12-1-2020

Berth Allocation at Passenger Terminals: A Bundle Auction Approach

Dimitrios Konstantinos Giampouranis

BERTH ALLOCATION AT PASSENGER TERMINALS: A BUNDLE AUCTION APPROACH

by

Dimitrios K. Giampouranis

A Thesis

Submitted in Partial Fulfillment of

the Requirements for the Degree of

Master of Science

Major: Civil Engineering

The University of Memphis

December 2020

Abstract

In this study we present a multi-round second price sealed-bid auction for the berth slot leasing for vessels (RoPax and/or cruise ships) at a public marine terminal. The auction mechanism is designed to maximize port operator profits by auctioning berth (time) slots in groups. The framework is being tested using simulation by varying the number of RoPax/cruise ship operating companies; the number of slots they bid for; and the mechanism design with regards to the winner determination, slot valuation, and max to min slot bid ratio among the bidders. Results are compared to a single item multi-round second-price auction where each berthing slot is auctioned individually.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The importance of developing a profitable and reliable mechanism to assign quay slots (time and berth) at seaports has long been recognized by the industry. However, most scientific papers are concerned with container terminals, where the majority of berth allocation is accomplished through a first-come-first-served basis and/or short/long term contracts (that define limits on vessels wait times; departure times; and berth productivity) (*1*), (*2*), (*3*) . Some of these approaches have been criticized for their limitations with regards to profitability for port operators and preferential treatment of high volume liner shipping companies, which lead to increased expenses, such as fuel consumption and labor related expenses, while waiting for the next available slot at the entrance of a port, increased traffic inside and nearby seaports, delayed deliveries etc. With regards to cruise/RoPax terminals, RoPax and cruise vessels operating companies usually engage in negotiations with the port authorities and/or port operators and derive contracts for reserving timeslots for their vessels. Parameters such as proximity to public transportation, time of day, seasonality, proximity to car parking lots, and berth size play significant role to these negotiations and the profits that port operators stand to make. Bulow and Klemperer (*4*) concluded that, provided certain assumptions are met, an auction will always lead to higher payoffs for the seller, if it contains one more participant (bidder) than a direct negotiation on the same object. That is, if a port operator engages in negotiations with a RoPax/cruise company, then an efficiently designed auction with at least 2 bidders will produce better payoffs for the port operator due to the enhanced level of competition.

Although the berth allocation problem is a very well documented and researched topic, it appears that limited research has been accomplished with regards to auctions as the main mechanism to efficiently distribute timeslots for berthing. Gosh (*1*) tested the effects of a sequential English auction for each slot individually. Strandenes and Wolfstetter (*5*) argued that single slot auctioning is not efficient for the berth allocation problem and created a group auction mechanism where all bidders have to report to the port operator all their expected profits from every feasible allocation. The port operator was responsible for choosing an allocation that maximized all the bidders' profits.

In this paper we propose a multi round second price sealed-bid auction framework, as an alternative to a single item multi-round auction, for the assignment of vessels at the berths of a public passenger/cruise terminal. The rational for investigating such an auction stems from two facts: 1) an auction with at least *k* bidders will always lead to higher profits than negotiations with *k-1* bidders, and 2) bundle/group auctions have been proven more beneficial than standard single-slot auctions when it comes to berth allocation. The auction mechanism proposed in this paper tries to maximize the port operator profits by auctioning berth (time)slots in groups/bundles. The framework is being tested using various combinations of number of cruise-RoPax operating companies, number of slots they bid for, and the mechanism design with regards to winner determination and payoff. Results from computational experiments are compared to a single item multi-round auction (from now on referred to as basic auction).

The rest of the paper is structured as follows: The next section presents the proposed bundle and basic auction. The third section presents results from a simulation developed to evaluate the proposed bundle auction. The final section concludes the paper and proposes possible extension for future research.

PROPOSED BUNDLE AUCTION

We propose a multi round second price sealed bid auction, where all available slots will be auctioned at the same time and each player will bid for all the slots they want, based on their valuation. Therefore, each bidder's offer includes all the slots they need, with the highest value for them. At each round the player with the highest bid wins the round and takes all the slots they bid for, paying the second highest offer, regardless of what slots the second highest offer was made for. The highest bid is determined using two different winner determination policies that are described in more detail later in this section. In the next round, the winner is removed from the pool of remaining players along with the slots they acquired. The procedure is terminated when all players have received slots. At each round, a reserve price is introduced for the slots that have not been awarded. A reserve price is defined as the minimum price that the auctioneer will accept as winning bid. The reserve price for each slot is calculated based on the mean profit made from all the winning bids in all previous rounds. We adopt the options of a reserve price to address situations where a second-best price for a slot (or bundle of slots) does not exist (e.g., at the last round where only one player exists). Thus, the reserve price, and in the way the proposed auction is set up, is only used at the last round of the auction. In that case, the winner will pay a reserve price for the slots awarded, so that their profit equals the mean profit of all the previous winners. Note that in the proposed action a reserve price does not alter the behavior of the bidders (it is still a dominant strategy to bid one's true value), since if the reserve price was higher than the bid, the bidder will not take the slot and their expected payoffs will be zero.

Rationale for second-price bundle auction

Standard auctions (e.g., English auction for each slot sequentially) have been examined in the related literature, but they are generally inefficient (*5*). In our proposed auction scheme, we utilize the advantages of a second price bundle-auction. We require that our mechanism satisfies the voluntary participation condition, which denotes that a player is charged zero if they lose and their (expected) payoff amount is at most less than their bid if they win. In a second-price auction, it is a dominant strategy to bid the maximum valuation price of the object auctioned, even if other bidders are overbidding, underbidding or colluding. This guarantees that players who bid truthfully always obtain non-negative (expected) profit and as other Vickrey–Clarke–Groves auctions, a second price sealed-bid auction guarantees truthfulness. Indeed, in a second price auction, players are charged zero if they lose, and their (expected) payoffs are at most the second highest bid if they win (*6*). As with many game theory applications, in real life, truthfulness might not be guaranteed due to players' irrational behavior. Having a second-price auction always guarantees that the player will end up with non-negative profits for the item(s) they are awarded, hence even for an irrational player bidding truthfully is encouraged by this type of auction.

Assumptions

To create and apply the proposed auction the following assumptions have been made:

i. The supply of slots by the port operator is always greater (or at least equal) than the demand by the bidders.

ii. There is imperfect information. That is, bidders are unaware of each other's valuation for each slot and for what slots they will bid.

iii. A possible situation where a bidder bids for more slots than they need to improve their position against the competition is allowed since we are interested in port operator's profit maximization and not equitable distribution of resources.

Slot valuation patterns

In this paper we assumed two different slot valuation patterns for each slot for each bidder: i) random, and ii) uniform to be used in the simulation experiments presented in the next section.

i. Valuation Pattern 1: Random

Each bidder has their own valuation for each slot which has been assigned randomly. That means, that a certain slot might be of high value for one player and of low value for another. This is a more generic way to determine each slot's valuation by every bidder.

ii. Valuation Pattern 2: Uniform

Under the second valuation pattern, the value of each slot is based on a uniform probability distribution. That is, all bidders have similar valuations for each slot (according to the distribution). This does not mean that the valuation for different slots are the same (i.e. players will value higher slots at peak demand period and lower slots at low demand periods, but their valuations at each period will be similar). This version allows for high competition between the bidders for the most desirable slots and possibly will increase the port operator's profits since at each round the second highest bid (i.e., price that the winner will pay) is close to the highest bid (i.e., winner's bid).

