SUBSIDY ALLOCATION MECHANISM FOR SUCCESSFUL IMPLEMENTATION OF GREEN CONTRACTING STRATEGIES

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ABSTRACT

Construction industry in the U.S. is one of the top Green House Gas (GHG) emitters. It produced 1.7% of the total U.S. GHG emissions in 2002. These emissions are equivalent to 6% of total U.S. industry related GHG emissions, earning it a third rank on the list of highest emitting industries. However, these numbers represent only a part of the total construction emissions but if we add all the direct and indirect construction emissions from the supply chain of construction projects, the construction emissions would represent up to 54% of the total U.S. emissions. Hence, there is a need to lower emission levels from each and every emitter in the construction supply chain. This research work, defining and addressing the importance of Lean Carbon Supply Chain (LCaSC) for construction projects, develops a subsidy allocation mechanism using a two-stage sequential game to model the Agency's and Contractor's behavior. The subsidy allocation mechanism would enable successful implementation of Green Performance Contracting strategies at a minimum cost.

KEYWORDS

Construction Supply Chain, Carbon Supply Chain, Game Theory, Implementation, Subsidy Design

INTRODUCTION

The construction industry is one of the top Green House Gas (GHG) emitters in the United States. It produced 1.7% of the total U.S. GHG emissions in 2002. These emissions are equivalent to 6% of total U.S. industry related GHG emissions, earning it a third rank on the list of highest emitting industries (EPA, 2008 & EPA, 2009). Although these numbers are enough to support efforts for reducing emissions from the U.S. construction industry, a sense of higher importance will emerge when these numbers, that represent only a part of the total construction emissions, are complemented with the emissions from the non-accounted life cycle phases of construction projects. Emission estimates prepared by the Green Design Institute at Carnegie Mellon University (CMU-GDI) show that life-cycle carbon emissions from the construction sector ranges between 41.7 and 67.6 MMTCO2-eq per $100 billion in economic activity. This means that for all the construction projects in 2002 valued at $861, the construction industry added 6.8% of the total U.S. emissions (CMU-GDI,

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2009). In a similar way, the Department of Energy (DOE) reports that the emissions from buildings were up to 32.2% in the year 2002. Thus if we add all such direct and indirect construction emissions from all sources, the construction emissions can represent a significant percentage of the total U.S. emissions (Cui et al. 2011). This requires that if agencies aim to effectively control emissions then they must focus on not only the onsite emissions but also on the offsite emissions from the elements feeding into the construction supply chains.

Recently, Maryland State Highway Administration (MSHA) sponsored a research project for reviewing the emission reduction technologies used by various Department of Transportation (DOTs) across the United States. The research was conducted by extensively reviewing the DOT project documents and by carrying out a survey. The results show that agencies were using 19 strategies to reduce emissions (Cui et al. 2011). These strategies were categorized on the basis of material, equipment and energy, green life-cycle and clean energy development. It was observed that these strategies were focused on reducing emissions from various elements in the construction supply chain. Since the construction supply chain management is a relatively new area of study (Arbulu and Ballard 2004, Vrijhoef and Koskela 1999), attempts are made here to define a construction supply chain specifically for this research work and then to identify how each element in the supply chain would contribute to emission reduction.

WHAT IS LEAN CARBON SUPPLY CHAIN (LCASC)?

A typical construction project can be broken down into several phases and during each phase thousands of options could exist that might offer different costs, quality and carbon emissions. For example, let us take the case of a construction project (as shown in Figure 1) and let us assume that the owner wants to reduce carbon emissions from the project. As per the current procedures he/she would use strategies that would reduce carbon emissions only during the construction phase. This means that the focus will be limited to reduction from equipment usage, electricity consumption and disposal or reuse of construction waste. Such practice reduces the emissions from construction phase but completely ignores the indirect emissions from all other phases. Each phase of the project (shown in the Figure 1) is discussed here with a brief explanation of how each phase can contribute towards the overall reduction of emissions from construction industry.

