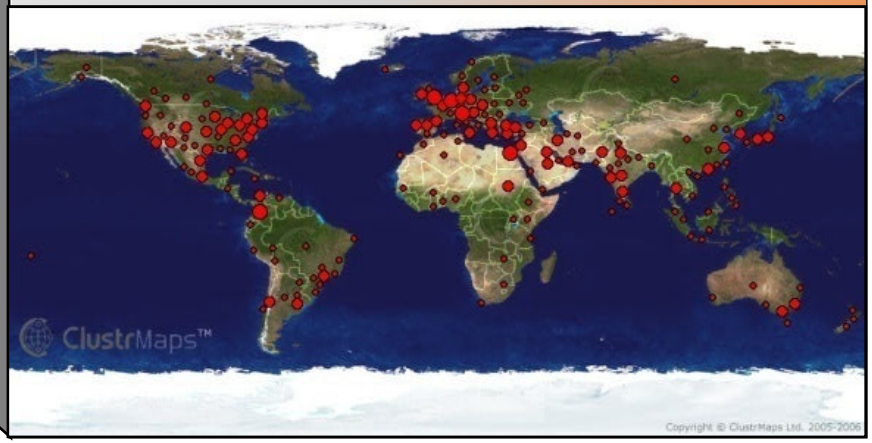
GAMS at a Glance



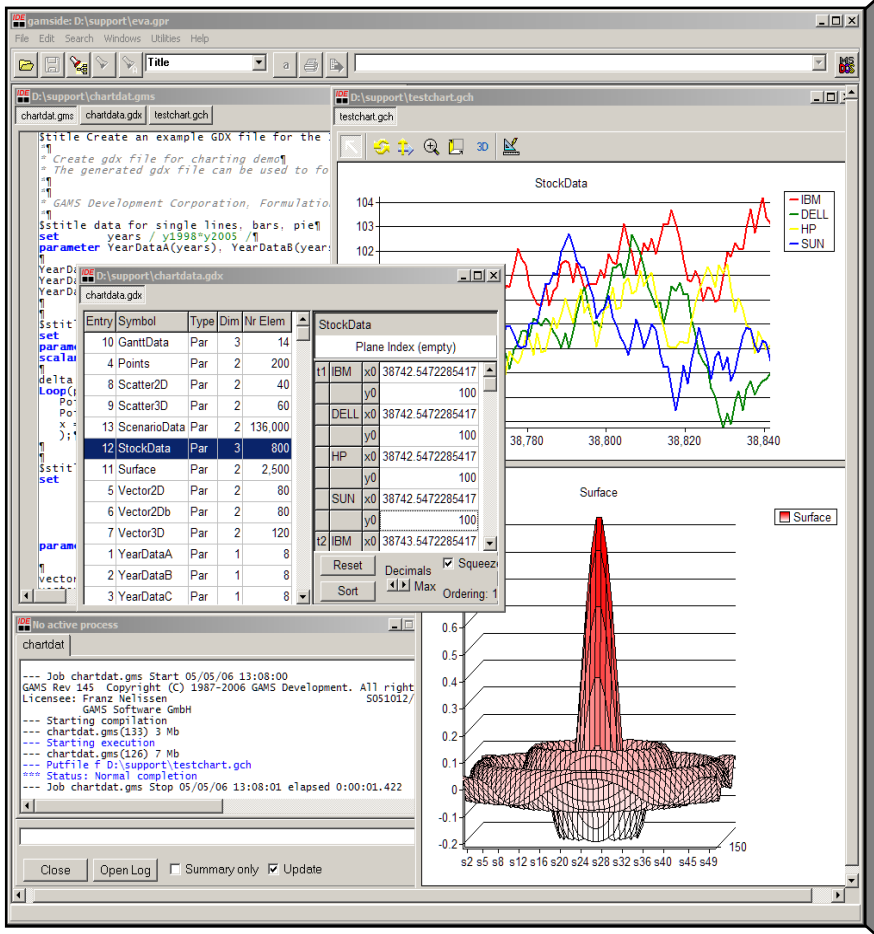
General **A**lgebraic **M**odeling **S**ystem

- Roots: World Bank, 1976
- Went commercial in 1987
- GAMS Development Corp. (DC)
- GAMS Software GmbH (Cologne)

