



FPL[®] E3 Reverse Auction

TEAM2

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0 EXECUTIVE SUMMARY

Fourth Party Logistics, Inc. (FPL), as a company in transportation industry, has demand of sourcing carriers for logistics services.

Our team has developed an electronic-easy-expressive auction solution for FPL to accomplish below business requirements:

- Encourage healthy competition between carriers to achieve lowest cost for logistics pricing.
- All business constraints of FPL are strictly honored the auction process.
- Besides overall business constraints reflected on carriers, multiple other factors need to be counted as well during the process, such as additional savings, carrier goodwill etc.
- Decision making process is shortened to a week by electronic procurement.

To achieve all the FPL objectives, our team made detailed analysis on multiple dimensions and decisions to compose our final solution as below:

- Bidding language:
 - We discussed the pros and cons of different auction types (sequential auction, parallel auction, and combinatorial auction). And we decided to choose combinatorial auction.
 - After analyzing multiple bidding languages, in order to achieve the target of providing bidders a language that is fully expressive, simple and natural, we developed a Pattern Based Expressive Bidding Language based on the ideas and concepts of OR-of-XORs bidding language. This bidding language allows bidders to bid on bundles defined by themselves as long as the bundles follow FPL's requirements and constraints.
- Lane requirements:
 - We divided all FPL's requirements into two groups: apply-to-all requirements and special requirements. The apply-to-all requirements include mandatory demands in sourcing decision making, and special requirements include multiple factors which can reflect carriers' overall performance. Based on these requirements, FPL can make comprehensive and rational decisions.
- Negotiation process:
 - In pre-negotiation step, our solution requires FPL to convey its requirements, bidding process, online UI and bidding language to bidders so that bidders can

- understand them accurately in advance. Adjustments to such information based on feedback from bidders can also be made.
- In during-negotiation step, our solution is composed of two rounds of auction. Bidders will receive feedback provided from FPL during the first-round clearing period, including lowest bidding prices, unpopular lanes and FPL discount information. FPL can go through scenario navigation to adjust its requirements as well. When auction is closed, winner determination process will generate the optimized auction results.
 - The post-negotiation step includes necessary unfulfilled-lane-negotiation with selected carriers, contract signing, and vendor management.
 - Pricing rules:
 - We discussed the advantages and disadvantages of a few pricing rules including First-price pricing rule and Vickery-Clarke-Groves Pricing Rule. Our solution is to apply First-price pricing rule.
 - Winner Determination
 - In this part, we compared multiple winner determination algorithms including enumeration of exhaustive partitions of items, dynamic programming, greedy winner determination, and combinatorial auction, branch on bids (CABOB). For FPL's best interests, we decided to use CABOB algorithm for the winner determination process.
 - Other Dimension
 - As multiple factors need to be taken into account during bidding, our solution includes the Supplier Quality Index (SQI) as one of the evaluation metrics of non-price factors to evaluate bidders' competitiveness.
 - As Carrier Delivery On-Time (CDOT) is one of the mandatory information required by FPL for decision making, for carriers without CDOT, we developed a CDOT Substitution mechanism to achieve fairness for winner determination.
 - We set bidding price limitation for bidding between the two-round auction to avoid vicious competition during the two-round auction.

1 BIDDING LANGUAGE

1.1 AUCTION TYPES OVERVIEW

1.1.1 SEQUENTIAL AUCTION

Items are auctioned one by one in a sequential auction. Even though algorithm complexity of a sequential auction is normally lower than other types. It has the following downsides.

- If a bidder prefers to bid on a combination of items, the bidder has to guess the items he/she will receive, which is very difficult. Such speculations will cause computational cost and other overhead. Therefore, it will be hard to bid rationally.
- Too much uncertainty remains about the other bidders' bids, which often causes inefficient allocations and bidders finally wouldn't be able to get combinations they want.

1.1.2 PARALLEL AUCTION

Items are auctioned simultaneously in a parallel auction. Comparing to a sequential auction, a bidder would partially know what the other bidder's bids are. However, it still has the following downsides.

- Uncertainty and overhead is, to some extent, reduced. However, the problems exist in a sequential auction still exist in a parallel auction.
- In a parallel auction, in order to prevent the scenario that no bidder bids until the end of an auction from happening, activity rules must be used. However, in such an auction, the game-theoretic equilibrium bidding strategies are not known.

1.1.3 COMBINATORIAL AUCTION

Bidders can place bids on different combinations of items in a combinatorial auction. Therefore, the need for lookahead and the downsides caused by uncertainty issues in a sequential or parallel auction are significantly reduced. Bidders can propose to bid on bundles of items as they wish.

1.1.4 OUR CHOICE AND RATIONALE

In the field of transportation, comparing to traditional auctions like sequential and parallel auctions, combinatorial auctions have the following advantages,

- In order to enable carriers to come up with complex bids, buyers have to provide accurate and detailed information. Therefore, the quality and quantity of the information delivered to carriers will be enhanced.
- Combinatorial auctions make buyers more aware of their bidders' business logics and the relationship between lanes and carriers and carriers' possible preferences and concerns over the lanes. Therefore, a win-win solution could be more easily reached.
- Because of the use of optimizations required by combinatorial biddings, nonfinancial information and considerations can be taken into account. comparing to a traditional auction, it is more likely that the auction is more efficient and could brings the buyer better services.

Therefore, we decided to adopt combinatorial auction as our solution for FPL.

