Consideration of the Environmental Cost in Construction Contracting for Public Works: A + C and A + B + C Bidding Methods

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Abstract: Growing concerns about sustainable development have brought about an urgent need to develop global efforts to mitigate environmental impact. Although construction projects and their related activities consume much energy and generate a significant amount of greenhouse gas (GHG) and other diesel emissions, the efforts to mitigate these emissions remain at an early stage. To address this issue, this paper explores opportunities to consider contractors' green capabilities during the bid evaluation phase. Based on reviews of the success story of the A + B bidding method, this paper suggests a modified bidding system in which contractors bid on the cost (part A) and environmental cost (part C) or on the cost (part A), time (part B), and environmental cost (part C) for public projects. An application of the proposed bidding methods is described using a bid for a highway reconstruction project. This case study reveals the potential impact of environmental cost criteria on the selection of a winning bid. The result of this case study indicates that the proposed bidding methods can offer bidding incentives to create sustainability initiatives for public works contractors. **DOI:** 10.1061/(ASCE)ME.1943-5479.0000124.

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Introduction

Climate change and greenhouse gas (GHG) emissions are at the center of global environmental discussions. Recently, the U.S. EPA concluded that six GHGs—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) are air pollutants that "endanger both the public health and the public welfare of current and future generations" (EPA 2009a). Although the form of GHG reduction policies remains controversial, it is evident that all industrial sectors consuming fossil fuel energy will be required to join efforts to reduce energy consumption and GHG emissions to address climate change.

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Construction activities to construct buildings and infrastructure also consume significant amounts of energy and generate considerable levels of GHG emissions. The EPA's report (EPA 2008a) on key industrial sectors stated that construction activities represented 1.7% of the total U.S. GHG emissions. This places the construction industry as the third highest contributor of GHG emissions among all U.S. industrial sectors, ranking just behind the oil and gas sector (7% of total U.S. GHG emissions) and the chemicals manufacturing sector (5.2% of total U.S. GHG emissions) (EPA 2008a).

In addition to GHG emissions, construction equipment is one of the major sources of diesel exhaust emissions, such as particulate matter (PM) and nitrogen oxides (NO_x). These emissions are major contributors to smog, acid rain, and other health hazards. The use of construction equipment accounts for 32% of NO_x and 37% of PM emissions from all nonroad mobile sources [EPA Clean Air Act Advisory Committee (CAAAC) 2006]. The construction industry has therefore attracted regulatory attention regarding air quality issues, for example, EPA's emission standards for nonroad diesel engines (EPA 2004) and California's recent rules for in-use off-road diesel engine emissions [California Air Resources Board (CARB) 2011]. However, the trend of those air pollutants from construction equipment has remained steady or decreased relatively slowly compared to the emissions from on-road vehicles over the past few years (EPA 2008b).

Contractors could mitigate emissions by replacing old equipment with pieces that are new and energy-efficient and by using cleaner fuels. By reducing transportation loads, the reduction of waste and the use of locally manufactured/supplied materials could further contribute to the decrease of emission levels. However, voluntary innovation by contractors on this issue is rare because the costs involved with improving the environmental performance of equipment outweigh the short-term benefits. In this context, some types of incentives are required to stimulate contractors' green efforts.

In this paper, it will be argued that giving a bidding preference to a green contractor during the evaluation of bids would be a cost-effective incentive for spurring on the innovation of contractors. This idea is based on the record of success of alternative contracting methods (ACMs). During the past two decades, the implementation of ACMs has increased among a number of state transportation agencies (STAs) to promote accelerated project delivery (Anderson and Damnjanovic 2008). The inclusion of time criteria in ACMs, such as the cost plus time method (also called the A + B method), has resulted in schedule reductions without any substantially adverse effect on other criteria, such as cost and quality. With that said, it is proposed to include the environmental cost of construction emissions as a criterion in new contracting methods to encourage contractors to undertake efforts to reduce emissions that arise from their activities. The methodology to evaluate the green efforts of bidders in the proposed contracting methods will be also presented.

Considering construction emissions as a criterion for awarding contracts encourages contractors to seek cleaner construction equipment, methods, and processes, moving beyond the incentives merely to account for and monitor construction emissions from a given project. With this bidding method, the client (predominately public entities in these scenarios, but also private entities) would be able to show stakeholders and end-users its commitment to the environment, achieving a green project delivery and maintaining a competitive advantage in an increasingly green market.

Emissions from Construction Projects

The significance of aggregated GHG emissions generated by construction operations has been assessed from various perspectives. Indirect GHG emissions from the supply chains of construction materials are not included in the following estimates on construction GHG emissions. The aforementioned EPA report on key industrial sectors (EPA 2008a), for example, used energy expenditures of industrial sectors [Department of Commerce (DOC) 2005] to estimate that construction produced 131 million metric tons (MMT) of CO_2e (1.7% of total U.S. GHG emissions) in 2002. Sharrard et al. (2007), however, states that emissions from on-road transportation sources utilized by the construction industry also need to be included. If this study's estimate of the energy use of construction-related transportation was included, the overall GHG emissions from the construction industry for 2002 would be 178 MMT of CO_2e. This level of energy consumption corresponds to 2.6–3% of the entire energy consumption of the U.S. (Sharrard et al. 2007). The construction industry is not directly affected by the EPA's recent final rule (EPA 2009c) on GHG emissions that requires the monitoring of emissions from major sources; however, it is expected that future regulations will have a tremendous impact on the industry [Associated General Contractors of America (AGC) 2010; EPA 2009b].

