Bidding Strategies for Carrier in Combinatorial Transportation Auction

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Abstract

In combinatorial auction for truckload transportation service procurement, we introduce the bidding strategy for carrier facing the hard valuation problem to all possible routes. The model uses a bid-to-cost ratio of carriers surveyed in Thailand to represent the bidding behavior in combinatorial freight procurement. This model facilitates carrier to value the bid price for interested packages that involve with pattern of transportation service under different competitive environment. The results of analysis with hypotheses in regression model reveal significantly that a pattern of transportation service, a number of competitors, and a pre-empty backhaul to new lane distance ratio with number of competitors do impact negatively on a bid-to-cost ratio of carrier, whereas a pre-empty backhaul to new lane distance ratio does impact positively on a bid-to-cost ratio of carrier in combinatorial transportation auction. To find optimal bid price for interested packages in the incomplete information game, the empirical study in stochastic optimization problem with Monte Carlo method can provide the best solution for carrier in order to acquire the maximum expected profit in the auction. The results present that the expected profit with optimal solution of bidder is more than the average benefit in the competition market obviously. While in turn the results also show that shipper could potentially reduce the cost of transportation service procurement regarding our solution algorithm considerably.

Keywords: A Bid-to-Cost Ratio, Bid Price, Combinatorial Auction, Transportation Procurement, Bidding Strategies, Optimization Problem.

1. INTRODUCTION

Land freight transportation by truck plays an important role in driving the economy since it has a main responsibility to deliver the goods or materials from producers to marketplaces inevitably. According to the statistics of Department of Land Transport in Thailand, it reported that land freight transportation in 2009 accounted for more than 84% of nationwide freight movement or 423.7 million tones. While demand of land freight transportation has been increasing continuously due to expanding of market, it then impacts directly to shippers who have not been sufficient of in-house transportation capacity. Thus, shipper has initially used the *Request for Proposal* (RFP) to invite a set of carriers to participate into the auction in order to procure transportation service with lane by lane (Sheffi, 2004). To buy the freight transportation service by RFP, most shippers have used it until in late 1990, while some shippers still manipulate this method including shippers in Thailand. Specifically, carriers engaging in this traditional auction have to submit bids on interested individual lane separately. Thus, it does not guarantee carriers to acquire a complete set or cycle route of individual lanes, and it may cause an empty backhaul or repositioning cost called *exposure problem* (Kwasnica, et al., 2005). In Thailand, the Department of Land Transport revealed that 46% of total truck shipments or 33 million trips were empty backhauls. It indicated that carriers consumed fuel uselessly estimated in amount of 22.5 billion baht lost per year

(Department of Land Transport, 2006), and particularly this problem is still the critical economic issue up to the present time.

Therefore, *Combinatorial Auction* (CA) has been considering for overcoming the problem. That is, it allows bidder to submit multiple bids in combination of individual lanes to address this problem (W. Elmaghraby and P. Keskinocak, 2002). Carriers joining in combinatorial auction could reduce empty backhaul or repositioning cost to meet economies of scope (Sheffi, 2004). In USA, many shippers have extensively applied CA to procure transportation service from carrier, and they have used the optimization model called *Winner Determination Problem* (WDP) to allocate the awarded bids to the winner in order to minimize the total cost of transportation service procurement (De Vries, et al., 2003; Caplice and Sheffi 2003; Song and Regan 2003). However, the number of possible routes (packages) for carriers to submit bids into combinatorial auction is exponential in the number of individual lanes announced by shipper. Thus, carriers face the hard valuation problem to determine the bid price for interested packages, and also they make a hard decision on which packages should be bided for (N. An, et al., 2005). Moreover, the studying on competitive bidding strategies for carriers to submit the optimal bid price into combinatorial transportation auction to obtain the maximum expected profit has less attention so far.

In this paper, the authors focus on finding the optimal bid price for truckload carrier in combinatorial transportation auction with pattern of transportation service under different characteristic of competition. We employ a bid-to-cost ratio of carriers in Thailand to represent the behavior of bidding in freight transportation service market, and we use Monte Carlo method to generate random number for competitive behavior of competitor in the simulation. We, furthermore, apply the stochastic optimization model to acquire the optimal bid price for bidder to obtain the maximum payoff in the auction. The paper is organized as follows: Section 2 reviews related literatures. In section 3, we present the research methodology with model and solution algorithm. The result analysis and empirical study is discussed in Section 4, and finally section 5 concludes the results for this paper and proposes the suggestion for future research.

2. LITERATURE REVIEW

This section reviews the related literatures on land freight transportation overview (2.1), transportation service procurement (2.2), combinatorial transportation auction (2.3), competitive bidding strategy (2.4) and bidding strategy in combinatorial transportation auction (2.5).

2.1 Land Freight Transportation Overview

Land freight transportation by truck is one of the most practical in nationwide shipment because it is expedient, fast and flexible based on geographic and infrastructure constraint in many countries including Thailand. In motor truck transportation service industry, there are partial shippers (e.g., manufacturers and retailers) using their private fleets to distribute products to marketplaces, while a large number of shippers have already used third party logistics to transport products instead (Foster and Strasser 1991). This is because of expanding in the business including limited in-house capacity and cost management. For freight transportation service by truck, it is distinctive mainly to Truck Load (TL) and Less-than-Truckload (LTL) (Chen, 2003) in which TL represents direct operation. It transports full loads from an origin to a destination without any intermediated stop. For LTL, it means the consolidating and hauling multiple shipments in one truck on regular route basis (Caplice and Sheffi 2003). Thus, we study in this paper on TL operation since it is particularly sensitive on economies of scope in freight transportation service.

2.2 Transportation Service Procurement

In freight transportation service procurement, there are 2 main parties between shipper and carrier in this mechanism. The basic item of transportation service procurement is called a lane that specifies a unidirectional shipment from an origin to a destination. The shipper has initially used RFP to invite a set of carriers and provides useful information for them to participate in the auction. The fundamental information is based on price and period of contract (Sheffi 2004). This process is similar to a simple first-price sealed-bid auction in which each carrier is able to submit his bids for interested items (Song and Regan 2003). In transportation service industry, carriers have realized the importance of economies of scope. They aim to have cost effectiveness in transportation network with minimum empty backhaul and repositioning cost. Carrier, therefore, could reduce cost of operation, while the result in turn also potentially lowers the shipper's cost for transportation service procurement (Caplice and Sheffi 2003). However, carriers engaging in RFP have to submit bids on individual lane separately, this format does not guarantee carriers for acquiring a cycle route or a complete set of individual lanes, and it may likely cause empty backhaul or repositioning cost in the transportation network (Chen 2003). Thus, the combinatorial auction has been studied in this area to overcome this problem recently.

