Warehousing Systems Design

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Credits

- *Faculty*
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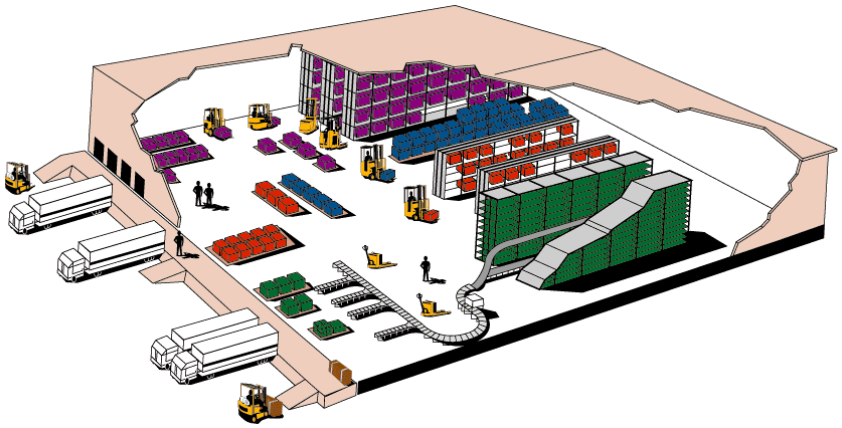
- *Graduate students*
  - *K. Huang*
- *Sponsors*
  - *Keck foundation, NSF, Ford Motor, UPS WWL,*

Distribution Warehouse: Functional Areas Illustration



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Changing Warehousing Requirements

- Faster turns, shorter life cycles
  - Warehouse operations
  - Warehouse design
- Proliferation of information technology
  - WMS, tracking
- Design-as-usual

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Warehousing Design Objective

The goal of warehouse design is to

- minimize the discounted present value of the costs of
- establishing and operating the warehouse over some horizon specified by the decision-maker,
- subject to a number of resource and performance constraints.

State-of-the-art in Warehousing Design: Review and Design

- Reviews, bibliography, and design
  - Van den Berg & Zijm (1999)
  - Ackerman (1999)
  - Rouwenhorst at al. (2000)
  - Miller (2001), chapter 5

Warehousing Types

- Distribution
  - Consolidation
- Production
  - WIP and finished goods storage
- Long-term storage
  - Archival, waste and emergency storage
- Contract
  - TPL

Warehousing Levels of Automation

- Manual
  - Picker to product, shelves
- Mechanized
  - Picker to product, person-aboard
- Automated
  - Product to picker, carousel
- Automatic
  - Product to shipping, A-frame

Warehousing Design: Current Characteristics

- Overwhelming complexity and variety
  - No monolithic model
  - Hierarchical, iterative models
  - Approximate analytical models
    - Dramatically limit number of alternatives
  - Final choice based on detailed simulation

Warehousing Design Hierarchy: Strategic Decisions

- Strategic: configure the infrastructure
  - Mission for the warehouses (if present)
  - Owned versus contracted (TPL)
  - Number, location, and function of the warehouses
  - Technology and size of the warehouses

Warehousing Design Hierarchy: Tactical Decisions

- Tactical: utilize the infrastructure through policies
  - Capacity balancing in the network
  - Customer and product allocation
  - Major operational policies

Warehousing Design Hierarchy: Operational Decisions

- Operational: schedule activities
  - Operating procedures
  - Short term scheduling
- Design feedback loops

State-of-the-art in Warehousing Design: Analysis

- Analysis of isolated components
  - Numerous, focused, uneven
  - Detailed simulation and animation
  - Clearly suboptimal
  - No impact on the practice of warehousing design
- Review of Published Research
  - Progress in Material Handling Research (1998)

State-of-the-art in Warehousing Design Continued

- No structured, integrated design methodology
  - No model for warehousing operations
  - No explicit design theory
- Consulting-university cooperatives for DSS and education
  - Twente, Dortmund, Darmstadt, Georgia Tech, Rensselaer

Warehousing Design Methodology Needs

- Integration of isolated research and methods
- Rich empirical data sets
- Rigorous mathematical models
- Synthesis and design tools

