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THE OPPORTUNITIES AND CHALLENGES FOR CONTRACTUAL CONSIDERATION OF CONSTRUCTION-RELATED CARBON EMISSIONS FROM CIVIL INFRASTRUCTURE PROJECTS

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ABSTRACT: Construction works of civil infrastructure projects generate a considerable amount of carbon emissions by utilizing a set of energy-intensive equipment and causing traffic congestion. However, the voluntary efforts of the contractor to mitigate these emissions are at an early stage. To address this issue, this paper explores the opportunities to take carbon emissions that would be caused from construction works into consideration in contracting methods and procedures. The opportunities for reducing carbon emissions from construction activities themselves are examined under the framework of Performance Contracting for Construction (PCfC), and carbon emissions from traffic congestion are attempted to be incorporated into the Road User Cost (RUC) calculation. This paper also identifies and discusses major challenges that must be confronted when considering the mitigation of these emissions in contracting methods and procedures.

Keywords: carbon emissions; construction contracting; environmental impact; road user cost

1. INTRODUCTION

For over a decade, there has been a growing interest on the impact of organizations on the natural environment, particularly in regard to the global warming issue. Increasing pressure from environmentally-conscious stakeholders, such as society and government has been placed on organizations to require the mitigation of the carbon footprints from their products and processes [1]. Building and construction sectors are at the forefront of confronting such environmental pressure, because their products, buildings and civil infrastructure, have the enduring nature with the high energy consumption attribute in use. Much effort, therefore, has been made in the area to develop energy-efficient products in building and construction sectors.

Meanwhile, the process to construct buildings and infrastructure has not been paid much attention in the sustainability efforts of the construction and building sector, even though construction processes cause a significant amount of direct and indirect carbon emissions [2]. In particular, the construction process of civil infrastructure produces a relatively high level of carbon emissions from their extensive use of energy-intensive equipment compared to that of buildings, and also greatly contributes to traffic congestion, which increases carbon emissions from the traffic sources. Public clients of civil infrastructure projects are, thereby, under increasing pressure to mitigate the carbon emissions from their projects. However, the voluntary efforts of contractors to reduce their construction-related carbon emissions remain minimal, since few mechanisms are in place to promote their efforts to mitigate such emissions.

In this context, this paper looks at construction contracting methods to identify how they could create contractors' mitigation efforts on their construction-related carbon emissions. First, it examines the significance of construction-related carbon emissions and their main contributors in civil infrastructure projects, and then reviews the environmental consideration in current construction contracting. Based on these reviews, this paper discusses the opportunities and challenges to consider construction-related carbon emissions within the existing contracting methods, and proposes the possible modification of the existing methods.

2. MOTIVATION

Carbon emissions from the construction process of a typical single project are relatively small compared to the manufacturing processes of other sectors, but the aggregated amount of emissions for construction is considerable due to the huge number of construction projects. U.S. Environmental Protection Agency (US EPA) reported that construction produced 131 million metric tons of CO_2e in 2002, and this level of carbon emissions account for 1.7% of total U.S. carbon emissions [3]. The construction industry was thus placed as the third highest contributor of carbon emissions among all U.S. industrial sectors, ranking just behind the oil and gas sector and the chemicals manufacturing sector. This estimate represents only the use of off-road equipment in construction, and the level of carbon emissions from construction would have been roughly doubled when including on-road transportation sources utilized by the construction industry [4]. In particular, heavy and civil engineering has higher emission intensities, which indicates the emission per the dollar value added by the industry, compared to other construction subsectors, such as building construction and specialty contractors [5]. For example, the emission intensity of highway, street and bridge construction is two times higher than the average emission intensity for the construction sector as a whole. In addition, the percentage of energy used for construction activities over the life-cycle of a civil infrastructure project is relatively high –up to 40% [6]– compared to a building project. This raises the particular need to control carbon emissions from civil infrastructure construction processes.

The main contributors of emission generation in civil infrastructure projects are the on-site operation of construction equipment [1] and the on/off-road transportation of materials and waste[2] [5]. The use of on-site electricity for small equipment, temporary lighting, and trailer, and employee commuting/other miscellaneous site-related activities are typically minor contributors [2]. The clear direction to mitigate carbon emissions is to improve the environmental performance of each source, such as equipment and transportation source, by replacing old equipment to newer and cleaner equipment, and using cleaner fuel such as biofuels and green electricity generated from renewable sources. Another direction is to improve the operational efficiency of overall operations, which leads to reduce the operation load (or transportation load) of each emission source. This can be done by the enhancement of productivity, the increase of the recycling materials, and the reduction of waste. But these strategies typically require considerable up-front investment, which are the main barriers to impede voluntary efforts of contractors. This motivates us to develop financial/non-financial incentives in contracting method which enable contractors to be compensated for their efforts on mitigating carbon emissions.

