Combinatorial Reverse Auctions in Construction Procurement

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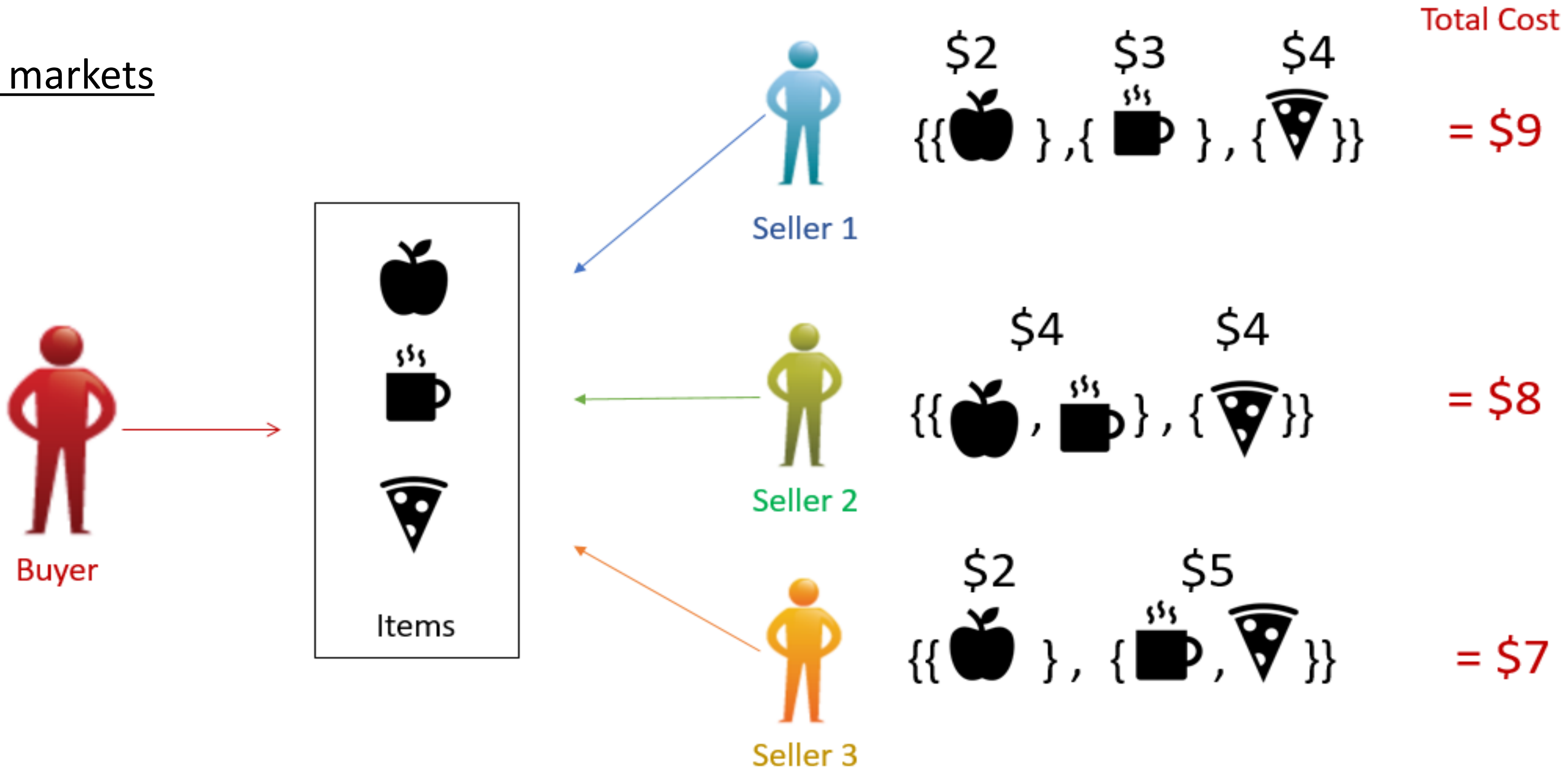
Combinatorial Auctions

- A **combinatorial auction** is a kind of smart market in which participants can place bids on combinations of discrete items, or “packages”, rather than individual items or continuous quantities.

