OR in Electronic Negotiations

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Content

1. E-Commerce and OR Techniques
2. Short History
3. Designing a Flexible Platform for Advanced Electronic Negotiations
4. Examples of what you can do with a generic optimizing negotiation platform
5. Experiences and Comments
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Mathematical Programming

Maximize expression subject to constraints.
Negotiation: A seller tries to

Maximize income subject to bid constraints.
### Example 1

<table>
<thead>
<tr>
<th></th>
<th>Bid A</th>
<th>Bid B</th>
<th>Bid C</th>
<th>Bid D</th>
<th>Bid E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commodity 1</td>
<td>100</td>
<td>102</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commodity 2</td>
<td>103</td>
<td>99</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Commodity 3</td>
<td>100</td>
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<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>Commodity 4</td>
<td>105</td>
<td>106</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Comb price</td>
<td></td>
<td></td>
<td>200</td>
<td>205</td>
<td>305</td>
</tr>
<tr>
<td>Commodity</td>
<td>Bid A</td>
<td>Bid B</td>
<td>Bid C</td>
<td>Bid D</td>
<td>Bid E</td>
</tr>
<tr>
<td>-----------</td>
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<tr>
<td>1</td>
<td>100</td>
<td>102</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>103</td>
<td>99</td>
<td>x</td>
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</tr>
<tr>
<td>3</td>
<td>100</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>105</td>
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</table>

- Column A contains four bids on commodities 1, 2, 3, 4. We denote these bids as: A1, A2, A3, A4.
- In the same way, column B contains three bids: B1, B2, B4.
- Columns C, D, E contains one combinatorial bid each, denoted C, D, E.

In order to apply Integer Programming, we define one binary variable per bid:
- A1 is 1 if bid A1 wins, otherwise A1 is 0.
- A2 is 1 if bid A2 wins, otherwise A2 is 0. etc...

We can now express the income from bid A1 as

$100 \times A1$

i.e. if $A1 = 1$ the income from bid A1 is 100, otherwise the income is 0.
Example 1

Maximize

\[100 \, A_1 + 103 \, A_2 + 100 \, A_3 + 105 \, A_4 + 102 \, B_1 + 99 \, B_2 + 106 \, B_4 + 200 \, C + 205 \, D + 305 \, E\]

subject to

\[A_1 + B_1 + C = 1 \quad \text{(only one bid can win Commodity 1)}\]
\[A_2 + B_2 + D + E = 1 \quad \text{(only one bid can win Commodity 2)}\]
\[A_3 + D + E = 1 \quad \text{(only one bid can win Commodity 3)}\]
\[A_4 + B_4 + C + E = 1 \quad \text{(only one bid can win Commodity 4)}\]
**Example 1**

Optimal solution:
B1 = 1, B4 = 1, D = 1,
all other variables are 0.
Income: 413.

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Maximize
100 A1 + 103 A2 + 100 A3 + 105 A4
+ 102 B1 + 99 B2 + 106 B4 + 200 C + 205 D + 305 E

subject to
A1 + B1 + C = 1 (only one bid can win Commodity 1)
A2 + B2 + D + E = 1 (only one bid can win Commodity 2)
A3 + D + E = 1 (only one bid can win Commodity 3)
A4 + B4 + C + E = 1 (only one bid can win Commodity 4)
Example 2

Same bids: what is my best income if I sell only three of the four commodities?

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Maximize

100 A1 + 103 A2 + 100 A3 + 105 A4
+ 102 B1 + 99 B2 + 106 B4 + 200 C + 205 D + 305 E

subject to

A1 + B1 + C = x1  (x1 = 1 only if Commodity 1 is sold)
A2 + B2 + D + E = x2  (x2 = 1 only if Commodity 2 is sold)
A3 + D + E = x3  (x2 = 1 only if Commodity 2 is sold)
A4 + B4 + C + E = x4  (x2 = 1 only if Commodity 2 is sold)
Example 2

Same bids: what is my best income if I sell only three of the four commodities?

Maximize

\[ 100A_1 + 103A_2 + 100A_3 + 105A_4 + 102B_1 + 99B_2 + 106B_4 + 200C + 205D + 305E \]

subject to

\[ A_1 + B_1 + C = x_1 \quad (x_1 = 1 \text{ only if Commodity 1 is sold}) \]
\[ A_2 + B_2 + D + E = x_2 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \]
\[ A_3 + D + E = x_3 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \]
\[ A_4 + B_4 + C + E = x_4 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \]
\[ x_1 + x_2 + x_3 + x_4 = 3 \]
**Example 2**

Same bids: what is my best income if I sell only three of the four commodities?