Winner determination

To determine the winning bid of each round of the proposed auction, we established two different cases described next.

i. ***Winner Determination Policy 1: Winner based on total bid.*** All bidders submit their offers and the winner is the one with the highest bid over all slots, regardless of how many slots they bid for. That is, a bid price of x_k for $n+1$ slots may lose to a bid price of x_l that for n slots, as long as $x_k > x_l$. This winner determination policy provides a significant advantage to players that bid for many slots at the same time and/or are willing to pay a higher amount. In case of a tie the winner is chosen based on the number of slots they bid for. Therefore, the bidder with the lowest number of slots wins (i.e., they pay higher average price). In case of a tie for the number of slots and the bid price the winner is chosen randomly.

ii. ***Winner Determination Policy 2: Winner based on average per slot bid.*** In this case and after all bidders submit their offers, the winner is determined based on their average per slot bid. For example, if a bidder offers x_k for n number of slots and a bidder l offers x_l for l number of slots the winner is determined by comparing $\frac{x_k}{n_k}$ and $\frac{x_l}{n_l}$. In case of a tie the winner is chosen based on the number of slots they bid for (but in this case, and in antithesis with winning determination policy 1, the bidder with the highest number of slots wins).

Single item multi-round second-price auction

The single item multi-round second-price auction applied in this research is used to evaluate the proposed multi-item second-price auction framework proposed. Under the basic auction the port operator auctions each slot sequentially. The winner is determined by their highest bid for each slot and the price paid to the terminal is equal to the second highest bid. The sequence with which the slots become available for bidding is important for the outcome of the auction. For this paper, we assume that the port operator has some knowledge of demand and berth location preference (from experience), and thus is able to initialize the auction with slots that they believe are of higher value and will drive the competition amongst the bidders up.

COMPUTATIONAL EXPERIMENTS

In this section we present results from numerical experiments performed to compare the proposed auction framework to the basic auction. We simulated 10,000 auctions for each winner determination policy, slot valuation pattern, and max/min slots bid ratio combination, and for the basic auction. Valuations for each slot and for each bidder were uniformly selected to range between 10 and 100. The number of bidders varied from 5 to 10, the minimum number of slots they bid for varied from 3 to 9, and the max to min slot bid ratio among the bidders from 1 to 3 (all with an increment of 1). The latter parameter means that if the minimum number of slots bid for is X then the bidders can bid for any number of slots between Unif[X, X] , Unif [X, $2X$], and Unif [X, $3X$] slots (where Unif[a,b] is the uniform distribution with bounds a and b). In summary, 126 unique combinations of winner determination, valuation patterns, and max to min slot bid ratio were used for each one of the 10,000 simulated auctions (i.e., 1.26 million different bundle auctions were evaluated). The total number of available slots was set to be greater or equal to the demand for slots.

Figures 1 through **6** summarize the results. **Figures 1** through **3** show the terminal operator's mean profit change and **Figures 4** through **6** the corresponding standard deviation (STD). More specifically, **Figures 1, 2, and 3** show the terminal operator's mean profit change (%) when we applied a maximum to minimum slots bid ratio of 1, 2, and 3 respectively. **Figures 4, 5, and 6**, show the same information but for the standard deviation of the terminal's profit. The assumption of normality was tested visually through histograms (**Figure 7** presents an example from one instance) and through the Anderson-Darling test (*7*). Results shown in **Figures 1** through **6** reveal very distinctive patterns that can be summarized as follows:

- For the case of uniform valuation pattern (and irrespective of the winner determination policy) the terminal operator is better off using the single item auction.
- For the case of random valuation pattern (and again irrespective of the winner determination policy) the terminal operator is better off using the proposed bundle auction.
- Mean profit differences between the basic and the proposed bundle auction decrease with the increase of number of bidders and slots they bid for (which is to be expected).
- For the case of random valuation pattern, the second winner determination policy provides significantly higher profits when the numbers of bidders are low and fluctuates to a lesser degree than any other case with number of bidders.
- Winner determination policy 2 under the random slot valuation pattern provides the most "robust" profits to the terminal operator among all three max to min slot bid ratios;
- For the case of random valuation pattern the second winner determination policy provides significantly higher profits when the numbers of bidders are low as compared to the same valuation pattern but with the first winner determination policy and fluctuates (with respect to the number of bidders) to a lesser degree than any other case.
- For the case of random valuation pattern, the second winner determination policy provides the best solution when the number of bidders and minimum number of slots bid for are low.

- The profit increase/decrease STD decreases with the increase in the number of bidders and minimum number of slots they bid for (irrespective of winner determination policy and valuation pattern).
- There are no significant differences for the STD values for any of the four combination of winner determination and slot valuation policies (although the second winner determination policy exhibits slightly lower values).
- When the max/min slots bid ratio is set to 1, there is no difference between the two winner determination policies. Either one can be used as they will yield the same results (which is to be expected).