1.2 BIDDING LANGUAGES FOR A COMBINATORIAL AUCTION

1.2.1 THE OR BIDDING LANGUAGE

Bidders bid on combinations of items using OR bidding language. The bids are joined with nonexclusive OR, so that it is highly possible that only a part of the bids from a bidder will be accepted.

$$S = (S_1, p_1) \text{ OR } (S_2, p_2) \text{ OR } \dots \text{ OR } (S_k, p_k)$$

1.2.2 THE XOR BIDDING LANGUAGE

Using XOR bidding language, a bidder can bid on a number of items. However, at most only one bid from a bidder will be accepted. It is a language that allows bidders to express their preference on the choice of item and it is expressive enough to represent item-price mappings.

$$S = (S_1, p_1) \text{ XOR } (S_2, p_2) \text{ XOR } \dots \text{ XOR } (S_k, p_k)$$

1.2.3 THE OR-OF-XORS BIDDING LANGUAGE

OR-of-XORs language combines OR and XOR bidding language together. It is a more natural way for bidders to show their preferences. It allows bidders to bid on bundles of items when ensuring the independence of each of the bundles.

$$\begin{aligned}
 S = & [(S_{11}, p_{11}) \text{ XOR } (S_{12}, p_{12}) \text{ XOR } \dots \text{ XOR } (S_{1k}, p_{1k})] \\
 & \text{OR } [(S_{21}, p_{21}) \text{ XOR } (S_{22}, p_{22}) \text{ XOR } \dots \text{ XOR } (S_{2k}, p_{2k})] \\
 & \text{OR } \dots \\
 & \text{OR } [(S_{k1}, p_{k1}) \text{ XOR } (S_{k2}, p_{k2}) \text{ XOR } \dots \text{ XOR } (S_{kk}, p_{kk})]
 \end{aligned}$$

1.2.4 THE OR* BIDDING LANGUAGE

Using OR* bidding language, bidders can bid on items as nodes in a graph and can submit edges in such a graph following the arbitrary XOR constraints. It is a generalization of the OR-of-XOR language.

	Expressiveness	Advantages	Disadvantages
OR	Not fully expressive	By making constraints on the combinations of items to be bid on, polynomial time winner determination can be reached.	Not expressive so that even basic logics and reasoning could be very hard to be expressed.
XOR	Fully expressive	Close to natural language so that it is easy to be understood by bidders.	Optimal winner determination algorithm is at least as hard as it is in OR language.
OR-of-XORs	Fully expressive	Full expressive power is maintained while the descriptions is shorter as in XOR language. Very natural to input preferences.	Monochromatic valuation of items is exponential.
OR*	Fully expressive	Exponentially more compact than OR-of-XORs language.	Less natural than OR-of-XORs language.

1.2.5 THE ADVANTAGES OF EXPRESSIVE BIDDING LANGUAGE

Expressive bidding language allows suppliers to express their offers in a dramatically detailed form. Bidders can express their offers creatively, precisely and conveniently using compact statements. Expressive bidding language has the following features and benefits.

- Bidder can propose their self-constructed bundles of items freely as long as it fits the formats and constraints provided by FPL, which dramatically increased the flexibility of the auction. In this way, bidders can express their preferences completely and creatively to fully meet their needs and demands. Savings are made possible by reducing economic inefficiency. A more economical way of supplying is established and a win-win situation could be more easily reached. They can also specify ranges for their offers, which could ensure flexibility when avoiding winner determination algorithm being too complex.
- Bidders now can provide discounts if trigger conditions are satisfied. The discount schedules could be highly flexible. For example, in order to deal with “empty back-hauls” problem, bidders can propose to offer deeper discounts if they can be granted multiple deliveries (back-haul deliveries) in one route or in multi-leg routes. This will lower both FPL’s and bidders’ cost. A win-win situation could be thus reached.
- Bidders can specify a variety of constraints by picking values for the attributes of an item. By expressive bidding, they can provide offers based on their capability (e.g. Whether they can handle refrigerated goods) so that they can choose a way to best match their specialties and efficiencies.
- Bidders could avoid exposure risks. With the help of expressive bidding, bidders can determine the bundles of items fully based on their own wills. They can price each of the items separately and the package of them together. So that exposure problem is overcome.
- Again, since bidders only bid on the bundles of their own interests, they do not need to guess which packages to commit to anymore. The bidding now allows more straightforward participations in markets. This generates the increase of market participants and more efficient allocations and thus furthers economic efficiency.

1.2.6 OUR CHOICE AND RATIONALE

Considering FPL’s business goals and requirements, including avoiding “empty back-hauls” and transporting both dry and refrigerated goods, we came to the conclusion that flexibility is a major concern in the design. Also, 100 lanes and large volumes in each lane will be bid on in

FPL's auction, we have to choose a language that is fully expressive, simple and natural to bidders. By using such a language, bidders can bid rationally and offer bids that best fit their capacity and efficiency. FPL will also be provided the opportunity to realize cost efficiency and receive high quality services.

Therefore, we propose to adopt expressive bidding language as our solution. Based on the ideas and concepts of OR-of-XORs bidding language, we developed our own mechanism, namely Pattern Based Expressive Bidding Language, that allows bidders to bid on bundles defined by themselves as long as the bundles follow FPL's requirements and constraints. Both OR and XOR bidding language are not natural enough, therefore not efficient enough. The expressive bidding language described below derives from OR-of-XORs bidding language to reach to optimal balance of expressiveness and compactness.

1.3 PATTERN BASED EXPRESSIVE BIDDING LANGUAGE

As we discussed above, expressive bidding language leads to a more detailed expression for both buyer and supplier, which further leads to better allocation decisions. There is no doubt that from traditional non-expressive combinatorial bidding language to the expressive bidding language, the combinatorial explosion problem has been largely diminished, however, to achieve a finer-grained matching of supply and demand, the diversity of provided language template has become the bottleneck.

To improve the existing method, we proposed a pattern based expressive bidding language presentation method(PbEBL). Compared with the previous work, a crucial difference is that instead of providing several fixed language templates for users to choose from, our method provides a simple uniform adaptive language pattern to express all possible expressions under the context of reverse auction. To be specific, we assume that every conditional requirement, like discount schedule from supplier and side constraint from buyer can be generalized as a pair of *triggers* and *actions*:

$$c_i = \langle T, A \rangle$$

where T is a set of the triggers of executing specific action, and A is the actions when t is met. For an example, given a supplier discount schedule: *"If my bid (bid i) is awarded more than 80 percent of the total volume of this lane, I will provide a discount of 5% off price"*, the trigger is *"bid i is awarded more than 80 percent of the total volume of this lane"* and the action is *"[Supplier] will provide a discount of 5% off price to bid i"*.