2.3 Combinatorial Transportation Auction

There are many industries applying combinatorial auction to enhance the allocation efficiency in their businesses. For instance: telecommunication spectrum (Rothkopf, et al., 1998), airport timeslot (Rassenti, et al., 1982), trading financial securities (Srinivasan and Whinston 1998) including truckload transportation procurement. A lot of papers in combinatorial transportation auction (Song and Regan 2003; De Vries, et al., 2003; Sheffi 2004; Elmaghraby and Keskinocak 2004) are mentioned the definition of CA that carriers are allowed to submit multiple bids to auctioneer simultaneously in which one bid consists of a combination of individual lanes (package) and a price. Therefore, carriers joining in CA could place bids on several distinct lanes and potentially would receive the cycle route in transportation network as well as address the exposure problem to obtain more cost efficiency (Caplice and Sheffi 2003; Song and Regan 2003; Lee, et al., 2007). In addition, shipper is able to use CA to minimize the cost of transportation service procurement as well. Sears Logistics Services (SLS) was an example of shipper using CA that could save the cost for transportation service procurement over $165 million per year (Ledyard 2002). Shippers can apply the optimization problem called winner determination problem that has been already studied to allocate the awarded bids to the winner with minimum cost of transportation service procurement (Caplice and Sheffi 2003; Song and Regan 2003). However, there is one issue that has not been discussed extensively. It is the bidding price for possible packages in combinatorial transportation auction. Because total number of all packages are exponential in the number of individual lanes proposed by shipper, thus carriers mostly face the hard valuation problem to determine bid price, and they also make a hard decision on which packages should be bided for (An, et al., 2005; Lee 2007). Moreover, the studying on pricing of possible packages by applying bidding strategies in combinatorial transportation auction has been less considered.

2.4 Competitive Bidding Strategy

Auction is one of the most successful applications in branch of such a game theory. It involves with how bidders decide how value to bid, and effect of bidding strategies of each bidder. For transportation service procurement auction, the term of auction applies in reverse auction between one shipper and several carriers. Each carrier joining in the auction would like to be a winner undoubtedly. Information of each carrier, therefore, is likely to be sensitive and unrevealed as a game of incomplete information called Bayesian game. Due to lack of information about the true valuation for packages of all competitors, thus the best strategy for bidder is a bid price that maximizes the expected payoff (Aliprantis and Chakrabarti, 2000). In reverse auction, the expected profit of bidder could be shown by *Expected Profit of Bidder = (Bid Price - Cost)*Probability of Winning with Bid Price* (Friedman 1955). The bidding strategy for bidder in the incomplete information game has the importance to determine how much to bid for so that bidder may obtain the maximum expected profit with the best solution. Friedman (1955) presented a bidding strategy for bidder to compete in the first-price sealed-bid auction. To create a bidding behavior of competitors, he applied the concept of the average bidder by combining all data of competitors to obtain one distribution function with competitors' bid over cost as random variable. He then used stochastic optimization model to determine where the optimum bid was. Finally, bidder could submit a sealed-bid in competitive bidding with optimal solution in order to obtain the maximum expected payoff. In addition, the probability of being lower than competitors by bidding with any bid-to-cost ratio was the area to the right on competitors' distribution curve.

Sugrue (1982) described how to find the actual optimal bid price with Friedman`s model. This model assumed that the cost of performing the operation was known prior to submitting the bid into the auction to get the maximum expected value. Loannou and Lev (1993) studied the average-bid method comparing with the low-bid method by which both methods based on the same assumption as Friedman`s model. Each bid of competitor was standardized by using bidder`s cost to be a bid-to-cost ratio in order to eliminate the impact of the project size to a bid-to-cost ratio in the research.

2.5 Bidding Strategy in Combinatorial Transportation Auction

For transportation service procurement in combinatorial auction, there is a little study in price-bidding strategy on this area. We, therefore, summarize the details as follows: Song and Regan (2002) studied combinatorial transportation auction in the carrier perspective and proposed the formula to calculate the bidding price for new lane; $p = c_i*(1+\beta)+c_j*\alpha_j$, where c_i was cost of servicing new lane(s) in bid; c_j was cost of the empty backhaul. They used distance of servicing to calculate the cost directly because it was proportional to mileage. While β was average profit margin for carrier which ranged during 4%-6%, and α_j was the carrier's risk of not acquiring those empty lane which was uniformly distributed on interval [0, 1]. An, et al., (2005) researched on bidding strategies into question which packages should be bided and how much to bid for. They then applied a fixed profit margin to value bid price. These two papers neglect the interaction of the competition among carriers in the auction. Ergun, et al., (2007) presented the bidding strategy by which was a stochastic bid price optimization problem for simultaneous transportation auction. They focused on both new proposed lane and existing lane, and they considered other carriers` competition. In the model, they used the lowest bid price of competitors for each lane denoted as random variable with uniform distribution function on interval $[l_i, u_i]$ for lane i; l_i was bidding on lane i which guaranteed winning the lane, while u_i was bidding on lane i which guaranteed losing the lane. The objective of this research was to maximize the expected profit of carrier with optimal bid price on the lanes being auctioned.

3. THE MODEL AND SOLUTION ALGORITHM

In this section, we start describing the respondent and questionnaire for finding relationship among interested factors in this paper. We then explain the description of the model, indicate assumptions, and present the notation. Next, we introduce the model formulation in combinatorial transportation auction, and we outline our solution algorithm in order to find the optimal solution for combinatorial auction in the incomplete information game.

3.1 Sample and Questionnaire

We design to have in-depth interview with carriers who provide freight service in many industries on different size of revenue in Thailand. First, the pre-questionnaire is used with some respondents to test the feedback and to check whether it is compatible with our research objective. Then the post-questionnaire will be employed to collect the data with many respondents by in-depth interview. For the objective of our questionnaire, we focus on finding the relationship among interested factors how they impact on a bid-to-cost ratio of carrier in combinatorial auction. The interested factors in this paper include a decrease ratio of pre-empty backhaul, a pre-empty backhaul to new lane distance ratio, number of competitors, and size of project. Finally, the relationship of these factors after testing will help us to find the optimal bid price of carrier in the competition afterwards.

3.2 Description of Model

In this study, we present the bidding strategy in a first-price sealed-bid combinatorial transportation auction for truckload service operation. This model focuses on the bid price generation problem of bidder with the interaction among carriers to interested package. For interested package, we consider both new lanes proposed by shipper and current servicing lanes of carrier simultaneously in order to meet economies of scope. In our model, we introduce a stochastic optimization problem to find the optimal solution for incomplete information game.

Specifically, we use a bid-to-cost ratio of competitors as random variable generated by Monte Carlo method to represent the competition behavior in combinatorial transportation auction.

3.3 Assumptions

We assume the details in this paper as the following:
- Bidder and Competitor are risk neutral.
- Bidder and Competitor do not have collusion.
- Bidder and Competitor have incomplete information.
- Bidder and Competitor would bid on combinatorial auction to have more network efficiency.
- Cost of freight transportation service is proportional to servicing distance only.
- Unit Cost of freight transportation service for carriers is the same.

3.4 Notations

We summarize all notations in our model formulation as follows:

Decision Variable

x_{ij} is the bid-to-cost ratio of carrier *i* for package *j*.

Result Variables

$\pi_{ij}(x_{ij})$ is the expected profit with the bid-to-cost ratio of carrier *i* for package *j*.

b_{ij} is the bid price of carrier *i* for package *j*.