The two biggest sources of energy consumption in construction are the on-site operation of construction equipment and the on/off-road transportation of materials, equipment, and waste (EPA 2009b; Bilec et al. 2006; Guggemos and Horvath 2006). The major opportunities to reduce GHG emissions in construction can thus be found in the operation of on-site equipment and off-site transportation. In particular, the carbon emission intensity—a ratio of GHG emissions per value added dollar—of highway, road, and bridge construction is more than double the average emission intensity for the construction sector as a whole (EPA 2009b). Therefore, the role of public transportation agencies, which mostly execute highway, street, and bridge construction, is important in mitigating GHG emissions from the construction of transportation facilities. In this context, the proposed bidding methods will aid these agencies by engaging their contractors in environmentally-conscious construction practices.

In addition, diesel is the major energy source for construction because of the predominant use of diesel engines in construction equipment. The diesel exhaust emissions from construction equipment contain a large amount of criteria air pollutants (CAPs), which could cause immediate and serious adverse health and environmental effects (EPA CAAAC 2006); off-road construction equipment causes a disproportionately high share of PM2.5 and NO_x in national inventories, equivalent to 2.8 and 3.8%, respectively (EPA CAAAC 2006). Particularly in the case of urban construction, such hazardous air pollutants are concentrated within a short time frame and a relatively small space, creating a scenario in which the potential for adverse health and environmental effects could be higher.

Currently, the EPA's regulations for off-road diesel engines (EPA 2004) have the greatest impact on construction diesel emissions. These regulations control the allowable emission rates of off-road diesel engines by their year of manufacture and horsepower (named successively Tier 1, Tier 2, Tier 3, Tier 4 Transitional, and Tier 4 Final). However, in construction, the average lifetime of construction equipment is relatively long. Consequently, a large share of in-use construction equipment was manufactured under Tier 1—the least stringent standard—and was therefore not affected by any existing EPA regulations. In addition, regulations are concerned with emission rates rather than with the actual amount of emissions generated by construction processes. Unfortunately, efforts to reduce emission rates are partly offset by increases attributable to the demands of an expanding economy in the sheer number of engines, their operating hours, and their horsepower. To cover this insufficiency, there exist several financial incentives that provide direct/indirect funding to contractors and equipment owners to replace old equipment with new and cleaner equipment, or to purchase emission reduction devices (Ahn et al. 2010). Some of those incentives have reportedly resulted in effective emission reduction in many case projects, but could not have brought industry-wide success. In this context, the proposed bidding methods will aid in achieving the industry-wide adoption of green construction practices.

Environmental Considerations in Construction Contracting

The environmental impact of construction activities has been widely contemplated in construction contracting in the form of contract specifications, contract allowances, and bidding preferences (Cui and Zhu 2011). Contract specifications require contractors and subcontractors to use construction equipment certified by the EPA or to install diesel emission retrofit devices, such as diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs). Such contract specifications are found in several public projects, such as the Central Artery project undertaken by the Massachusetts Highway Department, the Dan Ryan Expressway project undertaken by the Illinois DOT, and in every contract put forward by the New York Metropolitan Transportation Agency (EPA 2011). These types of contract specifications do not directly affect the selection of contractors in the bidding evaluation process, but they can potentially limit bid participation from small contracting companies that may lack the financial wherewithal to upgrade equipment and purchase emission control devices (ICF 2005). Contract allowances reimburse part or all of the initial purchase cost of green equipment and technologies to spur contractors' use of cleaner construction equipment. For example, Texas DOT Special Specification 5018 provides an incentive to contractors who use cleaner engines and fuels on roadway and maintenance projects, based on two factors, namely, engine horsepower and operation time of equipment on site (Cui and Zhu 2011). However, the use of bidding preferences that provide advantages to a green contractor in bidding evaluation has rarely been found.

In contrast to the efforts of mitigating diesel emissions delineated above, the GHG emissions and energy consumption from construction processes have rarely been a concern in contracting processes (ICF 2008). A handful of transportation agencies, such as the New York State Department of Transportation (NYSDOT) and the Metropolitan Transportation Commission in the San Francisco Bay area, have considered the importance of mitigating construction emissions in the planning phase, addressing the issue through environmental impact assessment reports (ICF 2008). In these cases, these analyses are used to compare overall energy consumption between No-Build and Build alternatives, rather than to identify mitigation opportunities for construction GHG emissions. Yet the emission intensity for transportation facility construction is considerable, and transportation agencies will need to identify mitigation opportunities more vigorously in the future. The proposed bidding methods, by encouraging contractors to compete regarding GHG emission reduction, would thus involve contractors in identifying cost-effective mitigation opportunities.

Evaluation of Green Capabilities of Contractors in Construction Contracting

The contractor's capability to perform green construction has not been considered in traditional contract and bid evaluation practices. Contractors are unlikely to voluntarily improve their capability (e.g., newer equipment, retrofitting, and cleaner fuel). The criteria to evaluate green capabilities of contractors therefore need to be included in the bid evaluation process to realize effective change. This line of thought is supported by the success of the A + B bidding method, which includes time in the low bid determination, to reduce schedules. It is therefore suggested an A (cost) + C (environmental cost) and/or an A (cost) + B (time) + C (environmental cost) bidding method. Each includes the environmental cost caused by construction-related activities in the bid evaluation.