PLANNING PHASE

Projects can be planned for the whole life cycle during the planning stage. If a project has an objective to reduce the overall emissions it has to be planned in advance. Reducing emissions might require special orientation of the structure, special construction equipment, high-efficiency HVAC and special methods (such as modular construction) during the various phases of the project. All this must be planned before the project begins. Planning would enable the owner to know the costs of using innovative approaches and the emission reductions from the project.

DESIGNING PHASE

Project design plays an important role in operational efficiency of the building. For example: a building is designed to reduce heat during summer months which reduces drastically the air conditioning costs for the users. However, this same construction might require extreme amount of heat during winters which might neutralize the benefits gained from savings in the summers. Thus the design aspects such as orientation of the buildings, window size, layout, glazing, etc. play a major role in the overall efficiency of the building and can be used effectively for emission reductions.

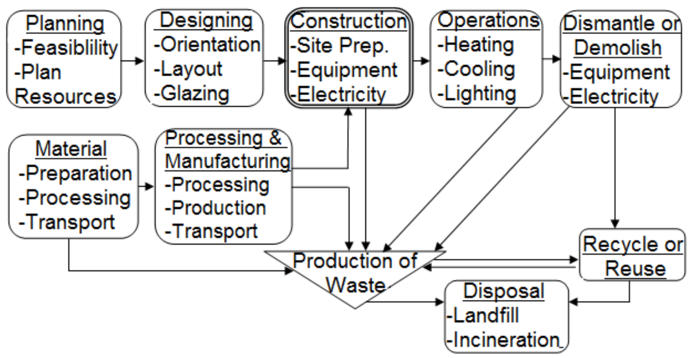

Figure 1: Typical Supply Chain Model of U.S. Construction Industry

CONSTRUCTION PHASE

The general trend observed in the U.S. construction industry is towards reducing onsite emissions. However, we have been largely ignoring the embodied carbon in the materials. Notice from Figure 1 that the construction materials reach the construction sites after passing through a variety of processes. Each processes between raw material extractions to onsite use, contributes to the overall emissions. For example, the trucks used for transporting materials also emit gasses and adds to the overall emissions.

OWNER'S USE

Building use contributes the maximum towards the emission because of the heating, cooling and lighting needs of the buildings (Report: TATA Steel and BCSA). If the owner uses traditional lighting, the constructed facility will consume more electricity than the high efficiency lights (Garbesi et al. 2011). Thus post-construction emissions management will also help to reduce the overall emission levels.

DISMANTLING OR DEMOLISHING

After the useful life, the structure is generally dismantled or demolished. If the building is planned and designed appropriately the dismantled or demolished parts of the structure would be reusable. On the other hand the demolishing and dismantling might require equipment, fuel and electricity which would add to the overall emissions of the project.

DISPOSAL

During construction, operations, dismantling, raw-material extraction and construction material production waste will be produced. This waste is either reused or disposed-off. The disposed-off waste will again add to the emissions from the construction industry.

It is evident from the above discussion that various phases of a project would contribute to the overall carbon emissions and it is inevitable to take adequate steps to reduce the carbon emissions throughout the construction supply chain. If implementable, the construction projects where emissions are reduced throughout the supply chain would satisfy the lean principles as well as the sustainable construction principles. The lean principles require that the product be developed considering customer's requirements, reducing wastes and increasing the efficiency (Liker 2004). On the other hand sustainability requires that the projects are economical, environment friendly and renders social benefits (Martinez et al. 2009). Carefully considering all the phases of the construction supply chain, it becomes evident that if emissions can be reduced during each phase of the project the lean principles and sustainability criteria will be satisfied. Thus we define Lean Carbon Supply Chain (LCaSC) as the concurrence of low carbon efforts, lean principles and sustainability throughout the construction supply chain.