$\Pr_{ij}(x_{ij})$ is the probability of winning with the bid-to-cost ratio of carrier *i* (x_{ij}) against the competitor for package *j*.

Intermediate Variables

mc_{ij} is the marginal cost of carrier *i* for package *j*.

oc_j is the operating cost for package *j*.

μ_{ij} is the pre-empty backhaul to new lane distance ratio of carrier *i* with package *j*.

γ_{ij} is the decrease ratio of pre-empty backhaul of carrier *i* with package *j*.

n is a number of competitors.

s_j is a size of project for package *j* (s_j =1 if l_j = 150 km.)

l_j is a new lane distance for package *j*.

$lpos_{ij}$ is a post-empty backhaul distance of carrier *i* for package *j*.

$lpre_{ij}$ is a pre-empty backhaul distance of carrier *i* for package *j*.

Parameter and Data

a_j is the shortest distance for a straight direction from an origin to a destination point of package *j*.

α is a step size.

ϕ_f is a unit cost of full truck load servicing.

ϕ_e is a unit cost of empty backhaul.

Sets

I is set of carriers.

J is set of possible packages.

3.5 Model Formulation

We present the bidding strategy formulation with stochastic optimization model for carrier in combinatorial transportation auction as described in the following:

$$Max\ \ \pi_{ij}(x_{ij}) = (b_{ij} - mc_{ij}) * \Pr_{ij}(x_{ij}) \tag{1}$$

Subject to:

$$\mu_{ij} \leq \frac{1}{\gamma_{ij}} \qquad \forall i \in I, \forall j \in J \tag{2}$$

$$\mu_{ij} \geq \frac{a_j}{l_j * (2 - \gamma_{ij})} \qquad \forall i \in I, \forall j \in J \tag{3}$$

$$0.2 \leq \gamma_{ij} \leq 1 \qquad \forall i \in I, \forall j \in J \tag{4}$$

, where

$$x_{ij} = x_{ij} + \alpha \tag{5}$$

$$b_{ij} = oc_j * x_{ij} \tag{6}$$

$$oc_j = \phi_f * l_j \tag{7}$$

$$mc_{ij} = \phi_f * l_j + \phi_e * (lpos_{ij} - lpre_{ij}) \tag{8}$$

$$x_{ij} = f(\mu_{ij}, \gamma_{ij}, n, s_j) \tag{9}$$

$$\mu_{ij} = \frac{lpre_{ij}}{l_j} \tag{10}$$

$$\gamma_{ij} = \frac{(lpre_{ij} - lpos_{ij})}{lpre_{ij}}. \tag{11}$$

For equation (1), we present a stochastic optimization model to obtain the maximum expected profit with the optimal bid-to-cost ratio of bidder for combinatorial auction. Because of incomplete information game, thus, we apply the Monte Carlo method for bidder to randomize μ_{ij} and γ_{ij} of competitor in package j under constraints (2), (3) and (4). In constraint (2), we apply this constraint to find the possible maximum μ_{ij} of competitor in package j whereas the possible minimum μ_{ij} of competitor in package j is acquired by constraint (3). To understand the economies of scope, we assume that all carriers would submit bid to reduce the existing empty backhaul (γ_{ij}) on the interval [0.2, 1] regarding constraint (4). Furthermore, we could describe the details of constraints (2) and (3) as below.

For equation (5), we use the step size (α) to increase value of a bid-to-cost ratio of bidder iteratively so that we could simulate how a bid-to-cost ratio of bidder does impact to the competitive bidding with expected profit and probability of winning. In addition, we could evaluate the bid price of carrier (b_{ij}) to package j with operating cost and a bid-to-cost ratio of carrier by equation (6). The equation (7) presents how to calculate the operating cost (oc_j) in which it is proportional to new servicing distance (l_j) of package j. Moreover, the marginal cost (mc_{ij}) that indicates the actual cost of carrier for servicing in package j can be expressed by equation (8). It involves with new lane distance including pre-empty backhaul ($lpre_{ij}$) and post-empty backhaul distance ($lpos_{ij}$) in transportation network of carrier. In equation (9), we use this equation to find the average bid-to-cost ratio of carrier in the transportation market with μ_{ij}, γ_{ij}, n and s_j for package j. In equations (10) and (11), we introduce the formula both μ_{ij} and γ_{ij} respectively in order to represent the transportation network of carrier with package j.

Constraint (2)
Pre-Empty Backhaul Distance $\leq$ New Lane + Post-Empty Backhaul Distance.
$lpre_{ij} \leq l_j + lpos_{ij}$.
$\mu_{ij} * l_j \leq l_j + lpre_{ij} * (1-\gamma_{ij})$.
$\mu_{ij} * l_j \leq l_j + \mu_{ij} * l_j * (1-\gamma_{ij})$.
$\mu_{ij} \leq 1 + \mu_{ij} * (1-\gamma_{ij})$.
$\mu_{ij} \leq 1 + \mu_{ij} - \mu_{ij}\gamma_{ij}$.
$\mu_{ij} \leq \frac{1}{\gamma_{ij}}$.

Constraint (3)
Pre-Empty Backhaul Distance + Post-Empty Backhaul Distance $\geq$ Shortest Distance (New lane).
$\mu_{ij} * l_j + \mu_{ij} * l_j * (1-\gamma_{ij}) \geq a_j$.
$\mu_{ij} + \mu_{ij}(1-\gamma_{ij}) \geq \frac{a_j}{l_j}$.
$\mu_{ij}(2-\gamma_{ij}) \geq \frac{a_j}{l_j}$.
$\mu_{ij} \geq \frac{a_j}{l_j * (2-\gamma_{ij})}$.

3.6 Solution Algorithm

For simulation with incomplete information game, we assume that bidder and competitor who are carriers do not know information among each other. Thus, we employ a Monte Carlo method in the algorithm for bidder to randomize value both μ_{ij} and γ_{ij} of competitor in order to represent the transportation network of competitor including the competitive behavior in the combinatorial auction. To find all feasible bid-to-cost ratios of competitor in the incomplete information game, at first we have to acquire all possible values both μ_{ij} and γ_{ij} of competitor to package *j*. Therefore, we initially randomize γ_{ij} of competitor as an independent continuous random variable which is uniformly distributed on an interval [0.2,1] under constraint (4). We then use constraint (2) and constraint (3) as described above to find the possible maximum μ_{ij} and minimum μ_{ij} of competitor to package *j* with uniformly randomized γ_{ij}. Next, we randomize μ_{ij} on interval [minimum μ_{ij}, maximum μ_{ij}] of competitor which is distributed uniformly as an independent continuous random variable with randomized γ_{ij}. With all possible values both μ_{ij} and γ_{ij} of competitor randomized to package *j*, we input all both values into equation (9) with number of competitors (n) and size of project *j* (s_j) to find all possible bid-to-cost ratios of competitor (x_{ij}) in the bidding game. Specifically, we can use equation (6) with each value of x_{ij} of competitor and operating cost of package *j* (oc_j) received from equation (7) to acquire all feasible bid prices of competitor (b_{ij}).

