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A GREEN PERFORMANCE BOND FRAMEWORK FOR MANAGING GREENHOUSE GAS EMISSIONS DURING CONSTRUCTION: PROOF OF CONCEPT USING AGENT-BASED MODELING

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ABSTRACT

A+C and A+B+C bidding methods have been recognized as innovative green contracting strategies for addressing climate change by reducing greenhouse gas emissions during the construction phase of infrastructure projects. However, there are practical issues including the possibility of opportunistic bidding that casts doubt on the successful implementation of these bidding methods. This study introduces a green performance bond framework as a potential solution and evaluates its feasibility and effectiveness in discouraging opportunistic bidding behaviors. In doing so, the A+C bidding environment is simulated using agent-based modeling and conduct simulation experiments in which contractors attempt to increase their probability of winning by intentionally submitting an unrealistic emission mitigation plan. The results show that applying the green performance bond framework can significantly reduce the over-emission and the probability of success of an opportunistic bid in all bidding scenarios.

1 INTRODUCTION

Architecture/Engineering/Construction (AEC) industry has gradually taken more responsivity for promoting sustainability and environmental stewardship. A substantial share of research studies has addressed the environmental assessment of sustainable design alternatives and operations practices. Recently, the AEC industry has become more interested in managing GHG emissions during the construction phase. Construction activities are responsible for producing approximately 1.7% of the total U.S. GHG emissions in 2002, placing the construction sector as the third highest GHG emitting sector (EPA 2009). Also, the construction sector is predicted to have the highest average annual rate of increase in GHG emissions for the period of 2011-2030 among seven industrial sectors (EPA 2009).

While the Clean Air Act considered GHGs as a pollutant (EPA 2008), the existing US government standards and regulations for construction emissions are currently limited to only hazardous air pollutants (Peña–Mora et al. 2009). Consequently, contractors may not take necessary actions to reduce GHG emissions if the incentives for carbon reduction provided by the government do not fully make up for their investment and effort. To address this problem, green contracting strategies, especially in highway projects, have been recognized as novel solutions for making construction practices more energy efficient and more environmentally friendly (Cui and Zhu 2011). The existing green contracting strategies practiced by public agencies can be categorized into three groups of contract specifications, contract allowances, and alternative bidding methods (EPA 2005). This study focuses on the third group and specifically A+C and A+B+C bidding methods. While the aim of these bidding methods is to incentivize contractors to lower their GHG emissions, opportunistic contractors can exploit this incentive mechanism to gain an unfair competitive advantage in the bidding process by intentionally submitting a lower environmental price that does not match with the amount of potential emission generated during construction. To address this issue, Asgari (2017) proposed a green performance bond framework and discussed its benefits against an emission liability insurance framework proposed by Song and Peña-Mora (2012). Despite its theoretical soundness, the concept of green performance bond has not been tested yet. This study uses agent-based modeling as a proof of concept tool to investigate the applicability of the green performance bond to provide insights into the potential benefits and implications of implementing this framework in reality.

Table 1: Potential Emission Mitigation Plans for a Construction Project.

Mitigation Plan	Description
Replacement with hybrid equipment	Hybrid construction equipment can lower the total environmental costs by 21.8% by consuming less energy and generating less CO2 emissions compared to conventional construction equipment.
Use of biodiesel (B20)	Using B20 with all construction equipment can reduce the total environmental costs by 4.8%
Use of retrofit devices: diesel oxidation catalyst (DOC)	Using DOC with all equipment can reduce the total environmental costs by 0.9%.
Use of retrofit devices: selective catalytic reduction (SCR) combined with diesel oxidation catalyst (DOC)	Using SCR+DOC with all equipment can reduce the total environmental costs by 7.6%.
Change of material sources: nearer concrete plant	Given all of the concrete is sourced from the nearer plant, the total environmental costs can be reduced by 5.5%.
Change of material sources: nearer source	Given all of the concrete is sourced from the nearer plant and all aggregate is sourced from the nearer pit, the total environmental costs can be reduced by 11.2%.