Success of the A + B Bidding Method

To rectify disadvantages in conventional competitive bidding systems in which a contractor is selected based only on a cost evaluation, various ACMs have been suggested and recently implemented. The A + B method, for example, which is also referred to as cost-plus-time bidding, has been increasingly utilized to accelerate project completion in highway construction (Anderson and Damnjanovic 2008). Within this system, each bidder is required to bid on two components: the total construction cost (A) and the total number of days necessary to complete the project (B). The lowest combined bid is calculated by using the following formula:

$$\text{Bid award cost} = \text{A} + (\text{B} \times \text{Road user cost}) \tag{1}$$

In this formula, A = cost estimate in dollars; B = time estimate in days; and Road user cost = daily road user cost in dollars per day.

The road user cost (RUC) represents the increased operating costs incurred by traffic delays (time and distance) and agency costs (inspection and traffic control), and is calculated by the owners, which are usually state highway agencies. As stated, the winning bid in the A + B method is determined by a combination of the A and B components. However, the cost reimbursement awarded to the winning contractor is determined based solely on the amount of the A bid. Incentive/disincentive (I/D) provisions are also usually included in this bidding system to ensure that the completion date is attained and to encourage a further reduction in the actual time required for construction.

According to the Federal Highway Administration's (FHwA) report on ACMs (Anderson and Damnjanovic 2008), 26 out of 30 responding STAs have used the A + B bidding system, and 13 have utilized the method more than 10 times. Further, 60% of the respondents stated that the A + B bidding method affected a 5% or greater reduction in project duration. A comprehensive evaluation of A + B contracting practices in Minnesota between 2000 and 2005 [Minnesota DOT (MnDOT) 2006] indicated a 15% reduction in estimated construction time when the time bid of the low combined bidder was compared to the maximum schedule estimate of the MnDOT. Furthermore, an 11% additional reduction was reported once actual construction time was compared to the low time bid plus extensions. No notable adverse effect on cost or quality has been reported when the A + B method has been utilized (Ellis et al. 2007).

Surprisingly, the actual impact of the time component in determining the lowest combined bid of the A + B bidding system is not that significant. In 90 out of 120 NYSDOT contracts in which the A + B bidding method was used, the lowest cost (A) bidder became the lowest combined bidder [even though it was not the shortest time (B) bidder in some cases] and was awarded the contract (Kent 2003). In only 30 out of 120 contracts, the combined lowest bidder did not have the lowest cost bid, but did have the shortest time bid. Furthermore, within these 30 bids, the difference between the lowest cost (A) bids and the cost (A) bids of the successful contractors [who had shorter time (B) bids but higher cost (A) bids] was typically small—less than 1% of the cost bid of the successful contractors (Kent 2003). This indicates that a success of the A + B bidding system in encouraging contractors to reduce completion times is seemingly connected to other motivational factors of a multiparameter bidding system, rather than relying on the actual impact of the time (B) bid in determining the lowest combined bidder. The most important factor of the A + B bidding system that enables its success is that the categorization of time as a bid component results in competition between contractors. To remain competitive among other bidders, contractors are forced to reduce construction time at the lowest cost. As a result, contractors' estimates concerning project duration tend to fall in comparison to the initial calculations of departmental engineers in most A + B bidding contracts (Ellis et al. 2007). This means that the use of the secondary factor does not increase the cost of the project, but offers an incentive to contractors to be more competitive in those secondary factors.

Cost + Environmental Cost and Cost + Time + Environmental Cost Bidding Methods

The proposed A + C and A + B + C bidding methods are based on the idea of the aforementioned multiparameter bidding system. In this type of bidding system, the winner is selected based on the combined dollar value of multiple components. In the A + C and A + B + C systems, bidders are required to bid on an additional C component that represents the environmental cost caused by their estimated construction energy use and emissions. The A + C method adds this C component to the conventional cost (A) bidding process. The $A + B + C$ system in turn modifies the $A + B$ bidding method by adding a C component. The weight of the C component can be used to increase the bidding preference for a green contractor. This idea is discussed further in the "Case Study" section. The winning contractor will thus submit the lowest total combined bid, which is calculated with the following formula:

$$\text{Bid award cost} = A + \{B \times \text{Road user cost}\} + (C \times \text{weight}) \quad (2)$$

In this formula, A = cost estimate in dollars; B = time estimate in days; Road user cost = daily road user cost in dollars per day; and C = estimated environmental cost. $\{B \times \text{Road user cost}\}$ is included only in the $A + B + C$ bidding method.

As with the $A + B$ bidding method, the A bid will be the sole determinant for the base cost reimbursement awarded to the winning contractor. Incentive/disincentive provisions should also then be included in the $A + C$ and $A + B + C$ bidding methods to ensure compliance with targets for the emission levels permitted by the contract and to encourage further reductions.