For the competition with competitor, bidder initiates a minimum bid-to-cost ratio firstly. Bidder then submits the initial bid-to-cost ratio into the auction against all feasible bid-to-cost ratios of competitor. In this step, bidder could acquire the probability of winning, $\Pr_{ij}(x_{ij})$, with this initial value. Furthermore, bidder could find the expected profit ($\pi_{ij}(x_{ij})$) in package *j* with initial bid price of bidder by equation (1). To find the maximum expected profit with the optimal solution (x^*_{ij}), the solution algorithm employs a step size (α) to increase value of a bid-to-cost ratio of bidder with equation (5) iteratively. The results of simulation will provide the expected profit and probability of winning with each of bid-to-cost ratio and bid price of bidder. Thus, the solution algorithm could definitely select the optimal bid-to-cost ratio in which presents the best solution including maximum expected profit and probability of winning for bidder in the combinatorial auction. The solution algorithm can be shown in Figure 1.

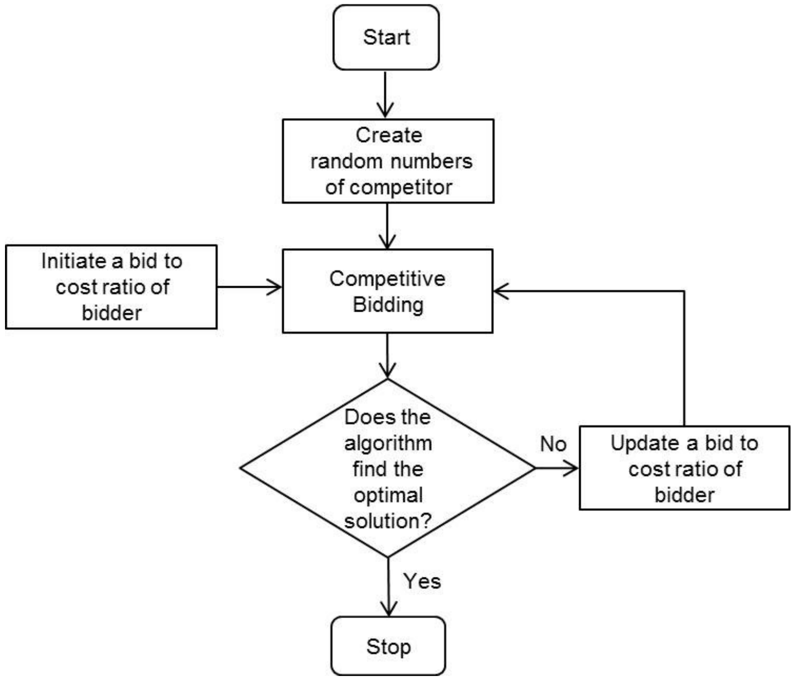

FIGURE 1: Solution Algorithm

4. RESULT ANALYSIS

In this section, we have two parts. For the first part, we summarize characteristics of respondents and factors, and we use statistical analysis to find the regression model as well as test hypothesizes whether interested factors impact on a bid-to-cost ratio significantly. We then create a bidding game for bidder and competitor in the second part. To compete between bidder and competitor in the incomplete information game, we use Monte Carlo method to create the bidding behavior of competitor. In addition, we employ the solution algorithm with stochastic bidding model to find the optimal solution for bidder. In this part, we can find the optimal bid price for bidder to submit into the auction, and obtain the maximum expected profit including probability of winning.

4.1 Respondent and Factor Characteristics

The respondents surveyed in this research are truck carriers who provide freight service in Thailand. About half of the total respondents have income between 20-100 million baht per year. For majority of respondents (37%), they are facing the problem of empty backhaul per total haul distance over 40%. Moreover, most 65% of respondents confront the empty backhaul (EBH) experience above 25% of EBH per total haul distance.

This survey shows that average of EBH per total haul distance is about 30%. In addition, construction, container, agriculture, consumer and electronic product are the top five of business types that respondents provide freight service to these customers (Table 1).This study also proposes hypotheses to test the relationship between a bid-to-cost ratio of carrier (x) and interested factors (μ, γ, n, s) as follows:

Hypothesis 1: A number of competitors (n) do not impact on a bid-to-cost in combinatorial transportation auction.

Hypothesis 2: A size of project (s) does not impact on a bid-to-cost ratio in combinatorial transportation auction.

Hypothesis 3: A pre-empty backhaul to new lane distance ratio (μ) does not impact on a bid-to-cost ratio in combinatorial auction.

Hypothesis 4: A decrease ratio of pre-empty backhaul (γ) does not impact on a bid-to-cost ratio in combinatorial auction.

Hypothesis 5: A pattern of transportation service ($\mu\gamma$) does not impact on a bid-to-cost ratio in combinatorial auction.

Hypothesis 6: A pre-empty backhaul to new lane distance ratio with number of competitors (μn) does not impact on a bid-to-cost ratio in combinatorial auction.

TABLE 1: Characteristic Respondents

Characteristics (n=50)	M	SD	Frequency	Percentage
Income Per-Year	474.9	963.2		
Below 20 Million Baht			7	0.14
20-100 Million Baht			21	0.42
100-500 Million Baht			12	0.24
Above 500 Million Baht			10	0.20
EBH per Total Distance	29%	18%		
Below 10%			6	0.18
10%-25%			6	0.18
25%-40%			9	0.27
Above 40%			12	0.37
Type of Business				
Agriculture			18	0.15
Construction			29	0.24
Energy			6	0.05
Consumer Product			18	0.15
Electronic Part			15	0.13
Container			22	0.18
Others			12	0.10

M = Mean, **SD** = Standard Deviation.

To find relationship of each independent variable to a bid-to-cost ratio of carrier, we use the statistical analysis by t-test to execute the data with each independent variable. The result of this research shows that a number of competitors (n), a pre-empty backhaul to new lane distance ratio (μ), a pattern of transportation service ($\mu\gamma$), and a pre-empty backhaul to new lane distance ratio with number of competitors (μn) do impact on a bid-to-cost ratio of carrier in combinatorial transportation auction significantly at the 0.05 level (Table 2). The coefficient and standard error of each independent variable are shown in Table 2 as well. Specifically, all independent variables tested by ANOVA are revealed that they all do impact on dependent variable significantly at the 0.05 level (Table 3). From testing by statistical analysis, we can present the regression model for the average bid-to-cost ratio of carrier in combinatorial transportation auction in Thailand defined previously in equation (9) with equation (12) instead as follows:

$$x_{ij} = 1.385 - 0.023n - 0.005s_j + 0.009\gamma_{ij} + (0.15 - 0.743\gamma_{ij} - 0.007n)\mu_{ij}. \qquad (12)$$

The results of regression model can explain that the bidding price of competitive auction to package j with a large number of competitors (n) will be lower compared with a small number of competitors. Because a large number of competitors represent the high competitive situation in combinatorial auction, thus, carrier understands the condition and accepts to decrease a bid-to-cost ratio to compete in the competition market inevitably. While a pre-empty backhaul to new lane distance ratio (μ) does impact positively to the bid-to-cost ratio of carrier. It indicates that carrier considers submitting a higher bid-to-cost ratio when new lane distance decreases with constant distance of pre-empty backhaul. In addition, a bid-to-cost ratio of carrier in the market has decreased obviously when a value of pattern of transportation service ($\mu\gamma$) increases. The maximum value of $\mu\gamma$ is equal 1 regarding equation (2). For example: μ_{11}=1, γ_{11}=1, $\mu_{11}\gamma_{11}$=1, l_1=150, it presents that the new lane for package1 proposed by shipper at 150km matches with the existing empty backhaul of carrier1 completely (γ_{11}=1). A carrier1 can eliminate the existing empty backhaul with package 1 totally ($lpos_{11}$=0) and enhance transportation network efficiency.