The trigger and action can be further decomposed into “Subject”, “Operation”, “Object”, “Range”, “Value” and “Unit”, which together formulate the basic pattern of nature language expression.

$$t = \langle \text{Subject} \rangle, \langle \text{Range} \rangle, \langle \text{Value} \rangle, \langle \text{Unit} \rangle$$

$$a = \langle \text{Subject} \rangle, \langle \text{Operation} \rangle, \langle \text{Object} \rangle, \langle \text{Range} \rangle, \langle \text{Value} \rangle, \langle \text{Unit} \rangle$$

Where $t, t \in T$ is a trigger, $a, a \in A$ is an action. Each $\langle \text{Element} \rangle$ can be chosen from a set of predefined set. By choosing the corresponding elements of sentence elaborately, we can fully represent almost all the bidding language. In this way, we bring the flexibility of bidding language one step further than former endeavors. In other words, previous practice of expressive bidding language is a set of expressive sentences, where the capacity of expression relies on the size of sentence set, our approach basically relies on the size of element set and some language rules (e.g. “year” can not be used on object “bid unit price”), user could choose arbitrary valid element composition as they wish.

Note that each conditional requirement may contain more than one trigger or action, here we give some examples for four basic cases and their corresponding pattern based expression:

Single Trigger Single Action(STSA) Most of the conditional requirement fall into STSA pattern, which include a specific action toward a single condition. The example we gave above is an example of STSA pattern, which can be represented as:

$$c_i = \langle T, A \rangle$$

$$t = \langle \text{Bid}_i \text{ awarded volume} \rangle, \langle \text{is greater than} \rangle, \langle 80 \rangle, \langle \text{percent} \rangle, t \in T$$

$$a = \langle \text{Buyer} \rangle, \langle \text{discount} \rangle, \langle \text{Bid}_i \text{ price per unit} \rangle, \langle \text{equals} \rangle, \langle 5 \rangle, \langle \text{percent} \rangle, a \in A$$

Note that sometimes the only trigger could even be ignored if it is generally applicable, for example “*Buyer limits at most 20 suppliers*” is a requirement from buyer toward the auction as a whole and applied to all suppliers, in this case the trigger is N/A or no condition:

$$c_i = \langle T, A \rangle$$

$$t = \text{N/A}, t \in T$$

$$a = \langle \text{limit} \rangle, \langle \text{total supplier number} \rangle, \langle \text{is less than or equals} \rangle, \langle 20 \rangle, \langle \text{unit} \rangle, a \in A$$

Also the subject of action could be self-evident, so in many case the subject in action could be ignored either (shown as below).

Create new Bid							
Lane	1.Pittsburgh-Cleveland		☐ is Return trip	Amount:	40	unit(s)	Base Price \$ 125 / unit
☒ customize pricing rules							
Trigger	Subject:	amount awarded	☐ Return trip	Range:	is greater than	Value:	80 percent Add
Action	operation:	discount			price per unit	Range:	equals Value: 5 percent Add
Rule	Trigger 1		Action 1		Create Bid		

Multiple Trigger Single Action(MTSA) In some case, one action is triggered by several related conditions, it is extremely convenient to use expressive language in such conditional requirement combinational expression. For an example, “if carrier A bids on a return lane, and is awarded more than 80% of the volume of each lane, the supplier will discount 5% of the price per unit”, such a requirement can be expressed like:

$$c_i = c_j = \langle T, A \rangle$$

$$t_1 = \langle \text{"This bid"} \rangle, \langle \text{has return trip} \rangle, \langle \text{true} \rangle, \langle \text{N/A} \rangle, t_1 \in T$$

$$t_2 = \langle \text{Bid}_i \text{ provided volume} \rangle, \langle \text{is greater than} \rangle, \langle 80 \rangle, \langle \text{percent} \rangle, t_2 \in T$$

$$t_3 = \langle \text{Bid}_i \text{ awarded volume} \rangle, \langle \text{is greater than} \rangle, \langle 80 \rangle, \langle \text{percent} \rangle, t_3 \in T$$

$$a = \langle \text{discount} \rangle, \langle \text{Bid}_i \text{ price per unit} \rangle, \langle \text{equals} \rangle, \langle 5 \rangle, \langle \text{percent} \rangle, a \in A$$

Create new Bid							
Lane	1.Pittsburgh-Cleveland		☒ is Return trip	Amount:		unit(s)	Base Price \$ / unit
☒ customize pricing rules							
Trigger	Subject:	this bid	☒ Return trip	Range:	has return trip	Value:	true N/A Add
Action	operation:	discount			price per unit	Range:	equals Value: 5 percent Add
Rule	Trigger 1		Trigger 2		Create Bid		

Single Trigger Multiple Action(STMA) Similarly, one single condition may trigger different actions simultaneously, for an example, to encourage long-term contract, buyer may “Favor supplier's 5 percent price per unit of Bid_i and award 3% Supplier Quality Index(SQI)”, which could be represented in our method as:

$$c_i = \langle T, A \rangle$$

$$t = \langle \text{Contract length}_i \rangle, \langle \text{is greater than} \rangle, \langle 3 \rangle, \langle \text{year} \rangle, t_1 \in T$$

$$a_1 = \langle \text{Bid}_i \text{ price per unit} \rangle, \langle \text{discount} \rangle, \langle \text{equals} \rangle, \langle 5 \rangle, \langle \text{percent} \rangle, a_1 \in A$$

$$a_2 = \langle \text{award}, \langle \text{SQI}_5, \langle \text{equals}, \langle 3, \langle \text{percent}, a_2 \rangle \rangle \rangle \rangle \in A$$

Create new Auction Rules						
Apply this rule Every supplier						
Trigger	Subject: contract length	Range: is greater than	Value: 3	Year	Add	
Action	operation: favor	Object: SQI	Range: equals	Value: 10	percent	Add
Rule	Trigger 1 Action 1 Action 2			Add this rule		