[1] Currently, the EPA's regulations for construction equipment (off-road diesel engines) control only diesel emissions which degrade local air quality, such as CO, NO_x, SO_x, HC and PM, but do not utilize a standard for carbon emissions [7]. Carbon emissions from construction equipment are highly likely to be also regulated in the future, since the states of California, Connecticut, Massachusetts, New Jersey, Pennsylvania, and Oregon have already petitioned the EPA to set a rule to regulate CO_2 emissions from construction equipment [9]. This future rule, however, would be effective to newly manufactured equipment after the establishment of the rule, and not effective to pieces of equipment currently being utilized.

[2] The construction sector accounts for 6% of light on-road truck use and 17% of medium/heavy truck use in US transportation [10].

In addition, traffic congestion caused by construction work greatly increases carbon emissions of traffic sources. When the average speed of traffic slows from 40 mph to 20 mph, there is approximately 30% increase of carbon emissions from traffic sources, and when slows to 10 mph, there is 125% of carbon emission increase [7]. The definite direction to mitigate such indirect construction-related carbon emissions is to accelerate project delivery. Various alternate contracting methods are proposed and being implemented to promote the acceleration of project delivery, but they only consider time loss of users, increased vehicle operation cost, and increased accident in the calculation of the incentives to be provided in contracting [8]. This raises the need of the discussion for taking into the consideration indirect construction-related emissions in existing alternate contracting methods.

3. ENVIRONMENTAL CONSIDERATION IN CONSTRUCTION CONTRACTING

The environmental impact of construction activities has been widely contemplated in construction contracting. Their most common form is contract specifications that directly describe the required actions of the contractor to mitigate its environmental impact. A wide array of contract specifications has been adopted in regards to air quality, noise and vibrations, and water pollution [11]. In particular, contract specifications that concern air quality issues caused by construction diesel emissions (i.e. NOx, PM, CO, VOCs, and SOx) have been found in many contracting practices in state DOTs. For example, the Connecticut Department of Transportation (CDOT) included the specification on diesel emission reduction in contracting procedures for the I-95 New Haven Harbor Crossing project [12]. This contract specification required all contractors and subcontractors to comply with idling specifications and to attach diesel emission retrofit devices, such as diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs), to their equipment. All pieces of construction equipment used in the project were then tracked in order to ensure their compliance on the contract specification. CDOT could withhold the payment for any work completed with non-compliant equipment. These contracting procedures have resulted in the reduction of yearly emissions by an estimated 20 tons of CO, 2 tons of PM, and 8 tons of HC [13].

Carbon emissions from construction processes, however, have rarely considered in the contracting procedures [14]. The efforts on addressing construction carbon emissions are limited to a construction energy analysis in the preplanning stage. Such analysis is used to evaluate the overall environmental impact from the construction of the proposed transportation facilities, rather than being connected to any contracting consideration to reduce construction carbon emissions.

4. CONSIDERATION OF DIRECT CARBON EMISSONS IN CONSTRUCTION CONTRACTING

In this section, we examine the opportunities to create contractual incentives to mitigate direct carbon emissions, which are generated from construction equipment and transportation sources utilized by construction processes. As discussed previously, the mitigation efforts on direct carbon emissions involve considerable up-front cost, and contractors are unlikely to put such efforts unless they brings economic benefits or advantages in the contracting procedures. The inclusion of carbon emission criteria in the contracting procedures, therefore, would realize effective change.

Various alternate contracting methods have been suggested and implemented, in order to address deficiencies of conventional bidding system. Among them, we look at Performance Contracting for Construction (PCfC), which the Federal Highway Administration (FHWA) has developed and is promoting [15], since PCfC provides great flexibility necessary to including carbon emissions into one of its project-specific goals. The examined opportunities and challenges in PCfC would further provide insights on contractual consideration of carbon emissions in other contracting methods.

4.1 Performance Contracting for Construction (PCfC)

Performance contracting is an approach where the client defines a set of project–specific goals, and measure performance of a contractor against the defined goals [15]. The defined performance goal specifies the desired level of project outcomes without defining how to obtain it. The measurement of the contractor's performance against the defined goals provides a basis for selecting a successful bidder in the bidding process with the use of Best Value awards, or providing incentives/disincentives to the contractor during and after construction.