Warehousing Design and Operations Education Status

- Mirrors state-of-the-art
  - Focused, uneven, analysis
- High demand
  - Bachelors, graduate, and professional
- Few educational materials
  - MHI and CICMHE (CD on MH principles)

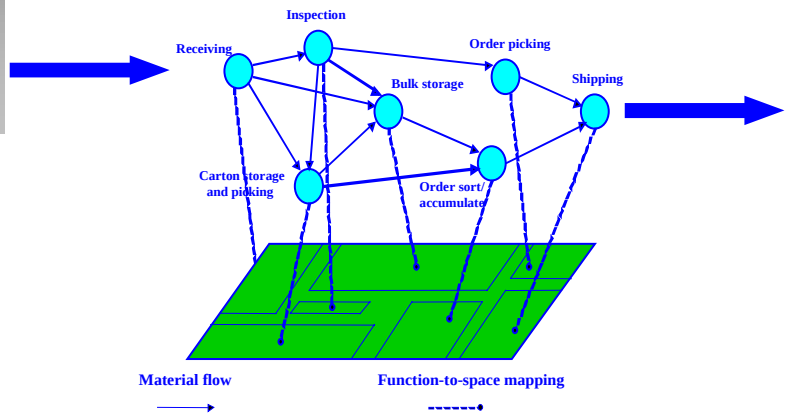
Warehousing Design Development at Georgia Tech

- Functional flow network
- Object oriented data base
- Mathematical design models
- Visualization

Warehousing Functions

- Receiving
- Storage - holding
- Order picking - retrieval
- Consolidation - sorting
- Shipping

Functional Flow Network for Basic Warehousing Functions



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Functional Flow Network Characteristics

- Every warehouse has a different functional flow network
- Different products can follow different and multiple paths
- Functions are mapped to areas, areas are mapped to material handling and storage equipment

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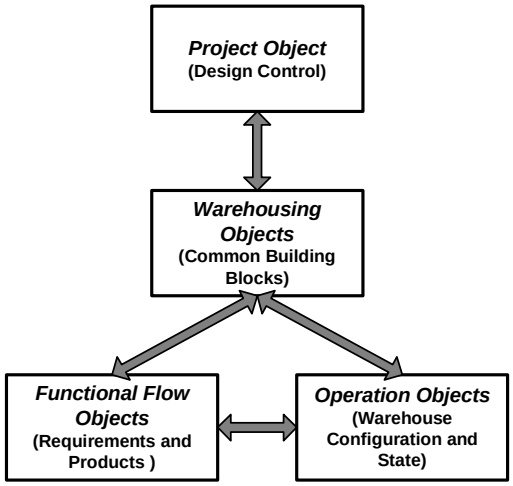
Object Classes in Warehouse Design



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Object Classes

- Design Object
  - Design project status
- Warehousing Objects
  - Equipment and policies and protocols
- Functional Flow Objects
  - Products and flows requirements
- Operations Objects
  - Design specification

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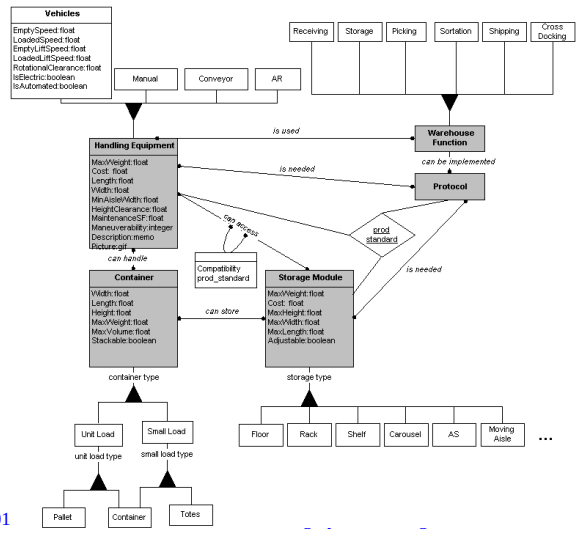
Warehousing Objects Structure (Equipment and Personnel)