Multiple Trigger Multiple Action(MTMA) Finally, several complex and intricate links between conditions and actions may induce a Multiple Trigger Multiple Action requirement. For an example, to award long-term supplier of good quality, buy may “*Favor bids by 5 percent and extend grace period to 2 days, when the contact length is greater than 5 years and the SQI is greater than 90*”, which could be represented in our method as:

$$c_i = \langle T, A \rangle$$

$$t_1 = \langle \text{Contract length}, \langle \text{is greater than}, \langle 5, \langle \text{year}, t_1 \rangle \rangle \rangle \in T$$

$$t_2 = \langle \text{SQI}, \langle \text{is greater than}, \langle 90, \langle \text{N/A}, t_2 \rangle \rangle \rangle \in T$$

$$a_1 = \langle \text{Bid price per unit}, \langle \text{discount}, \langle \text{equals}, \langle 5, \langle \text{percent}, a_1 \rangle \rangle \rangle \rangle \in A$$

$$a_2 = \langle \text{Extend}, \langle \text{Grace period}, \langle \text{equals}, \langle 2, \langle \text{day}, a_2 \rangle \rangle \rangle \rangle \in A$$

Create new Auction Rules

Apply this rule

Every supplier

Trigger

Subject:

contract length

Range:

is greater than

Value:

5

Year

Add

Action

operation:

extend

Object:

grace period

Range:

equals

Value:

2

Day

Add

Rule

Trigger 1

Trigger 2

Action 1

Action 2

Add this rule

Rule ID	Apply to	Operation	Objective	Range	Trigger	operation
1	This auction	Limit	Supplier number	<= 20	N/A	View Rules Comment Delete
2	Every supplier	Limit	Total volume rate	<= 30%	N/A	View Rules Comment Delete
3	Every supplier	Include	Valid Aggrements	N/A	N/A	View Rules Comment Delete
4	Every supplier	Favor	Bid	10 %	Lead time is less than or equal to 1 days	View Rules Comment Delete

1.4 SUMMERY

With our provided pattern based expressive language, conditional requirements from both sides could be represented in a fine-grained method using trigger-action pairs. Together with carrier features like CDOT and SQL, and other auction factors, those trigger-action pairs could be further digested and executed by following negotiation algorithms.

2 LANE REQUIREMENTS

During the process of third-party logistics auction, certain lane requirements need to be met according to the several business constraints of FPL. To win the auction, the requirements which bidders need to meet are divided into two main categories: the apply-to-all ones and special ones. Those lane requirements will be given to the 3PL carriers as choosing from list or filling in the blanks in FPL's auction user interface. And how well the carriers meet those requirements defined according to business constraints and what kind of combination best serves FPL demands will be taken into consideration during winner determination process based on the winner determination algorithm we chose, which will be discussed in later part of the report.

2.1 APPLY-TO-ALL REQUIREMENTS

2.1.1 LANE ORIGIN-DESTINATION PAIRS

FPL has certain demands for origin-destination pairs based on its business needs for product transportation. Therefore, those lanes of choices will be defined in our auction user interface and the third-party logistics bidders need to choose from the pool of origin-destination pairs provided to meet FPL's business requirement.

2.1.2 EQUIPMENT TYPES

There are basically two types of transporting equipment requested by FPL according to its business requirements: refrigerated trucks and dry trucks. And it's bounded with specific origin-destination paired lanes. For instance, the equipment demanded for the lane from Pittsburgh to Cleveland is dry truck, while from Pittsburgh to Baltimore is required as refrigerated trucks.

In our auction user interface, the bidding carriers can either choose the lane or equipment type to filter the lanes, when by choosing one from the drop-down list, the other will be limited to a certain range of lanes or a specific type of equipment based on the system initial setup.

2.1.3 WEEKLY VOLUME

Together with each lane defined in FPL business requirements, there is weekly volume specified. For example, for the lane from Pittsburgh to Cleveland, the weekly volume requires transported is 50.

Similar to equipment type, the weekly volume is also initially set up in the system. As carrier choose one specific lane, it can only fill in a range of volume equal to or less than the initial set up of the total weekly volume needed for this lane.

2.1.4 CDOT RATING

One of the most important factor for FPL to evaluate the carriers and determine the optimized combination of service provider is the CDOT (Carrier Delivery On Time) rating. As specified in FPL's business requirements, the CDOT rating required for refrigerated lanes is above 98% and the overall CDOT rating should be no less than 95%.

Therefore, as one of the required information for bidders to provide, if the lane carrier is bidding on is a refrigerated lane, the CDOT rating of the bidding carrier should be higher than 98%, and if it's a dry lane, the bidding carrier should have a rating above 95%, otherwise, the system will automatically exclude the bid before the winner determination process.

2.1.5 TRANSPORT LEAD-TIME

As different carrier's capability to satisfy customer's requirements on transporting lead-time may varies significantly, it is one of the crucial factors to evaluate whether one specific carrier is appropriate due to business constraint. Therefore, within the bundle submitted by the bidders, transportation lead-time should be counted as one of the required parameters to input and be taken into account in winner determination process.

2.2 SPECIAL REQUIREMENTS

2.2.1 ROUND-TRIP OR ONE-WAY LANE

In real business world, one dilemma all transportation companies meet with is how to avoid the empty back-haul cost in their daily operation, which is the reason we took this factor into account during the process of developing this solution.

In specific, we provide option for carrier bidders to specify whether their bidding price is for a one-way lane or a round-trip lane.

The reason we avoided giving credit or discounts directly to the carriers who bid for one-way lane is that as FPL may not be the single customer for the third-party logistics carriers, who may provide service to a specific back-way lane for some other customer, they can provide a much lower price than treating this one-way lane choice as an empty back-haul one. FPL can benefit

from those kinds of scenarios to determine the optimized combination of service providers hence minimize its cost.

2.2.2 EHS PERFORMANCE

Another crucial factor to take into consideration when selecting transportation service provider is its EHS (Environmental Health & Safety) performance. Besides high CDOT rating, the transportation needs to be carried out safely without causing any damage to products, environment or personnel.

Therefore, in our user interface, the EHS related information can be input by the carrier bidders. And extra credit will be given to the carriers with better EHS performance during winner determination process.

2.2.3 COOPERATION RECORD

To the perspective of vendor management cost, there is a significant price for changing carriers. In specific, trainings need to be provided to the new carrier for the business requirements; related team needs to build up relationships with new people; the risk is higher when working with a new unfamiliar third-party, etc.