CONCURRENCE OF LOW CARBON, LEAN PRINCIPLES AND SUSTAINABILITY IN CONSTRUCTION SUPPLY CHAINS

Researchers have demonstrated that though the lean principles and sustainability are different concepts both these approaches are aligned towards efficient use of resources (Horman et al. 2004). We can synchronize the two methodologies together and can achieve better results in terms of cost, environment, social benefits, value enhancement and waste reduction (Horman et al. 2006). However it is sometimes very difficult to simultaneously achieve all these results. Few researchers have pointed out that sustainable projects can turn out to be costlier than the traditional projects due to the prevailing practices (Smith 2003) and thus it can increase the overall cost of the project. Conversely, Toyota's South Campus Project and Pentagon Renovation project are undisputed examples where the lean production principles were used to deliver sustainable projects (Lapinski et al. 2006 and Horman et al. 2004). It is also known that such projects can be managed to stay within reasonable costs (Smith 2003, Lapinski 2006). So a question comes in our mind is -What steps can we take to achieve a LCaSC and ensure that such projects are implementable? Similar questions arose when the 19 strategies were identified during the MSHA project. Several strategies out of the 19 strategies were found to be highly efficient in terms of achieving the concurrence of low carbon, lean principles and sustainability in the construction supply chain but were not implementable because of the increase in the cost. Our focus in this paper is just on two such strategies.

Engine retrofitting and engine repowering and upgrading are highly efficient strategies (Cui et al. 2011) and would enable the concurrence of all the objectives. However, it will be very difficult to implement these strategies as these strategies requires the contractors to make heavy initial investment. A rational contractor would always focus on profit margins and since such investments could reduce their profits, implementing such strategies mandates that the agencies give subsidies to effectively pull the contractors to adopt the Lean and Green strategies. This paper puts forward a game theoretic model to design an appropriate subsidy allocation mechanism.

HOW CAN WE IMPLEMENT THE LCASC?

Cui et al. (2011) identified 19 Green Performance Contracting (GPC) strategies which can be effectively used at different time points in the highway construction supply chains. Majority of these strategies can be conveniently incorporated into the existing construction practices. For example the contractors can be asked to use an effective waste management plan or employ low emission modes for shipping materials. Thus the LCaSC is fairly achievable in every State in the U.S. However, there are a few strategies for which the contractors may show resistance due to the cost of upfront investment. In such cases the contactors would expect subsidies to accept the LCaSC. Since achieving low carbon emissions is a priority for Agencies it is necessary that the agencies designs appropriate policies to pull the contractors to adopt the strategies. Thus the Agencies will have to decide whether to implement the LCaSC strategies by keeping them voluntary or making them mandatory. Each option would offer its own share of benefits and drawbacks. In the following part of this paper describes the existing Agency-Contractor practices as a two-player sequential game and also provide a mechanism for allocating subsidies for successfully implementing the GPCs to achieve the LCaSC objectives.

EXISTING PRACTICES – THE AGENCY CONTRACTOR GAME

The existing system of contract management in government projects does not stress for the adoption of Lean Carbon Supply Chain (LCaSC). The Agencies at Federal and State levels allocate public sector works to the contractors that have the ability to meet the Agencies' expectations set forth in a set of performance criteria. These criteria, on majority of the projects, do not require the contractor to adopt the LCaSC. Thus the contractor is free to adopt (A) or reject (R) the LCaSC.

For a rational contractor, adopting or rejecting the LCaSC would depend only on whether the LCaSC provides more benefits or not. The contractor would be happy to adopt the LCaSC if it guarantees higher benefits. Otherwise a rational contractor would definitely reject the implementation of LCaSC. Even if the LCaSC comes with a promise of benefits that are at par with the benefits from traditional supply chain, a rational contractor would definitely reject changing the supply chain as it would reduce the risks associated with trying something new. This situation between the Agency and the Contractor can be represented as a sequential game as shown in Figure 2.