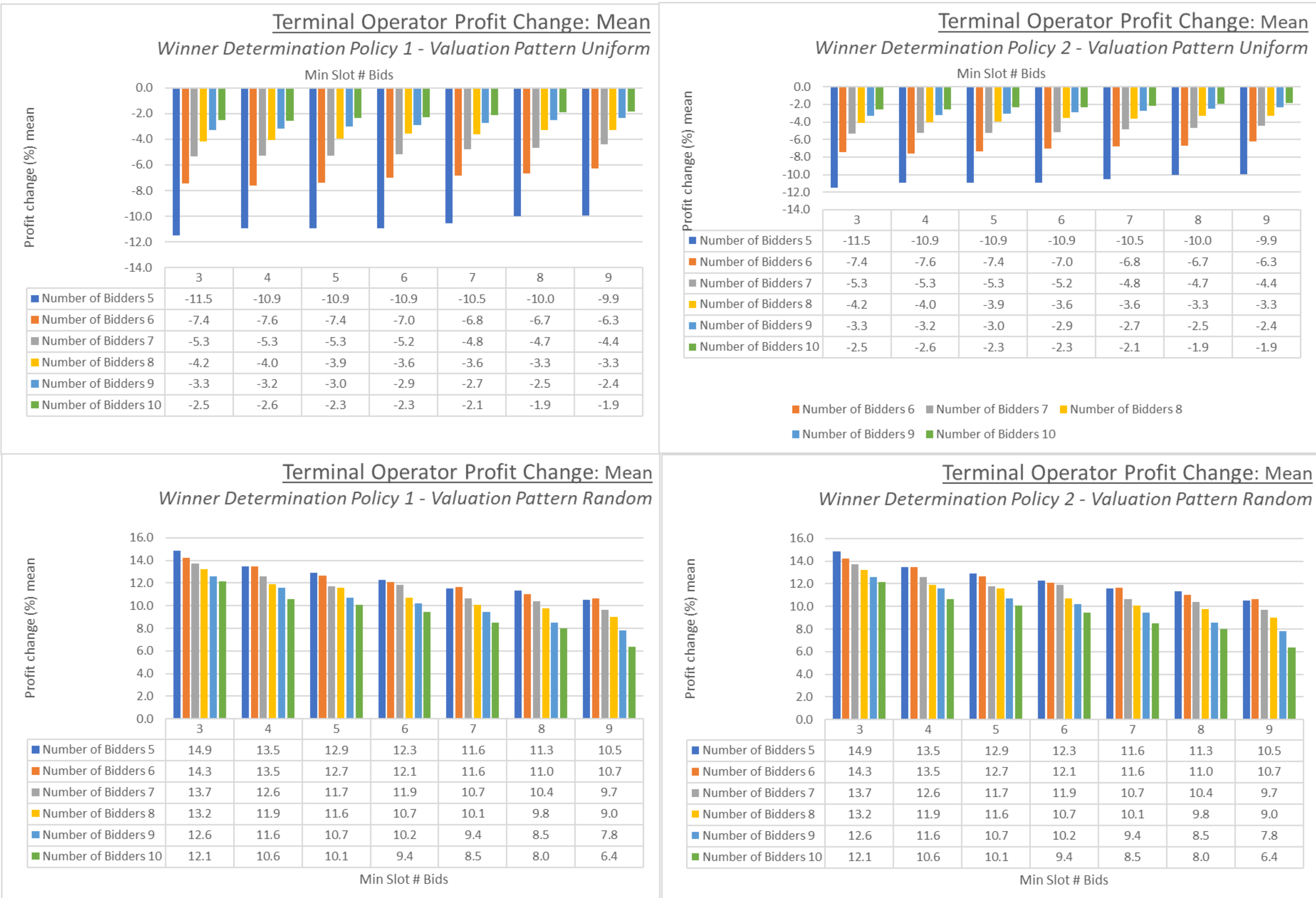


Figure 1 Profit Change (%) Mean-Slots Bid Max/Min Ratio of 1

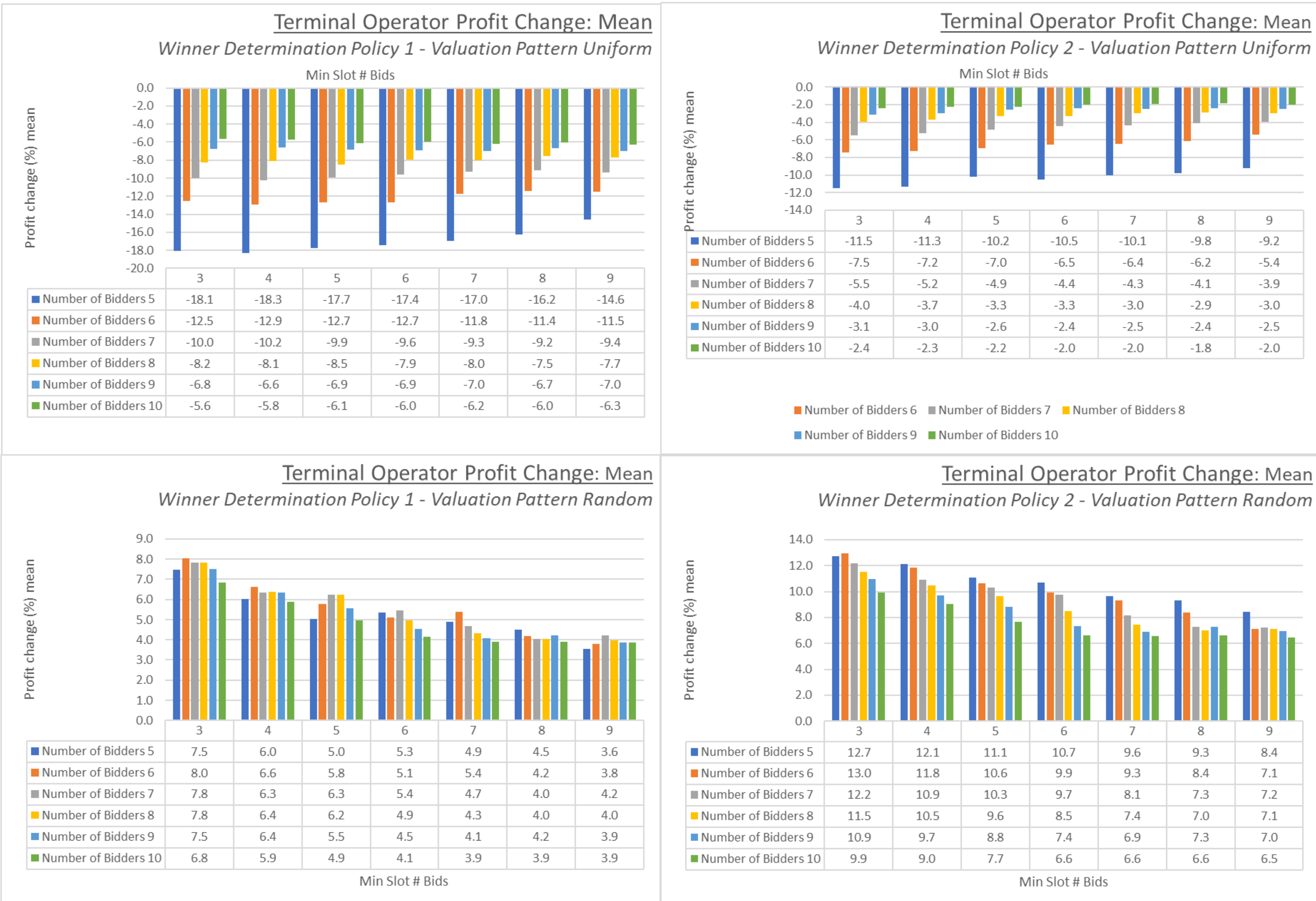
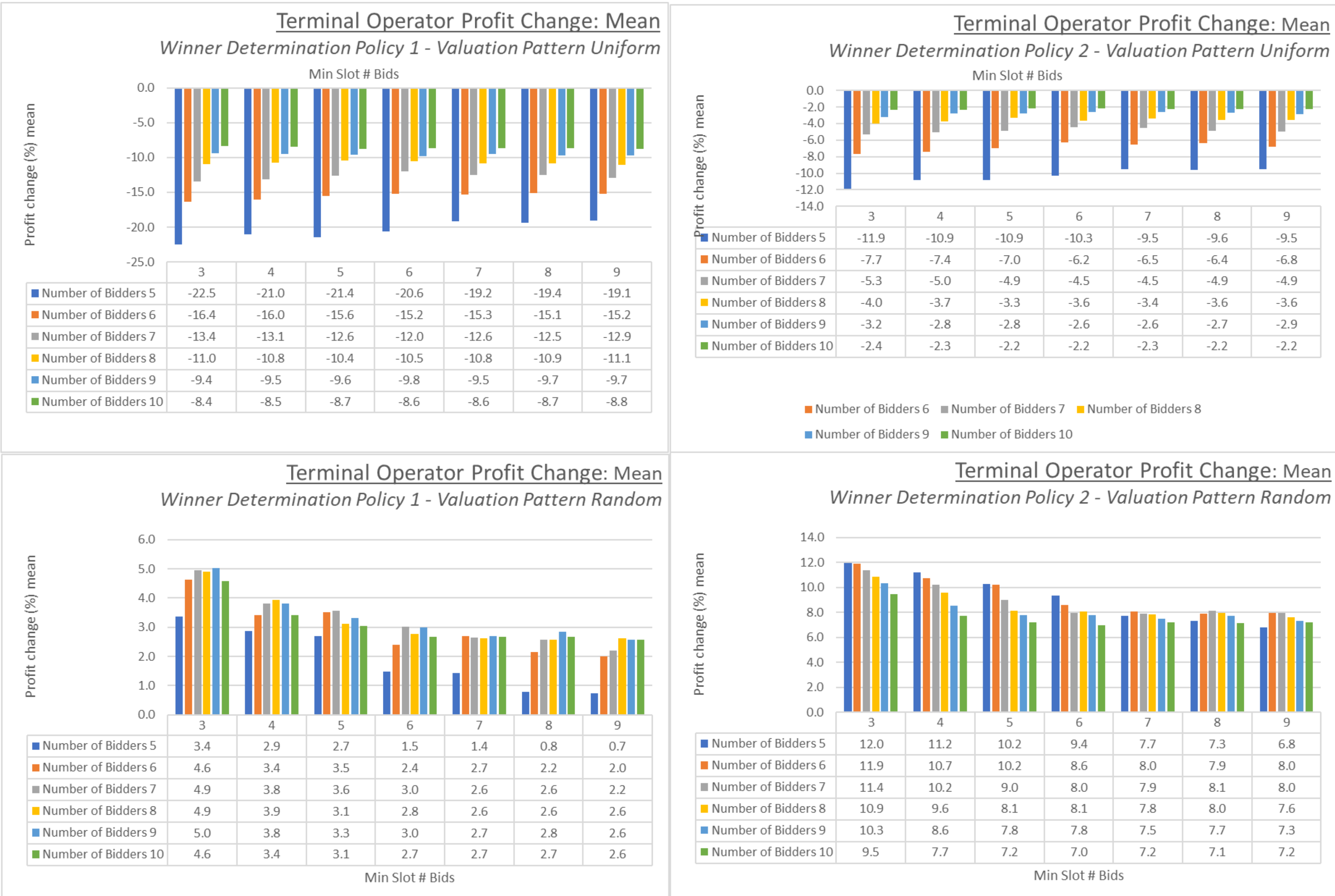