Thus carriers with cooperation history with FPL should be given extra credit during the winner determination process. Based on this ground, carriers are allowed to add their past cooperation record with FPL in their bidding information.

2.2.4 GOODWILL FACTORS

There will be for sure multiple carriers participate in the bidding process that have never worked with FPL before. For those bidders, all related information to prove their goodwill is encouraged. The factors can be their past customer list, financial report, the profiles of employees especially truck drivers' experience, the reports of trucks including the mileage, maintenance records etc.

Those factors will also be taken into account when selecting new 3PL service providers which FPL never cooperated with before.

All the above mentioned information that's useful for determining a carrier's reliability and quality will be given a proper weight and then a weighted value called Supplier Quality Index(SQI) will be calculated. This index will be used in the winner determination algorithm to

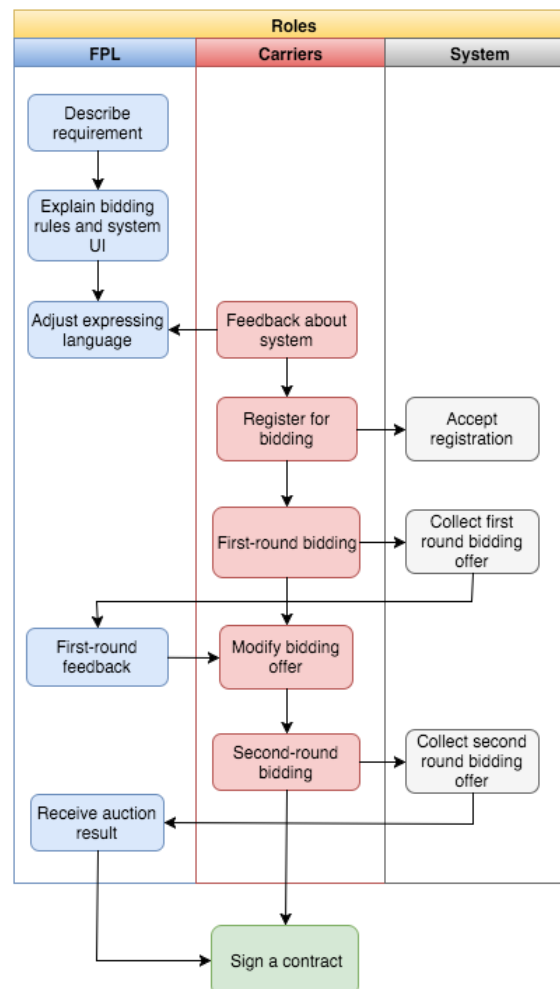
take part of the closing process because the quality of the carrier is of great importance in order to ensure the on-time delivery of products and transportation safety.

3 NEGOTIATION PROCESS

The combinatorial reverse auction process of Fourth Party Logistics involves one buyer, which is FPL itself, and sourcing third-party logistics services from multiple bidders.

Within our reverse auction solution designed for FPL, the negotiation process is divided into three parts. Firstly, during the pre-negotiation step, the bidding rules, bidding parameters, related auction policies are defined. Secondly, the during-negotiation step includes the procedures from bidders registering on the online auction website, submitting bidding bundles, and two-round auctions for feedback or winner determination. Lastly, the post-negotiation step contains providing final determined carriers' feedback to specific carriers, contracts preparation and further vendor management.

The following figure is an overview of the negotiation process.



3.1 PRE-NEGOTIATION

In this process, actions from both FPL and bidders are required. FPL reveals information about requirements, bidding rules and expressive UI to carriers; afterwards, carriers also share information about themselves with FPL so that FPL can refine the bidding rules based on new information, meanwhile filter out unqualified candidates. Finally, carriers may decide to register in order to continue or not, which is also the starting step of “During Negotiation”.

3.1.1 REQUIREMENT DESCRIPTION

In pre-negotiation, FPL exposes certain requirements to economically narrow suppliers down to qualified candidates. At the same time, FPL reserves rights to add requirements and side constraints in expressive allocation evaluation. The reason that we do not force FPL to lock in the scenario before bidding starts is that volumes of bundles are too huge, and FPL is not rushed to make a fast auction.

FPL sends lane requirements to carriers to match qualified candidates. Currently FPL has requirements as follows:

1. Want overall CDOT rating of 95% and CDOT rating of 98% on refrigerated lanes

FPL has a clear requirement on refrigerated lanes. Carriers with CDOT rating lower than 98% on refrigerated lanes may not bother to register, which provides cleaner data for the following process.

Seeking for more opportunities, FPL doesn't turn down fresh faces. Carriers which haven't cooperate with FPL don't have CDOT rating, however, they may reveal information about performance instead. Performance will be compared and evaluated according to companies with qualified CDOT rating and calculated as Supplier Quality Index(SQI). Carriers satisfy standards as CDOT rating of 98% on refrigerated lanes may register for bidding.

2. Weekly lane requirements

Specific lane requirements with origins, destinations, equipment type and weekly volumes will be provided to carriers in advance. Carriers may decide the most competitive service they are able to provide and add it to the bidding bundle later.

Other requirements and side constraints may be added in expressive allocation evaluation as scenario navigation.

3.1.2 BIDDING RULES

Rounds of Bidding

Rounds of bidding should be clarified first. Between rounds selected information is revealed to carriers, and then carriers may modify their offer in order to win. Rounds of bidding can be flexible for a win-win situation. Possibilities of additional rounds of bidding should also be declared.

Our design is a two-round bidding after analyzing following pros and cons.

Bidding Rounds	Pros	Cons
Single Round	1. Easy to manage 2. Efficient and time-saving	1. No opportunity for carriers who may offer a more competitive bidding 2. Fatal mistakes may not be corrected without feedback
Multi Rounds	1. Carriers are able to approach to a competitive bid within their budget 2. Fatal errors can be corrected in following rounds 3. More likely to reach win-win situation	1. Time consuming 2. Scenario navigation is not practical in multi rounds 3. Quotes may be ill defined in following rounds 4. Algorithms and strategies dealing with two similar bids are required 5. May lost qualified candidates due to long process

Considering the tradeoffs of single round and multi rounds bidding, we provide a flexible, revenue-maximizing, while efficient and easy to handle bidding process, which is a two - round bidding process.