2 A+C AND A+B+C BIDDIG METHODS

Cost + Environmental cost and Cost + Time + Environmental cost (known as A+C and A+B+C, respectively) bidding methods are innovative green contracting strategies that take into account the estimated environmental cost caused by the construction activities as one of the contractor selection criteria besides cost and schedule (Ahn et al. 2013). For example, in an A+B+C bidding method, participating contractors need to submit a bid including the total construction cost (A component), the total number of days needed to finish the project (B component), and the environmental cost during the construction phase (C component). The winning contractor is the one with the lowest total combined bid, calculated by the following equation (Ahn et al. 2013):

$$Total\ Combined\ Bid\ =\ A\ +\ \{B\ \times\ Road\ User\ Cost\}+\ \{C\ \times\ weight\}$$

where A: the construction cost estimate in dollars, B: the construction time estimate in days, the Road User Cost: the daily road user cost in dollars per day, C: the estimated environmental cost, and the weight of the C component decreases/increases the bidding preference for a greener construction.

In the above equation for calculating the bid, Ahn et al. (2013) use the concept of eco-cost (Vogtländer et al. 2001) to define the environmental cost and calculate it by combining the environmental costs of GHG emissions generated and energy used by construction activities:

$$C = \Sigma(emission\ estimate \times ecocost\ of\ emission) + \Sigma(fossil\ fuel\ use \times ecocost\ of\ material\ depletion\ )$$

The efficacious execution of the A+B bidding method in highway construction projects is key in supporting the idea of A+C and A+B+C bidding methods; Using A+B method has helped owners reduce project duration without any negative impact on cost or quality (MnDOT 2006; Ellis et al. 2007; Anderson and Damnjanovic 2008).

The C component is not a fixed value and there are numerous ways construction contractors can lower it by mitigating the GHG emissions of the construction activities. They can use cleaner fuels and replace old equipment with new and more energy efficient pieces. By value engineering and optimizing their operations, they can cut transportation loads and wastes and increase the share of locally manufactured/supplied materials. Table 1 presents the possible mitigation plans for a pavement rehabilitation and re-construction project and the change to the total environmental cost by the adoption of the mitigation plans (Ahn et al. 2013).

Putting the idea of A+C and A+B+C bidding methods into practice could lead to serious issues. One concern for owners is the risk of unintentional over-emission due to reasons such as human error, inefficient construction methods, field rework, and improperly sized equipment (Song and Peña-Mora 2012). Another concern is when a contractor intentionally and unreasonably underreports the promised emission level in the bidding phase with the hope of increasing the competitiveness of his overall bid. This is called an opportunistic bidding behavior and is generally defined as *"a contractor's intentional ignorance of possible risks involved that may significantly increase costs or decrease profitability, such as the use of the most optimistic cost estimation for the bid price"* (Ho and Liu 2004). For example, an opportunistic contractor submits a mitigation plan that is not consistent with his equipment, staff, management capability, and previous performances, indicating that the contractor may not meet the promised emission level and misuse the C component to win the project. An appropriate framework must eliminate incompetent contractors from the bidding process and lower their chance of winning the project bidding if they submit unrealistic mitigation plans.

3 GREEN PERFORMANCE BOND

This section briefly explains a framework based on the concept of green performance bond, first introduced by Asgari et al. (2017). This framework can be a practical solution to the challenges that owners could face in implementing A+C and A+B+C methods by involving the effort of all major parties and providing preventive, rather than compensatory, measures in cases of over-emission. In the green performance bond framework, owners require contractors to acquire a green performance bond from a surety company (underwriter) and submit it part of their bid package to be eligible to bid for a green project so that the owner is protected against any environmental damage costs due to the contractor's failure to meet the promised level of emissions.