Figure 2 Profit Change (%) Mean-Slots Bid Max/Min Ratio of 2



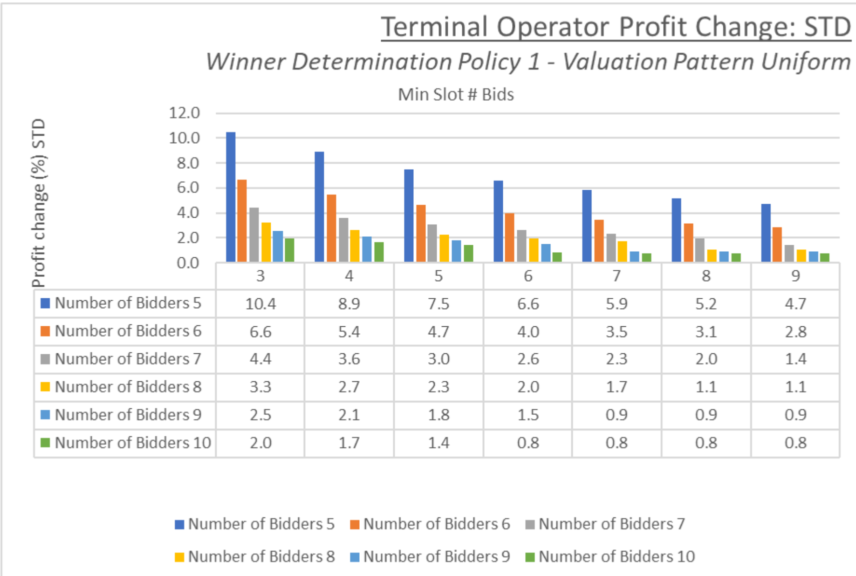
	3	4	5	6	7	8	9
Number of Bidders 5	-22.5	-21.0	-21.4	-20.6	-19.2	-19.4	-19.1
Number of Bidders 6	-16.4	-16.0	-15.6	-15.2	-15.3	-15.1	-15.2
Number of Bidders 7	-13.4	-13.1	-12.6	-12.0	-12.6	-12.5	-12.9
Number of Bidders 8	-11.0	-10.8	-10.4	-10.5	-10.8	-10.9	-11.1
Number of Bidders 9	-9.4	-9.5	-9.6	-9.8	-9.5	-9.7	-9.7
Number of Bidders 10	-8.4	-8.5	-8.7	-8.6	-8.6	-8.7	-8.8

	3	4	5	6	7	8	9
Number of Bidders 5	-11.9	-10.9	-10.9	-10.3	-9.5	-9.6	-9.5
Number of Bidders 6	-7.7	-7.4	-7.0	-6.2	-6.5	-6.4	-6.8
Number of Bidders 7	-5.3	-5.0	-4.9	-4.5	-4.5	-4.9	-4.9
Number of Bidders 8	-4.0	-3.7	-3.3	-3.6	-3.4	-3.6	-3.6
Number of Bidders 9	-3.2	-2.8	-2.8	-2.6	-2.6	-2.7	-2.9
Number of Bidders 10	-2.4	-2.3	-2.2	-2.2	-2.3	-2.2	-2.2

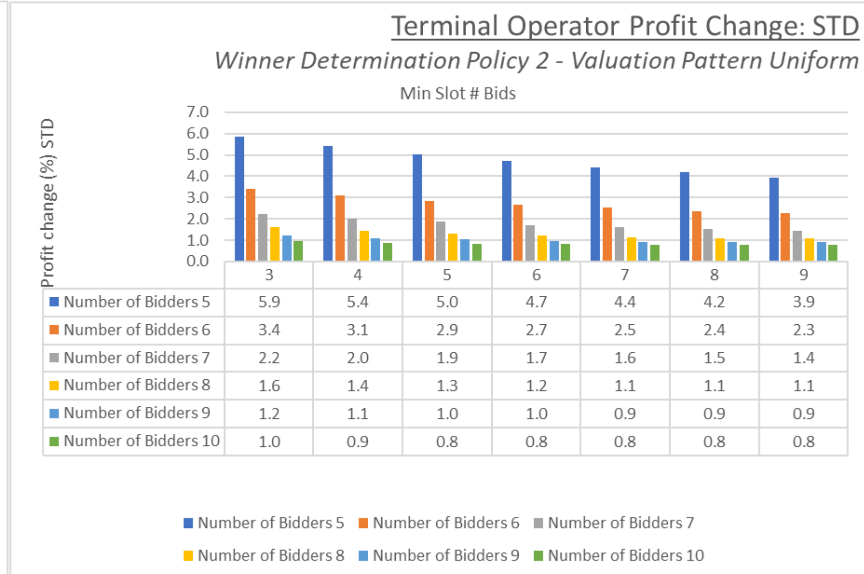
	3	4	5	6	7	8	9
Number of Bidders 5	3.4	2.9	2.7	1.5	1.4	0.8	0.7
Number of Bidders 6	4.6	3.4	3.5	2.4	2.7	2.2	2.0
Number of Bidders 7	4.9	3.8	3.6	3.0	2.6	2.6	2.2
Number of Bidders 8	4.9	3.9	3.1	2.8	2.6	2.6	2.6
Number of Bidders 9	5.0	3.8	3.3	3.0	2.7	2.8	2.6
Number of Bidders 10	4.6	3.4	3.1	2.7	2.7	2.7	2.6