- Broad academic & commercial user community and network



GAMS at a Glance

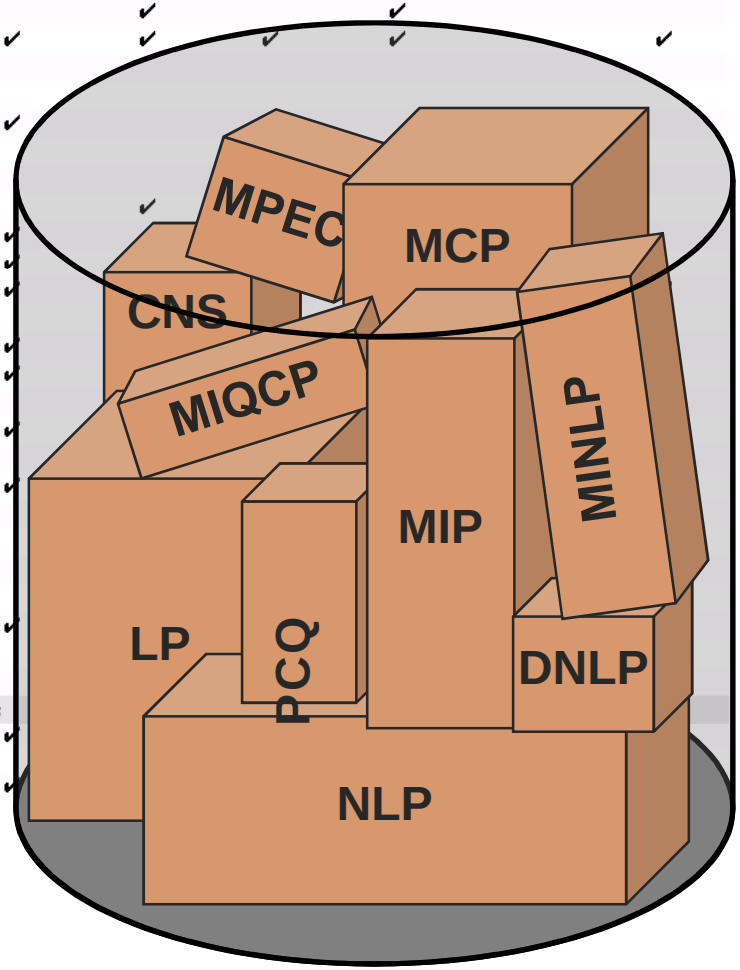


General **A**lgebraic **M**odeling **S**ystem

- Algebraic Modeling Language
- 25+ Integrated Solvers
- 10+ Supported MP classes
- 10+ Supported Platforms
- Connectivity- & Productivity Tools
  - IDE
  - Model Libraries
  - GDX, Interfaces & Tools
  - Grid Computing
  - Benchmarking
  - Compression & Encryption
  - Deployment System
  - …

Supported Model Types (GAMS 22.6)

Solver/Model type availability - 22.6 December 24, 2007	LP	MIP	NLP	MCP	MPEC	CNS	DNLP	MINLP	QCP	MIQCP	*Stoch.*	*Global*
ALPHAECP								✔		✔		
BARON 8.1	✔	✔	✔				✔	✔	✔	✔		✔
BDMLP	✔	✔										
COIN	✔	✔										
CONOPT 3	✔		✔			✔	✔					
CPLEX 11.0	✔	✔										
DECIS	✔											
DICOPT								✔				
KNITRO 5.1	✔		✔				✔					
LINDOGLOBAL 5.0	✔	✔	✔				✔					
LGO	✔		✔				✔					
MILES				✔								
MINOS	✔		✔				✔					
MOSEK 5	✔	✔	✔				✔					
MPSGE												
MSNLP			✔				✔					
NLPEC				✔	✔							
OQNLP			✔				✔					
OSL V3	✔	✔										
OSLSE	✔											
PATH				✔		✔						
SBB												
SNOPT	✔		✔				✔					
XA	✔	✔										
XPRESS 18.00	✔	✔										
Contributed Plug&Play solvers												
AMPLwrap	✔	✔	✔	✔	✔	✔	✔					
DEA	✔	✔										
Kestrel	✔	✔	✔	✔	✔	✔	✔					

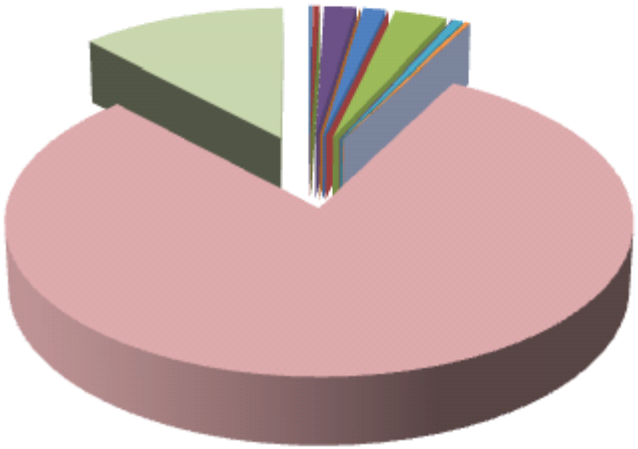


Supported Platforms (GAMS 22.6)