Information revealed between rounds

Information which will be revealed is also declared and must be approved by carriers, since some information may involve trade secrets. FPL may consider to sign contracts with carriers in order to be exempt from relating legal issues.

Information is published for healthy competition. Such kinds of information include the lowest price of certain lane; bids rank of certain carrier (one carrier can only know his own rank). In this way, bidders are encouraged to provide more attractive bidding bundle. Since we allow scenario navigation in following process, information revealed is not determinant factor for final results. This should also be declared in advance.

Price Fluctuation

In this bidding rule, FPL wants bidders to express their real offer in the first round. Although collusion is not likely happen when number of carriers are big, we add this part in case. To avoid collusion in the first round resulting unreasonable prices, we limit price fluctuation according to price ranges in the first round, for example, to limit the price deduction range to 20% in the second round. In this way, bidders are encouraged to give a real trading price in the first round.

3.1.3 EXPLANATION ABOUT BIDDING SYSTEM

Unlike traditional tangible products, transportation service involves more facets. We provide a user friendly system to collect bidding offers from carriers. Bidding UI is designed on selected bidding language so it may be confusing to bidders. FPL is obliged to explain usages of bidding system UI to carriers.

3.1.4 DEALING FEEDBACK FROM CARRIERS

After explanation of system, carriers will give feedback about mismatch of expressing language and their real conditions. Some of them is significant and ought to be considered.

This iteration is important because system UI will be more expressive with suggestions from carriers.

3.2 DURING-NEGOTIATION

3.2.1 CARRIER REGISTRATION

As the combinatorial reverse auction process held by FPL encourages competition and aims at long-lasting benefit, all carriers participates in the auction process need registration for easier management and further contacts based on real-time business needs.

3.2.2 FIRST-ROUND BIDDING

Open Bidding Period

This step serves as an open-window for bidders' bidding package acceptance by the online auction system. In our solution, bidders are allowed to participate in a two-round auction. Within each round, there is a certain open bidding period and the carriers need to submit their bidding package(s) following the bidding language explained in earlier part.

The package details can be modified during the whole open bidding period. During the first round bidding, bidding packages can be retrieved by bidders as well.

Scheduled

Clears occur at a specified set of nominal times. The specification may be an explicit enumeration or implicit description.

Random

Clears occur according to random distribution. This policy could prevent bidders from applying time-dependent strategies. Usually the parameters of the distribution are known to bidders so that the bidders can have some expectation of timing.

Bidding Activity

Clears occur whenever a new bid is admitted. This is a timing policy of continual auctions. There is a variation of this policy where auctions clear when a new bid is received from each bidder, or when a certain number of bids are received. Such a policy allows synchronized auction.

Bidder Inactivity

Clears occur when no bid has been received in a certain period of time.

If we choose bidding activity or inactivity policy, malicious bidders could choose to always bid late so that whole bidding process could be dragged. Even though scheduled clear timing policy is easy to be implemented, it encourages time-dependent bidding strategies. After careful considerations, we decided to adopt random clear timing policy. Though such a policy brings in uncertainty. It could prohibit time-dependent strategies. We can provide bidders information and parameters of the policy to weaken the negative influence caused by random distribution.

Scenario Navigation

During the clearing period of the first-round bidding, FPL will engage in scenario navigation with the system. To be specific, FPL can adjust the parameters of their side constraints and preferences, such as limitation percentage of monopoly prevention, the lead-time preferences for each lane etc. By flexibly adjust these metrics, FPL can obtain a quantitative understanding of the effects of different side constraints and preferences. The feedback described in the following provided to bidders is generated after FPL determines the optimized combination of multiple parameters based on scenario navigation step.

First-round Feedback

During the first-round auction clearing period, FPL auction system will process the received bidding packages to retrieve information on below aspects which will be provided back to the bidders as first-round feedback:

- **Lowest price of each lane:** this information will serve as an encouragement for bidders to lower their bidding price, which potentially benefits FPL to minimize its cost by pushing bidders to bid with lowest price.
- **Lanes with volume coverage below 100%:** due to FPL business constraint, each lane coverage needs to be fully satisfied to ensure smooth business operation. To encourage bidders' active participation in the unpopular lanes, the list of those with volume coverage below 100% will be reported back to all bidders for them to adjust their bidding bundles in the second-round auction.
- **Lane discounts:** for the least welcomed lane(s), FPL can decide on a certain amount of discount as a stimulus for more participation and competition of carriers, and this information will be provided in the feedback to bidders during the clearing period of the first-round bidding.

3.2.3 SECOND-ROUND BIDDING

Open Bidding Period

During the second-round bidding open period, bidders are allowed to revise their previous bidding package(s) based on the feedback received or submit new bidding packages. The bidder with the lowest price offered in the first-round bidding is not allowed to raise the price during the second-round. If no change is made, the auction system will count the first-round bidding package as the final submission for specific carrier.

The retrieval of first-round bidding submissions are not allowed during the second-round auction.

Real-time Feedback

FPL can repeat the scenario navigation step and flexibly adjust their feedback providing based on the current bidding status. To be specific, the bidders can be aware of current lowest bidding prices of each lane, the unpopular lane(s) which has higher chance to win the auction, and the discount information of certain lanes to achieve win-win situation.

3.2.4 CLOSING PERIOD OF WINNER DETERMINATION

After closing of the second-round auction, the FPL auction system will process all packages finalized during the second-round and compute by using the winner determination algorithm, which will be discussed in later part of the report.

3.3 POST-NEGOTIATION

3.3.1 CONTRACTS PREPARATION

Based on selected carrier result retrieved from the winner determination algorithm, the next step for FPL is to carry out real-life negotiation with certain carriers on detailed terms for contracts and finalize contracts for both parties with signatures.