Figure 1, adapted from Asgari et al. (2017), presents the three phases of the proposed green performance bond framework. In the pre-bidding phase, contractors first need to go through the general prequalification process and be evaluated in order to expect support from the surety. The general qualification criteria can vary from one surety to another but are almost the same as the criteria for bid and performance bonds: capacity, character, and capital (Russell 2000; Awad and Fayek 2012).

In the bidding phase of a specific project, participating contractors need to submit the project specific information and a plan for controlling and mitigating the risks associated with the promised level of GHG emissions to the surety. Given their performance in the general qualification, the project specific information, and the viability of their submitted mitigation plan, the surety issues a green performance bond and charges contractors a premium fee. As explain in the previous section, the lowest total combined bid determines the winning contractor.

During the construction phase, the surety company and the owner monitor and track emissions of the winning contractor, making sure the contractor stays on track and meets the promised level of emissions. If the contractor successfully meets the limit, the surety may maintain the premium rate or offer the contractor a better premium rate for future green projects. Otherwise, if the contractor goes beyond the limit, the contractor may face both immediate and future consequences. Failure to meet the promised emission level and opportunistic bidding behavior can be potentially mitigated or discouraged by both the penalty by the owner and the premium rate determined and charged by the surety company for future projects. Also, in dealing with overly optimistic (impractical) mitigation plans, the surety company may take a proactive measure by rejecting the plan or charge higher premium to contractors with history of over-emission. As a result, the charged higher premium decreases the contractor's competitiveness by offsetting the effect of their intentionally underreported emission level. In the following section, a simulation model is used to examine the effectiveness of the green performance bond in addressing this issue.