Solver/Platform availability - 22.6 December 24, 2007													
	x86 MS Windows	x86_64 MS Windows	x86 Linux	x86_64 Linux	Sun Sparc SOLARIS	Sun Sparc64 SOLARIS	Sun Intel SOLARIS	HP 9000 HP-UX 11[1]	DEC Alpha Digital Unix 4.0	IBM RS-6000 AIX 4.3	Mac PowerPC Darwin	Mac Intel32 Darwin	SGI IRIX[2]
ALPHAECP	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔	
BARON 8.1	✔	32bit	✔	32bit						✔			
BDMLP	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
COIN	✔	32bit	✔	✔			✔				✔	✔	
CONOPT 3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CPLEX 11.0	✔	✔	✔	✔	✔	✔	✔	10.0	8.1	✔		✔	9.1
DECIS	✔	✔	✔	✔	✔	32bit	✔	✔	✔	✔			✔
DICOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
KNITRO 5.1	✔	32bit	✔	✔	✔	32bit					✔	✔	
LINDOGLOBAL 5.0	✔	✔	✔	✔	✔	✔					✔	✔	
LGO	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔
MILES	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MINOS	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MOSEK 5	✔	✔	✔	✔	✔	✔	✔	3.2			✔	✔	
MPSGE	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MSNLP	✔	✔	✔	✔	✔	32bit		✔			✔	✔	
NLPEC	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
OQNLP	✔	32bit	✔	32bit									
OSL V3	✔	32bit	✔	32bit	✔	32bit		V2		✔			V2
OSLSE	✔	32bit	✔	32bit	✔	32bit				✔			
PATH	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SBB	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SNOPT	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
XA	✔	32bit	✔	✔	✔	32bit		✔	✔	✔			
XPRESS 18.00	✔	32bit	✔	32bit	✔	32bit		16.10		✔			
[1]GAMS distribution for HP 9000/HP-UX is 22.1.													
[2]GAMS distribution for SGI IRIX is 22.3.													
Contributed Plug&Play solvers													
AMPLwrap	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			
DEA	✔	✔	✔	✔	✔	✔		✔	✔				
Kestrel	✔	32bit	✔	32bit	✔								
For backward compatibility we maintain older versions of operating systems and solvers. Please call.													

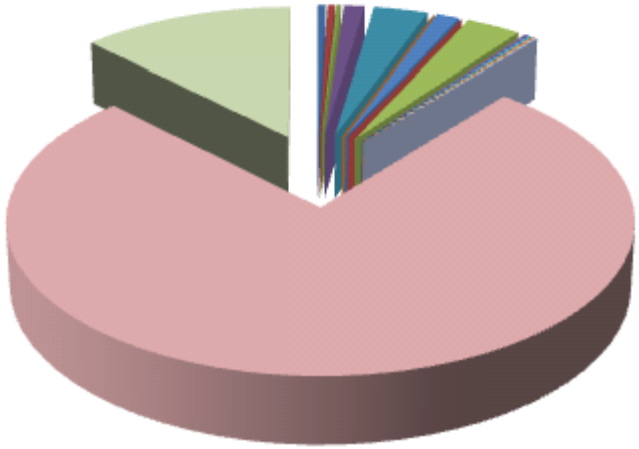
Downloads by Platform

GAMS 22.5



525+ Downloads a week

GAMS 22.6



550+ Downloads a week

- aix
- axu
- hp7*
- dar
- dii
- leg
- lei
- lnx
- lx3
- sgi**
- sig
- sol
- sox
- vis
- wei

Algebraic Modeling Systems in Manufacturing

Is there a Role for Algebraic Modeling Systems?

- Optimization is an essential part of any engineering activity
  - from strategic decision making with time horizons of decades
  - to micro level control with time horizons of micro seconds

- Besides the sheer size of the problems, models need to capture
  - Organizational structures
  - Technical conditions and machine functions
  - Laws of nature
  - Human behavior

Algebraic Modeling Systems in Manufacturing

- Optimization, spurred by advances in computing technology, has become an integral part of industrial systems.
- Industry and service providers offer solutions to domain specific problems at any level of industrial activities
- However, many problems are too specific and limited to be addressed by existing “standard” solutions.

Algebraic Modeling Systems in Manufacturing

- AMLs as GAMS often used as a black box utility offering
  - Effective integration into existing applications
  - Protection of modeling investment
  - Cutting-edge technology

- Very effective vehicle to study and improve existing processes and procedures

  è The process of defining and specifying characteristics, relationships, objectives and data in formal mathematical terms provides a platform to better understand and streamline the overall system

Agenda

- General Algebraic Modeling System
- **Reel Production Model**
- Corrugated Board Trim-loss Model
- Batching and Scheduling Model

Manufacturing of Wooden Reels

- Used mainly in the wire & cable industry
- Differ in diameter (18-100+ inches)
- Ends are two-ply and of a given thickness
- Made of lumber

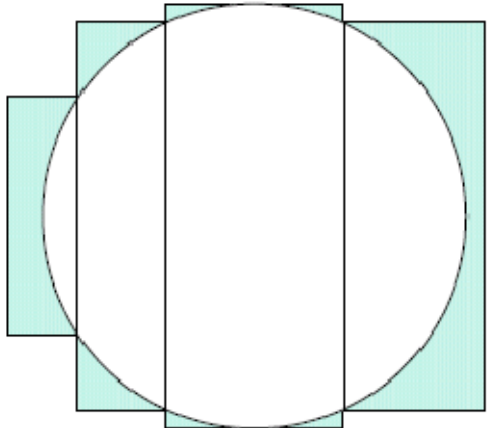
Reel Model – Goal

Goal is

to minimize waste

- given a collection of reel orders
- given a current lumber inventory
  - batched on pallets with different quantities of rectangle lumbers
  - different widths (8), length (10) and thicknesses (4)

with a model running on daily basis.



Ferris (2003)

Reel Model – Additional Difficulties

Additional Difficulties are

- Reuse yesterday's leftovers preferentially
- Cutting down lumbers done by batch (pallet)
- Some pieces of lumber have bad knots, bark etc.
  à Stochasticities
- Machine to join low-priced lumbers (e.g. two-by-fours)
- ...

