Prescriptive Analytics for Facility Location: an AIMMS-based perspective

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Outline

- Analytics for Facility Location
- AIMMS – Analytics Platform
- Modeling for Facility Location
- Location of Distribution Centers
- Location of Depots in Postal Logistics
- Location of Production Plants
- From Model to Application
- More about AIMMS
Analytics for Facility Location
The New Trend: Analytics

Better Decisions based on Data Analysis

Analytics at Work:
Smarter Decisions, Better Results

The Analytics Edge:
The Reality of Data, the Models Essence
The Analytics Maturity Levels

*Prescriptive Analytics: Insight to Action*

Analytics based on Optimization Modeling provides Recommended Actions during the Decision Making Process.
Analytics for Facility Location

Analysis of best locations in a network

Important field in Operations Research, Analytics & Optimization

... solid theory
... rich collection of algorithms
... large area of applications

... eventually using

Modeling & Optimization!
AIMMS – Analytics Platform
The AIMMS System

AIMMS: integrated & interactive modeling system

- Modeling language
- Extensive development tools
- Seamless solvers links
- Integrated GUI
- Advanced deployment
- Development of apps
- Win UI and Web UI
AIMMS Features (selection)

- Point & Click / Drag & Drop IDE
- Global & local compilation
- Procedural execution & definitions
- Advanced diagnostic & development tools: debugger, profiler, MP Inspector, data pages
- Data management & batch run options
- Modeling of time constructs
- Broad class of commercial and open source solvers
- Broad call of model types (LP, MIP, NLP, MINLP, CP, etc.)
AIMMS Features (selection cont’d)

- Update, call-back, parallel solver options
- Extensive matrix update functionality
- Advanced & interactive GUI objects: Gantt-chart, Pivot table, Network object, etc. (for analyst, developer, and end user)
- GIS connectivity
- Units, Multi-Language & Conventions
- GUI Templates for standard look-and-feel of applications
- Multi-Developer Support
- Advanced Deployment options: AIMMS PRO and Web UI
- Much more...
Modeling for Facility Location
“Suppose that you want to teach the “cat” concept to someone. Do you explain that a cat is a relatively small, primarily carnivorous mammal with retractile claws, a distinctive sonic output, etc.? I’ll bet not. You probably show the person a lot of different cats, saying “kitty” each time, until it gets the idea. To put it more generally, generalizations are best made by abstraction from experience.”

Location of Distribution Centers
Location of Distribution Centers
Model, Optimization, and Visualization
Location of Distribution Centers

Multi-Commodity Network Flow

**CommodityFlow**

- **Type**: Variable
- **Identifier**: CommodityFlow
- **Index domain**: (c, p, d, r)
- **Definition**: The flow variable has 4 dimensions:
  
  - c = commodity
  - p = plant
  - d = distribution center
  - r = region served

**TotalCost**

- **Type**: Variable
- **Identifier**: TotalCost
- **Definition**: The objective function that is to be minimized is essentially the addition of production and transportation costs augmented with the fixed and variable charges for distribution centers and the throughput of commodities through these centers.
Location of Distribution Centers

Location Decisions as Binary Variables
Location of Distribution Centers

Supply & Demand Constraints

**SupplyConstraint**
- **Identifier**: SupplyConstraint
- **Index domain**: \((c, p)\)
- **Definition**: 
  \[
  \sum_{(d, r)}\text{CommodityFlow}(c, p, d, r) \leq \text{InitialSupply}(c, p) + \text{AddSupply}(c, p)
  \]
- **Comment**: The supply constraint specifies that for each commodity \(c\) and each production plant \(p\), the total amount shipped to customer regions via distribution centers cannot be more than the (available) production capacity.

**DemandConstraint**
- **Identifier**: DemandConstraint
- **Index domain**: \((c, d, r)\)
- **Definition**: 
  \[
  \sum_{p}\text{CommodityFlow}(c, p, d, r) \geq \text{Demand}(c, r) \times \text{RegionServed}(d, r)
  \]
- **Comment**: The demand constraint specifies that the demand for each commodity \(c\) in each region \(r\) should be supplied by all plants, but only through the chosen distribution center.
Location of Distribution Centers

Flow Balance Constraints

For every distribution center $d$, the total throughput for $d$ (from all plants, to all regions, and for all commodities) equals the total accumulated demand of all regions served by this center.