Combinatorial Reverse Auctions

<u>In procurement markets</u>



Buyer (auctioneer) proposes packages to suppliers

Suppliers bid on packages

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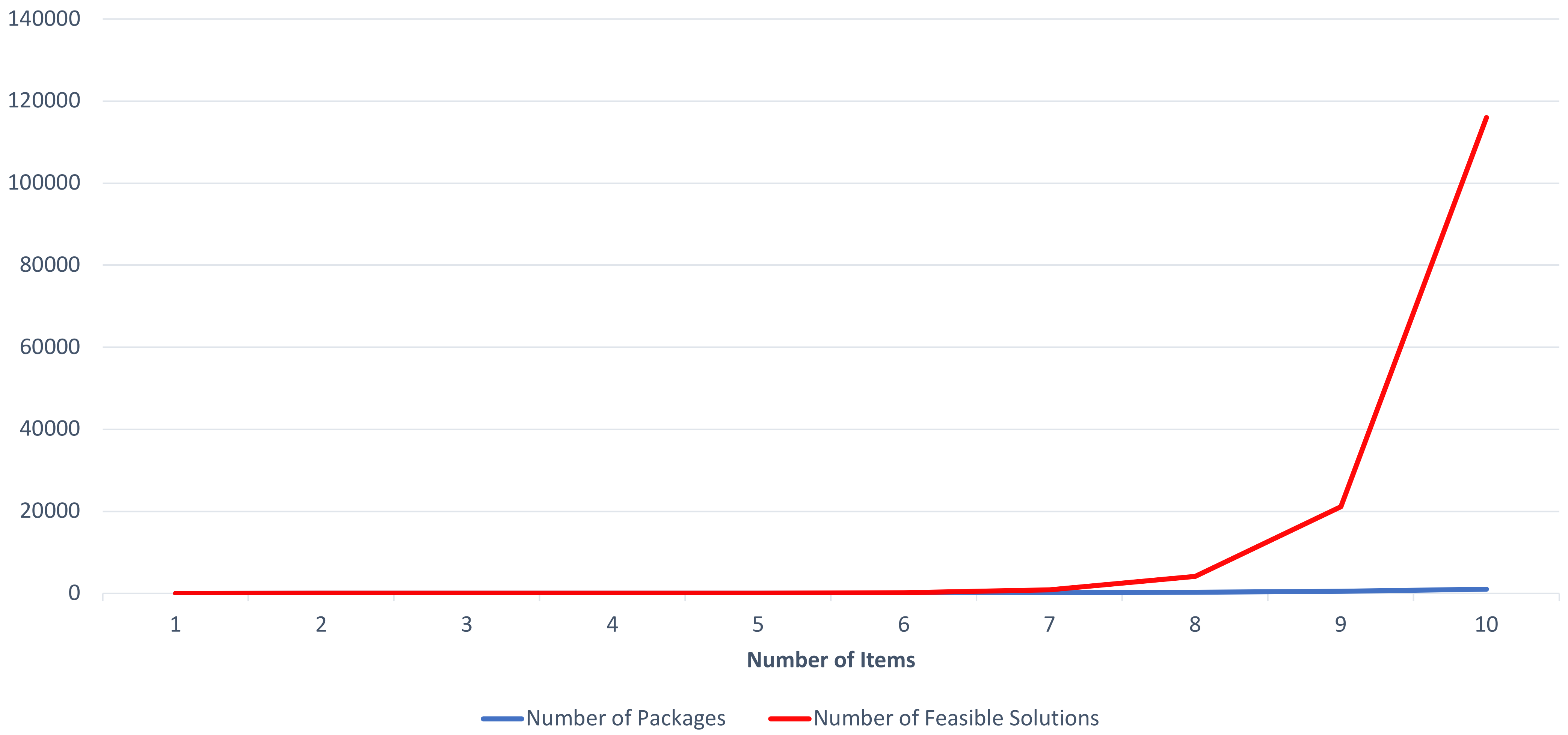
Complexity – NP Hard



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Other Issues

- How to determine packages?
- "Dead-lock"
- Bidding "Fatigue"
- Exploitation
- Auction Design
  - First price? Second Price?
  - Open? Sealed-Bid?
  - Bid language? (OR, AND/OR)

Supplier	Items	Bid
1	{A,B}	$10
2	{B,C}	$20
3	{A,C}	$30

Project Focus

- Construction procurement often involves negotiations between many parties over multitudes of different components.

- The process of allocating contracts to suppliers is a great challenge in minimizing project costs while meeting stringent specification and schedule requirements.