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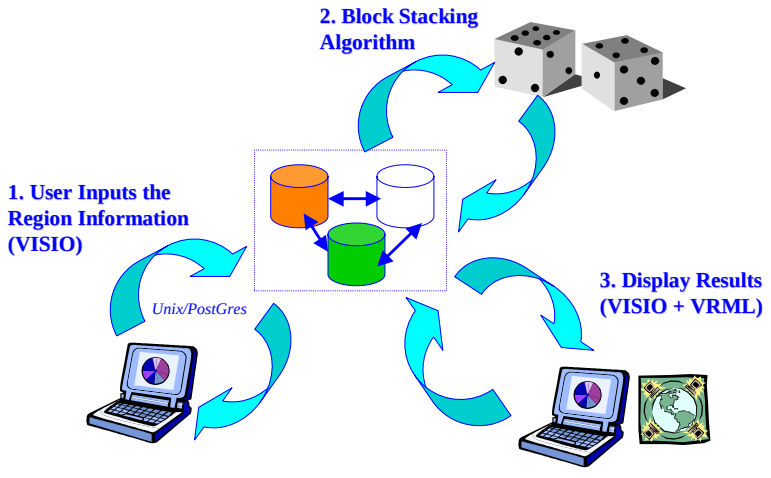
Block Stacking Example: Software Program Interactions



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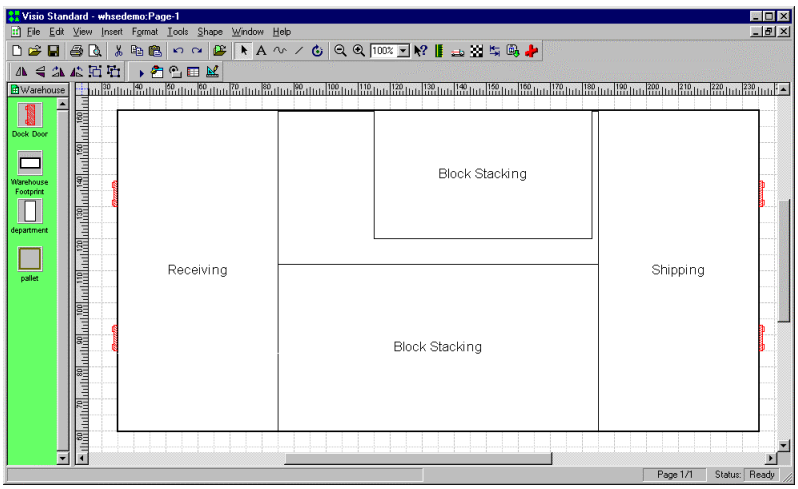
Department Block Layout in Visio



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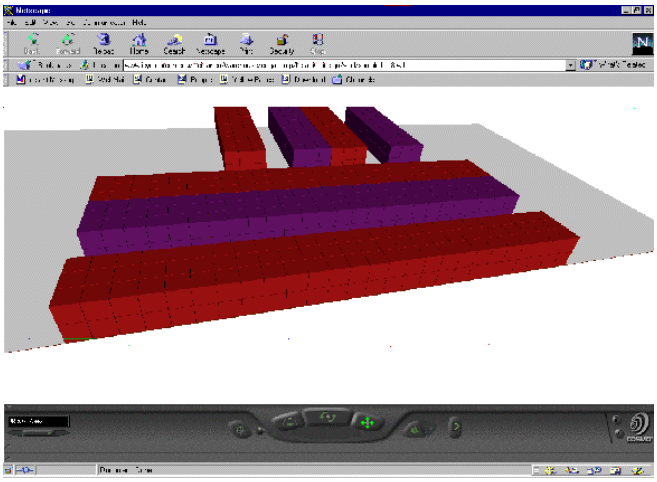
Block Stacking Layout in VRML