The C bid (environmental cost) is defined based on the concept of the eco-costs (Vogtländer et al. 2001), and is calculated with the following formula:

$$\begin{aligned} &C(\text{environmental cost}) \\ &= \Sigma(\text{emission estimate} \times \text{eco-cost of emission}) \\ &\quad + \Sigma(\text{fossil fuel use} \times \text{eco-cost of material depletion}) \quad (3) \end{aligned}$$

The environmental cost is determined by combining the environmental cost of emission generation (the amount of each emission generated by construction activities multiplied by the eco-cost of each emission) and the environmental cost of energy use (the amount of fossil fuel consumed multiplied by the material depletion eco-cost of the fossil fuel used). The following section discusses how the C bid of each contractor can be calculated. It also contains a detailed discussion of how eco-cost is determined.

Environmental Assessment of a Construction Project

To determine the C bid, bidders are required to assess the environmental impact that will be caused by their construction activities, such as air pollutant emissions and energy consumption. The environmental assessment of a construction project can be performed with life-cycle assessment (LCA), such as a process-based or an input-output approach. A process-based approach analyzes the known energy input and output for each step of the construction process and produces reliable estimates that are able to consider variations in construction means and methods (Fava et al. 1991). The input-output approach addresses this problem of data collection by using averages and general analyses of past projects or by using sector-by-sector interaction data (Hendrickson et al. 1998). These approaches have strengths and limitations. To combine the advantages of both approaches, several hybrid models have been suggested for building construction (Guggemos and Horvath 2006; Sharrard et al. 2008).

For $A + B$ and $A + B + C$ bidding methods, a process-based approach is recommended because it ensures better accountability of environmental impact assessment of construction plans (equipment fleet, fuel, and material source selections) of bidders, and thereby permits bidders to benefit from any improvements regarding their green capabilities. In contrast, an input-output approach tends to provide average estimates that are based on past projects and do not consider the selection of construction methods and equipment.

The scope of the environmental impact assessment, especially when a process-based approach is chosen, also needs to be carefully defined at the bid letting stage; otherwise, environmental impact estimates could vary greatly. This will be closely connected with project delivery methods (e.g., design-bid-build or design-build). In the case of design-bid-build projects, there would generally be no significant difference in the environmental impact related to the material use between the bidders. Then the scope of environmental impact assessment includes only direct emissions generated by on-site equipment operation and transportation (from final suppliers to the construction site). In contrast, design-build projects require the inclusion of the environmental impact related to the material use of each bidder (e.g., recycled material and pavement type) in the assessment boundary.

Environmental Cost Calculation in the $A + C$ and $A + B + C$ Bidding Methods

For the implementation of the $A + C$ and $A + B + C$ bidding methods, the result of the environmental impact assessment of bidders needs to be expressed in a single monetary value. There are a number of impact assessment methods that interpret the LCA result and provide an LCA-based single indicator, for example, Eco-indicator 99 (Goedkoop and Spriensma 1999) and Life Cycle Assessment—An Operational Guide to the ISO Standards 2001 (Guinee et al. 2001). In this paper, the eco-costs proposed by Vogtländer et al. (2009) were chosen, because (1) the eco-costs are expressed in a standardized monetary value that can be easily understood; and (2) the calculation is transparent compared to a damage-based model that involves complex calculations with subjective weighting of the various aspects contributing to the overall environmental burden (Bengtsson and Steen 2000; Finnveden 2000).

Most methods to calculate a single indicator are based on damage costs, also referred to as external costs. This is the monetary value assigned to the damage caused by a unit of emission or material use. The eco-costs, however, are based on prevention costs, also referred to as abatement costs. These are the costs required to reduce emissions to a sustainable level in a certain region (e.g., the European Union) with the most expensive available measures. For example, the prevention cost of CO_2 is the cost of replacing coal-fired power plants with windmill parks at the sea. Table 1 summarizes the eco-costs of emissions and material depletion related to construction activities. One drawback of using eco-costs is that they have been calculated for situations in the European Union. Therefore, it can be replaced with other impact

Table 1. Eco-Costs of Emissions and Material Depletion (Vogtländer et al. 2009)

Environmental burdens	Eco-costs	
	(€/kg)	($/kg)[a]
Emissions		
CO_2	0.135	0.1755
CO	0.24	0.312
SO_2	7.55	9.815
NO_x	5.29	6.877
$PM_{2.5}$	27.44	35.672
VOC	3.54	4.602
Material depletion		
Diesel	0.7	0.91
Petrol	0.7	0.91

[a]Calculated with the currency rate of €1 = $1.3 as of Dec. 27, 2011.

assessment methodologies that are developed for the United States, if available.

Case Study

To illustrate the proposed bidding system, a hypothetical case study for the A + C bidding method was developed based on the LCA case study of Cass and Mukherjee (2011) and its actual bidding information. The chosen project is a pavement rehabilitation and reconstruction project of a 7-mile four-lane road in the state of Michigan. Cass and Mukherjee (2011) quantified the environmental impact from construction equipment use, transportation, material manufacturing, equipment manufacturing, and fuel production. Because this project was delivered by design-bid-build, this case study includes only the emissions and fuel use from construction equipment use and transportation. For the quantification of emissions from construction equipment use and transportation, Cass and Mukherjee (2011) used an emission calculator, e-CALC (Sihabuddin and Ariaratnam 2009), which is based on EPA's NONROAD model (EPA 2008b). This paper uses their transportation results as is. The emissions and fuel use from construction equipment, while based on Cass and Mukherjee (2011)'s input data, are recalculated with the use of EPA's NONROAD model, which allows for better testing of the impact of various fleet configurations. The total eco-costs of each emission and fuel use are then assessed based on the eco-cost indexes listed in Table 1. Table 2 summarizes the amount of emissions, fuel consumption, and their eco-costs. The construction equipment use and on/off-site transportation in the case project are estimated to consume approximately 713 metric tons of fossil fuel (diesel), and to generate 2,264 metric tons of CO_2 emissions and 18 metric tons of NO_x emissions. The total eco-cost corresponding to those amounts of fuel use and emissions is found to be approximately 1.14 million dollars. The material depletion eco-cost of fuel consumption is higher than aggregated emission eco-costs, and the eco-cost of CO_2 emissions accounts for approximately 80% of aggregated emission eco-costs and 35% of total eco-costs.