Can combinatorial reverse auctions be used to reduce construction costs?

Company Overview:
Shaksy Engineering Services

- Based in Muscat, Oman
- Civil Contractor
- Founded in 2009
- $200M in projects
- Focus on Commercial & Residential projects
- Plans for regional expansion

Company Challenges

- Improve (and standardize) sourcing material and services
- Low supplier bidding participation
- High complexity, >1000 line items in projects
- Hard to capture supplier cost synergies
- Bid normalization
    - Quality
    - Lead time
    - Payment Terms
    - Risk

Motivation

- Good Procurement is important in construction **The Charted Institute Of Building*
- $15.5 Trillion market by 2030 ***Global Construction Perspective Report*
- Procurement is not very sophisticated in construction projects
- Large body of knowledge on combinatorial auctions
- Not many empirical studies
- Not any studies focused on construction industry

Literature

Some relevant literature:

- The Charted Institute of Building. (2010). A Report Exploring Procurement in the Construction Industry. The Charted Institute of Building.
- Lunander A, L. S. (2012). Combinatorial Auctions in Public Procurement: Experiences from Sweden.
- Caplice, C., & Sheffi, Y. (2005). Combinatorial Auctions for Truckload Transportation.
- Parkes, D. C. (2006). Iterative Combinatorial Auctions.

Methodology Outline

Identify Leverage Items based on:

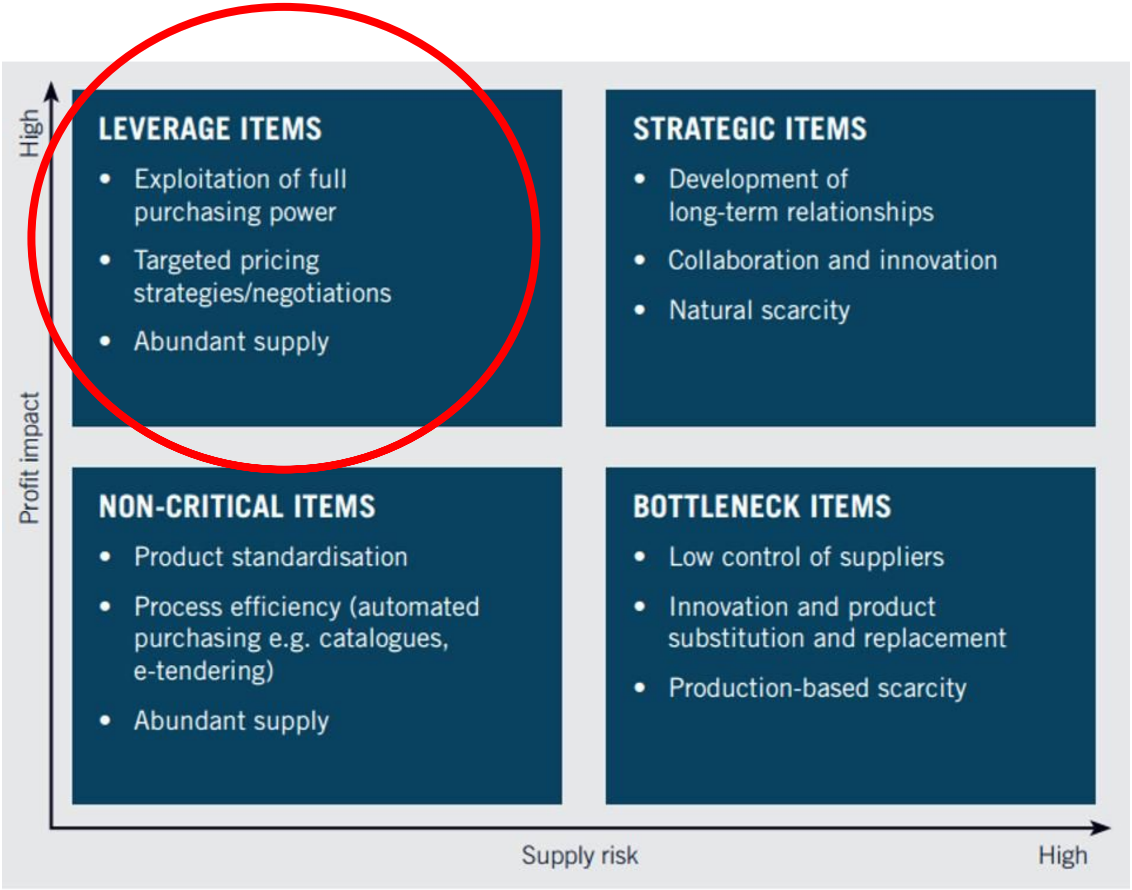
- Number of suppliers (>2)
- Number of line-items (>10)
- Value (>30k OMR or $78k)