3.3.2 NEGOTIATION FOR UNFULFILLED LANE(S)

After the winner determination process, there is a possibility that some lanes are still not 100% covered by carriers. FPL need to carry out individual negotiations with carriers who have potential interest to reach a common ground on pricing and other terms of service.

This is the most efficient way for this step and FPL can be flexible in decision making.

3.3.3 VENDOR MANAGEMENT

Due to long-term cooperation for FPL with the selected carriers, vendor management plans are needed to achieve best performance from the carriers. The plan needs to include CDOT rating, as a crucial factor for logistics performance; pricing negotiation, to adjust price occasionally for both parties' benefit; timely meetings between both parties, to enhance better cooperation.

4 PRICING RULES

4.1 FIRST-PRICE PRICING RULE

4.1.1 INTRODUCTION

In a sealed-bid first-price auction, bidders submit simultaneous “sealed bids”. The terminology comes from the original format for such auctions, in which bids were written down and provided in sealed envelopes to the sellers, who would then open them all together. The highest bidder wins the object and pays the value of his bid.

In this type of auction, bidding bidder’s true value is no longer a dominant strategy. By bidding true value, bidder would get a payoff of 0 if lose, and would also get a payoff of 0 if you win, since he would pay exactly what it was worth to the seller. As a result, in the bidding system, the optimal way to bid in a first-price auction is to “shade” bidder’s bid slightly upward, so that if one bidder wins he will get a positive payoff.

4.1.2 ADVANTAGES

Easy for Winner Determination

Winner Determination process only depends on the lowest price that a bidder will pay and does not depend on other bidders’ bids. It is relatively easy for our algorithm to determine the winning price.

Easy to understand

The first-price pricing rule is very easy to understand compared to other bidding rules. It has been widely used in the real world and most bidders are already familiar with it. This will increase the competition among carriers and is good for attracting more carriers and generate optimal price.

4.1.3 DISADVANTAGES

Bidders tends to “shade” bidder’s bid

As mentioned above, bidders tend to bid slightly upward to win a positive payoff. Bidders’ cost of auctions also tends to increase because bidders are prone to spend resources learning about competitor’s strategies.

4.2 VICKERY-CLARKE-GROVES PRICING RULE

4.2.1 INTRODUCTION

The VCG pricing rule can be understood as each winning bidder pays the amount he bids for the package received, and is rebated the increment to the maximizing total bid caused by his participation. When there is only one item for sale, this is just the second-price auction procedure, where bidders simultaneously submit sealed bids for the item and the highest bidder wins the item, but pays the amount of the second-highest bid. When many identical items are being sold, it is the uniform-price procedure.

The remarkable strategy of VCG is: no matter how the other individuals bid, each bidder can do no better than to bid his own valuations.

4.2.2 ADVANTAGES

Incentive of bidding truthfully

Unlike First-Price pricing rule, the VCG pricing rule can motivate the bidders to bid at their true values. The reason is with First-Price pricing rule all the bidders will tend to bid lower than the true values in order to maximize their benefit. For example, if A1 knew that all other bids were \$4 or less, it would change its bid from \$5.00 to \$4.01 and win the same item but pay less. Of course, the other bidders don't really know what the others will bid, and instead must speculate. This leads to inefficiencies. However when the bidders are aware that you are running a VCG auction and trust that you will be honest in determining the prices, bidders know that they have to pay the second highest price plus a certain amount, so his/her bid won't determine the final price to pay. As a result, the bidders tend to bid at their true valuations in order to win the bid because that way he/she can have chances to win. This prevents the overbidding and hence motivates the bidders to bid truthfully in order to win the auction.

Increase efficiency

When each bidder bids truthfully, bidders will save the time and cost spent on learning about competitors' values or strategies, as a result the cost of the auction is reduced and the total revenue will be maximized. The waste of cost spent on speculating can be saved and the outcomes are always efficient.

4.2.3 DISADVANTAGES

Excessive effort for bidding communication

Due to the obvious complexity of the Groves pricing rule compared to First-price rule, it requires exponentially growing efforts for FPL at the stage of pre-negotiation to communicate with bidders for the detailed explanation of the Groves pricing rule. If the understanding of carrier is not thorough and bidders don't bid with their true valuations for the service, the purpose of the Groves pricing rule is lost and will cause discrepancy in revenue.

Increase complexity for winner determination

Often, the winner determination problem in VCG processes will be NP-hard. As for FPL's sourcing process, multiple items and side constraints are included in the decision making process, this will cause significant inefficiency for the winner determination process.

Bidder's reluctance to expose bidding strategy

Due to the mechanism of Vickery-Clarke-Groves pricing strategy, certain information of specific bidders will be exposed to the rest. For the bidders who are reluctant to have strategy revealed may not be truthfully bidding with their willing price during the first round of bidding.

4.3 OUR CHOICE AND RATIONALE

In our solution, we decided to use First-Price pricing rule. In order to eliminate the disadvantages of this pricing rule, we have the following restrictions adopted. Two-round bidding system allows the bidders to know the lowest bidding price among all bidders after the first round, which will stimulate them to decrease the price in the second round in order to be competitive. A price fluctuation is enforced which means that the difference of a bidder's prices on the same package in two rounds cannot exceed a certain percentage (e.g. 10 percent). This percentage will be determined based on multiple factors before the auction.

These mechanisms motivate bidders to bid on bidder's true value and avoid upward bidding, thus reducing the cost a bidder potentially spends on learning competitor's strategies.

5 WINNER DETERMINATION

The winner determination problem we have is to label the bids as winning or losing so as to minimize the sum of the accepted bid prices to accommodate as many lanes as possible for FPL. Each lane must be allocated to at most one bid.

We have examined several algorithms commonly used for optimization, listed their pros and cons and evaluated which algorithm is the most suitable for the winner determination of the FPL auction system.

Combinatorial reverse auction format is utilized in this auction. It means that the carriers can bid on packages of combined lanes. Each bid includes the bidding lanes and volume, price, Supplier Quality Index (SQI), and bidder ID. The bidder ID will be used to retrieve the CDOT of this carrier from database for the algorithm to determine the winner(s). The CDOT values will be used by the algorithm to ensure that among the winning bidders, a percentage of 95% of CDOT in general and a CDOT rating of 98% on refrigerated lanes will be guaranteed. The algorithm will take the SQI into consideration when deciding which bid to take or reject. The SQI reflects how reliable a carrier is, evaluated from aspects like reputation, company size, lead-time, CDOT, etc. The algorithm will be configured to select less than 20 winning bidders, the exact number will be determined based on the combinations available to meet the lanes requirements given all the bids.