Reel Model - Four Phase Solution in GAMS

Cutting Stock Problem

I. Generate circular patterns using column generation
- Algorithm using LP and MIP
- 1000+ different patterns are generated

II. MIP Model to select circular patterns
- Pattern selection s.t. given orders and lumber inventory

III. MIP Model to find optimal batches (pallets) of lumber
- Over- and Underproduction allowed but penalized (-3% to +5%)
- Loop that softens constraints until feasible (limits * 1.5)

IV. Clean-up solution due to required diameter-grouping of orders

à Application needs about 20-30 minutes

Reel Model - Impact

- Model showed potential waste savings of ~40%
- (Maybe) More important: The overall analytic framework revealed
  - Need of a new inventory system
  - Need to reeducate staff
  - Elimination of stochasticities
  - (Usually) Omit joining and (re)cutting

  to improve and streamline processes

à Having understood and eliminated the weaknesses of their system, the company is able to run the application on a daily basis with an average waste lowered from 20% to 12%

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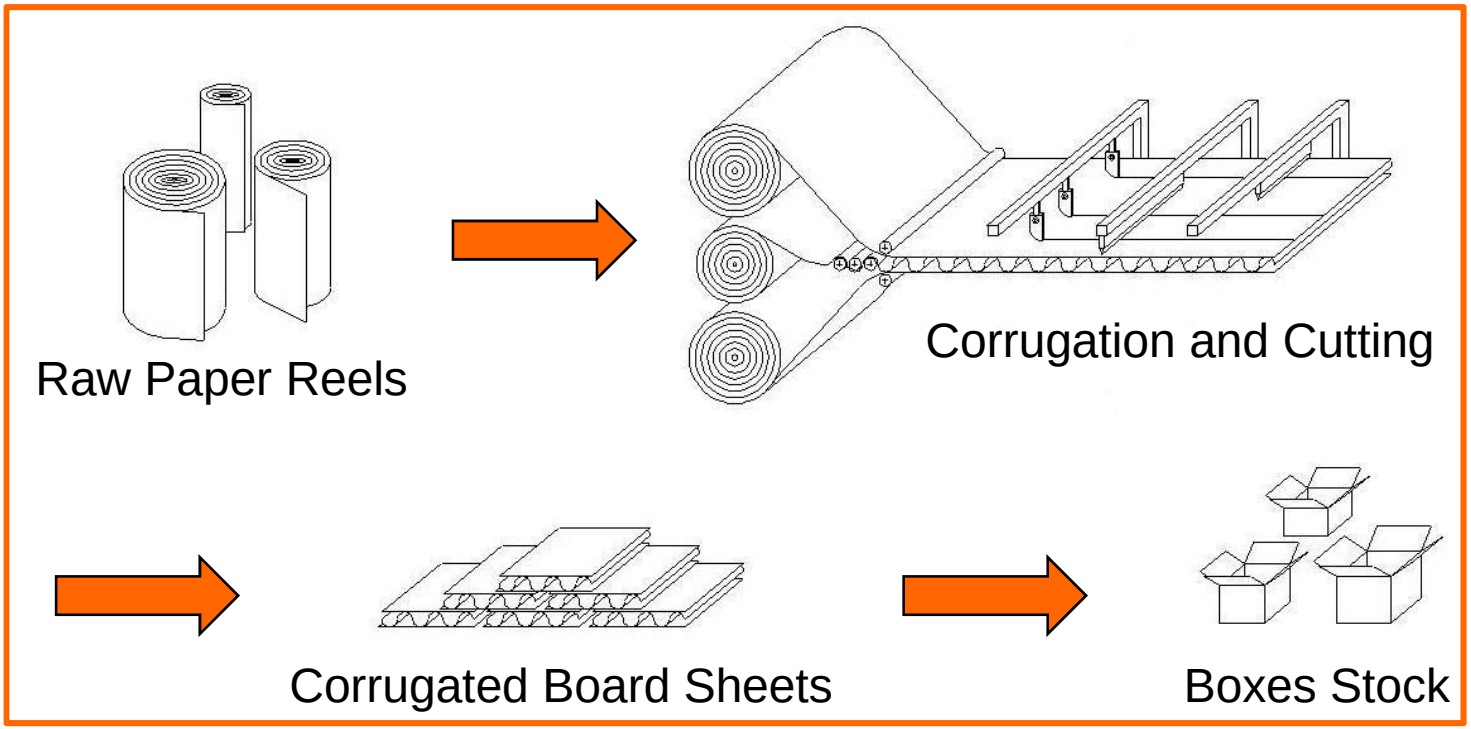
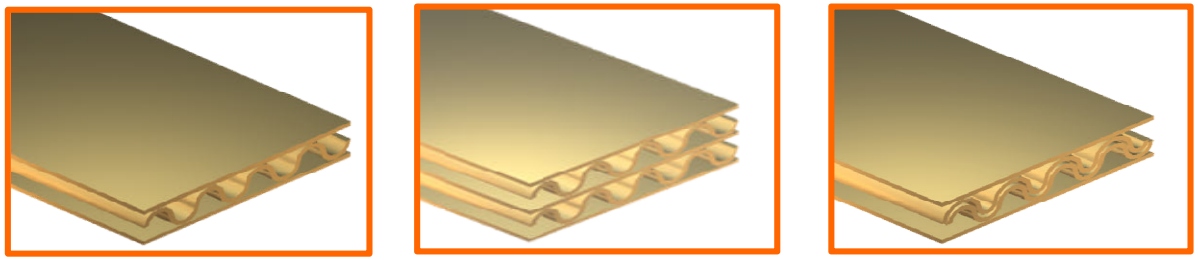
- **Corrugated Board Trim-loss Model**
- Batching and Scheduling Model