Aggregate line-items into item groups

Generate Packages / Simulate Bidding

Run Optimization Models

Sensitivity Analysis



-Kraljic Matrix-

Data

- 7 Scenarios based on the number of suppliers and number of items
  (metal works, mechanical, electrical, plumbing, HVAC components, window and door panels, signboards, woodwork, etc.)
- 3 – 7 Suppliers per scenario (27 in total)
- 4 – 14 items per scenario (53 in total)
- Fixed costs (for each supplier)
- Discount rate (for each supplier)
  - Estimated based on experience

	Supplier 1	Supplier 2	Supplier 3
HVAC	15,720	**13,650**	24,502
Pipping	2,476	**2,150**	3,858
Electrical	3,945	**3,525**	6,148
Sanitary Ware	11,025	**9,800**	19,747
Lighting	7,936	**6,200**	12,524
Communication	**16,150**	41,570	22,351
Security	**5,152**	13,705	7,948

Package Generation – Item Selection

Normalize each row

	Supplier 1	Supplier 2	Supplier 3
Item 1	-0.38832	**-0.7476**	1.135917
Item 2	-0.38819	**-0.7477**	1.135892
Item 3	-0.42185	**-0.71995**	1.141801
Item 4	-0.46073	**-0.68658**	1.147315
Item 5	-0.29095	**-0.82226**	1.113211
Item 6	**-0.79526**	1.122661	-0.3274
Item 7	**-0.86744**	1.093764	-0.22632

$$Q'_{i,p} = \mathrm{round}\left[-N\left(T^*_{i,s} + \mathcal{R}\right)\right] + 1$$

	Package 1	Package 2	Package 3
Item 1	0	**1**	0
Item 2	0	**1**	0
Item 3	0	**1**	0
Item 4	0	**1**	0
Item 5	0	**1**	0
Item 6	**1**	0	0
Item 7	**1**	0	0

Package Generation – Proxy Bidding

- Apply discount rates (d) to each package/supplier pair

$$c_p = \left(\sum\nolimits_{p \in P^1} c_p\right)\left(1 - d\sum\nolimits_{p \in P^1} c_p\right)$$

c_p: Package Bid Value

P^1: Single Item Packages

	Package 1	Package 2
HVAC	0	1
Pipping	0	1
Electrical	0	1
Sanitary Ware	0	1
Lighting	0	1
Communication	1	0
Security	1	0
Supplier 1	21,211	40,764
Supplier 2	54,664	35,075
Supplier 3	30,115	35,075

Optimization – Model 1

- Most basic Integer Programming model (Andersson et al., 2000)
- Doesn't distinguish between suppliers
- Doesn't consider costs
- Lowest total cost
- Fast

$$\operatorname{argmin} Z(\boldsymbol{x}) = \sum_p c_p x_p$$

$$s.t \sum_p Q_{i,p} x_p = 1, \forall i \in I$$

x_p: Binary decision variable

c_p: Package cost

$Q_{i,p}$: Item/package matrix

$Z(x)$: Total cost (objective)

Optimization – Model 2

$$\text{argmin } Z(\boldsymbol{x}, \boldsymbol{y}) = \sum_p c_p x_p + \sum_s f_s y_s$$

$$s.t \sum_p Q_{i,p} x_p = 1, \forall i \in I$$

$$\sum_p R_{s,p} x_p - M y_s \leq 0, \forall s \in S$$

Linking constraint

$$S^{min} \leq \sum_s y_s \leq S^{max}$$

Supplier limits

$$x_p \in \{0,1\}, \forall p \in P$$

$$y_s \in \{0,1\}, \forall s \in S$$

f_s: supplier fixed cost

y_s: supplier selection decision variable

$R_{s,p}$: supplier/package matrix

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Optimization – Model 3

- **Iterative** solver
- Same formulation as Model 2
- Use solver to generate packages
- Initialized with single item packages
- Stops when no new unique package is generated
- Deterministic model -always gives the same answer