Mitigation Options

There are many options that bidders could have adopted to reduce their fuel consumption and emissions in the case project. The impact of such mitigation options to the C bid (total eco-costs) is evaluated in this section to examine the magnitude of bidding preference that the adoption of the mitigation options can have in the proposed bidding system. Fig. 1 illustrates the change to the environmental cost (total eco-costs) by the adoption of different mitigation options. It is assumed that the contractor can control the fleet configuration of his/her construction equipment, but cannot control transportation vehicles that generally belong to material suppliers.

- **Replacement of old equipment to newer equipment:** As discussed earlier, newer equipment is manufactured under more stringent emission standards mandated by the EPA. For example, the NO_x emission rate of a Tier 3 excavator is 50% of that of a Tier 1 excavator with the same engine size. Cass and Mukherjee (2011) assumed that the model year of all the equipment used in the case project was 2008, and determined the tier information of equipment accordingly. But this assumption is

Table 2. Emissions, Fuel Use, and Their Eco-Costs of the Case Study

Energy use and emission sources	CO (kg)	NO_x (kg)	PM (kg)	THC (kg)	CO_2 (kg)	SO_x (kg)	Fuel use (kg)
On/off-site transportation	1,961	3,490	9	340	872,148	8	273,740
On-site construction equipment	3,756	6,917	445	506	1,393,097	27	439,682
Total emissions	5,718	10,407	454	845	2,265,245	35	713,422
Total eco-costs ($)	1,784	71,566	16,200	3,891	397,551	344	649,214

Note: 1) Emissions and fuel use are based on the study conducted by Cass and Mukherjee (2011), and the transportation results are identical. 2) Emissions and fuel use from construction equipment are based on Cass and Mukherjee's (2011) input data, but recalculated using EPA's NONROAD model. The NONROAD model allows for better testing of the impact of various fleet configurations. 3) The eco-cost is newly calculated with the eco-cost index in Table 1. THC belongs to a larger group of VOC (EPA 2010a), so the eco-cost of VOC is applied.

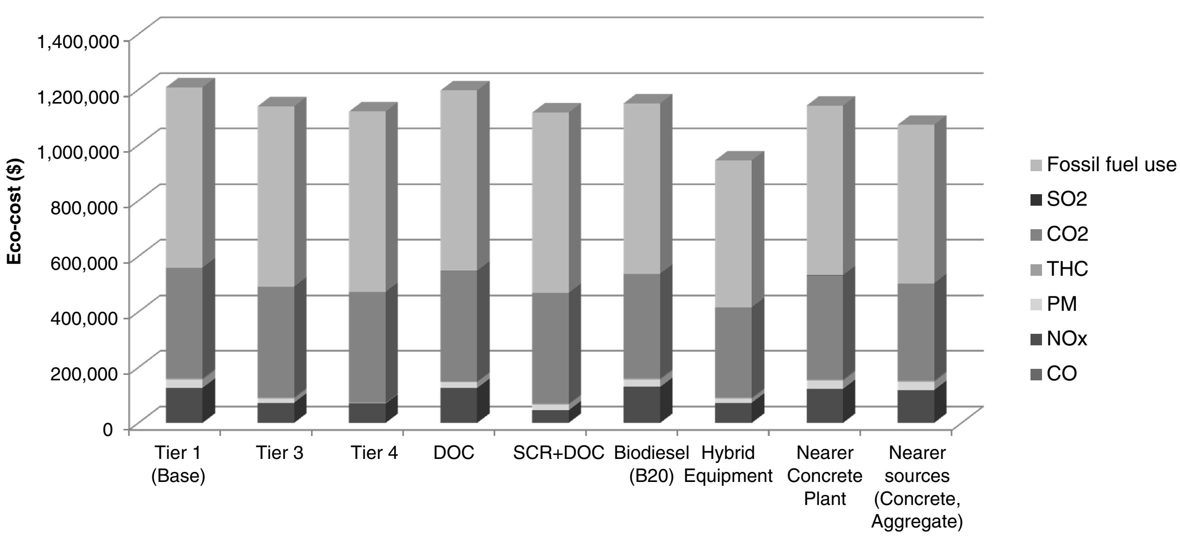

Fig. 1. Comparison of total eco-costs between mitigation options

quite optimistic, as they mentioned in their paper. Therefore, it was assumed that all the equipment used in the base scenario is Tier 1, and it was evaluated that the reduction of total eco-costs in the cases that all the equipment used is Tier 3 and Tier 4. A Tier 4 scenario (equipment manufactured after 2011) is not realistic for this project, but is tested for future reference. The total eco-costs of the Tier 3 and Tier 4 scenarios are reduced by 5.7 and 7.2%, respectively, compared to the base scenario (Tier 1) (see Fig. 1). The eco-cost savings in the Tier 3 and Tier 4 scenarios would be greatly underestimated compared to the real environmental benefits from replacing old equipment with newer equipment. The EPA's NONROAD model that is used to calculate the emissions in this paper uses fuel consumption rate and CO_2 emission rate of Tier 0 engines for all engines of different Tiers because of lack of data (EPA 2010b). The improvement of fuel economy in newer equipment, therefore, was not reflected in this result.