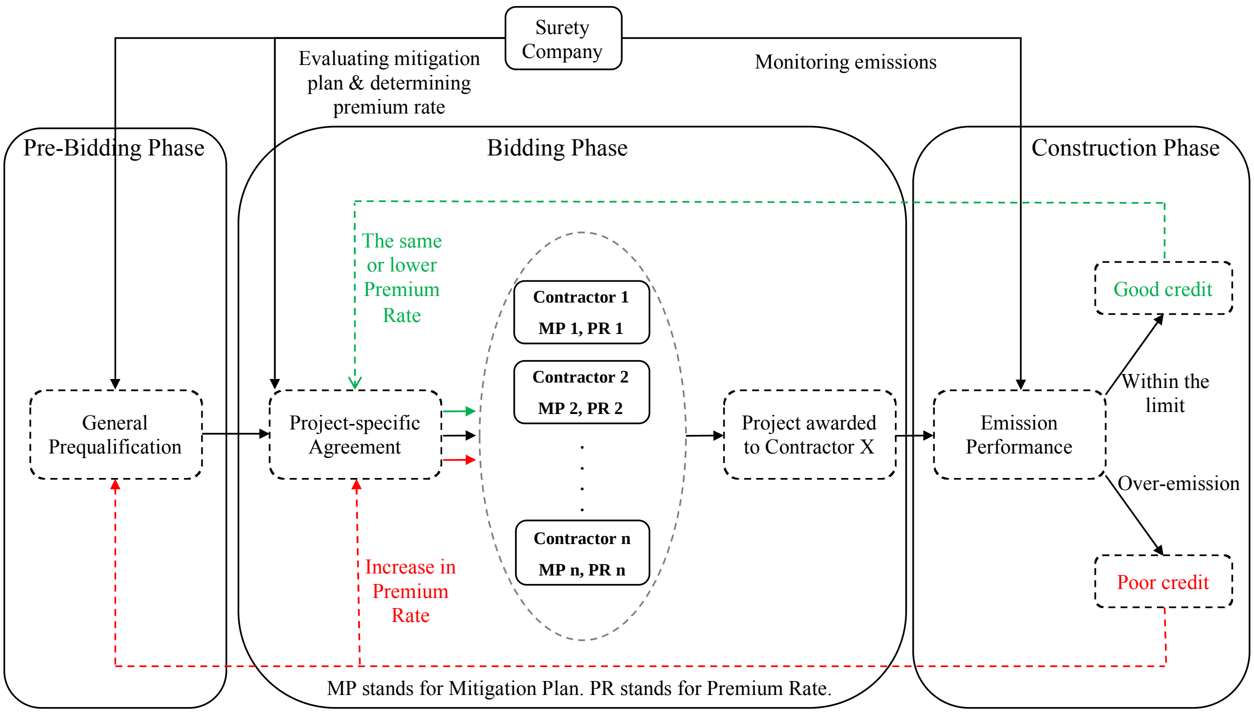

Figure 1: The proposed framework based on the concept of green performance bond (adapted from Asgari et al. (2017)).

4 METHODOLOGY: AGENT-BASED MODELING

To investigate the practical potential of the green performance bond framework in dealing with opportunistic bidding behavior, the A+C bidding environment is simulated using agent-based modeling. Then, this model is used to design and conduct simulation experiments that aim to evaluate the effectiveness of the framework. Agent-based modeling (ABM) is a powerful modeling and simulation paradigm. In ABM, the behaviors and interactions of autonomous agents are simulated at the micro level with the aim of evaluating their impacts on the macro level. ABM can be useful for conducting ex-ante analysis of complex systems and developing proof-of-concept models for various research purposes (Axelrod 1997). The A+C bidding environment can be perceived as an interactive, dynamic and complex system of heterogeneous and autonomous agents (owners, contractors and surety companies). Figure 1 presents an abstraction of the agent-based model to that is developed in this study.

AnyLogic, a Java based multimethod simulation modeling software, is used to implement the conceptual agent-based model explained above. Four classes of objects are defined in the model: owner, contractor, surety, and project. The class 'project' is not an agent but since a project has its own Parameters, Variables, Functions, Collections, and Statechart, project is defined as an active object. In each run of the simulation model, 1000 projects are generated consecutively. Once generated, a set of characteristics such as the planned construction budget (10 M$) and the planned project duration (10 time units) are assigned to a project. Each contractor has a number of attributes and parameters including initial bonding capacity, net worth, and current work volume as well as a function for markup decision. Contractors, observing the newly generated project, are given estimated construction costs for completion of the project, randomly drawn from a uniform distribution around the project budget. See Awwad et al. (2014) to learn more about the details of the agent-based model of the bidding environment.