Optimization – Model 4

$$\operatorname{argmin} Z(\boldsymbol{x}, \boldsymbol{y})$$

$$= \sum_s \left(\sum_i c_{i,s} x_{i,s} - d_s \left(\sum_i c_{i,s} x_{i,s} \right)^2 \right) + \sum_s f_s y_s$$

$$s.t \sum_s x_{i,s} = 1, \forall i \in I$$

$$\sum_i x_{i,s} - M y_s \leq 0, \forall s \in S$$

$$S^{min} \leq \sum_s y_s \leq S^{max}$$

$$x_{i,s} \in \{0,1\}, \forall i \in I, \forall s \in S$$

$$y_s \in \{0,1\}, \forall s \in S$$

- Non-linear
- **Discount term** moved to objective function
- Assumes we know pricing functions
- Genetic algorithm

Optimization – Output

- Allocation matrix
- Values assigned to final allocation
- Total cost
- Compare to baseline (all items to lowest supplier)
- Computation time

	Supplier 1	Supplier 2	Supplier 3
HVAC	0	1	0
Pipping	0	1	0
Electrical	0	1	0
Sanitary Ware	0	1	0
Lighting	0	1	0
Communication	0	1	0
Security	1	0	0

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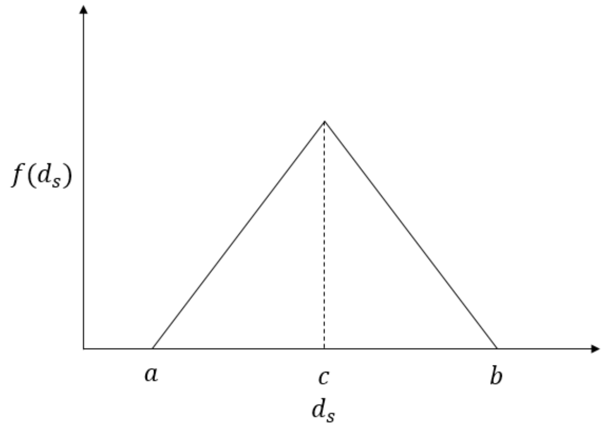
Summary of Optimization Models

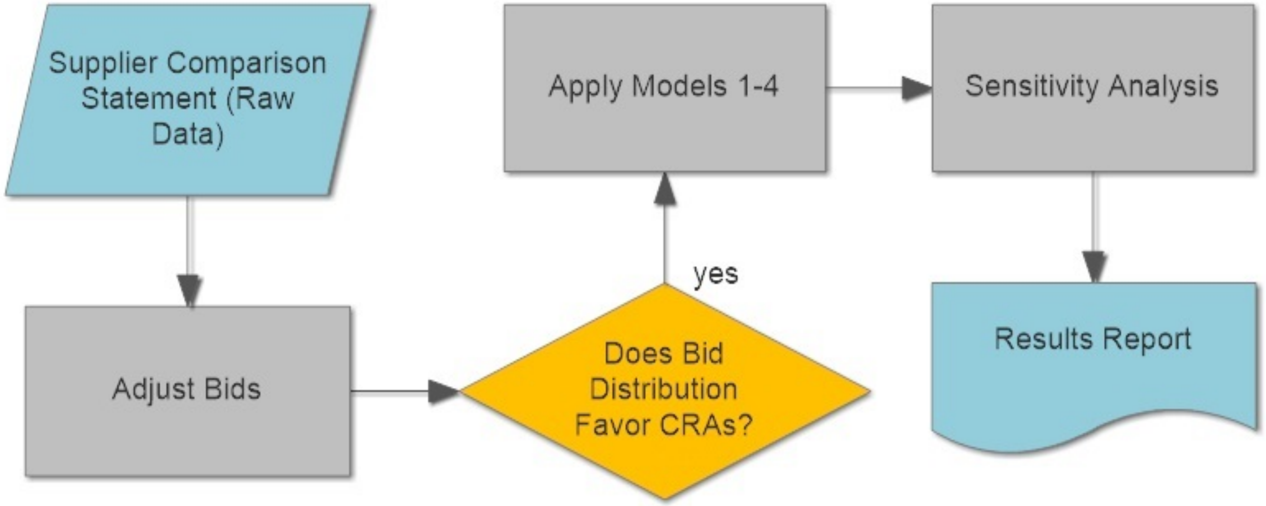
Model	Description	Reason for use	Pros	Cons
1	Baseline CRA	Test various solvers and benchmark performance of other models	Easiest to solve and can be solved using a variety of solvers	Doesn’t differentiate between suppliers and doesn’t model fixed costs
2	CRA with supplier constraints	Model supplier fixed costs and constraints	Faster to solve than subsequent models if a limited number of packages are used	Will usually not find a better solution than subsequent models if packages are sparse
3	Iterative CRA	Better simulate real auctions where bidding is limited and doesn’t take place simultaneously	More realistic and has the potential to converge to a better solution than previous models on auctions with many items and suppliers	May take longer to carry out due to multiple rounds
4	Non-linear Model	Including the pricing function in the objective function allows the solver to search over the entire allocation space	Reduction in number of decision variables and does not require package bids as inputs	Involves solving a non-linear objective function and may not be feasible for larger auctions