	3	4	5	6	7	8	9
Number of Bidders 5	12.0	11.2	10.2	9.4	7.7	7.3	6.8
Number of Bidders 6	11.9	10.7	10.2	8.6	8.0	7.9	8.0
Number of Bidders 7	11.4	10.2	9.0	8.0	7.9	8.1	8.0
Number of Bidders 8	10.9	9.6	8.1	8.1	7.8	8.0	7.6
Number of Bidders 9	10.3	8.6	7.8	7.8	7.5	7.7	7.3
Number of Bidders 10	9.5	7.7	7.2	7.0	7.2	7.1	7.2

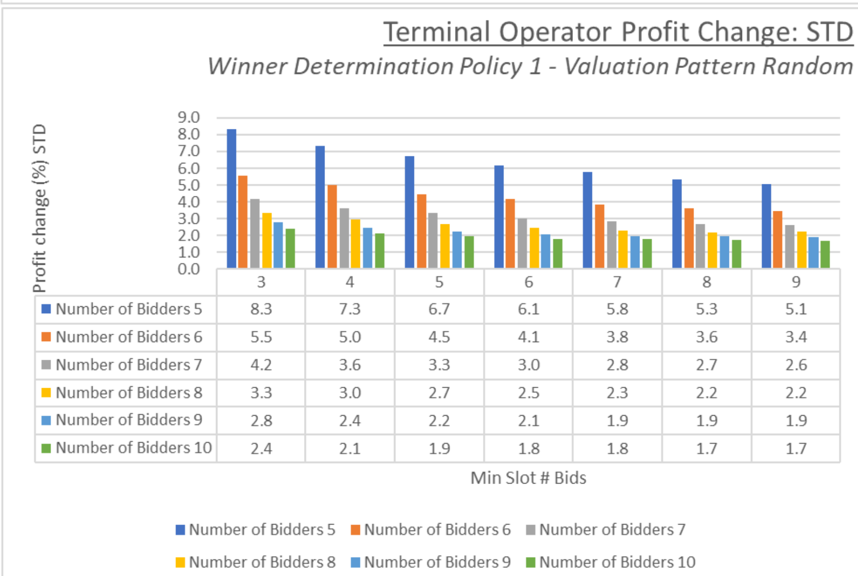
Figure 3 Profit Change (%) Mean-Slots Bid Max/Min Ratio of 3



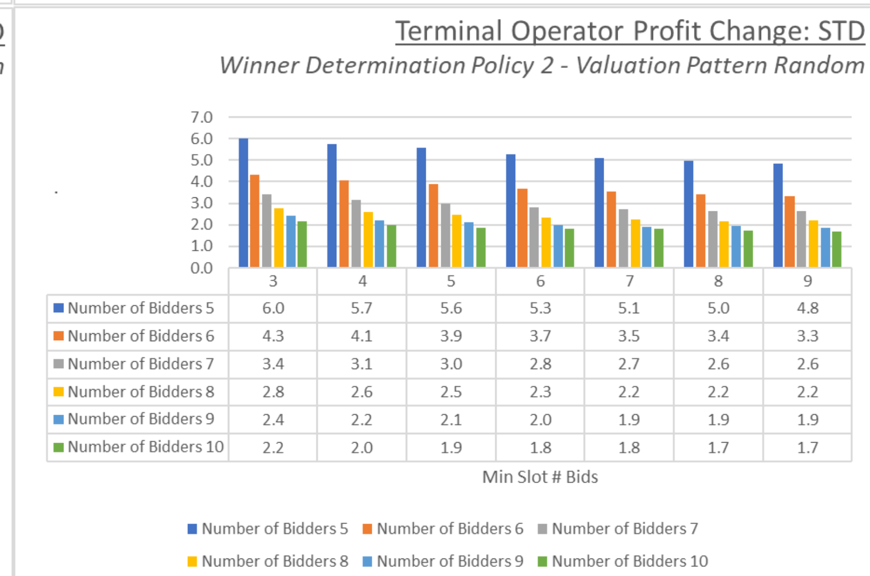
	3	4	5	6	7	8	9
Number of Bidders 5	10.4	8.9	7.5	6.6	5.9	5.2	4.7
Number of Bidders 6	6.6	5.4	4.7	4.0	3.5	3.1	2.8
Number of Bidders 7	4.4	3.6	3.0	2.6	2.3	2.0	1.4
Number of Bidders 8	3.3	2.7	2.3	2.0	1.7	1.1	1.1
Number of Bidders 9	2.5	2.1	1.8	1.5	0.9	0.9	0.9
Number of Bidders 10	2.0	1.7	1.4	0.8	0.8	0.8	0.8



	3	4	5	6	7	8	9
Number of Bidders 5	5.9	5.4	5.0	4.7	4.4	4.2	3.9
Number of Bidders 6	3.4	3.1	2.9	2.7	2.5	2.4	2.3
Number of Bidders 7	2.2	2.0	1.9	1.7	1.6	1.5	1.4
Number of Bidders 8	1.6	1.4	1.3	1.2	1.1	1.1	1.1
Number of Bidders 9	1.2	1.1	1.0	1.0	0.9	0.9	0.9
Number of Bidders 10	1.0	0.9	0.8	0.8	0.8	0.8	0.8

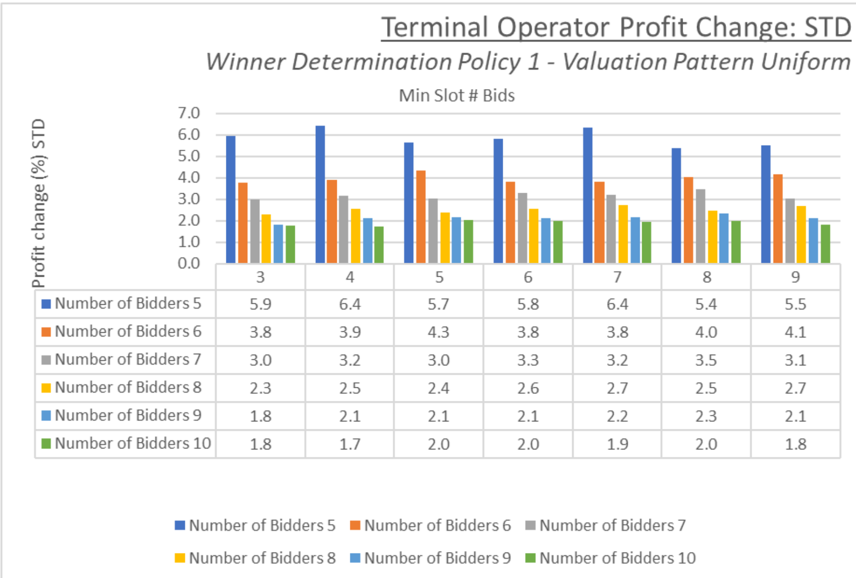


	3	4	5	6	7	8	9
Number of Bidders 5	8.3	7.3	6.7	6.1	5.8	5.3	5.1
Number of Bidders 6	5.5	5.0	4.5	4.1	3.8	3.6	3.4
Number of Bidders 7	4.2	3.6	3.3	3.0	2.8	2.7	2.6
Number of Bidders 8	3.3	3.0	2.7	2.5	2.3	2.2	2.2
Number of Bidders 9	2.8	2.4	2.2	2.1	1.9	1.9	1.9
Number of Bidders 10	2.4	2.1	1.9	1.8	1.8	1.7	1.7