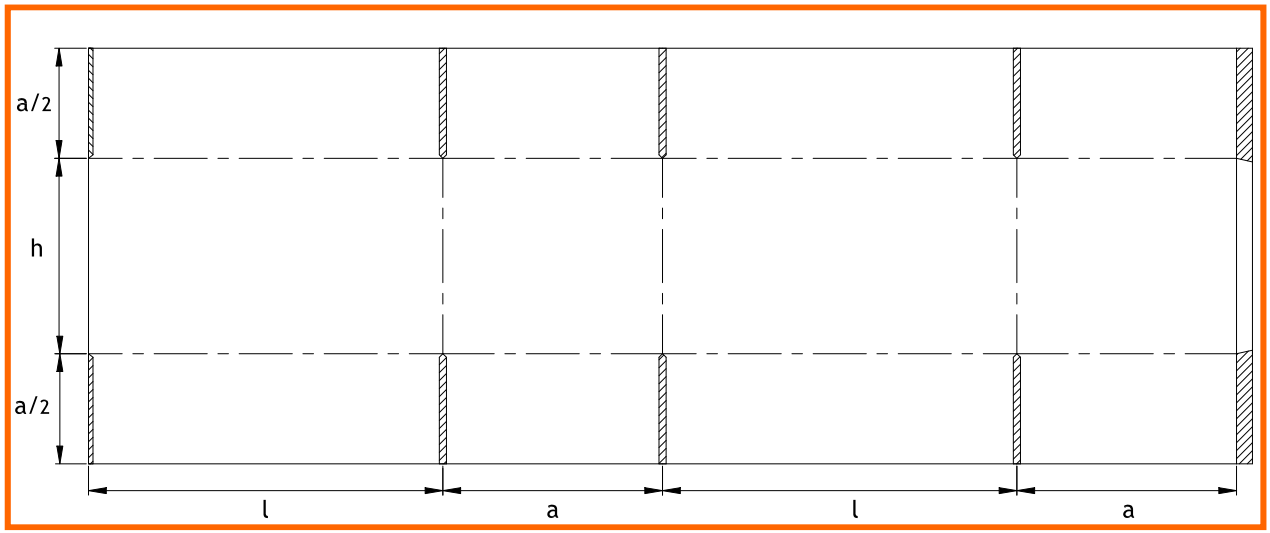
Board Model - Characterization

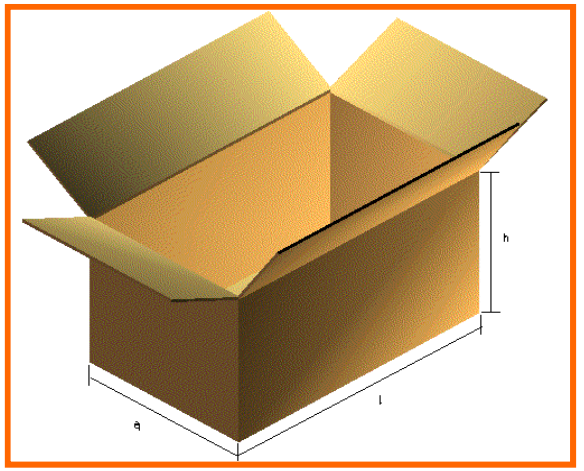




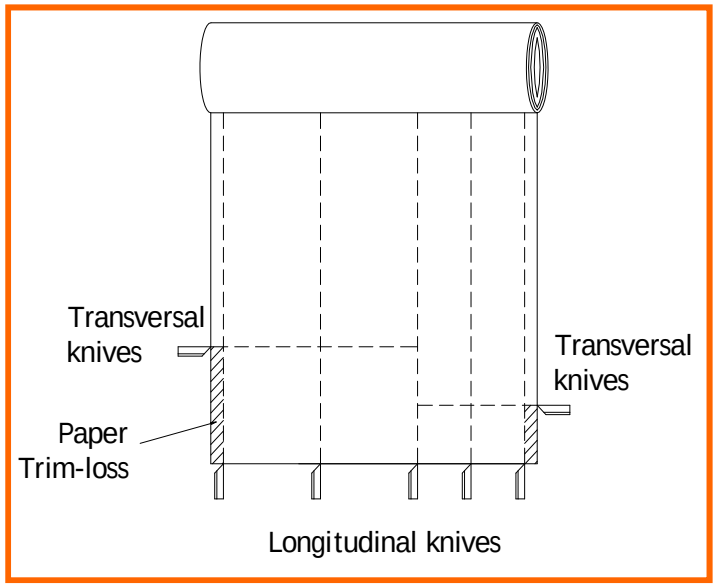
Rodríguez, Vecchietti (2007)

Board Model – Folding of Board Sheets

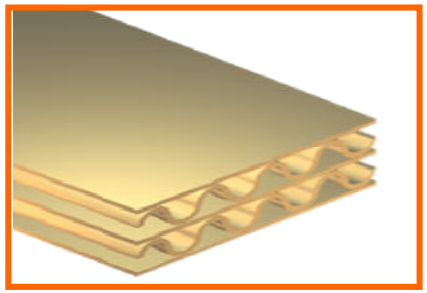




Board Model – Complexity



- Minimize paper waste
  - Minimum = 18 mm
- 5 longitudinal knives
  - Up to 4 lanes
- 2 transversal guillotines
  - Up to 2 different lengths