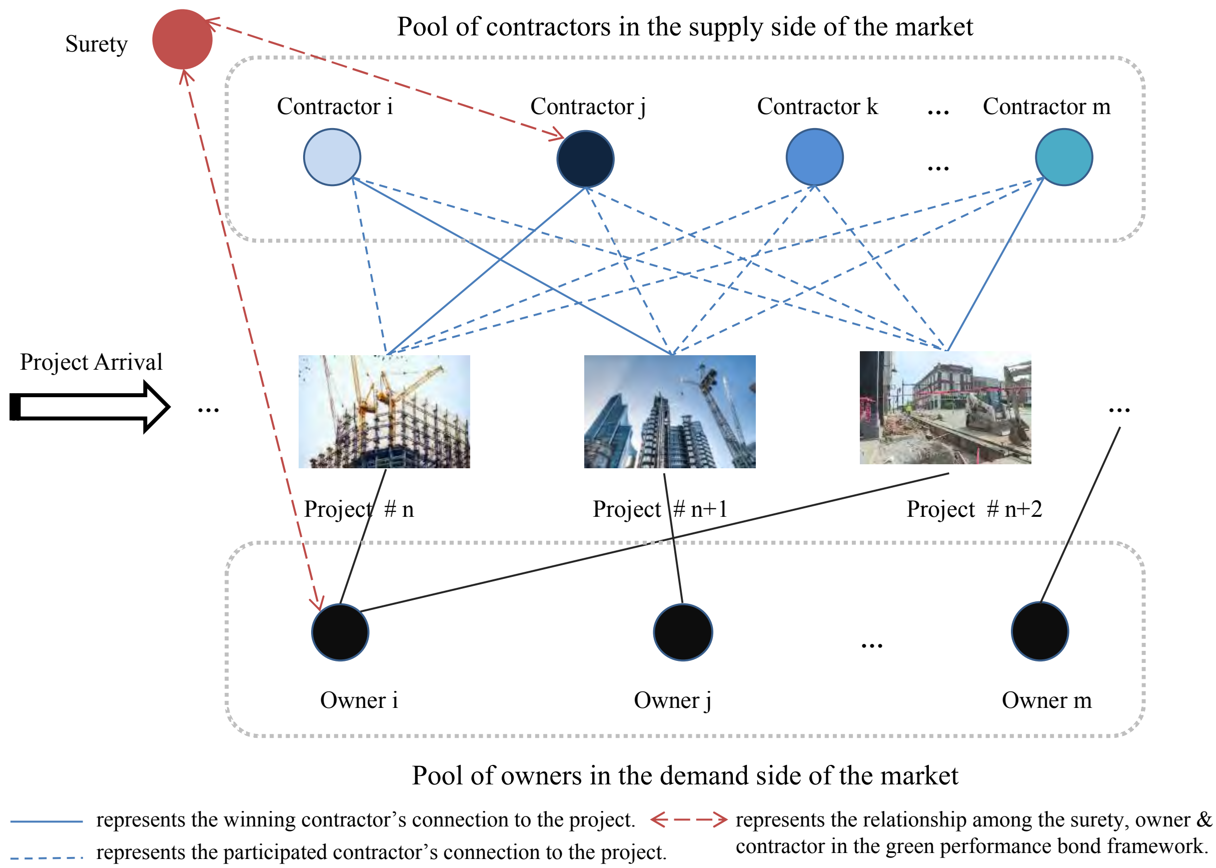

Figure 2: The Abstraction of the A+C Bidding Environment.

The main assumptions of the model are the following: (1) The winning contractor for a project is selected through the A+C bidding process. (2) Contractors in the market will remain the same throughout the simulation. (3) All contractors have the same characteristics including size, initial working capital (which is zero), and general and administrative (G&A) costs. (4) All contractors have the same level of construction cost estimating accuracy, management capability and expertise. (5) Each contractor is assigned an estimated construction cost for each project, drawn from the uniform distribution [9.7M$,10.3M$]. This is a reasonable assumption as the expected accuracy range of estimate class 1 with maximum preparation effort is ±3% (Christensen et al. 2011). (6) Each contractor chooses a markup randomly drawn from the uniform distribution [3%,5%]. This is aligned with the markup rates reported in the literature (Ross & Williams 2012). (7) The actual construction cost for the winning contractor is equal to its estimated construction cost. (8) The environment cost of the project is equal to 4%-6% of the construction budget. (9) There are five potential mitigation plans (Plan 1, 2, 3, 4 and 5) that reduce the environmental cost by 0%, 5%, 10%, 15%, and 20%. (10) If there is a gap between the promised level of GHG emission in the bidding phase and the actual level of GHG emission at the end of the project, the contractor requires to pay a penalty in dollar equivalent to the amount of over-emission. (11) The total over-emission of a contractor in the past projects has an inverse relationship with its eco-credit. A contractor's eco-credit has also an inverse and non-linear relationship with the premium the surety company is charging. Therefore, the more over-emission in the past, the lower eco-credit and the higher premium. (12) All contractors add the premium charged by the surety company to their bid price.

Table 2: Mitigation Plan Assigned to Contractors.

Agent	Contractor 1	Contractor 2	Contractor 3	Contractor 4	Contractor 5
Mitigation Plan	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Environmental Cost Reduction	0%	5%	10%	15%	20%

Table 3: Opportunist Contractor and Its Environmental Cost in Experiment Set B.