The max throughput constraints make sure that for each distribution center $d$ the total volume of commodities to be delivered to its customer regions remains below the maximum allowed throughput.
Location of Distribution Centers

Model-based Analysis Demo

DEMO
Location of Postal Depots
Location of Postal Depots
Model, Optimization, and Visualization
Location of Postal Depots
Minimizing Capital and Variable Costs

Model Explorer: distribution.ams

- Main distribution
- Input Data Declaration
- Excel Declaration
- Model Declaration
  - DistributionModel
    - TotalCosts
    - DepotsUsed(d)
    - NumberRidesLarge(f, d)
    - TransportLarge(f, d)
    - NumberRidesSmall(d, l_pc4)
    - TransportSmall(d, l_pc4)
  - CostsRidesLarge_Init(d, l)
  - CostsRidesLarge(d, l)
  - CostsRidesSmall_Init(d, l_pc4)
  - CostsRidesSmall(d, l_pc4)
  - SatisfyDemand(l_pc4)
  - CapConstRideLarge(d)
  - CapDepotConstLarge(d)
  - CapPlantConstLarge(t)
  - FlowConservationByDepot(d)

- Results Declaration
- GUI Declaration
- StartupProcedure
- ReadDataFromExcel
- CloseWorkbook
- MainInitialization
- MainExecution
- MainTermination
- Example Base
- Redefined Identifiers [read-only]
Location of Postal Depots

Location and Ride Decisions as Integer Variables
Location of Postal Depots

Flow Capacity Constraints

**CapConstrRideLarge**
- **Type**: Constraint
- **Identifier**: CapConstrRideLarge
- **Index domain**...
- **Text**
- **Unit**
- **Property**
- **Definition**
  
  $\text{TransportLarge}(f, d) \leq \text{MaxCapacity\_large} \times \text{NumberRidesLarge}(f, d)$

**CapDepotConstrLarge**
- **Type**: Constraint
- **Identifier**: CapDepotConstrLarge
- **Index domain**...
- **Text**
- **Unit**
- **Property**
- **Definition**
  
  $\sum(f, \text{TransportLarge}(f, d)) \leq \text{CapacityDepot}(d) \times \text{DepotIsUsed}(d)$
Location of Postal Depots

Flow Conservation Constraints

\[
\text{Definition:} \quad \sum_{f} \text{TransportLarge}(f, d) = \sum_{i\_pc4} \text{TransportSmall}(d, i\_pc4)
\]
Location of Postal Depots

Model-based Analysis Demo

DEMO
Location of Production Plants
Location of Production Plants

Business Analytics for Plant Location-Allocation
Demand & Supply Location Analytics

Underlying network structure

Capacitated location - allocation model with options for expansion of existing capacity and additional side constraints
**Objective**: minimize overall Transport * Distance

\[
\text{Objective} = \sum (\text{Plant,Zipcode}, \text{Transport(Plant,Zipcode)} * \text{Distance(Plant,Zipcode)}) + \\
\sum (\text{NewPlant,ZipcodeNP,Zipcode}, \text{TransportNP(NewPlant,ZipcodeNP,Zipcode)} * \text{DistanceZC(ZipcodeNP,Zipcode)})
\]

**Performance indicator**: overall weighted distance travelled

\[
\text{Indicator} = \frac{\text{Objective}}{( \sum (\text{Plant,Zipcode}, \text{Transport(Plant,Zipcode)}) + \\
\sum (\text{NewPlant,ZipcodeNP,Zipcode}, \text{TransportNP(NewPlant,ZipcodeNP,Zipcode)}) )}
\]
Demand & Supply Location Analytics

Business Questions

- Which existing plants to include/exclude?
- Should capacity of existing plants be expanded/reduced? How much?
- Should location of new plants be considered?
- Which specific location choices to allow for new plants?
- How much capacity to allow for new plants?

Main challenges:
- Very large scale problem
- Extremely large number of demand points
- Very many potential locations for new plants
- Several new plants (capacity) types allowed at any location
Demand & Supply Location Analytics

“Boardroom” Analysis Requirements

Allow easy selection for several model options:
• Consider/Don’t consider specific existing plants
• Allow/Don’t allow location of new plants
• Select specific location choices allowing for new plants
• Tune in the accuracy of the solution process

Allow for group interaction with the model:
• Visualize allocation results
• Compute Key Performance Indicators (KPIs)
• Establish relationships between investment levels

AIMMS: fast and flexible to accommodate all these requirements
Location of Production Plants

Minimizing the Total Travelled Distance
Location of Production Plants

Organizing Model Formulation in Several Parts
Location of Production Plants

Location Decisions as Binary Variables
Location of Production Plants

Allocation Decisions as Binary Variables
(in case “only one plant per zip code”)
## Location of Production Plants