Maximize

\[
100A_1 + 103A_2 + 100A_3 + 105A_4 + 102B_1 + 99B_2 + 106B_4 + 200C + 205D + 305E
\]

subject to

\[
\begin{align*}
A_1 + B_1 + C &= x_1 \quad (x_1 = 1 \text{ only if Commodity 1 is sold}) \\
A_2 + B_2 + D + E &= x_2 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \\
A_3 + D + E &= x_3 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \\
A_4 + B_4 + C + E &= x_4 \quad (x_2 = 1 \text{ only if Commodity 2 is sold}) \\
x_1 + x_2 + x_3 + x_4 &= 3
\end{align*}
\]
Example: e-Sourcing with optimization

e-Sourcing vs traditional production planning / supply chain management:

Bids rather than collected (internal) data.
Example: e-Sourcing with optimization

Minimize cost function
subject to bid constraints and business rules
e-Sourcing with optimization and scenario analysis ("What-if" analysis)

Minimize cost function

subject to

bid constraints and business rules

Try different business rules until you are happy with the outcome
Another example:
Two-sided market

Maximize
surplus
subject to
bid constraints from
buyers and sellers

Maximize
turnover
subject to
bid constraints

Potential goal for a market-maker charging
its clients based on transaction volume
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Some (incomplete) History

• First combinatorial auctions done by Net Exchange in 1993.
• Later in 1990’s: Schneider Logistics, using solver from Net Exchange, used emailed Excel sheets to serve its client in combinatorial bidding.
• Late 1990’s: Combinatorial auctions get more attention in the AI-related field of multi-agent systems.
• Being unaware of traditional optimization techniques, some researchers develop their own heuristic algorithms for handling the simplest cases of combinatorial auctions
Some (incomplete) History

• In 1999, we wrote a paper pointing out the usefulness of Integer Programming.
• As we pointed out, these basic facts are obvious for anyone with an OR or optimization background.
• As typical for AI, there were some claims of some "super algorithms" being much faster than an OR approach, but these claims have more or less disappeared.
• Of course, there are always special cases...
Our History

• In 2000, Trade Extensions was formally founded

• 2000: Two-sided combinatorial bid matching (project together with OM Technology aiming at power exchanges)

• 2000-2002: more projects, including
  • The world’s first on-line combinatorial auction with direct feedback to bidders (packaging sourcing for Volvo, performed early 2001)
  • Dynamic solution of scenarios combining package bidding with business rules (like adding a penalty for each extra allocated supplier per region, etc)
Example of "what-if" in early packaging sourcing for Volvo, examining tradeoff between number of suppliers and total cost.
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Our Initial Design Challenge

- **A general-purpose platform**
  - Data is simply defined as lots, lot fields, bid fields, etc with no specific semantics attached
  - Tools for designing bid forms etc.
- **Powerful tools for defining the semantics**
  - Allow flexible formulas based on any fields
  - Create a toolbox for creating business rules based on any fields, any thinkable measure, etc.
  - Goal: As flexible as low level MIP, easy enough to use by a typical trained buyer/seller/trader.
- **Good algorithmic understanding on how to treat the underlying MIP problems**
  - Smart modelling and translations
  - Transforming MIP problems into simpler ones, based on knowledge of occurring special cases, etc
- **Combine all this with activity rules, bidding rules, bid feedback, project management tools, document handling, role hierarchies etc**
Our Initial Design Challenge

Result:

• When our competitors need several man weeks to create a customer-specific project including programming of user-interface etc, we can create it in days or hours, no programming needed, just defining proper input fields and business rules in the existing platform
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Related things you can do

• Multi-level supply chains, worked example follows
• Two-Sided Market with Multiple Buyers and Multiple Sellers
  • Directly in sourcing GUI:
    • Alt 1: Define pairs of buy and sell lots, define a rule that applies per lot pair and ensures volumes match.
    • Alt 2: Separate lots for bidders at buy or sell side.
  • Customized GUI, unchanged solver
• Optimize number of facings per product on the shelves of a Retail Store
  • Let each product be a lot, and each facing a bid, where the rate of the i:th facing corresponds to the profit of placing this facing on the shelf.
  • Define business rules limiting the total space per shelf etc.
• Warehouse optimization
  • Lots describe different routes between origins, warehouses and destinations
  • Bids reflect different costs, such as price per ton x km
  • Rules on e.g. number of warehouses (cost of extra warehouses)
  • Result: Optimal set of warehouses
• In essence, a large number of optimization problems can be relatively nicely modelled in the e-commerce tool thanks to focus on generality and flexibility
Supply Chain Example: Printing a Catalogue

Paper Mills → Printers → Distribution Centers
Many parameters to consider

Find matching volumes. Optimize with regards to:
- Bids from paper mills and from printers
- Maximum capacities
- Volume discounts
- Paper waste
- CO2 footprint
- etc