Because the marginal cost of carrier1 (mc_{11}) in this package could be low due to no post-empty backhaul ($lpos_{11}$=0) regarding equation (8). Thus, carrier1 has the competitive advantage to compete with competitor, and he could submit bid price with the low bid-to-cost ratio into the auction. On the other hand, if carrier1 has no competitive advantage in package1, for example: μ_{11}=1, γ_{11}=0.2, $\mu_{11}\gamma_{11}$=0.2, l_1=150, the new lane in package1 is able to eliminate the empty backhaul of carrier1 only at 20% (γ_{11}=0.2, $lpos_{11}$=120). The marginal cost (mc_{11}) in this example should be higher than the previous one. Therefore, in this case carrier1 has to submit the bid price with the higher bid-to-cost ratio to cover more marginal cost for package1 into the auction necessarily.

TABLE 2: Statistical Analysis

Independent Variable	Coefficients	Standard Error	t-Stat	P-value	Hypothesis
Intercept	1.385	0.0253	54.840	0.000	-
n	-0.023	0.0052	-4.389	0.000*	Rejected H1
s	-0.005	0.0032	-1.471	0.141	Accepted H2
μ	0.150	0.0107	0.007	0.000*	Rejected H3
γ	0.009	0.0234	0.371	0.711	Accepted H4
$\mu\gamma$	-0.743	0.0270	-27.547	0.000*	Rejected H5
μn	-0.007	0.0026	-2.717	0.007*	Rejected H6

Note: *significant at the 0.05 level.

TABLE 3: Regression Model

Research Statistics	
Multiple R	0.594
R Square	0.353
Adjusted R Square	0.352
Standard Error	0.309
Observations	2394

ANOVA	*Df*	SS	MS	F	*Significance F*
Regression	6	125.191	20.865	217.3107	0.000*
Residual	2387	229.188	0.096		
Total	2393	354.378			

Note: *significant at the 0.05 level.

4.2 Empirical Study

To find the optimal bid price, we simulate the bidding game in combinatorial auction with incomplete information between bidder and competitor who are truck carrier. Because bidder does not know any information of competitor, thus bidder has to evaluate the all feasible bid-to-cost ratios of competitor with any possible μ and γ of competitor. The solution algorithm uses the Monte Carlo method to generate random number between μ and γ of competitor according to constraints (2), (3) and (4). With number of competitors (n), size of project (s), any possible μ, and γ of competitor randomized, then bidder could evaluate the all feasible bid-to-cost ratios of competitor regarding equation (12).To find probability of winning with bidder's bid, we consider the bid-to-cost ratio of bidder against all randomized bid-to-cost ratios of competitor by one to all to estimate the probability of winning. For example: There are 10 random numbers of competitor as follows: 0.95, 0.97, 0.98, 0.99, 1.01, 1.02, 1.03, 1.05, 1.10, 1.15; Then we input 1.0 as a bid-to-cost ratio of bidder. Thus, the probability of winning with bidder's bid should be 60%. Specifically, we use the solution algorithm with stochastic optimization problem to find the optimal bid-to-cost of bidder in which reaches the maximum payoff for the competition as described in section 3.6.

In Figure 2 as our simulation in example 1, shipper who is a manufacturer announces to invite truck carriers (10-wheeled truck) to join into the bidding. Shipper would like carrier to transport the product with full truckload freight service only 1 lane (one package) from location A (Factory) to location B (Marketplace) directly about 150 km (l_1=150, a_1=150, s_1=1). As defined, there are 2 carriers joining in this auction between bidder and one competitor (n=1). For current transportation network of bidder, bidder normally provides the freight service with only one way from location B to location A. By this reason, bidder then has the empty backhaul problem inevitably ($lpre_{11}$=150). However, the new lane proposed by shipper (l_1=150, μ_{11}=150/150=1) in Figure 2 matches with the existing empty backhaul of bidder completely and eliminates this empty backhaul problem ($lpos_{11}$=0, γ_{11}= (150-0)/150=1). Therefore, bidder then gains the competitive advantage from this package since bidder has the low marginal cost. In equation (8), the marginal cost of bidder is at 225 baht; mc_{11}= (7.5*150) + 6*(0-150). Whereas, operating cost which is proportional to new lane distance of package 1 equals 1,125 baht; oc_1= 7.5*150. Thus, bidder could submit the low bid price to gain high benefit both expected profit and probability of winning because of having low marginal cost. Moreover, bidder is able to eliminate the empty backhaul problem and improve his transportation network with package 1 efficiently.

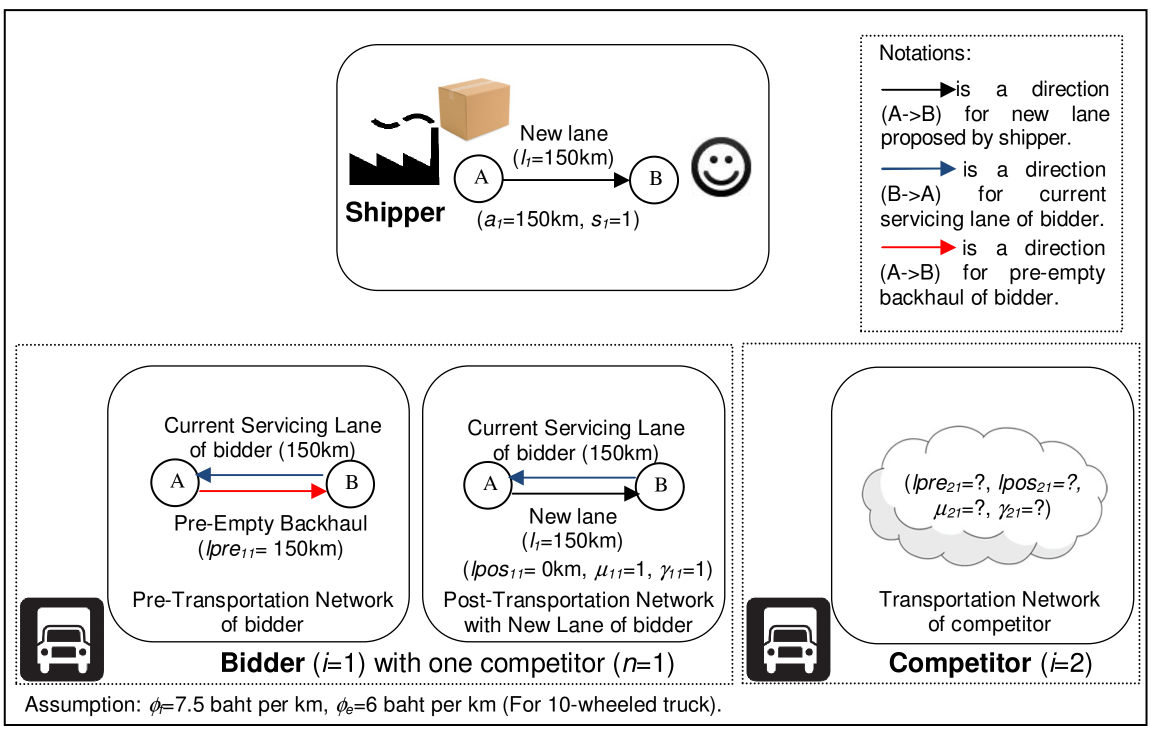

FIGURE 2: A Bidding Simulation for Incomplete Information Game (Example 1)