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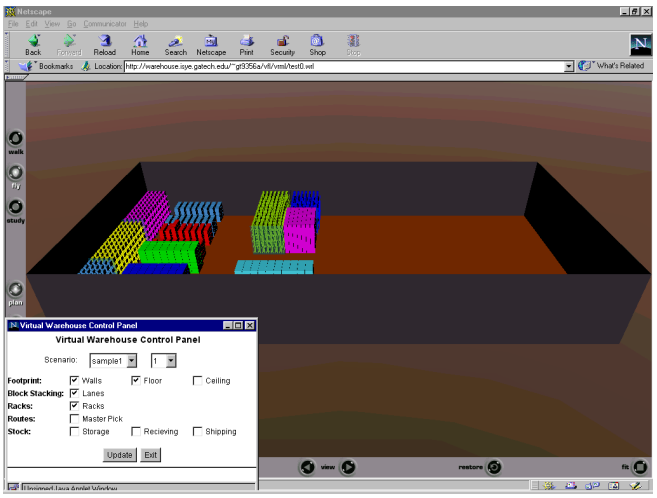
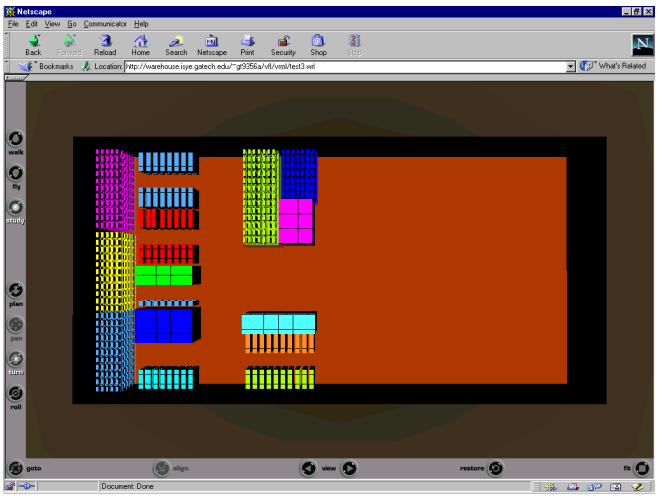
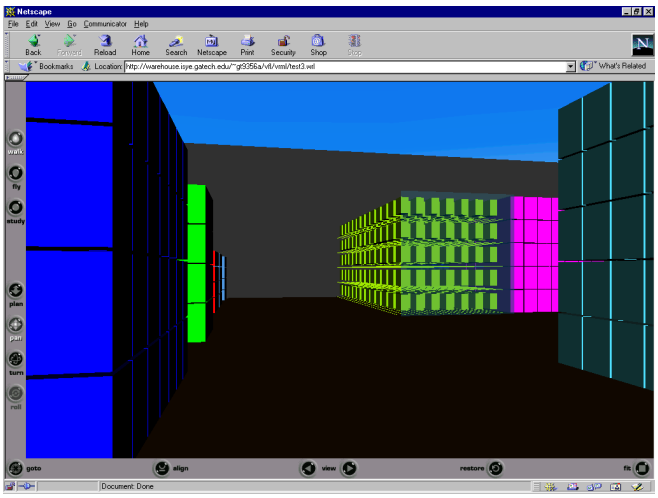
Warehouse VRML Visualization: Side View with Storage Systems



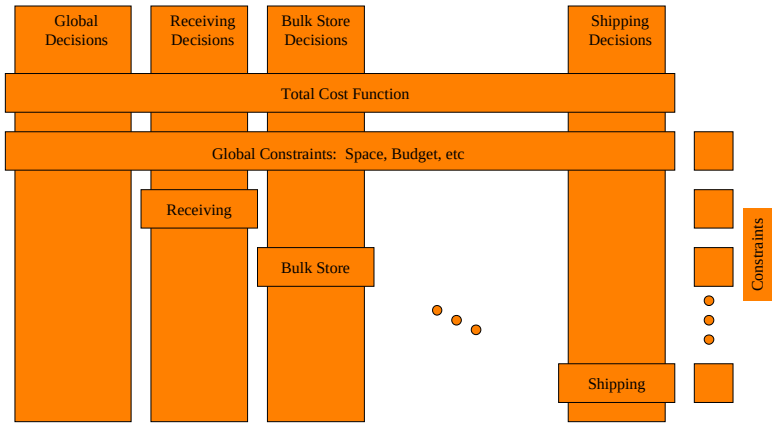
Warehouse VRML Visualization: Top View with Storage Systems