Experiment:	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Opportunist contractor	Cont. 1	Cont. 1	Cont. 1	Cont. 1	Cont. 2	Cont. 2	Cont. 2	Cont. 3	Cont. 3	Cont. 4
Aimed environmental cost reduction	0%	0%	0%	0%	5%	5%	5%	10%	10%	15%
Submitted environmental cost reduction	5%	10%	15%	20%	10%	15%	20%	15%	20%	20%
Percentage of underreporting	5%	10%	15%	20%	5%	10%	15%	5%	10%	5%

4.1 Description of the Experiments

Three sets of experiments (A, B, and C) are designed and conducted to examine the practicality of the proposed green performance bond framework in dealing with opportunistic bidding behaviors. To ensure the consistency and reliability of the results each experiment has been run for 100 times.

Experiment Set A: the purpose of the experiment set A is to show how A+C bidding method is benefiting the more environmentally responsible contractors. Experiment A0 is a scenario in which contractors are selected based on only the construction cost. In experiment A1, contractors are evaluated based on both their construction and environmental bids. Without using a mitigation plan, it is assumed that a project has a specific emission level but contractors have potential mitigation plans that reduce the environmental cost. The reduction in the environmental cost as a result of the mitigation plan is presented in Table 2. This study assumes that the contractors achieve their promised mitigation plan and do not act opportunistically in this experiment set. Experiment A1 is named “the base scenario”.

Experiment Set B: the purpose of the experiment set B is to show how an opportunist contractor can take advantage of the A+C bidding method to win more contracts while not acting environmentally responsible. In each experiment of this set (B1 to B10), one contractor is bidding opportunistically which means the contractor proposing a mitigation plan in the bidding phase that he will not intend to implement in case he wins the bidding. Table 3 presents the opportunist contractor and the percentage of the underreported environmental cost. For example, if contractor 1’s environmental cost is 0.5M$ in the experiment B3, he submits 0.35M$ for the environmental cost.

Experiment Set C: the purpose of the experiment set C is to show how the green performance bond framework can prevent an opportunist contractor taking advantage of the A+C bidding method. The settings of the experiments of this set (C1 to C10) are exactly similar to the ones of the set B except that the green performance bond framework is in place. The premium determination is a key component of the green performance bond. This study uses a quadratic function to establish the relationship between a contractor’s eco-credit and premium rate. First, the eco-credit is determined by taking into account the over-emissions of a contractor in all previous projects using the following equation:

$$Ecocredit = \frac{1}{1+\sum_{i\in contractor's\ past\ projects}\frac{overemission\ of\ project_i}{environmetal\ cost\ of\ project_i}}$$

Eco-credit is a positive number between zero and one. Once the eco-credit is determined, a premium rate and premium can be assigned to the contractor for a future project using the following functions:

$$Premium\ Rate = (1 - Ecocredit)^2$$

$$Premium = C \times Premium\ Rate + k$$

In the above equation, *C* is the environmental cost and *k* is a fixed fee for all contractors. Since its value has no impact on the bidding outcome, k is set to be zero.

5 SIMULATION RESULTS & DISCUSSION

This section presents the results of the simulation experiments and discusses key observations and insights on these results. Table 4 presents the results of the experiment set A. Because the market in the experiment A0 is homogeneous and all contractors are similar in their characteristics and actions, the market shares and profits are almost evenly distributed among all contractors. The small differences ensue from the fact that some key variables for each contractor including cost estimates and markups are drawn randomly from a defined distribution for every single project. Looking at the results of the experiment A1, a direct relationship can be observed between the environmental cost reduction by the mitigation plan and the market shares as well as the profits. Comparing the results of A1 and A2 suggests that implementing A+C method changes the distribution of market share and profit in favor of those contractors with a better mitigation plan (proposing lower environmental costs).