Using this approach, State DOTs could reallocate some of the risk for achieving desired project outcomes to the contractor. Contractors could also enjoy the flexibility in determining the way to achieve the desired project outcomes, rather than adhering to the use of a specific method. This flexibility allows them to select the innovative methods to accomplish the goal with the better profitability.

The implementation of PCfC requires defining the methodology to measure performance against the goals to determine to what extent they were met. The measurement methodology should describe what gets measured by whom and when, as well as how to measure. Table 1 provides the sample set of goals and their measurement methods. The public client could use multi-level performance goals in order to measure multiple levels of performance. For example, *Injuries* goal in Table 1 would have five levels of performance goals with the different level of required incident rate. Performance level score against each goal is weighted and summed to a total score, which affects the evaluation of the contractor in the bidding process and the assessment of incentives/disincentives during/after the project.

Table 1. Examples of Performance Goals and Their Measurement Methods in PCfC [15]

Category/ Element	Performance Goal	Measure of Effectiveness? Unit of Measure?	How to measure? What processes?	How often? When?	Who will evaluate this?
Safety / Injuries	Incident Rate (IR) for Worker injuries is less than 4.0	Incident Rate for the Entire Project	Contractor's officially reported Incident Rate	End of Project	Construction Contractor or Independent Evaluator or State DOT
Environmental / Recycling and Reuse	Capture and recycle / recover 90% of recyclable materials used on project	Tons for project	Ratio of recycled / recovered tons over available tons	At 25%, 50%, 75% and 100% project completion	Construction contractor, Independent Evaluator or State DOT

4.2 Performance goal of carbon emissions

The framework of PCfC provides the flexibility necessary to enable DOTs to set the new performance goal that leads to the reduction of construction carbon emissions. Along with other performance goals in environmental category such as noise, recycling, and watershed quality, carbon emissions could be then set as one of performance goals, for example:

- Performance goal: Reduce 20% of construction carbon emissions
- Unit of measure: Tons of CO_2e for project
- How to measure: Ratio of reduced tons of CO_2e over available tons of CO_2e (estimated baseline)
- When: At 25%, 50%, 75% and 100% project completion
- Who will evaluate this: Construction contractor, Independent Evaluator or State DOT

The goal on construction carbon emissions could have various levels of performances goals with the different level of required reduction ratio. This inclusion of construction carbon emission in performance goals would let the contractor with less carbon emissions to have an advantage in the bidding evaluation process and also to get reimbursed on their investment on greener construction with provided incentives.

Several challenging issues still remain to be addressed before construction carbon emissions can be incorporated as the performance goal in PCfC. The most important issue concerns *how to measure* performance level against the construction carbon emission goal, since formal procedure and methodologies to assess construction carbon emissions continue to be lacking. One possible reliable method is to gather the energy bills for the entire construction project, including on-site electricity charges and fuel bills for on-site construction equipment and transportation trucks, which allows identifying the energy consumption level and calculating its associated carbon emissions using fuel-based emission factors (e.g. kg CO_2e per each gallon of diesel). Implementation of this method in construction requires the cooperative efforts with subcontractors and material suppliers who run their own equipment, but they are reluctant to disclosing data that could affect their reimbursable costs. Alternatively, tracking only specific data, such as the operational hours of equipment and the distance/loads of transportation, and computing GHG emission levels using activity-based emission factors (e.g. kg CO_2e per each hour of equipment operation), seemingly is the easiest method to pursue. It is thus being used to verify construction diesel emissions in existing contract specifications, but involves some degree of uncertainty in its result, since activity-based emission factors has higher level of uncertainty compared to fuel-based emission factors.

Another major issue concerns how to set the baseline on construction carbon emissions that provides a basis of determining the contractor's performance. It is imperative to develop the estimate on construction carbon emissions in preplanning phase of the project, in order to set the baseline. This would be somewhat analogous to develop the engineer's estimate on cost to evaluate the contractor's cost performance. Several methods based on the life-cycle assessment methodology are available to develop such carbon emission estimates of civil infrastructure projects, but those methods generate much different estimate on carbon emissions, depending upon the characteristics of the project [2]. Also, there would exist a great gap between estimates developed by those methods and actual emissions measured during/after construction, since those methods have not been widely tested within civil engineering works.