Let us assume that an Agency wants to achieve low carbon footprint. The Agency can either promote the LCaSC as a voluntary (V) option for the contractor or can force its implementation by making it mandatory (M). Let us assume that the Agency decides to "encourage" the use of materials and processes that come from LCaSC. Thus, the Agency keeps the option of adopting the LCaSC as voluntary and lets the contractor decide whether to adopt (A) or reject (R) the move. Since the materials and processes through the LCaSC are new and might not warrant against the originating risks, a contractor would get a payoff of P_1 when rejecting the LCaSC and payoff P_2 when accepting the LCaSC. Needless to say that in the current condition, i.e. *without any financial support*, P_1 will be greater than P_2 which means that the contractor will reject the use of LCaSC. Thus for the sub-game from Contractor node when Agency keeps LCaSC voluntary, the solution will be the set of strategies (Voluntary, Reject) denoted as (V,R). In these circumstances the Agency gets a payoff of G_3 which is less than G_1. It must be noted that if the contractor rejects all the materials and processes coming from LCaSC, the G_3 payoff will be equal to zero. *Thus if an Agency lets the Contractor decide to adopt or reject the LCaSC and does not provide subsidies, the Agency would not achieve its objective of reducing carbon footprint.*

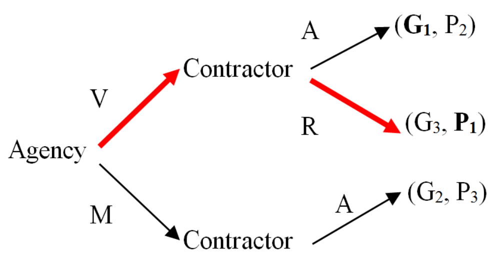

Figure 2: Existing Agency-Contractor Model Encouraging LCaSC

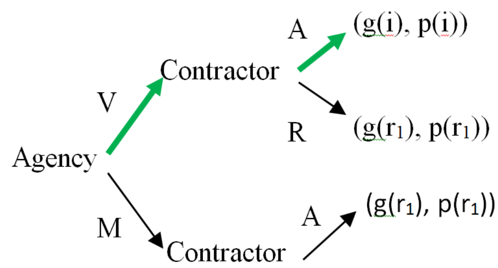

Figure 3: Desired Model With Subsidy Mechanism for LCaSC

Under the existing conditions, now knowing that the strategy of encouraging the adoption of LCaSC would fail for the Agency, it can enforce the LCaSC. This strategy will mandate the contractors to adopt (A) the LCaSC for government projects. Employing the mandatory (M) strategy will enable the Agencies to realize a payoff of G_2 and would enable the contractor to get a payoff of P_3. Definitely this strategy would yield G_2 such that $G_2>G_3$. *This means that the Nash Equilibrium for the game will be strategy set (Mandatory, Accept), which can be denoted as (M, A).* However, when (M, A) strategy is used the contractor would get P_3 such that $P_3< P_1$. Because of the reduced payoffs to the contractors, the Agency might have to bear the consequences of contractor burnout, increase in bidding values for projects, harsh criticism from the taxpayers, political backlash, and severe damage to its own image. All these factors can increase the indirect costs (some of which might not be quantifiable) of the LCaSC program which can result in very big differences between the payoffs G_1 and G_2.

Thus the option of forcibly implementing the LCaSC program will not be feasible in the absence of a mechanism to attract contractors to adopt LCaSC program. Hence the Agencies must develop mechanism that would direct the Contractors to adopt the LCaSC when the Agencies keep the LCaSC program voluntary. This means that we must develop conditions that would enable the Nash Equilibrium to shift to the (V, A) path. This has been achieved in this paper by developing a subsidy allocation mechanism.

NEW MODEL FOR SUCCESSFUL IMPLEMENTATION OF LCASC

Implementing Lean Carbon supply chain in construction requires the Agencies to develop appropriate mechanisms. The mechanism must ensure that Agencies' objective of reducing carbon footprint is achieved at minimum costs as wells as the contractors are motivated to adopt the LCaSC.

In the revised model, the Agencies and Contractors have the same set of strategies as discussed in the existing Agency-Contractor Model. The Agencies have two strategies to implement the LCaSC. The first strategy is to keep the LCaSC policies Voluntary (V). In this set-up the contractors will have the choice to Adopt (A) the LCaSC or Reject (R) the LCaSC. The second strategy available to the Agencies is to make the LCaSC Mandatory (M). In this condition, the contractor would be forced to Adopt the LCaSC. Each of the strategies has its own merits and demerits.