However, bidder does not know any information about existing transportation network of competitor regarding incomplete information game. In Figure 2, we, thus, introduce a cloud in competitor's side to represent the unknown information of competitor ($lpre_{21}$=?, $lpos_{21}$=?, μ_{21}=?, γ_{21}=?). Therefore, bidder initially has to find any possible transportation network of competitor with package 1 indicated by μ_{21} and γ_{21}. Under constraint (2), constraint (3) with a_1/l_1=1 and constraint (4), the possible random number both μ_{21} and γ_{21} of competitor in package 1 can be generated by Monte Carlo method. The all possible values both μ_{21} and γ_{21} obtained by randomization as solution algorithm are plotted on the graph as shown in Figure 3.

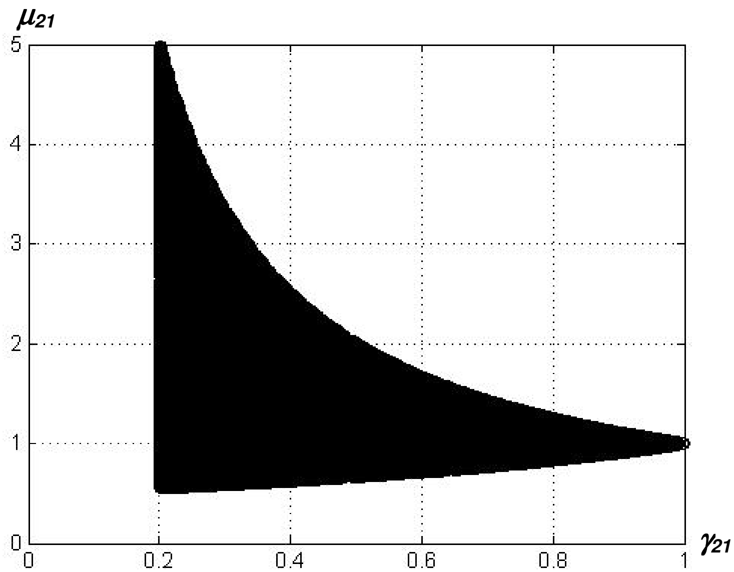

FIGURE 3: The Possible Transportation Network of Competitor (μ_{21} and γ_{21}) with new lane (a_1/l_1=1)

To acquire all feasible bid-to-cost ratios of competitor for package 1 (x_{21}), we input each value both μ_{21} and γ_{21} randomized with n=1 and s_1=1 into equation (12). The result with all feasible bid-to-cost ratios of competitor under the possible transportation network of competitor is presented in Figure 4. For the competition, at first we start using the initial bid-to-cost ratio of bidder from a minimum possible bid-to-cost ratio of competitor. Then we do simulate a bid-to-cost ratio of bidder (x_{11}) against all feasible bid-to-cost ratios of competitor. The probability of winning with a bid-to-cost ratio of bidder could be acquired from this step. In addition, we use step size (α=0.001) in equation (5) to increase a bid-to-cost ratio of bidder to compete with all possible bid-to-cost ratios of competitor on and on. The results of bidder for each bid-to-cost ratio (x_{11}) to compete with competitor can be shown in Table 4.

In Table 4, we present the simulated bids that show the outcome of bidder to package 1 both expected profit ($\pi_{11}(x_{11})$) and probability of winning ($\Pr_{11}(x_{11})$) for each value of x_{11} including bid price (b_{11}). Regarding the stochastic optimization model in equation (1), it will select the bid-to-cost ratio of bidder that provides the maximum expected profit. While the solution algorithm will be stopped until they find the optimal solution as procedure. Thus, the optimal bid-to-cost ratio of bidder in the combinatorial auction (x^*_{11}) definitely is 0.772. While the optimal bid price of bidder to submit into the competition market equals 868.50 baht. In addition, the maximum expected profit with the best solution ($\pi_{11}(x^*_{11})$) is at 638.1 baht. Besides, the expected profit per marginal cost ($\pi_{11}(x^*_{11})/mc_{11}$) and probability of winning ($\Pr_{11}(x^*_{11})$) with optimal solution are at 283.6%, 99.16% respectively. Specifically, the result of simulation shows that bidder who has the competitive advantage in this game can obtain the expected profit per marginal cost more around 0.6% comparing the optimal solution with average bid-to-cost of bidder in the market (*average* x_{11}= 0.766 with γ_{11}=1, μ_{11}=1,n=1, s_1=1; $\pi_{11}(0.766)/mc_{11}$=283%; average b_{11}=861.75)