- **Use of retrofit devices:** Adding advanced pollution control devices such as a diesel oxidation catalyst (DOC), a diesel particulate matter filter (DPF), and a selective catalytic reduction (SCR) system of NO_x would reduce diesel emissions from construction equipment. The installation of a DOC can reduce PM between 20 and 50%, HC by 50%, and CO by 40% (EPA CAAAC 2006). An SCR system, an emerging technology for nonroad equipment that is expected to be used mostly in combination with DOC or DPF, can reduce NO_x between 70 and 90% (EPA CAAAC 2006). The use of DOC and SCR+DOC with all equipment used in the base scenario reduces the total eco-cost by 0.9 and 7.6%, respectively (see Fig. 1).
- **Use of biodiesel (B20):** The substitution of biodiesel fuels for petroleum diesel will reduce life cycle emissions for construction equipment. Still, biodiesel cannot be used in its pure form (B100) without a certain engine modification (EPA CAAAC 2006). A blend of 20% biodiesel and 80% regular diesel (B20) will reduce life-cycle energy consumption and CO_2 emissions by 9%, PM by 11.8%, and CO by 4.1%, but increase NO_x by 3.5% and HC by 1.6% (Pang et al. 2009). The use of B20 with all construction equipment saves total eco-costs by 4.8% (see Fig. 1).
- **Replacement with hybrid equipment:** Many manufacturers of construction machinery have recently released hybrid construction equipment. Compared to conventional construction equipment, hybrid construction equipment is known to consume approximately 30% less energy and generate less CO_2 emissions (Komatsu Ltd. 2008). However, the impact of hybrid equipment on other emissions is still unknown. In this case study, emission rates from hybrid equipment of other air pollutants are assumed to meet the Tier 3 standards. This scenario has 21.8% lower eco-costs compared to the base scenario.
- **Change of material sources:** Using nearer material sources will reduce overall emissions and fuel use generated from material transportation. In the case project, the transportation of concrete generated the highest emissions among 16 items of material delivered, and concrete was delivered from two different plants—one was 22.9 km (14.2 mi) from the job site, and the other was 42.3 km (26.3 mi). When assuming that all of the concrete is sourced from the nearer plant, the eco-costs are reduced by 5.5%. In the case that all aggregate is also sourced from the nearer pit (between the two different pits used), the eco-costs are reduced by 11.2%

Bidding Preference in the A + C Bidding Method

The effect in the A + C bidding process of various mitigation options and shifts in the weight upon the bid gap is explored further in Fig. 2. The bidding preference featured in Fig. 2 indicates the percentage of the A bid gap that a bidder can gain by adopting mitigation options against another bidder who does not have any mitigation plan (i.e., who stays with the base scenario); the A bids

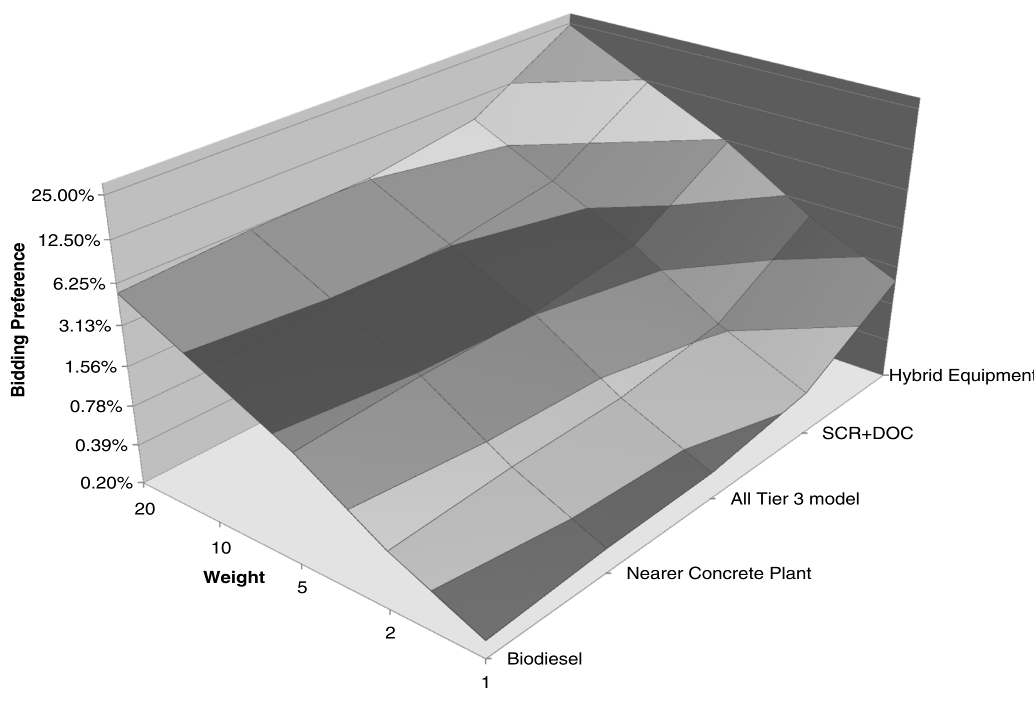

Fig. 2. Change of the bidding preference by adopting each mitigation measure in the case study