This new model provides the same strategy sets to the Agencies and the Contractors, but the payoffs would be determined using a new mechanism designed for reducing the overall carbon footprint. Graphically, this new Agency-Contractor model can also be expressed as a sequential game as represented in Figure 3. In this game also, the Agency gets the chance to play first and the Contractor being the second player has the option to select the best strategy that would maximize his/her payoffs. The payoffs for Agencies will be in terms of monetary benefits for reducing societal carbon footprint which has been represented by the function $g(\cdot)$. Conversely, the payoffs for Contractors will be in terms of monetary benefits (profitability) from the project and have been represented by the function $p(\cdot)$.

SOLUTION TO THE GAME

In order to have the Nash Equilibrium (NE) along the path (V, A) following conditions must be satisfied:

$p(i) > p(r_1)$ (Eq. 1) *and* $p(i) > p(r_2)$ (Eq. 2)

$g(i) \geq g(r_1)$ (Eq. 3) *and* $g(i) \geq g(r_2)$ (Eq. 4)

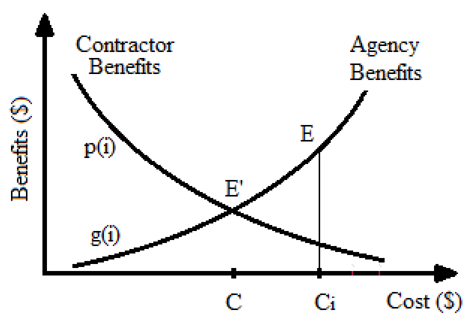

Figure 4: Agency and Contractor Benefit Functions

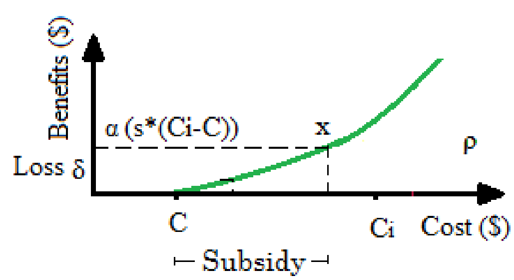

Figure 5: Subsidy Allocation Mechanism from Contractor's Perspective

In the above four conditions, $p(\cdot)$ and $g(\cdot)$ represent benefit functions for the Contractor and Agency respectively. Graphically these functions have been shown in figure 3. The figure shows representative behavior of the functions $p(\cdot)$ and $g(\cdot)$ under initially considered ideal conditions. Notice that when a Contractor invests \$C to procure materials and/or execute processes through the traditional supply chain the benefits realized by the Agency and the Contractor can be represented by the point E'. But since the Agency now desires to achieve higher benefits (represented by point E in Figure 4), which will require additional investment of (Ci – C), the contractor will expect to receive subsidies to bear the increased costs. Thus, we must develop a subsidy allocation mechanism that would provide motivation to the contractor to adopt the LCaSC.

DESIGN OF SUBSIDY ALLOCATION MECHANISM

Let us say that we introduce a subsidy allocation program (represented conceptually in Figure 5) defined by function S: R → R, where:

$$S(s) \begin{cases} = 0 & \text{if } Ci \leq C \\ = \bullet\,(s^*(Ci-C)) & \text{if } Ci > C \end{cases} \qquad \text{(Eq. 5)}$$

Where,

$0 \leq s \leq 1$, representing the percentage of subsidy allocated for bearing the additional cost of Ci-C and

$\bullet\,(\cdot)$ is a function that converts the subsidized amount into Contractor's benefit.