Warehouse VRML Visualization: Interior View



Design Optimization Model



Optimization Model Characteristics

- Optimization decomposed by functional areas
- Joint space (area), manpower, budget constraints modeled as resources
- Economic analysis joint objective function

Optimization Model Time Units

- Two fundamental time units
- Epoch (year)
- Time period
  - Discount factor and frequency

Year 1 *e = 1*							Year 2 *e = 2*						
Mon *t=1*	Tue *t=2*	Wed *t=3*	Thu *t=4*	Fri *t=5*	Sat *t=6*	Sun *t=7*	Mon *t=8*	Tue *t=9*	Wed *t=10*	Thu *t=11*	Fri *t=12*	Sat *t=13*	Sun *t=14*

Year 1 *e = 1*				Year 2 *e = 2*			
Winter 2001 *t=1*	Spring 2001 *t=2*	Sum. 2001 *t=3*	Fall 2001 *t=4*	Winter 2002 *t=5*	Spring 2002 *t=6*	Sum. 2002 *t=7*	Fall 2002 *t=8*

Functional Areas

- Set of candidate technologies L
- Binary selection variables y
- Continuous flow variables v
- Investment cost, fixed cost, variable cost
- Individual commodity capacity constraints

Functional Areas Equations

$$\sum_{j=1}^{N} \sum_{l \in L_j} TechInvestCost_j \cdot y_{jl}$$

$$\sum_{j=1}^{N} \sum_{l \in L_j} \sum_{t=1}^{T} cdf_t \cdot freq_t \cdot TechFixedCost_{jlt} \cdot y_{jl}$$

$$\sum_{j=1}^{N} \sum_{l \in L_j} \sum_{t=1}^{T} cdf_t \cdot freq_t \cdot TechFlowCost_{jlpt} \cdot v_{jlpt}$$

$$v_{jlpt} \leq TechFlowCap_{jlpt} \cdot y_{jl}$$

Resource Equations (Flow)

$$\sum_{r=1}^{R}\sum_{j=1}^{N}\sum_{l\in L_j}\sum_{t=1}^{T} cdf_t \cdot freq_t \cdot ResProdCost_{rjlpt} \cdot v_{jlpt}$$

$$\sum_{j=1}^{N}\sum_{l\in L_j}\sum_{p=1}^{P} ResProdReq_{rjlpt} \cdot v_{jlpt} \leq ResCap_{rt}$$

Throughput and Conservation of Flow

- Throughput requirements by commodity and type
- Three types of conservation of flow
  1. Simple
  2. Simple + inventory
  3. Simple + inventory + transformation

Flow Requirements and Type 1 Simple Conservation

$$\sum_{l \in L_j} v_{jlpt} \geq FlowReq_{jpt} \qquad \forall j, \forall p, \forall t$$

$$\sum_{i=1}^{N} x_{ijpt} = \sum_{l \in L_j} v_{jlpt} \qquad \forall j, \forall p, \forall t$$

$$\sum_{k=1}^{N} x_{jkpt} = \sum_{l \in L_j} v_{jlpt} \qquad \forall j, \forall p, \forall t$$

Type 2 Inventory Conservation of Flow

$$\sum_{i=1}^{N} x_{ijpt} = \sum_{l \in L_j} u_{jlpt}$$

$$\sum_{l \in L_j} u_{jlpt} + \sum_{l \in L_j} w_{jlp(t-1)} = \sum_{l \in L_j} v_{jlpt} + \sum_{l \in L_j} w_{jlpt}$$

$$\sum_{k=1}^{N} x_{jkpt} = \sum_{l \in L_j} v_{jlpt}$$

Type 3 Transformation Conservation of Flow

$$\sum_{i=1}^{N} x_{ijpt} = \sum_{l \in L_j} u_{jlpt}$$

$$\sum_{l \in L_j} u_{jlpt} + \sum_{l \in L_j} w_{jlp(t-1)} = \sum_{l \in L_j} v_{jlpt} + \sum_{l \in L_j} w_{jlpt}$$

$$\sum_{k=1}^{N} x_{jkpt} = \sum_{l \in L_j} v_{jlpt} + \sum_{q \in COMP_p} ProdTransform_{qp} \cdot \partial_{jlqpt} - \sum_{q \in ASSY_p} \partial_{jlpqt}$$