Table 3. Bid Tabulation Using A + C Bidding Method

Bidder	Construction cost (A) ($)−(rank)	Bid gap with the lowest bid ($)	Submitted mitigation plan	Environmental cost (C) ($)	Total combined bid (A + C) ($)−(rank)	Bid gap with the lowest bid ($)
X	21,735,224 (1)	0	None	1,208,498	22,943,722 (1)	0
Y	23,368,422 (2)	1,633,199	Hybrid equipment	945,424	24,313,846 (2)	1,370,125
Z	23,730,070 (3)	1,994,846	SCR+DOC	1,116,990	24,847,061 (3)	1,903,339
W	25,475,759 (4)	3,740,535	B20	1,150,502	26,626,261 (4)	3,682,539

Note: 1) A bid tabulation is based on the actual bid tabulation of the case project (Michigan DOT 2009). 2) The weight of the C bid is set at 1 (when the weight is set higher than 5, Bidder Y wins the bid.).

of those two bidders are assumed to be identical to the actual awarded cost of this case project, which is approximately 21 million dollars. For example, a bidder who plans to use hybrid equipment will have the same combined bids as another bidder who has a 1.21% lower A bid but does not have any mitigation plan. The weight to the C bid can be used to increase the bidding preference, based on the discretion of the owner. This weight should be determined considering the balance between the financial cost that contractors should put for implementing mitigation plans and the magnitude of the bidding preference that contractors have under the A + C bidding method. For example, a bidder using B20 can have a bidding preference under the A + C bidding method, the magnitude of which will be equivalent to 0.27% of the A bid in this case study. This level of bidding preference is comparable to the additional financial cost to the bidder using B20 instead of petroleum diesel, without placing any weight on the C bid. Therefore, even with no weight (weight = 1), the owner can spur contractors' use of B20 under the A + C bidding method. However, if the owner wants to encourage contractors to replace old equipment with newer equipment, then the weight may need to be set higher.

Table 3 illustrates the simulated bid tabulation using the A + C bidding method. The A bids (construction cost) of bidders are based on the actual bid tabulation of the case project (Michigan DOT 2009). Bidders are assumed to have different mitigation strategies for their construction emission and energy use. For example, Bidder Y is assumed to use hybrid equipment, Bidder Z is assumed to use SCR+DCR for all construction vehicles, and Bidder W is assumed to use B20 instead of petroleum diesel, whereas the lowest bidder for the A bid (Bidder X) is assumed to have no mitigation plan. When the bidding system shifts from the traditional to the A + C method, Bidders Y, Z, and W can reduce the final bid gap between themselves and the lowest bidder (Bidder X). In this case study, the gap between the A bids of Bidder X and other bidders was more than 7%, so the green efforts of bidders cannot reverse the final bid result in the A + C bidding system. However, in the scenario in which the weight is set more than 5, the second lowest bidder in the traditional bidding method could be awarded the bid in the A + C bidding method. This case study thus illustrates that the green efforts of bidders can be a critical factor when determining the bid result in the A + C bidding method. In particular, when the A bid gap between bidders is below 2%, introducing mitigation measures would significantly impact the determination of the winning bidder.

Discussion

Giving the bidding preference to greener contractors has several advantages over contract specifications and contract allowances. First, the provision of bidding preferences still offers opportunities for bid participation from small contracting companies that do not have the financial capability to implement green plans but do have good cost competiveness; contract specifications may limit bid participation from such companies. In addition, the bidding preference to be provided under the A + C bidding method will be proportionate to the actual absolute amount of emission reduction to be achieved. The effectiveness of additional cost investment for emission reduction is guaranteed with the provision of bidding preferences; the amount of emission reduction to be achieved under contract specifications is uncertain until the completion of a project. Last but not least, the provision of the bidding preferences will let bidders compete on the cost-effectiveness of their mitigation plans, as has been observed in the practices of the A + B bidding method. The owner, therefore, will achieve greener construction practices with a minimum increase in cost. This way of paying the additional expense of green construction is more reasonable than contract allowances or some type of contract specifications in which the owner is required to reimburse the incremental costs incurred by a contractor's green practices.

Thus far, however, without regulations, private owners lack significant motivation to seek greener contractors because of the added cost in doing so. In contrast, public entities have expressed great interest in and moved toward attracting greener contractors, utilizing various subsidy and incentive programs to indirectly pursue reductions in emissions (Ahn et al. 2010). Current and future regulatory actions require public entities to inventory their GHG emissions, set the reduction target, and build the mitigation plans to meet that target (White House 2009). The GHG emissions generated by construction work largely contribute to the GHG inventory of some public entities, such as DOTs. Thus, the application of the A + C and A + B + C bidding methods will most likely draw the interest of public entities, where they can contribute to and accelerate ongoing efforts to mitigate energy use and emissions. Transportation projects in particular, such as road and bridge construction, could incorporate and greatly benefit from A + C and A + B + C bidding methods because of their relatively high emission intensities. Projects to reconstruct or rehabilitate transportation facilities that use the A + B bidding method could also benefit from a shift to the A + B + C system. Public owners could then pursue further mitigation of energy use and emissions by incorporating the traffic emissions generated by delays and detours resulting from road construction in the A + B + C bidding method. Current road user cost calculations used in the A + B bidding method include only vehicle operating and time costs resulting from traffic delays and detours, and do not include the additional costs of GHG emissions resulting from traffic delays and detours (NJDOT 2001).