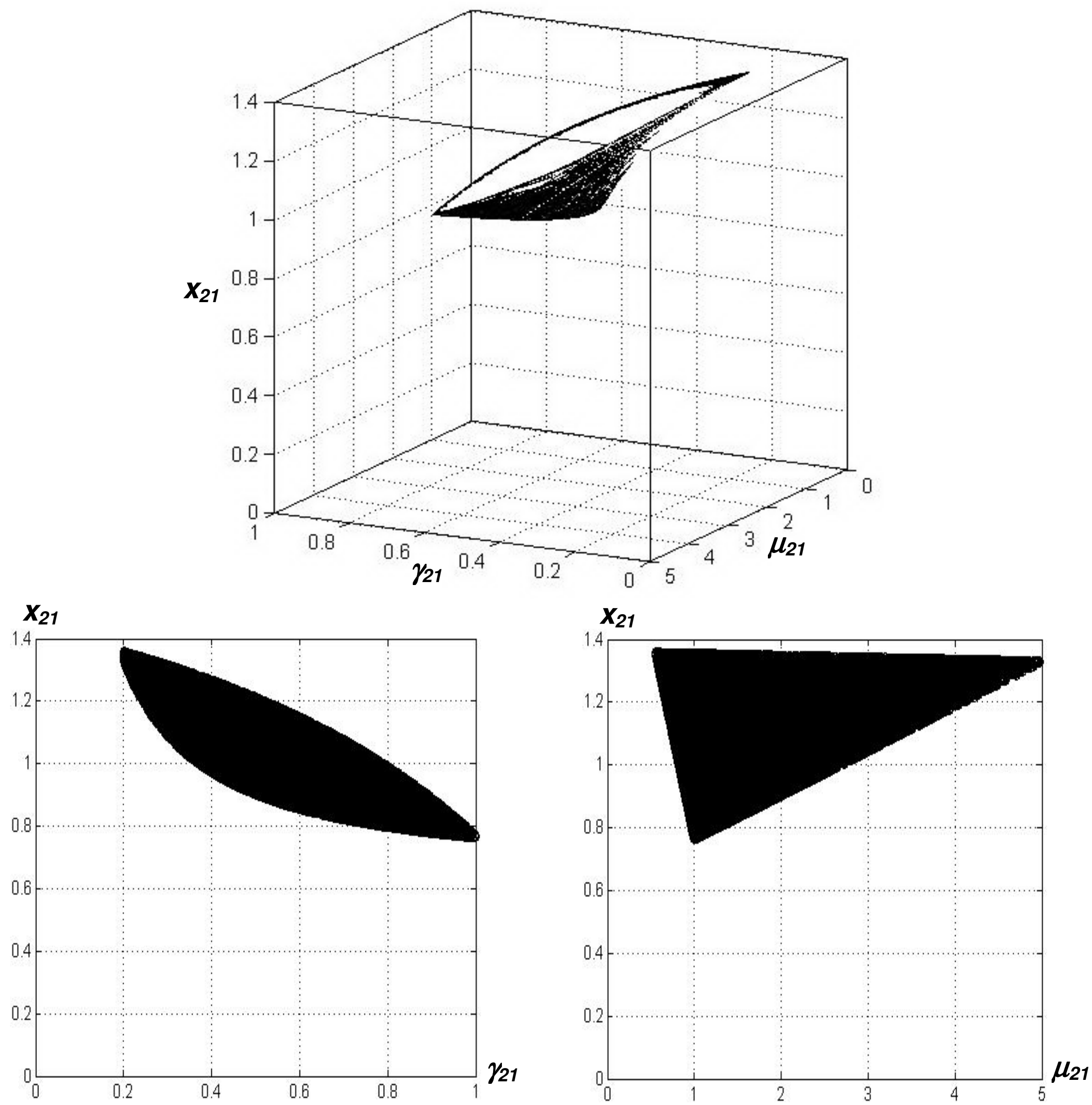

FIGURE 4: The Feasible Bid-to-Cost Ratios of Competitor (x_{21}) at a_1/l_1=1, n=1, s_1=1

TABLE 4: Simulated Bids of Bidder in Example 1 (a_1/l_1=1, n=1, s_1=1)

A Bid-to-Cost Ratio	Bid Price (Baht)	Marginal Cost (Baht)	Probability of Winning	Expected Profit (Baht)
0.765	860.63	225	100.0%	635.63
0.766	861.75	225	100.0%	636.75
0.767	862.88	225	99.8%	636.41
0.768	864.00	225	99.70%	637.08
0.769	865.13	225	99.59%	637.50
0.770	866.25	225	99.44%	637.66
0.771	867.38	225	99.31%	637.94
0.772	**868.50**	**225**	**99.16%**	**638.10**
0.773	869.63	225	98.98%	638.05
0.774	870.75	225	98.80%	638.00
0.775	871.88	225	98.61%	637.88
0.776	873.00	225	98.40%	637.63
0.777	874.13	225	98.18%	637.31

Assumption: ϕ_f=7.5 baht per km, ϕ_e=6 baht per km (For 10-wheeled truck).

In addition, we introduce another bidding game for bidder (Example 2) as shown in Figure 5. There are 2 carriers joining in this game between bidder and one competitor (n=1). Shipper announces to procure transportation service only 1 lane (one package) from location A (Factory) to location B (Marketplace) directly at 150km (l_1=150, a_1=150, s_1=1) as the same details in example 1. For the current transportation network of bidder, bidder transports the product from location C to location A in one way only at 150km. Thus, bidder faces the empty backhaul problem from location A to location C ($lpre_{11}$=150). While the new lane proposed by shipper in package 1 (l_1=150, μ_{11}=150/150=1) as shown in Figure 5 could reduce the existing empty backhaul of bidder only 20% ($lpos_{11}$=120, γ_{11}=(150-120)/150=0.2). Regarding equation (8), the marginal cost of bidder equals 945 baht (mc_{11}= 7.5*150+ 6*(120-150)) in which is higher than in the example 1 particularly. For operating cost of bidder, it is similar to the example 1 because of the same distance (oc_{11}=1,125). Therefore, bidder in this example 2 has no competitive advantage and could not submit the low bid price into the combinatorial auction due to high marginal cost.

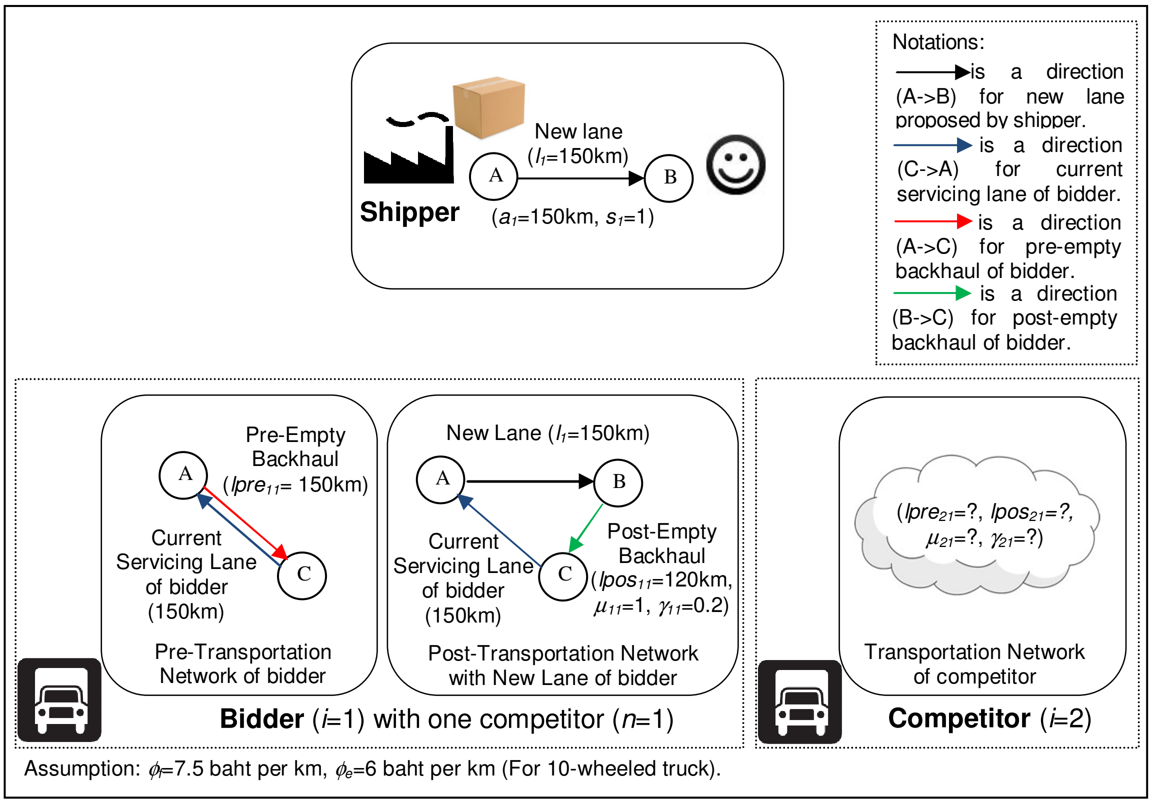

FIGURE 5: A Bidding Simulation for Incomplete Information Game (Example 2)

To find the optimal bid of bidder in this auction, because bidder does not know any information of competitor as incomplete information game, so we use the solution algorithm to generate a randomized number both γ_{21} and μ_{21} subject to constraints (2), (3), and (4). Under similar environment of competition to example 1 (a_1/l_1=1, n=1, s_1=1), thus, the results of possible transportation network with package 1 of competitor and the competitor`s bidding strategy in this simulation are shown as the same in Figure 3 and Figure 4 respectively. After we have any possible bid-to-cost ratios of competitor regarding equation (12), we then do simulate a bid-to-cost ratio of bidder against all feasible bid-to-cost ratios of competitor according to the solution algorithm.