5. CONSIDERATION OF INDIRECT CARBON EMISSONS IN ROAD USER COST CALCULATION

Indirect construction carbon emissions from congested traffic due to construction works can be mitigated along with the efforts toward accelerating the project delivery. Alternative contracting methods such as A+B bidding method, Incentives/Disincentives, Lane rental method, and PCfC are used by many state DOTs to expedite construction. These methods involve the calculation of the Road User Cost (RUC) that represents the loss of road users due to operating and time delays from construction [8]. The RUC calculation provides designers with information to allow making better-informed decision in regards to staging, allowable work hours, project delivery methods and the actual design itself. Current procedures for the RUC calculations, however, undermine the effect of indirect construction carbon emissions, and thereby could not provide proper information that allows designers to take into consideration the impact of their decisions on indirect construction carbon emissions. In other words, the degree of preference for expedited construction should be reinforced considering its impact on reducing indirect construction carbon emissions, so that the efforts of the contractor for accelerating the delivery should be more highly evaluated.

In this context, we examine the opportunities to include the effect of indirect construction carbon emissions in the RUC calculation, and also discuss the challenges to be resolved to implement the suggested RUC calculation.

5.1 Road User Cost Calculation

The RUC calculation of existing models typically includes three main components, as follows:

RUC = Value of Time Lost + Vehicle Operating Cost + Accident Cost [8]

The *Value of Time Lost* represents the opportunity cost of user time dedicated to traveling and is determined by the difference of travel speed during and after construction, and unit value of time for each user class. The *Vehicle Operating Cost* takes into account the rise of fuel cost due to increased traveling time and is calculated by multiplying a change of fuel mileage (liter per kilometer) from traveling speed change with fuel price and length of the work zone. The *Accident Cost* describes the damage from increased accidents in a work zone, and is determined by a change of accident rate in a work zone and average crash dollar value. Most parts of these components are a function of speed change in a work zone, and most RUC models provides the analysis on it based on average travel speed and daily traffic volume.

5.2 The Inclusion of Environmental cost from carbon emissions in RUC calculation

In order to reflect the effect of indirect construction emissions, the RUC calculation should include their environmental cost, along with other three main components such as *value of time lost*, *vehicle operating cost*, and *accident cost*. The environmental cost from indirect construction emissions represents the dollar value assigned to the damage caused by additional carbon emissions generated by traffic congestion. The social cost of a unit of carbon emissions has been suggested by many previous studies [17], and the amount of additional carbon emissions can be determined by additional fuel consumption of traffic and fuel-based emission factors.

The calculation of the environmental cost of indirect construction emissions can be then described as follows:

$$EC = AFC \times EF_{fuel} \times P_{carbon}$$

where EC=the environmental cost from additional carbon emissions; AFC=additional fuel consumption of traffic; EF_{fuel}=fuel-based emission factor for carbon emissions; and P_{carbon}=the external cost of carbon emissions.

The impact of adding *environmental cost* to RUC can be estimated from the comparison with other main components of the RUC calculation. It should be noted that both *environmental cost* and *vehicle operating cost* are dependent to the fuel consumption of traffic. The ratio of *environmental cost* to *vehicle operating cost* could then be determined by investigating the values of independent variables of both cost components. *Environmental cost* has two independent variables; it can be assumed that the external cost of carbon emissions is 55 dollars per ton of CO_2e [17] and fuel-based emission factor is 8.86 kg CO_2e per gallon of gasoline [18]. *Vehicle operating cost* has one independent variable; it can be assumed that fuel price of gasoline is 3 dollars per gallon [19]. The *environmental cost* is then estimated to be around 16 percent of *vehicle operating cost*. Adding *environmental cost*, therefore, does not lead to a significant rise of RUC, since *vehicle operating cost* typically represents only 5 to 15 percent of the total RUC [16]. This helps the designers to identify what extent the RUC should increase to take indirect carbon emissions into account. The most challenging issue in calculation of environmental cost is that a definitive external cost of carbon emissions has not determined despite a decade of discussion. It is then imperative to define its level for the RUC calculation through extensive studies.

6. CONCLUSIONS

In this paper, we explored the opportunities and challenges to incorporate construction carbon emissions into existing contracting methods and procedures, in order to create the efforts of the contractor to mitigate its direct and indirect carbon construction emissions. It was found that the mitigation of direct carbon emissions could be dealt with within PCfC. In addition, this paper investigated the inclusion of environmental cost from indirect construction emissions in the RUC calculation. However, major challenges are also found to remain in the measurement methodology of direct construction emissions, and the determination of an external carbon cost for the RUC calculation. Further research needs to address the identified challenges.

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