- # layers
- Paper types
- Wave types

Problem Size

- **36 carton types**
- **352 paper types and widths**
- **Thousands combinations**

Board Model – Complexity

- Combinatorial Problem

- Complexity
  - Binary decisions *(pattern assignment)*
  - Non-convex (*paper use: demand, stock*)
  - ~100 orders to be combined
  - Orders can be subdivided in different patterns

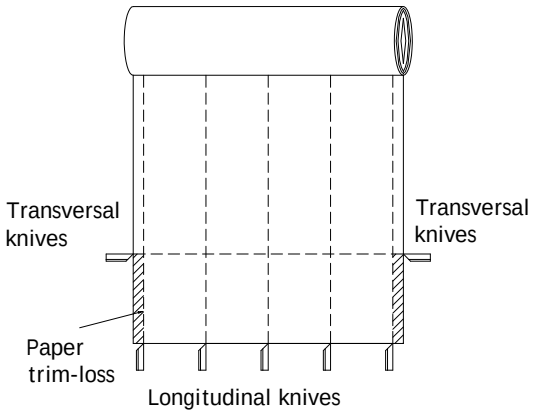
Complex combinatorial cutting patterns problem

- Main motivation
  - Paper cost about 70% final product cost
  - Paper loss is tightly related to the company profitability

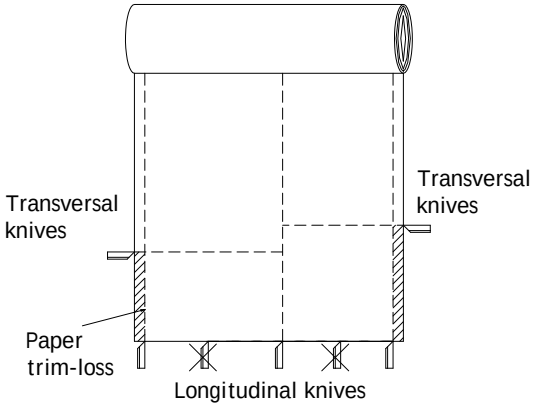
Board Model – Solution Strategies

- MINLP
  - At that point global optimality could not be guaranteed
- Linearization
  - Additional continuous and binary variables and constraints
  - Not solvable in acceptable time horizon
- Two-Step Algorithm
  - Cutting patterns pre-generation (LP)
  - Cutting patterns selection and length (MIP)

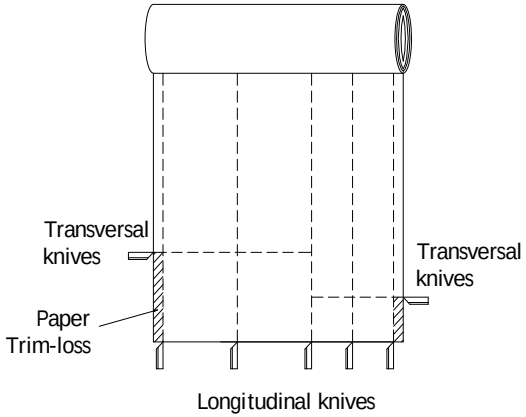
Board Model – Generated Cutting Patterns