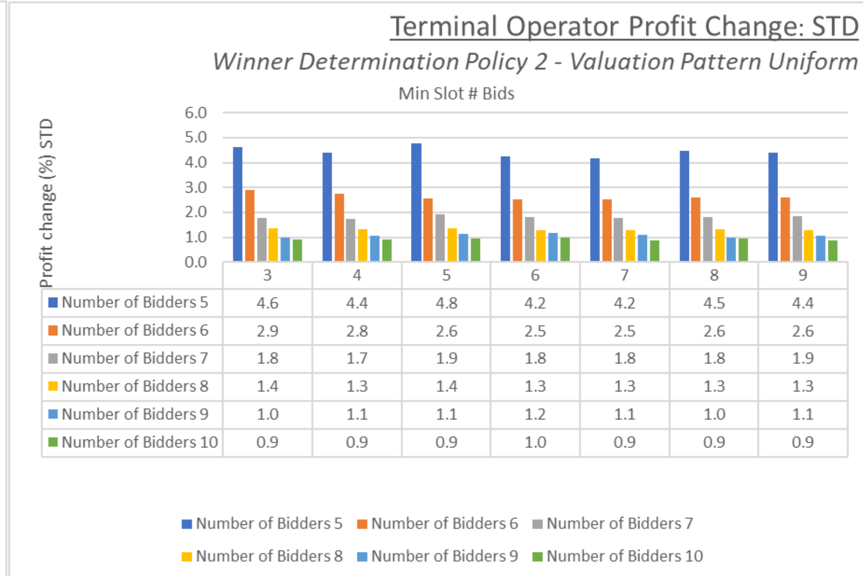


	3	4	5	6	7	8	9
Number of Bidders 5	6.0	5.7	5.6	5.3	5.1	5.0	4.8
Number of Bidders 6	4.3	4.1	3.9	3.7	3.5	3.4	3.3
Number of Bidders 7	3.4	3.1	3.0	2.8	2.7	2.6	2.6
Number of Bidders 8	2.8	2.6	2.5	2.3	2.2	2.2	2.2
Number of Bidders 9	2.4	2.2	2.1	2.0	1.9	1.9	1.9
Number of Bidders 10	2.2	2.0	1.9	1.8	1.8	1.7	1.7

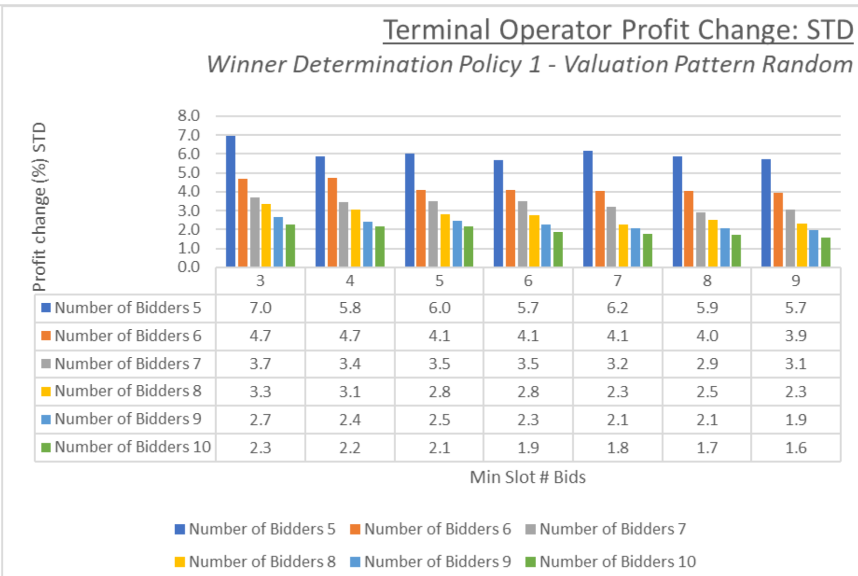
Figure 4 Profit Change (%) STD-Slots Bid Max/Min Ratio of 1



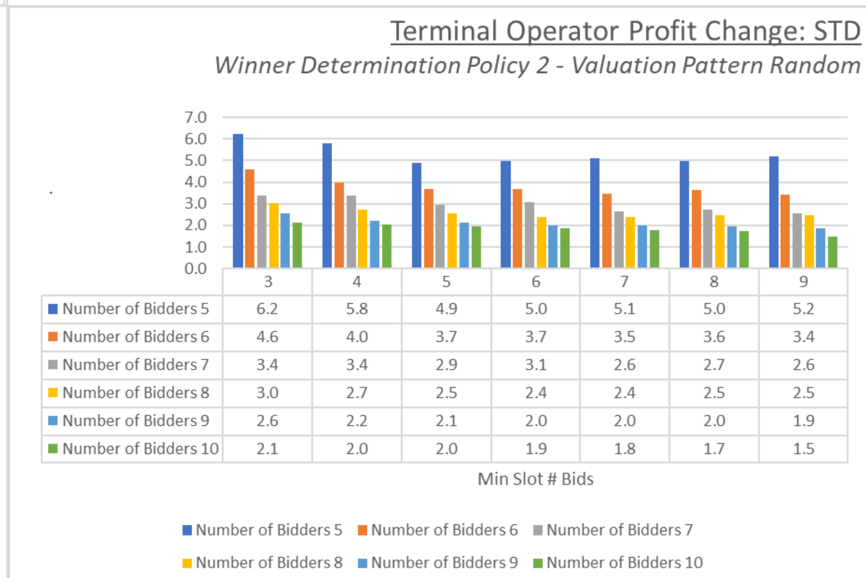
	3	4	5	6	7	8	9
Number of Bidders 5	5.9	6.4	5.7	5.8	6.4	5.4	5.5
Number of Bidders 6	3.8	3.9	4.3	3.8	3.8	4.0	4.1
Number of Bidders 7	3.0	3.2	3.0	3.3	3.2	3.5	3.1
Number of Bidders 8	2.3	2.5	2.4	2.6	2.7	2.5	2.7
Number of Bidders 9	1.8	2.1	2.1	2.1	2.2	2.3	2.1
Number of Bidders 10	1.8	1.7	2.0	2.0	1.9	2.0	1.8