In Table 5, we finally show the simulated bids of bidder in example 2 with expected profit ($\pi_{11}(x_{11})$) and probability of winning ($\Pr_{11}(x_{11})$) for each bid-to-cost ratio of bidder (x_{11}). Regarding the stochastic optimization model, it presents that the optimal bid-to-cost ratio of bidder in the combinatorial auction (x^*_{11}) is 1.058 certainly. The optimal bid price equals 1,190.25 baht. In addition, the maximum expected profit with the optimal solution ($\pi_{11}(x^*_{11})$) is at 97.46 baht. In Table 5, it introduces that the expected profit per marginal cost ($\pi_{11}(x^*_{11})/mc_{11}$) and probability of winning ($\Pr_{11}(x^*_{11})$) with optimal solution are at 10.31%, and 39.74% respectively. Even bidder who has the competitive disadvantage in this game gains $\pi_{11}(x^*_{11})/mc_{11}$ only 10.31% with $\Pr_{11}(x^*_{11})$ at 39.74%. However, the optimal solution obtained from this solution algorithm can enhance the expected profit per marginal cost and probability of winning of bidder increasingly over 10.31% and 39.72% respectively comparing with average bid-to-cost of bidder in the transportation market (average x_{11}= 1.353; μ_{11}=1, γ_{11}=0.2, n=1, s_1=1; $\pi_{11}(1.353)/mc_{11}$=0%, $\Pr_{11}(1.353)$=0.02% ; average b_{11}=1,522.12).

TABLE 5: Simulated Bids of Bidder in Example 2 (a_1/l_1=1, n=1, s_1=1)

A Bid-to-Cost Ratio	Bid Price (Baht)	Marginal Cost (Baht)	Probability of Winning	Expected Profit (Baht)
1.050	1181.25	945.00	41.21%	97.359
1.051	1182.38	945.00	41.02%	97.371
1.052	1183.50	945.00	40.84%	97.403
1.053	1184.63	945.00	40.66%	97.432
1.054	1185.75	945.00	40.48%	97.456
1.055	1186.88	945.00	40.29%	97.451
1.056	1188.00	945.00	40.09%	97.419
1.057	1189.13	945.00	39.91%	97.430
1.058	**1190.25**	**945.00**	**39.74%**	**97.462**
1.059	1191.38	945.00	39.55%	97.441
1.060	1192.50	945.00	39.35%	97.391
1.061	1193.63	945.00	39.17%	97.386
1.062	1194.75	945.00	38.99%	97.378
1.063	1195.88	945.00	38.81%	97.365
1.064	1197.00	945.00	38.62%	97.322

Assumption: ϕ_f=7.5 baht per km, ϕ_e=6 baht per km (For 10-wheeled truck).

From the empirical study, we summarize that carrier who has either competitive advantage or competitive disadvantage on new package proposed by shipper can gain more expected profit from our optimal solution compared with the average bid price in transportation market. While in turn it also shows that shipper potentially receives the benefits from our solution algorithm in combinatorial transportation auction. Shipper could lower the cost of transportation service procurement greatly when carrier has the competitive advantage with new package. Because of carrier's low marginal cost, thus, carrier is able to submit the low bid with high expected profit. For example 1, bidder could submit the optimal bid at 868.5 baht that is lower than operating cost of new lane around 256.5 baht. Even the shipper's cost for procurement with optimal bid of bidder regarding the solution algorithm is likely higher than the average bid price of bidder in transportation market (861.75 baht) around 0.78%. However, shipper gains fully benefits with the optimal bid of bidder in which lowers shipper's cost for transportation service procurement by 22.8% of operating cost.

For carrier who has the competitive disadvantage with high marginal cost, due to carrier has to take a hard effort to compete into the auction considerably regarding the solution algorithm. Therefore, carrier would submit the optimal bid price that is less than the average bid price in transportation market. By this reason, shipper could decrease the cost of transportation service procurement also. For example 2, bidder would submit the optimal bid price at 1,190.25 baht that is lower than the average bid price of bidder in transportation market (1,522.12 baht). Thus, shipper potentially obtains the benefit to reduce the cost of transportation service procurement with optimal bid of bidder around 21.8% of average bid price in transportation market.

5. CONCLUSION AND FUTURE RESEARCH

For this paper, we propose the bidding strategies for carrier with interaction between bidder and competitor in order to find the optimal bid price for bidder in combinatorial transportation auction. First, the study finds the relationship among involved factors in the regression model to a bid-to-cost ratio of carrier in Thailand by using statistics analysis. The result analysis shows that a pattern of transportation service, a number of competitors, a pre-empty backhaul to new lane distance ratio, and a pre-empty backhaul to new lane distance ratio with number of competitors do impact on a bid-to-cost ratio of carriers in Thailand significantly. A bid-to-cost ratio of carrier has been dropped obviously when a value of pattern of transportation service increases. In addition, the bidding price is likely to decrease when a number of competitors and a pre-empty backhaul to new lane distance ratio with number of competitors increase. Whereas, a pre-empty backhaul to new lane distance ratio raises, it does impact positively to the bid-to-cost ratio of carrier in transportation market.

To find the optimal bid-to-cost ratio for bidder in the incomplete information game, we then introduce the solution algorithm in which employs the stochastic optimization model, and we use Monte Carlo method to generate the bidding behavior of competitor. The result acquired by solution algorithm could find the optimal bid-to-cost ratio for bidder to obtain the maximum expected profit and probability of winning. Moreover, the outcomes of simulations with incomplete information game show that the optimal solution of bidder regarding solution algorithm can enhance the expected profit over cost compared with average bid-to-cost of carrier in the transportation market substantially. In addition, in turn the results present that shipper also gains the benefit from the optimal solution in combinatorial transportation auction by which shipper could lower cost of transportation service procurement considerably.

While we focus on the competition between bidder and competitor with the incomplete information game in this paper, the study on combinatorial transportation auction with known information among players is another interesting theme that researcher should be considered in the future research. This is to find the optimal bid price in this circumstance and also discover the relationship between benefits and level of known information among players in the general.

6. ACKNOWLEDGEMENTS

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