Table 4: Results of Experiment Set A.

Experiment:	A0	A1
Market Share of Contractor 1	20%	12%
Market Share of Contractor 2	20%	16%
Market Share of Contractor 3	20%	19%
Market Share of Contractor 4	20%	23%
Market Share of Contractor 5	20%	30%
Profit of Contractor 1 (M$)	74	45
Profit of Contractor 2 (M$)	74	57
Profit of Contractor 3 (M$)	76	71
Profit of Contractor 4 (M$)	72	87
Profit of Contractor 5 (M$)	75	111

Tables 5 and 6 present the results of the experiment set B and C, respectively. These tables provide the market shares and profits of all contractors and compares the performance of the opportunist contractor with the ones in the experiment A1 (the base scenario). The opportunist contractor is highlighted in gray for each experiment and the OBB stands for opportunistic bidding behavior. For example, in experiment B5, contractor 2 is bidding opportunistically and his resulted market share and profit are 19% and 65, respectively. And the last two rows indicate that the contractor 2 has gained additional 23% gains in market share and 16% gains in profit due to the opportunistic bidding behavior.

The results of the experiment B, in particular the last three rows of Table 5, shows that the A+C bidding method without the protection of the green performance bond can be taken advantage of by opportunistic contractors which results in unfair distribution of market share and profit as well as significant GHG over-emission. Also, observing the changes in market shares and profits of the opportunistic contractors in experiments B1, B5, B8, and B10 suggests that contractors with no previous record of reducing the GHG emissions have more incentive to bid opportunistically and over-emit during the project.

Comparing the performance of opportunistic contractor in each experiment of the set C with its counterpart experiment of the set B proves that implementing green performance bond framework leaves no rational incentives for opportunistic bidding behaviors as the highlighted market shares and profits in Table 7 are considerably lower than the ones in Table 6. Also, the last two rows indicate that a contractor would lose market share and profit if he chooses to bid opportunistically in A+C contracts protected by the green performance bond.

In Tables 5 and 6, the row "Number of Opportunistic Success" presents the number of times the opportunistic contractor won the bidding only due to lowering his overall bid by misreporting its target emission level. In other words, the second-best bid would have won the bidding if the contractor did not bid opportunistically. Comparing the experiments of set B with its counterpart ones of set C, the number of opportunistic success has been reduced significantly by implementing the green performance bond framework.

Table 5: Results of Experiment Set B.

Experiment:	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Market Share of Contractor 1	15%	18%	22%	24%	11%	11%	11%	12%	11%	12%
Market Share of Contractor 2	16%	14%	14%	13%	19%	22%	25%	15%	14%	15%
Market Share of Contractor 3	19%	18%	17%	17%	19%	18%	17%	23%	26%	19%
Market Share of Contractor 4	23%	23%	21%	20%	23%	22%	21%	23%	22%	27%
Market Share of Contractor 5	27%	26%	26%	25%	27%	26%	26%	26%	27%	27%
Profit of Contractor 1 (M$)	52	59	65	66	41	42	41	44	42	45
Profit of Contractor 2 (M$)	58	53	49	49	65	72	76	56	51	55
Profit of Contractor 3 (M$)	70	67	64	62	71	68	63	81	83	70
Profit of Contractor 4 (M$)	85	85	80	75	87	81	78	87	82	95
Profit of Contractor 5 (M$)	101	99	97	95	102	98	95	99	101	101
Over-emission due to OBB (M$)	3.8	9.2	16.4	24.1	4.7	11.1	19.2	5.8	12.8	6.8
Number of Opportunistic Success	25	56	91	120	29	61	94	32	66	34
Change in Market Share due to OBB	23%	49%	76%	95%	23%	43%	64%	20%	32%	17%
Change in Profit due to OBB	16%	30%	43%	46%	14%	25%	33%	13%	16%	10%

Table 6: Results of Experiment Set C.