	3	4	5	6	7	8	9
Number of Bidders 5	4.6	4.4	4.8	4.2	4.2	4.5	4.4
Number of Bidders 6	2.9	2.8	2.6	2.5	2.5	2.6	2.6
Number of Bidders 7	1.8	1.7	1.9	1.8	1.8	1.8	1.9
Number of Bidders 8	1.4	1.3	1.4	1.3	1.3	1.3	1.3
Number of Bidders 9	1.0	1.1	1.1	1.2	1.1	1.0	1.1
Number of Bidders 10	0.9	0.9	0.9	1.0	0.9	0.9	0.9



	3	4	5	6	7	8	9
Number of Bidders 5	7.0	5.8	6.0	5.7	6.2	5.9	5.7
Number of Bidders 6	4.7	4.7	4.1	4.1	4.1	4.0	3.9
Number of Bidders 7	3.7	3.4	3.5	3.5	3.2	2.9	3.1
Number of Bidders 8	3.3	3.1	2.8	2.8	2.3	2.5	2.3
Number of Bidders 9	2.7	2.4	2.5	2.3	2.1	2.1	1.9
Number of Bidders 10	2.3	2.2	2.1	1.9	1.8	1.7	1.6



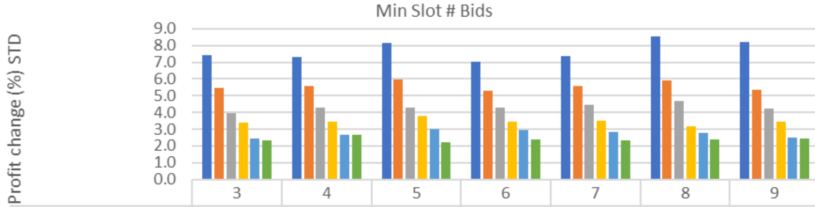
	3	4	5	6	7	8	9
Number of Bidders 5	6.2	5.8	4.9	5.0	5.1	5.0	5.2
Number of Bidders 6	4.6	4.0	3.7	3.7	3.5	3.6	3.4
Number of Bidders 7	3.4	3.4	2.9	3.1	2.6	2.7	2.6
Number of Bidders 8	3.0	2.7	2.5	2.4	2.4	2.5	2.5
Number of Bidders 9	2.6	2.2	2.1	2.0	2.0	2.0	1.9
Number of Bidders 10	2.1	2.0	2.0	1.9	1.8	1.7	1.5

Figure 5 Profit Change (%) STD- Slots Bid Max/Min Ratio of 2

Terminal Operator Profit Change: STD

Winner Determination Policy 1 - Valuation Pattern Uniform

Min Slot # Bids



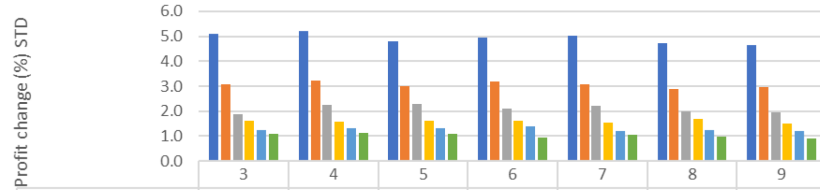
	3	4	5	6	7	8	9
Number of Bidders 5	7.4	7.3	8.2	7.0	7.4	8.5	8.2
Number of Bidders 6	5.4	5.6	6.0	5.3	5.6	5.9	5.4
Number of Bidders 7	4.0	4.3	4.3	4.3	4.4	4.7	4.2
Number of Bidders 8	3.4	3.4	3.8	3.5	3.5	3.2	3.5
Number of Bidders 9	2.4	2.7	3.0	3.0	2.8	2.8	2.5
Number of Bidders 10	2.3	2.7	2.2	2.4	2.3	2.4	2.4

Number of Bidders 5 Number of Bidders 6 Number of Bidders 7
Number of Bidders 8 Number of Bidders 9 Number of Bidders 10

Terminal Operator Profit Change: STD

Winner Determination Policy 2 - Valuation Pattern Uniform

Min Slot # Bids

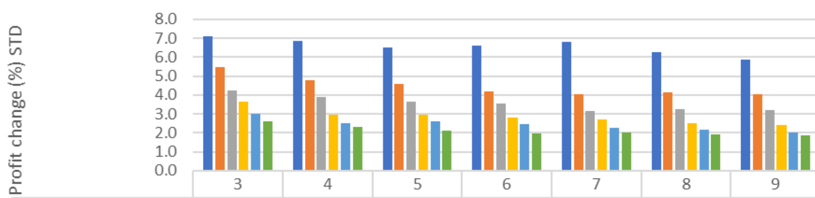


	3	4	5	6	7	8	9
Number of Bidders 5	5.1	5.2	4.8	4.9	5.0	4.7	4.7
Number of Bidders 6	3.1	3.2	3.0	3.2	3.1	2.9	2.9
Number of Bidders 7	1.9	2.2	2.3	2.1	2.2	2.0	2.0
Number of Bidders 8	1.6	1.6	1.6	1.6	1.6	1.7	1.5
Number of Bidders 9	1.2	1.3	1.3	1.4	1.2	1.2	1.2
Number of Bidders 10	1.1	1.1	1.1	0.9	1.0	1.0	0.9

Number of Bidders 5 Number of Bidders 6 Number of Bidders 7
Number of Bidders 8 Number of Bidders 9 Number of Bidders 10

Terminal Operator Profit Change: STD

Winner Determination Policy 1 - Valuation Pattern Random



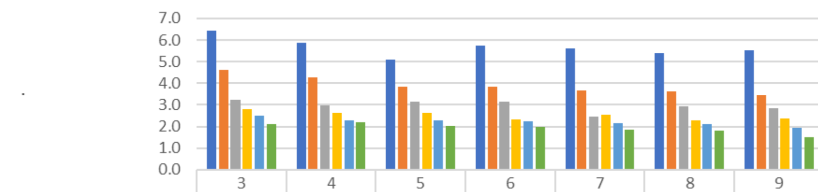
	3	4	5	6	7	8	9
Number of Bidders 5	7.1	6.8	6.5	6.6	6.8	6.3	5.9
Number of Bidders 6	5.5	4.8	4.6	4.2	4.0	4.2	4.1
Number of Bidders 7	4.3	3.9	3.7	3.6	3.2	3.2	3.2
Number of Bidders 8	3.7	3.0	2.9	2.8	2.7	2.5	2.4
Number of Bidders 9	3.0	2.5	2.6	2.5	2.3	2.2	2.0
Number of Bidders 10	2.6	2.3	2.1	2.0	2.0	1.9	1.9

Min Slot # Bids

Number of Bidders 5 Number of Bidders 6 Number of Bidders 7
Number of Bidders 8 Number of Bidders 9 Number of Bidders 10

Terminal Operator Profit Change: STD

Winner Determination Policy 2 - Valuation Pattern Random



	3	4	5	6	7	8	9
Number of Bidders 5	6.4	5.9	5.1	5.7	5.6	5.4	5.5
Number of Bidders 6	4.6	4.3	3.8	3.8	3.7	3.6	3.5
Number of Bidders 7	3.2	3.0	3.1	3.1	2.4	2.9	2.8
Number of Bidders 8	2.8	2.6	2.6	2.3	2.5	2.3	2.4
Number of Bidders 9	2.5	2.3	2.3	2.2	2.2	2.1	1.9
Number of Bidders 10	2.1	2.2	2.0	2.0	1.9	1.8	1.5