Sensitivity Analysis

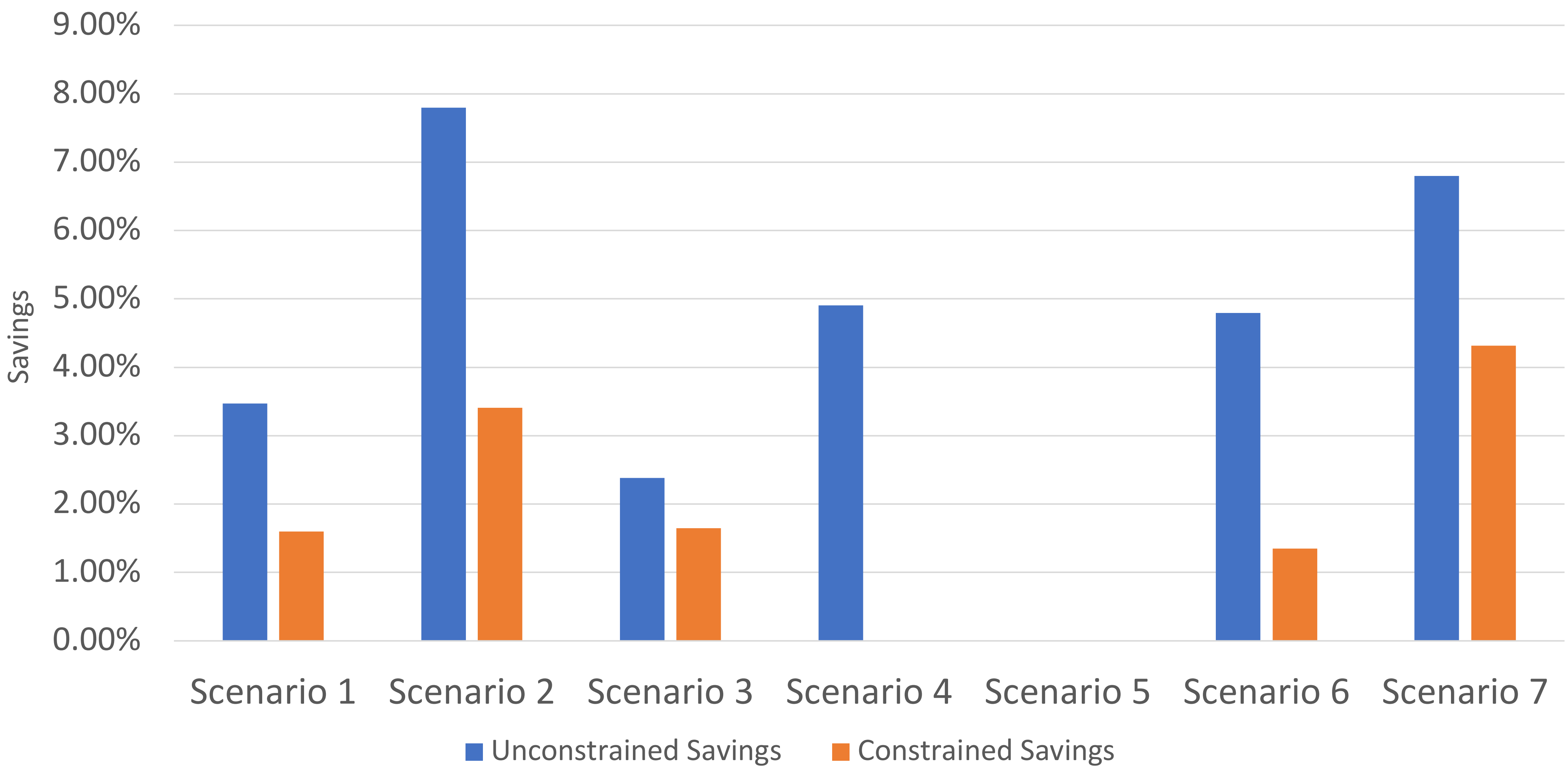
Considering 7 scenarios with different number of items and suppliers;