Contractors would benefit from the adoption of A + C and A + B + C bidding methods. Voluntary and regulatory GHG emission reporting programs, client preferences for green products, fossil fuel price increases, and environmental legislation will each force contractors to reduce their energy use and emissions. Within the A + C and A + B + C bidding methods, however, they will not be forced to adhere to specific mitigation strategies; instead, they will be able to create and adapt innovative means to mitigate construction emissions and energy use. Successful strategies to reduce energy use and emissions would then enhance the competitiveness of a given contractor and increase his/her chance of winning a bid within the A + C and A + B + C systems. The potential approaches toward emission reduction in construction are extremely diverse; attempts to restrict them within contract specification would be counterproductive. Some reduction is possible within the traditional approach, of course—replacing old equipment with pieces that are newer and cleaner and shifting to cleaner fuel will reduce emissions in construction. However, a much more drastic reduction could be accomplished through the design of more energy-efficient construction processes and methods. The A + C and A + B + C bidding methods provide the flexibility necessary to allow for innovation, and could lead to profound mitigation strategies within contracting and construction procedures.

However, there exist many challenges for the implementation of the A + C and A + B + C bidding methods. The first challenge is the burden placed on bidders to estimate construction emissions and develop their C bids and the bidders' resistance because of this burden. In the design-bid-build projects in which bidders have the same bill of quantity—bidders have the same specifications quantities of material and mostly similar levels of required equipment operation hours—the required input data from bidders is not that great. Public entities, therefore, would reduce the burden on bidders by providing a tool to support the calculation procedures. However, in design-build projects, bidders are required to be equipped with the ability to perform such procedures by themselves. In addition, public entities need to develop their own impact assessment method to convert emissions and energy use into a monetary value. Because the eco-costs used in this paper were developed for the European Union, the eco-cost values need to be updated or replaced according to the situation of a region where public entities authorize the execution of contracts.

In addition to the A + C and A + B + C bidding methods, public owners should consider performance contracting for construction (PCfC), which the FHwA has developed and is promoting [Science Applications International Corporation (SAIC) 2006]. This would further incorporate construction emissions into contracting procedures. PCfC suggests defining a set of performance goals that a contractor must meet, with measurement methodologies in place to evaluate the performance of the contractor regarding each goal. To incorporate emissions in PCfC, the mitigation of construction emissions needs to be a performance goal. The contractor's performance toward the goal of emission reduction can then be evaluated to determine whether the contract has been fulfilled. The mitigation of construction emissions has yet to be set as a performance goal within a PCfC pilot project, however. In contrast, other environmental impacts, such as construction noise and material recycling/reuse, have been included. To pursue the mitigation of construction emissions within PCfC, performance measures need to be defined according to the level of reduction from the construction emission baseline desired. The baseline can be defined using construction quantification methods. Setting performance goals to mitigate construction emissions would not only achieve the desired levels of construction emissions, but would also affect bid evaluation processes within the best value award system of PCfC.

Conclusion

In this paper, the A + C and A + B + C bidding methods were presented to address the growing social requirement to mitigate construction emissions and to discuss the benefits of these methods both to public clients and contractors. Furthermore, the challenges involved in the implementation of these bidding systems were discussed. The case studies demonstrate that the proposed bidding methods could provide certain bidders—those with more effective plans for emission mitigation—with a higher chance of winning a bid. In fact, adopting the A + C and A + B + C bidding methods would encourage contractors to identify and quantify construction emissions and develop greener construction methods. This would prepare the construction industry for the risk of future regulatory actions that will have direct and indirect effects on the daily operations of contractors, and further allow the industry to proactively address growing pressure from environmentally-conscious stakeholders. Furthermore, the consideration of construction emissions in contracting would allow public clients to effectively control construction emissions from their contractors. This would allow public clients to adequately address current and future regulations requiring them to inventory and reduce their emissions.

With that said, this study has some limitations inherited from the assumptions made in the development of the case study. First, bidders do not develop such detailed plans necessary for the LCA analysis in the bidding preparation phase unless required to do so by the owner. Bidders, therefore, have a common baseline of emission estimate that is developed based on as-built data. However, the investigation of emissions of different bidders with different plans would identify possible deviations of bidders' estimates because of their selection of different construction means and methods, even before adopting any additional mitigation plans. This would allow a more thorough examination of whether or not including emissions as a bid component is feasible. Further, the environmental cost index needs to be investigated to determine the optimum price level at which contractors are encouraged to pursue meaningful efforts to develop greener construction methods, yet the price should not distort the bidding process by placing excessive weight on the emissions portion of a bid within the A + C and A + B + C bidding methods. To successfully and fully implement these innovative bidding methods, further research needs to address these limitations of the research. In addition, reliable methods and procedures to develop a bid on construction emissions and verify actual construction emissions need to be developed to create a level playing field for all bidders.

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