Experiment:	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Market Share of Contractor 1	4%	3%	3%	2%	14%	15%	15%	15%	16%	16%
Market Share of Contractor 2	17%	18%	18%	18%	5%	4%	3%	19%	19%	20%
Market Share of Contractor 3	21%	22%	22%	22%	23%	23%	23%	6%	4%	24%
Market Share of Contractor 4	26%	26%	26%	27%	27%	26%	27%	28%	28%	7%
Market Share of Contractor 5	32%	31%	32%	31%	31%	33%	32%	33%	33%	35%
Profit of Contractor 1 (M$)	18	14	12	12	53	56	55	55	60	58
Profit of Contractor 2 (M$)	64	67	66	67	22	18	15	71	70	73
Profit of Contractor 3 (M$)	80	81	82	81	86	84	85	27	21	89
Profit of Contractor 4 (M$)	97	99	98	101	100	98	101	104	106	33
Profit of Contractor 5 (M$)	119	117	120	118	119	123	123	124	124	130
Over-emission due to OBB (M$)	1.0	1.4	1.8	2.4	1.2	1.8	2.3	1.4	2.1	1.6
Number of Opportunistic Success	9	11	15	18	11	14	17	11	15	12
Change in Market Share due to OBB	-67%	-76%	-80%	-80%	-69%	-76%	-80%	-71%	-78%	-72%
Change in Profit due to OBB	-60%	-70%	-74%	-74%	-61%	-69%	-74%	-62%	-70%	-62%

For verifying the simulation results, first the model is decomposed into several computational components and then the calculations of each component are manually computed, compared and verified with the model computations. The validation of the simulation results is a challenging task in the development of agent-based models. The agent-based model developed in this study is used to conduct a thought experiment for hypothetical scenarios. Therefore, appropriate techniques for validating the results are limited. In this study, first, structural validation is performed to ensure that the conceptual model is the mathematical/logical/verbal representation (imitation) of the problem (Sargent 2013). Then, sensitivity analysis is conducted to examine how uncertainty in the model inputs can change the model outputs and whether the outcomes are within a realistic and expected range.

The results of this study are bounded to the assumptions of the developed model. Some assumptions are made so that a comparison between the results of having the green performance bond in place and the results of not having it can be done. The author acknowledges that not all variables and factors affecting the bidding process are included in the model and that the model is not be a perfect representation of reality. For example, in real-world situations, contractors do not remain static in response to the changes in their environment. They constantly try to improve their qualifications and mitigation plans, and change their bidding behavior (opportunistic or other) to gain competitiveness in the market.

It is worth emphasizing that the developed model is not to serve as a decision-making tool. As Axelrod (1997) argues that agent-based modeling may not necessarily represent an empirical application, the goal is to provide a deeper understanding of the green performance bond framework, which might not be possible by intuition.

6 CONCLUSION

A+C and A+B+C bidding methods are innovative green contracting strategies for addressing climate change and reducing greenhouse gas emissions during construction. However, there some practical challenges that cast doubts on their successful implementation in large scale. This study introduces a framework based on the concept of green performance bond that are able to tackle those challenges in particular opportunistic bidding behavior. The main contribution of this study is to verify and evaluate the practical potential of the proposed framework in addressing opportunistic bidding behaviors. This study uses agent-based modeling to simulate the A+C bidding environment and conduct simulation experiments in which contractors try to increase their probability of winning by intentionally submitting an unrealistic emission mitigation plan. The results of the simulation suggest that the green performance bond framework is able to meaningfully decrease the over-emission and the probability of success of an opportunistic bid in the A+C bidding method. Future studies can employ game theoretic analysis and agent-based models to model the interaction among all stakeholders and parties and investigate impacts of the green performance bond on the construction industry. Also, scenarios in which contractors change their mitigation plan or their behavior from opportunistic to non-opportunistic over time can be studied.

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