Min Slot # Bids

Number of Bidders 5 Number of Bidders 6 Number of Bidders 7
Number of Bidders 8 Number of Bidders 9 Number of Bidders 10

Figure 6 Profit Change (%) STD Slots-Bid Max/Min Ratio of 3

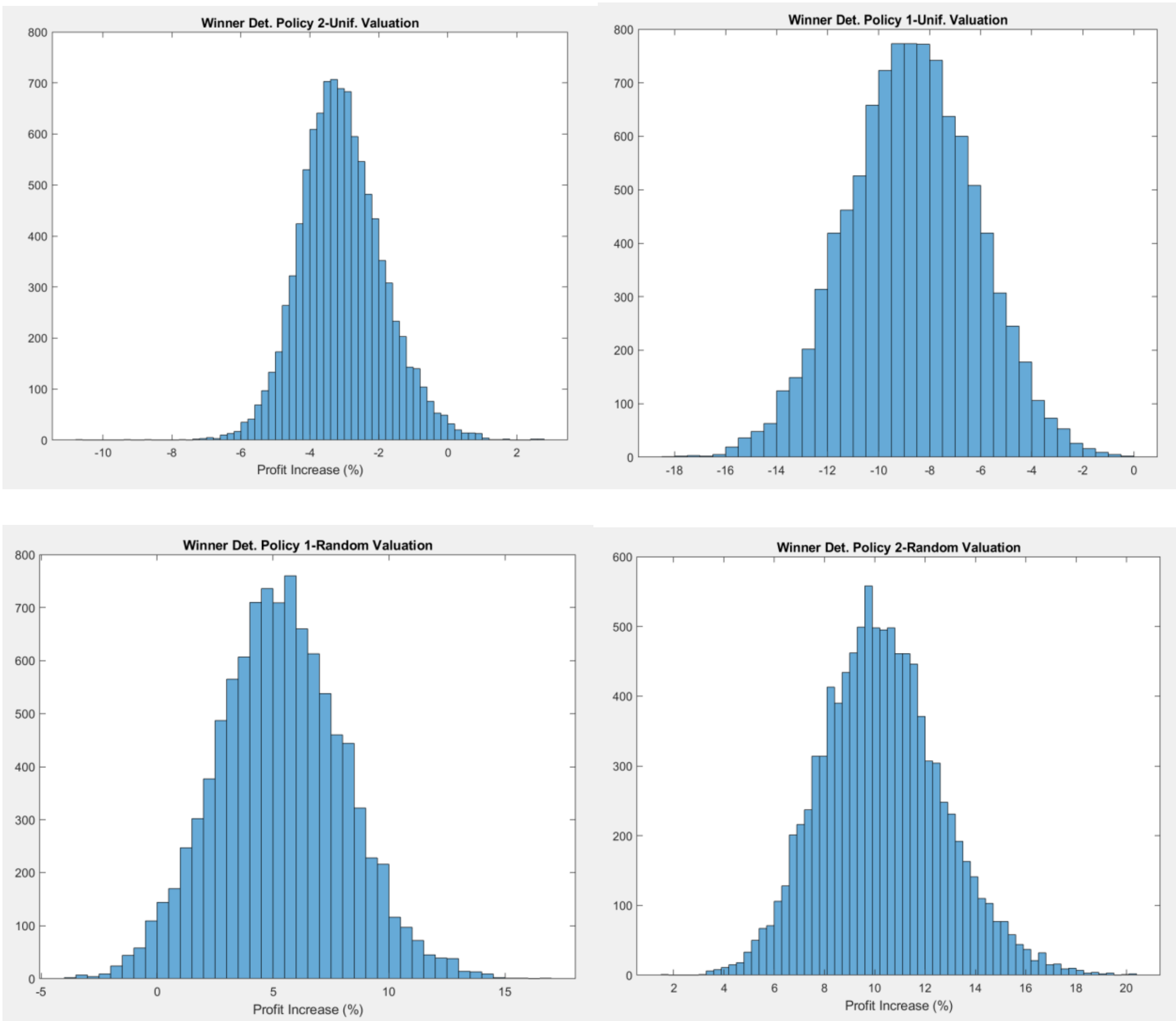


Figure 7 Example of profit increase histograms (minimum slot # bids=3, minimum players=9)

DISCUSSION

In this thesis we proposed an auction theory framework for berth slot leasing in busy passenger marine terminals. Different variations of the proposed bundle-auction, with regards to winner determination, slot valuation, number of bidders, and maximum to minimum slots bid ratio are being tested and compared to a basic auction described in the methodology section as a sequential second price auction for each slot individually. This study focuses on how to help port operators maximize their profits by choosing the correct auction for different circumstances.

Results from computational experiments show that the proposed bundle auction works particularly well when bidders have different valuations for each slot. Also, better results are reached when the winner of each round was determined based on their average per slot bid and not on their total bid. The basic auction produced significantly higher profits when bidders have similar valuations for each slot (according to a probability distribution).

From this study, several future research opportunities arise as different winner determination policies, expected payoff strategies and different valuation patterns can be applied and tested for their effectiveness. An optimization algorithm for determining the optimal sequence of making slots available for bidding is also considered. The approach can be used in relation to different yield and customer satisfaction strategies and policies of the passenger terminal operations, reflecting decision dilemmas of busy passenger terminals, serving either RoPax or cruise vessels. Furthermore, the proposed auction framework can be applied in different types of terminals or even different transactions relating to the operation of freight intermodal terminals' resources allocation, after necessary alterations have been made.

REFERENCES

1. Gosh, M. Bidding for a Berth: An Auction Based Queue Management Mechanism for Ports. *Singapore Port & Maritime Journal*, 2002, pp. 162–169.

2. Psaraftis, H. N. When a Port Calls... An Operations Researcher Answers. *Operations Research/Manangement Science Today*, 1998, pp. 38–41.

3. Theofanis, S., M. Boile, and M. M. Golias. Container Terminal Berth Planning: Critical Review of Research Approaches and Practical Challenges. *Transportation Research Record*, No. 2100, 2009, pp. 22–28.

4. Bulow, J., and P. Klemperer. Auctions Versus Negotiations. *The American Economic Review*, Vol. 86, No. 1, 1996, pp. 180–194.

5. Pettersen Strandenes, S., and E. Wolfstetter. Efficient (Re-)Scheduling: An Auction Approach. *Economics Letters*, Vol. 89, No. 2, 2005, pp. 187–192. https://doi.org/10.1016/j.econlet.2005.05.025.

6. Archer, A., C. Papadimitriou, K. Talwar, and É. Tardos. An Approximate Truthful Mechanism for Combinatorial Auctions with Single Parameter Agents. *Internet Mathematics*, Vol. 1, No. 2, 2004, pp. 129–150. https://doi.org/10.1080/15427951.2004.10129086.

7. Anderson, T. W., and D. A. Darling. Asymptotic Theory of Certain “Goodness-of-Fit” Criteria Based on Stochastic Processes. *Annals of Mathematical Statistics*, No. 63, 1952, pp. 193–212.