### Supply & Demand Constraints

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>cPlantCapacity</td>
<td>constraint</td>
</tr>
<tr>
<td>Index domain</td>
<td>{iPlant}</td>
</tr>
<tr>
<td>Text</td>
<td>(\text{vTransport}(iPlant, 1Zipcode) \leq \text{pMaxCapacity}(iPlant))</td>
</tr>
<tr>
<td>Comment</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>cMeetSales</td>
<td>constraint</td>
</tr>
<tr>
<td>Index domain</td>
<td>{1Zipcode}</td>
</tr>
<tr>
<td>Text</td>
<td>(\text{sum}(iPlant, \text{vTransport}(iPlant, 1Zipcode)) + )</td>
</tr>
<tr>
<td>Comment</td>
<td></td>
</tr>
</tbody>
</table>

```plaintext
if AllowNewPlants then
  \text{sum}(iNewPlant, \text{vTransport}(iNewPlant, 1Zipcode)) \\
  >= \text{pSales}(1Zipcode)
endif
```
Location of Production Plants
Capacity Constraints (linked to binaries)

vTransport(iPlant,iZipcode) <= vZipcodeWithPlant(iZipcode,iPlant) * pSales(iZipcode) ;

The amount transported from a plant to a zipcode must be 0 in case the plant is not connected, or can be max sales otherwise.

sum( iZipcode, vTransportNP(iNewPlant,iZipcodeNP,iZipcode) ) <= pMaxNewCapacity(iNewPlant) * vOpenNewPlantAtZipCode(iNewPlant,iZipcodeNP)

Total amount transported from a new plant to all zipcodes must be 0 in case the new plant is not open, or can be max new capacity otherwise.
Location of Production Plants

Model-based Analysis Demo

DEMO
Location of Production Plants

Solution of Larger Case Instance
Location of Production Plants

Business Analysis Results

• **Optimized solutions**: up to 47% **better** than (heuristic) solutions (based only on BI techniques)
• A friendly tool allowing for **group interaction** with the model
• Easy, graphical **selection** for several model options
• **Fast** solving / computation (using state-of-the-art solvers)
• Quick and insightful **visualization** of the allocation results
• **Insight** in various relationships between investment levels
From Model to Application
AIMMS: Applying Analytics and Optimization

_iterative & interactive_

*Create and modify large **models** in a clear and concise way*

*Import **data** from different sources*

*Use powerful **solvers** or construct your own solution approach*

*Visualize the results and interact with your model using the **GUI** builder*

**Deploy** to end-users
- AIMMS GUI
- Custom GUI
- Excel add-in
- Web
- Local or remote

**Import**
- ODBC
- OLE DB
- XML
- Text

**Use**
- IBM CPLEX
- Gurobi Optimization
- KNITRO
- CONOPT
AIMMS Development and Deployment

AIMMS Developer and AIMMS PRO Platform
Analytics Solution Visualization

AIMMS Windows-based User Interface
Analytics Solution Visualization

Network Structure and Time Dynamics
Analytics Solution Visualization
AIMMS PRO and Web-based User Interface
Analytics Solution Visualization
Customized Web-based User Interface
More about AIMMS...
More about AIMMS Use Options...

**AIMMS, integrated & interactive modeling system**
- Modeling language, integrated GUI, direct access to solvers, advanced deployment options, and extensive development tools
- Development of AIMMS Apps

**AIMMS PRO & Web UI**
- Collaboration and deployment platform for AIMMS Apps
- Central optimization and management
- Quick delivery of value to end users

**Supports the complete optimization chain**
- from rapid prototyping to large-scale deployment
- from development to operational use
- from single use to multi use
- from desktop to published (Web UI) application

WHERE ARE DATA-DRIVEN MANAGERS HEADED?
Organizations expect that the ability to visualize data differently will be the most valuable technique in two years. Other techniques and activities that are currently delivering the most value today will still be done, but will be of less value.

![Diagram showing the progression of data-driven techniques over 24 months.]

**SOURCE:**
MIT SLOAN Management Review
... and AIMMS Differentiating Factors

Underlying beliefs behind AIMMS:

- Solving the problem is oftentimes *not enough*

- *Creating valuable information* around the problem: interactive IDE for developers, integrated graphics, scenario analysis, developer tools, multi-solution analysis, end-user deployment features, data connectivity, units integration, extended algorithmic capabilities, etc.

- *Providing an optimization and collaboration platform*: sharing ideas and getting insight lead to better decisions

- *Maintaining an ecosystem* of experts, partners, community members, etc. in order to assure that the users will be successful
THANK YOU!

Questions?

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