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Inventory Equations

$$\sum_{j=1}^{N} \sum_{l \in L_j} \sum_{t=1}^{T} cdf_t \cdot freq_t \cdot TechStoreCost_{jlpt} \cdot w_{jlpt}$$

$$w_{jlpt} \le TechStoreCap_{jlpt} \cdot y_{jl}$$

$$\sum_{r=1}^{R} \sum_{j=1}^{N} \sum_{l \in L_j} \sum_{t=1}^{T} cdf_t \cdot freq_t \cdot ResProdCost_{rjlpt} \cdot w_{jlpt}$$

$$\sum_{j=1}^{N} \sum_{l \in L_j} \sum_{p=1}^{P} ResProdReq_{rjlpt} \cdot w_{jlpt} \le ResCap_{rt}$$

$$\sum_{p=1}^{P} \sum_{j=1}^{N} \sum_{l \in L_j} \sum_{t=1}^{T} cdf_t \cdot freq_t \cdot h_t \cdot ProdValue_{pt} \cdot w_{jlpt}$$

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Transformation Equations

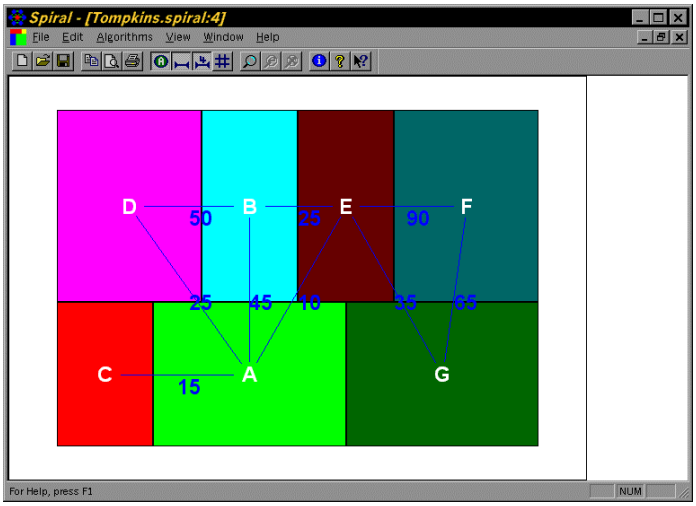
$$\partial_{jlpqt} \leq TransformCap_{jlpqt} \cdot y_{jl}$$

$$\sum_{p=1}^{P}\sum_{q=1}^{P}\sum_{j=1}^{N}\sum_{l \in L_j}\sum_{t=1}^{T} cdf_t \cdot freq_t \cdot TransformCost_{jlpqt} \cdot \partial_{jlpqt}$$

Iterative Warehouse Design Algorithm

- Solve capacitated warehouse flow model (CMF)
  - MIP
  - Determines flows, technologies and areas
- Solve conceptual block layout (WBL)
  - Block layout heuristics or MIP
  - Determines location, transportation costs
- Iterate

Conceptual Layout Illustration



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Transportation Equations

$$\sum_{p=1}^{P}\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T} cdf_t \cdot freq_t \cdot TransportCost_{ijpt} \cdot x_{ijpt}$$

$$\sum_{r=1}^{R}\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T} cdf_t \cdot freq_t \cdot ResProdCost_{rijpt} \cdot x_{ijpt}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{p=1}^{P} ResProdReq_{rijpt} \cdot x_{ijpt} \le ResCap_{rt}$$

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Future Research

- Draft paper and presentation on the web: www.isye.gatech.edu/~mgoetsch
- Computational test cases
- Please lend us your data!!

Thank You
Can I Answer Any Questions?