In order to avoid monopoly, the algorithm will not allocate more than 30% of total lane volume to one single bidder. We have also considered preventing one bidder from winning the whole volume of one lane. But since we intend to encourage the bidders to compete and provide lower prices, and there might be situations that one bidder offers a much lower price if he/she can take the whole volume of one lane, we decided not to restrict one bidder from winning one lane in order to receive as low prices as possible.

Besides that, the algorithm will be configured to allow at least 15% winning carriers are the ones that have never cooperated with FPL before. This way FPL can establish relationships with some new carriers to bring diversity and discretize risks.

5.1 ALGORITHM DISCUSSION

5.1.1 ENUMERATION OF EXHAUSTIVE PARTITIONS OF ITEMS

One way of solving the winner determination problem is to enumerate all exhaustive partitions of the items for bidding. A partition is a set of subsets of items so that each item is included in at most one of the subsets. An exclusive partition is a partition where each item is included in exactly one subset of the partition.

Enumeration algorithm is straightforward and easy to operate in theory. However, the number of exhaustive partitions is $O(2^m)$ and $\omega(2^{m/2})$, from which we can tell that the number of exhaustive partitions gets extremely large when the number of items (m) increases. As a result, the enumeration of exhaustive partitions is not a proper way for winner determination there are less than a dozen or so items in the auction.

FPL has 100 lanes for bidding. So the number of exhaustive partitions could be enormous, which makes it inefficient and even impossible to enumerate all the partitions to optimally determine the winner.

5.1.2 DYNAMIC PROGRAMMING

Dynamic programming is a way to explore the exhaustive partitions more efficiently. The algorithm determines the highest possible revenue that can be obtained from the items in one set, going through small sets to large ones. The time complexity of dynamic programming is $O(3^m)$, which is much faster compared to enumeration of exhaustive partitions. But dynamic programming generates each combination S even if no bids have been placed on S . This causes the complexity of the algorithm if the number of items is large for example above 20 in practice. Since FPL has 100 lanes for bidding, which is much higher than that boundary, dynamic programming is not a good choice for winner determination in our case.

5.1.3 GREEDY WINNER DETERMINATION

Greedy search algorithm uses a heuristic function that can search nodes within the space and find the locally optimal node at each stage in order to finding a global optimum solution. In our problem, the bids combinations can be treated as nodes in decision tree. The greedy algorithm will loop until each bid has been determined as a winner or loser. The bid that meets the constraint and has a lowest price will be determined as winner. Then the bid will be eliminated from the bids pool as well as all conflicting bids. Since our goal is to obtain the trucking lanes at low cost, a greedy allocation can be computed sequentially by selecting the lowest bids, while not overlapping with previous selected bids.

Although the computational complex of greedy winner determination is relatively fast, it may not be able to find optimal solutions correctly, since the bids may contain combinations and greedy algorithm fails to handle this situation correctly.

5.1.4 COMBINATORIAL AUCTION, BRANCH ON BIDS

CABOB (Combinatorial auction, branch on bids) algorithm is a depth-first, branch-and-bound tree search technique that provides excellent performance on solving the winner determination problem. CABOB algorithm supports large item numbers and combinations. The algorithm addresses several special cases during the search, and uses LP for upper bounding and a relatively simple greedy algorithm for lower bounding. Empirical results shows that CABOB solves winner determination problem within seconds for auction item size of hundred and bids size of thousands.

And for our auction design, we choose to use CABOB algorithm because:

1. It allows bidding on all combinations. Unlike the greedy search algorithm that restricts the combinations, CABOB supports search on all combinations. Also, the search tree is in order so it avoids the inefficiencies that occurs. It's likely that the carriers would like to bid on bundles so we will have to choose an algorithm supporting this function.
2. It capitalized heavily on the sparseness of bids. Unlike the dynamic program which uses the same amount of time irrespective of the number of bids, CABOB algorithm improves search efficiency greatly. In practice the space of bids is likely to be extremely sparsely populated. In our case, there are 100 lanes for carriers to bid, which generates 1.27×10^{30} combinations. Sparseness of bids implies that the relevant partitions are a small subset of all partitions. Unlike the dynamic program, our algorithm only searches in the space of relevant partitions. As a result the runtime of our algorithm depends on the number of bids received, while in the dynamic program it does not.

6 OTHER DIMENSIONS

Other than the business requirements mentioned above, we have added additional dimensions into the requirements to improve our auction process.

6.1 SUPPLIER QUALITY INDEX(SQI)

We have added a weighted value called Supplier Quality Index (SQI) into the winner determination algorithm, which will be used to measure the goodwill of bidders. SQI will be, along with the bidding price, used to determine the winner for our multiple-round bidding system. We decided to include this factor into our auction system because FPL values the importance of carriers' quality such as on-time delivery of products, transportation safety and supplier relationship as well. This metric provides additional dimension and a flexible way to determine the winning carrier.

6.2 CDOT

Carrier Delivery On-Time (CDOT) is a mandatory information required for FPL for decision making. We have developed a mechanism to calculate CDOT for those carriers without CDOT, which is to predict a CDOT rating using factors from carriers already have CDOT rating. The mechanism is relatively easy to implement and will attract more carriers for bidding, and help FPL receive more optimal price.

6.3 BIDDING PRICE LIMITATION

We set bidding price limitation for bidding between the two-round auctions to avoid vicious competition and to motivate bidders to bid at their true values. A price fluctuation limit, which can be adjusted according to FPL's needs, will be set between the two rounds. Also, bidders can only maintain or lower their bidding price after first round's bidding. Canceling order or lifting bidding price after first round's bidding will be forbidden. This mechanism will improve our auction system's efficiency, and eliminate the shortcomings in the pricing rule that we chose to use.

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