From condition (1) we notice that we must have p(i) greater than $p(r_1)$ so that the contractor selects strategy A when Agency selects strategy V. Thus if we add appropriate subsidies the condition would (1) can be satisfied and we can have following relation:

$$p(i) = p(r_1) + \bullet\,(s^*(Ci-C))$$

Rearranging the terms and making s as the subject of formula we get:

$$s = \frac{\bullet^{-1}\,[p(i) - p(r_1)]}{(Ci-C)} \qquad \text{(Eq. 6)}$$

Equation (6) is the designed subsidy allocation mechanism from the Contractor's perspective and defines the relationship between the subsidy amount and the corresponding Contractor's benefits. The above equation can be used as demonstrated in Figure 5. Let us say that when a Contractor is required to invest \$(Ci-C) additional it will realize a reduced benefits calculated as $p(i) - p(r_1) = \delta_C$. Thus the numerator in Equation 6 becomes $\bullet^{-1}\,[\delta]$. From Figure 5 we can see that for δ benefits the $\bullet^{-1}\,[\delta_C]$ locates a point x on the subsidy program which can be projected on the x-axis giving us a portion of (Ci – C) and thus we get the subsidy allocation percentage s.

SUBSIDY DESIGN FROM AGENCY'S PERSPECTIVE

In the previous section we developed subsidy considering the Contractors only. But since the subsidy will be given away from government funds, the Agency's concerns must also be included in the design of subsidies. Thus we consider here the condition 4 which states that to achieve the equilibrium along the (V, A) strategy path we must have $g(i) \geq g(r_2)$. This means that as long as the Agency's benefits from the planned benefits are higher than the benefits from enforcing the LCaSC, it would be beneficial for them to purse the V strategy. This means that the Agency can consider developing a subsidy program S′(s) which would enable the Agency to make sure that while providing the subsidies, the Agency is not giving away more than the optimal amount. This requires that the Agency develop a comparison mechanism that would enable it to design subsidies protecting Agency's interests. Let us say that the Agency defines a subsidy program as:

$$S'(s) \begin{cases} = 0 & \text{if } Ci \leq C \\ = \beta(s) & \text{if } Ci > C \end{cases} \quad \text{(Eq. 7)}$$

where,

$\beta(s)$ = is a function that would convert the subsidy amount into Agency's loss

With the defined Subsidy program we can say that the inequality in condition (4) can be changed into equality by addition of an appropriate subsidy as shown in below:

$$g(i) - \beta(s(Ci - C)) = g(r_2)$$

Making s as the subject of formula as before we get

$$s = \frac{\bullet^{-1}[g(i) - g(r_2)]}{(Ci - C)} \quad \text{(Eq. 8)}$$

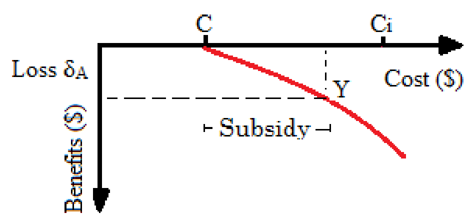

Figure 6: Subsidy Allocation Mechanism from Agency's Perspective

Equation (8) gives us the subsidy allocation mechanism from the Agency's perspective and defines the relationship between the subsidy amount and the Agency's corresponding's benefits. Let us say that when the Agency pays a certain amount to the Contractor as a subsidy it will realize reduced benefits calculated as $g(i) - g(r_1) = \delta_A$. From Figure 6 we can see that for δ_A lost benefits we can locate a point Y on the subsidy program and we can project this point on the x-axis using the $\beta^{-1}[\delta_A]$ which gives us a portion of (Ci – C) and thus the subsidy allocation percentage s. Thus using the mechanisms in equations (6) and (8) we can determine the minimum amount of subsidy that would satisfy the contactor and the Agency simultaneously.

CONCLUSION

This research was focused towards emissions from the construction industry. EPA has ranked construction industry as the third highest emitter in the U.S. However this ranking is based only on the emissions during the construction phase. Studies show that pre-construction and post-construction phases have also contributed to emissions significantly. If all the emissions are added together the overall emissions from construction industry will be very high. Since all the post-construction and pre-construction activities are dependent on the supply chain, each and every element of the chain contributes with the embodied emissions. This mandates Agencies to develop mechanisms to control emissions from all the elements of the construction supply chain.

Green Performance Contracting strategies identified by researchers can be used to control emissions from the whole life cycle but would require Agencies to develop subsidy allocation mechanism. This paper has developed a subsidy allocation mechanism which will enable the agencies to design subsidies to implement various GPC strategies.

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