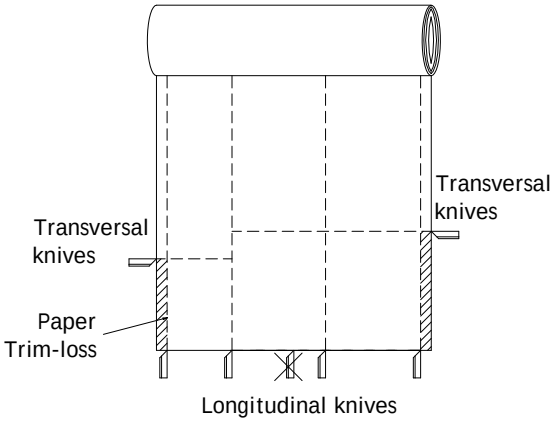
Same order sheets



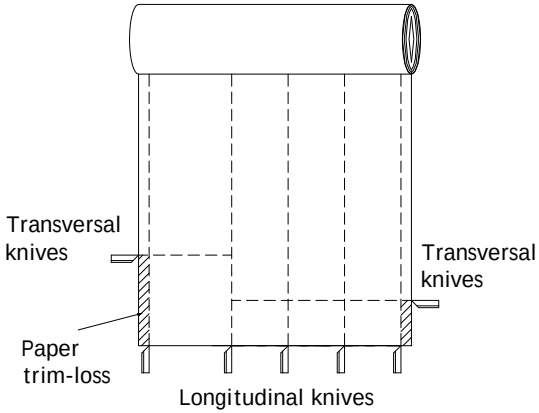
Pattern type 1-1



Pattern type 2-2

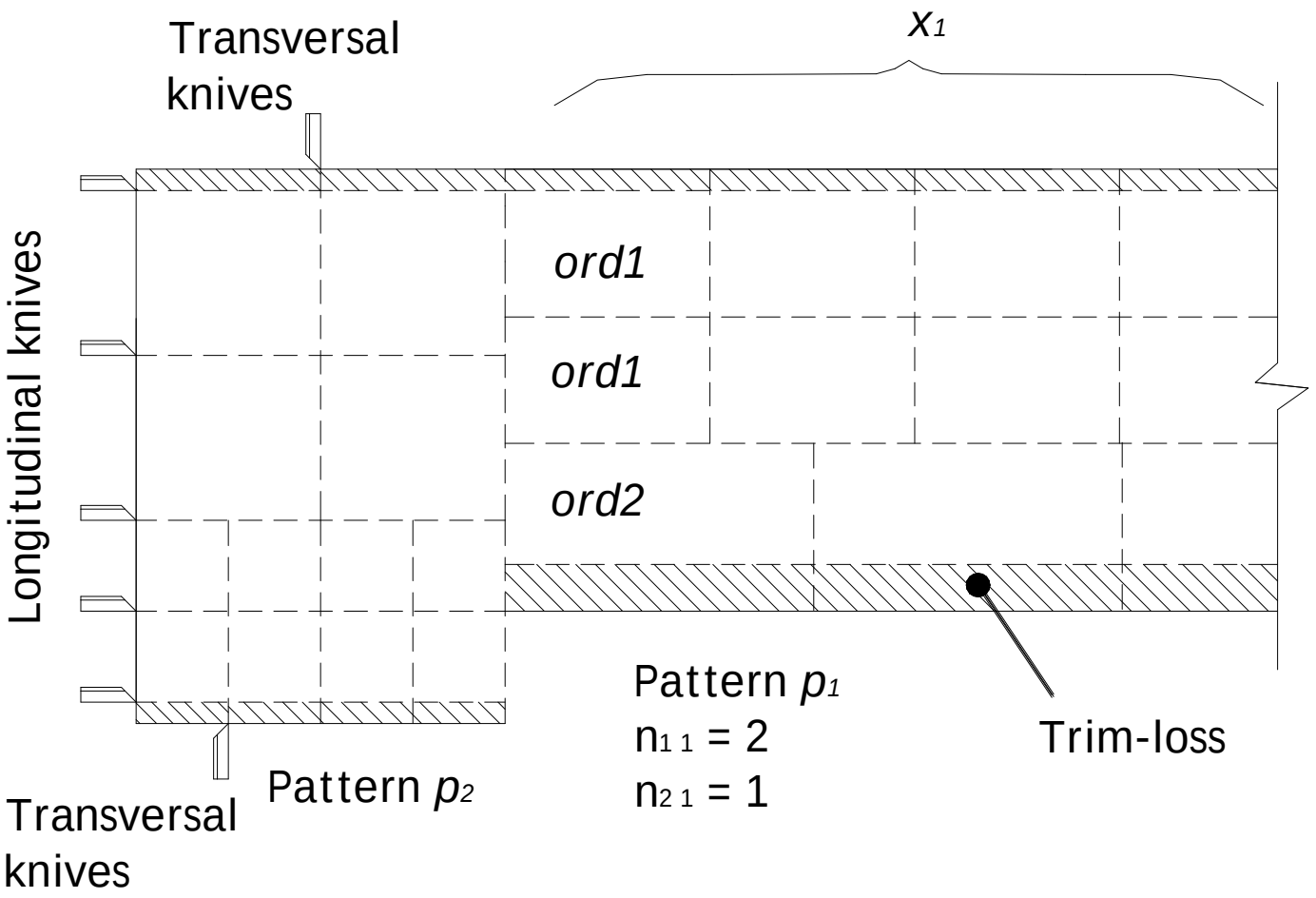


Pattern type 1-2



Pattern type 1-3

Board Model – Pattern Selection



Board Model – Conclusion

- Introduction of an algorithmic layer helped to overcome missing Global Optimization
- Model implemented and linked to company ERP system
- Big step forward within the company supply chain system
  - Old system using Excel
    - 4 hours for one solution
    - People did not trust in it and deviated from solution
  - New system using GAMS
    - minutes for several scenarios
    - trim-loss costs reduced by 30%

What do we learn?

- Increasing need of Global Optimization
- Need of Layers around Pure Optimization
  - Thin-layer Algorithms
  - Automatic Reformulations
    - EMP – Extended Mathematical Programming
      - Bilevel programming
      - logical constructs (indicators, disjunctions)
      - systematic constraint modifications
        - » activation and deactivation
        - » softening and tightening

à Makes GAMS ready for new cutting-edge approaches

à Continuously bridge the gap between academia and industry

Agenda

- General Algebraic Modeling System
- Reel Production Model
- Corrugated Board Trim-loss Model
- **Batching and Scheduling Model**

Batch Model – Characterization

Given

- a set of orders with release/due time and demand
- a set of processing units with min/max batch sizes, processing times and processing costs per order
- a set of stages with parallel processing units at each stage

determine

- the number and size of batches required to meet each order (batching decision)
- the assignment of batches to processing units at each stage
- the sequencing of assigned batches in each processing unit

such that the time necessary to meet all orders is minimized.