Adding More Steps in the supply chain:
- Include bids from carriers to handle transport between Paper Mills, Printers, and Distribution Centers (not included here)
### Examples of Business Rules

<table>
<thead>
<tr>
<th>Name</th>
<th>Scope selected by the following filters</th>
<th>Apply Rule Per</th>
<th>Limit Type</th>
<th>Relative To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Per Print Plant</td>
<td>Bidders: Printers</td>
<td>From Print Plant</td>
<td>Allocation (M kgs or copies)</td>
<td>Max Total Volume (M kgs or copies) Printing Capacity Per Week (M kgs or copies)</td>
</tr>
<tr>
<td>Weekly Print Capacity</td>
<td>Bidders: Printers</td>
<td>From Print Plant Week</td>
<td>Allocation (M kgs or copies)</td>
<td>Max Total Volume (M kgs or copies) Printing Capacity Per Week (M kgs or copies)</td>
</tr>
<tr>
<td>Number of printers per Edition</td>
<td>Bidders: Printers  Lots: DC Germany or UK [INVERTED FILTER]</td>
<td>Edition</td>
<td>Number of Bidders</td>
<td></td>
</tr>
</tbody>
</table>

- Apply this rule to the Printers, and on all lots except Germany and UK
- Apply this rule once per Edition
- Limit the number of allocated printer suppliers
## Using the rules in a Scenario

<table>
<thead>
<tr>
<th>Rule Definitions</th>
<th>Apply Rule Per</th>
<th>Limit Type</th>
<th>Relative To</th>
<th>Min Limit</th>
<th>Max Limit</th>
<th>Min Condition (i.e. at least this or nothing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 Capacity Per Print Plant</td>
<td>Bidders: Printers</td>
<td>From Print Plant</td>
<td>Allocation (M kgs or copies)</td>
<td>Max Total Volume (M Copies)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>H2 Weekly Print Capacity</td>
<td>Bidders: Printers</td>
<td>From Print Plant Week</td>
<td>Allocation (M kgs or copies)</td>
<td>Printing Capacity Per Week (M Copies)</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>H3 Number of printers per Edition</td>
<td>Bidders: Printers</td>
<td>Edition</td>
<td>Number of Bidders</td>
<td></td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

- **Allocate each Printer at most its total capacity**
- **Allocate each Printer at most 1.2 x weekly capacity** (i.e. we analyze the case where we loosen the capacity limits slightly)
- **At most one printer per Edition, except for Germany and UK**
### Using rules for balancing the Supply Chain

#### Table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Scope selected by the following filters</th>
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<th>Min Limit</th>
<th>Max Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td></td>
<td>Print Plant Code, Paper Grade</td>
<td>Allocation × “Paper Consumption (M kgs)”</td>
<td></td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Balance the chain for each Print Plant and Paper Grade**

**Paper Consumption is negative for paper mills and positive for printers**

**Max limit is zero means that the amount of delivered paper must be at least the amount consumed**
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General Observation

• Virtually any thinkable optimization problem occurring in electronic negotiations can be modelled and treated with OR techniques.
• With proper design of a general-purpose platform, this works fine in practice.
• You need to carefully model the problems, transform MIP problems, etc, to get good solver performance.
• You must respect the fact that we are dealing with NP-hard problems. As long as you and your client are aware of this, there is always a proper way to treat very complex instances.
Managed Problem Complexity

• 5-level supply chain
• Hundreds of thousands of bids
• Tens of thousands of lots
• Thousands of bidders
• Millions of bid parameters
• Volume discounts, What-If scenarios, etc
• It works!
Experiences: Related important issues

- Bid collection
- Feedback
- Termination
- Bid evaluation
- Bid analysis

Good optimization analysis requires good data
Bid collection

• On-line, web-browsers
• Bid forms, e.g. MS Excel
• Data validation
  • Data types
  • Range checks
  • Checks on relations between values
• Sorting and viewing lots / items
  • Predefined
  • Bidder controlled
  • Dynamically, e.g. By closing time
• Collection of sub-parameters
• Collection of general parameters, certifications, capacities, discounts etc.
Feedback

• On bid total or by parameter:
  • Rank
  • Best bid / distance to best bid

• Conditional feedback
  • For example, show any of these above only if best bid has passed a certain value or change is sufficiently large
Termination

- Fixed times
- Prolongations
  - Based on e.g. latest bid on the lot
  - Based on bids on other lots
  - In parallel, sequence or independently
Bid evaluation / rating

- Mathematical expressions to compute bid values from parameters and sub-values
Bid analysis

• Reports for quickly identifying outlier bids, e.g. based on median or historical price
• Ditto for outlier parameter values in bids
• Analysis of competitiveness of bidders, optionally with special analysis of historically awarded lots
• Analysis of bidder activity