- Assume discount rates (d_s) are triangularly distributed
- Monte Carlo simulation
- Measure average savings
- Measure variability of total cost
- Measure variability of allocations





Results



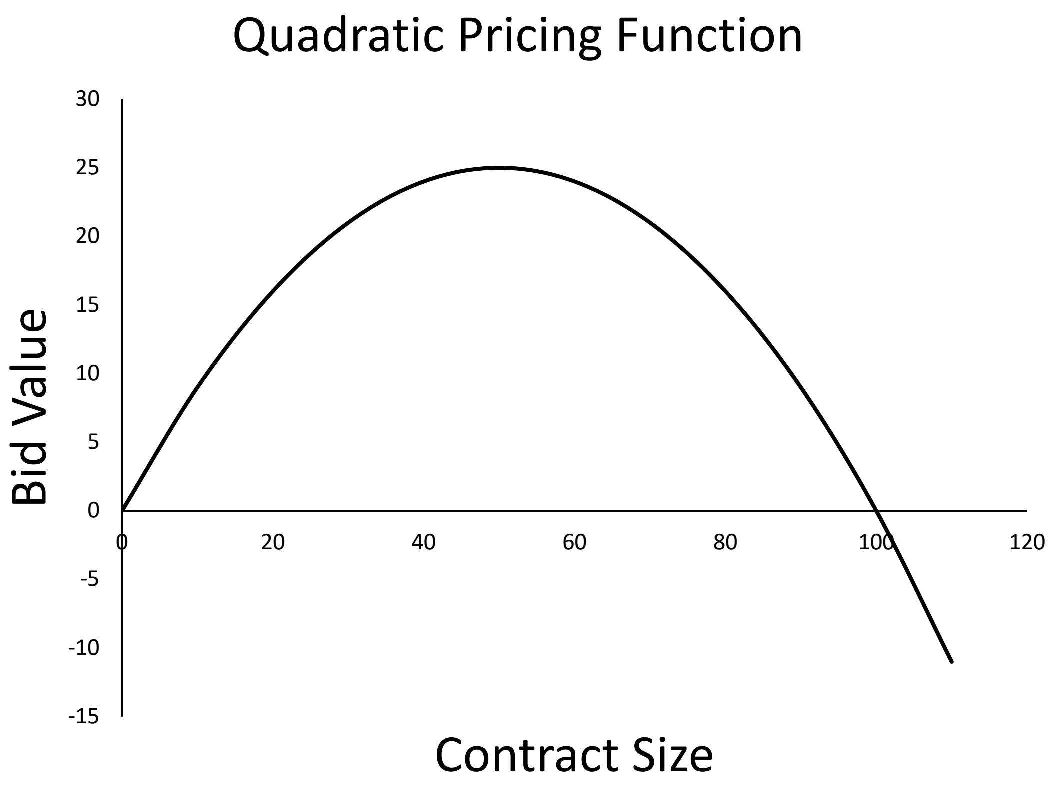
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Savings
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5
Scenario 6
Scenario 7
Unconstrained Savings
Constrained Savings

Results

- 6.4% savings for unconstrained models ($320k)
- 2.7% for constrained models ($150k)
- Model 3 produced the lowest costs and was fastest
- All models had low cost variability (<2%)
- Models 1, 2 and 4 had a higher allocation variability

Limitations

- Proxy bidding, realistic?
- Pricing function – not monotone
- Supplier capacities not considered
- Cost of implementation?
- Understandability, black box?



Recommendations

- Use models as decision support systems
- Navigation tool for negotiations (iterative model)
- What-if analyses with different:
  - Bid adjustments
  - Item aggregations
  - Discount distributions
  - Supplier constraints

Areas for Future Research

- Practical experiment with real package bidding
  - Data analytics on bidding
- More theoretical pricing function
- Stochastic optimization
  - Consider variability in pricing structures

THANKS

Q & A