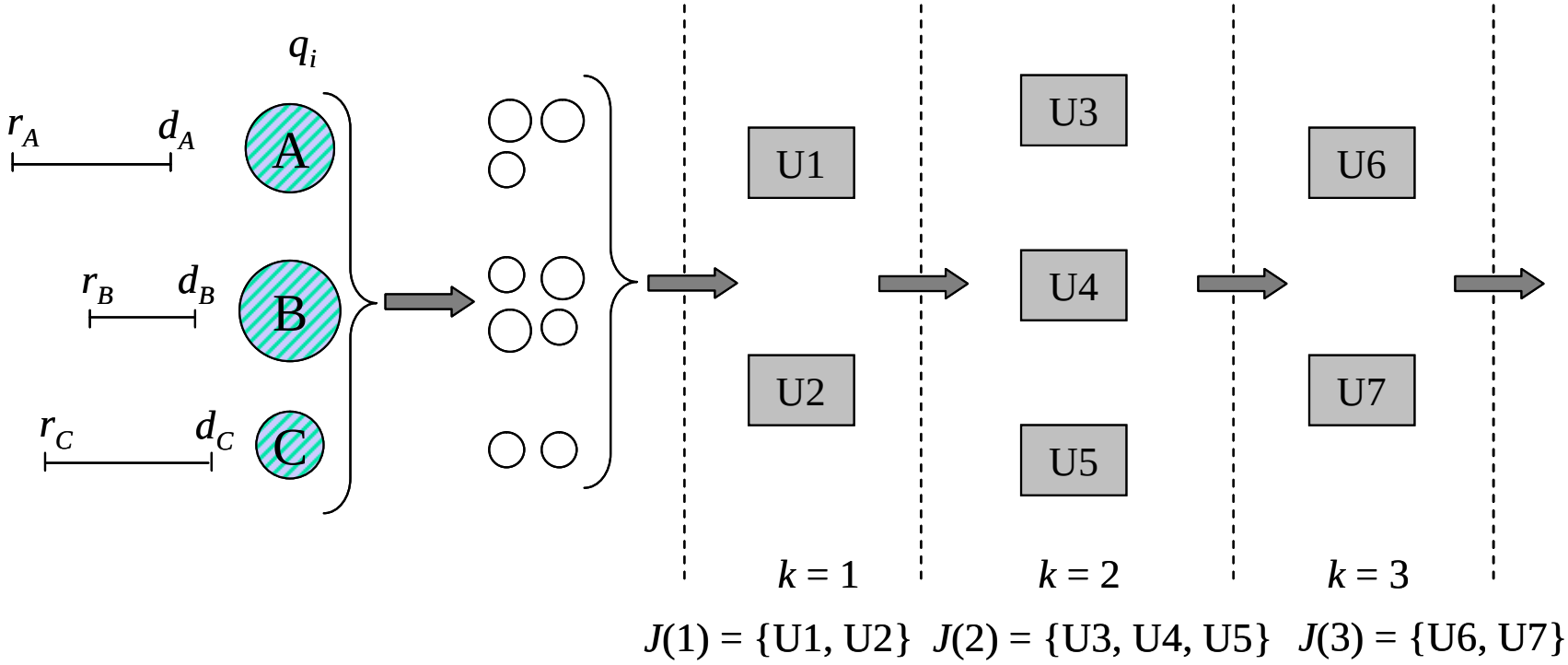
Ferris, Maravelias, Sundaramoorthy (2008)

Batch Model – Example

Orders: $i \in I = \{A, B, C\}$ **Batches**

Stages: $k \in K = \{1, 2, 3\}$

Units: $j \in J = J(1) \cup J(2) \cup J(3)$



$J(1) = \{U1, U2\}$ $J(2) = \{U3, U4, U5\}$ $J(3) = \{U6, U7\}$

Batch Model – Approach

- Decompose MIP by creating MIP-subproblems by fixing batching decisions
- Run MIP-subproblems with small time limit to separate difficult from easy ones
- For difficult batch selections determine second round of partitioning based on assignment variables in first stage and again solve with time limit to separate difficult from easy ones
- If necessary, continue with partitioning based on second (third, fourth, etc) stage assignment variables

è Large number of independent MIPs which could be solved in parallel using the GAMS/Grid facility

GAMS/Grid Facilities Code

```
mymodel.solvelink=3;
loop(scenario,
  demand=sdemand(scenario); cost=scost(scenario);
  solve mymodel min obj using mip;
  report(scenario) = var.l );

Repeat
  loop(scenario$h(scenario),
    if(handlestatus(h(scenario))=2,
      mymodel.handle=h(scenario); h(scenario)=0;
      execute_loadhandle mymodel;
      report(scenario)=var.l ));
  if(card(h), execute 'sleep 1');
until card(h)=0 or timeelapsed > 100;
```

Batch Model – GAMS/Grid Facts

- **Scalable**:
  - support of massive grids, **but also**
  - multi-cpu / multiple cores desktop machines
  - “1 CPU - Grid”

- Platform **independent**

- Only **minor changes** to model required

- **Separation** of model and solution method
  à Model stays **maintainable**

Batch Model – SUNgrid

www.network.com

www.gams.com/sungrid

- On-demand grid computing service operated by Sun Microsystems with GAMS available
- Access to enormous computing power over Internet
- Opteron-based servers with 4 GB of RAM per CPU
- Solaris 10 OS, and Sun Grid Engine 6 software.
- $1 per CPU-hour (Currently 3 month free)

Thanks for your time!

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