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Mathematical Model to Improve the Environmental Performance of Construction Waste Management

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ABSTRACT:

In general, construction waste management process plays an important role in environmental sustainability. There is an immediate need to protect our environment by reducing the waste using appropriate measures. In the construction waste management process, reusing and recycling the waste plays a key role in reducing the total cost of the process. In this project, the mathematical model is proposed to evaluate the total cost of construction waste management with and without reusing and recycling processes. For the constructed model, the numerical examples are explained in a detailed manner. The total cost values are analysed by comparing the models which are formulated earlier.

Keywords: Construction waste, Reusing, Recycling, Illegal dumping, Environmental pollution, Total cost, Waste disposal.

1. INTRODUCTION:

Construction industry is considered as one of the largest producers of solid waste all over the world (Marzouk & Azab 2014). Due to the rapid development of construction industry over the last decade, a huge amount of construction waste is generated from increasing amount of construction activities. Construction waste is nowadays becoming a serious environmental issue and so it has attracted worldwide concerns from many economies around the world, either developing or developed (Mills et al., 1999; Begum et al., 2006; Hao et al., 2007; Wang and Yuan, 2009).
Construction waste means the waste which arises from construction activities like civil and building construction, demolition activities, road work, etc., (Shen et al., 2004; Tam and Tam, 2008). Construction waste materials include excavated materials, concrete, tiles, bricks, ceramics, asphalt concrete, glass, plastics, etc.,. Some materials can be reused and recycled from the construction wastes. The primary goals of construction waste management are to minimize the environmental impact, reduce landfill usage, and promote sustainable construction practices.

To respond to the challengs, increasing research efforts have been devoted to construction waste management strategies and its measures, ranging from the waste reduction treatment and recycle through the final disposal (yuan et al., 2012). To address the above research gaps, this study aims to investigate the environmental performance of construction waste management by considering the dynamic interrelationships of major factors influencing construction waste management. This study is based on the system dynamic (SD) approach. The novelty of the study mainly lies in the aspect of interactive relationships among major factor affecting the construction waste management process; which is fulfilled by identifying the main factors influencing the environmental performance of construction waste management and further examining the interactive relationships among the factors. In this study, the proposed model evaluate the total cost process to improve the environmental performance of construction waste management in construction projects.

2. LITERATURE REVIEW:

In line with the increasing acceptance of sustainable development as an important mission (WCED, 1987), the construction industry has recognised the need to alleviate its adverse impact on the environment. Based on the economic factors such as transportation, labor, and disposal costs, etc., Mills et al., (1999) conceived a proper waste management plan to choose a most cost-effective waste management plan. A benefit cost analysis was performed by Begum et al., (2006) to investigate the feasibility of waste minimization through the employment of several mathematical equations. Amodel was developed by Duran et al., (2006) to aasess the economic viability of creating markets for recycled construction waste under different economical instrument scenarios. Many methods for managing the construction wastes had developed, such as

establishing a waste management plan, adopting advanced construction technologies, conducting on-site waste sorting, and using precise building methods (Lu and Yuan, 2010). By using a systematic approach, a model was developed by Yuan et al., (2011) for investigating the cost benefit of the CWM process by taking into account the dynamics and interdependence nature of the process. K. Muthu Selvi and W. Ritha (2023) investigated the mathematical model to improve the environmental performance of construction waste management.

The rest of the paper is structured as follows: Section 3 deals with the mathematical model to find the total cost of CWM process, Section 4 explains the numerical examples for the mathematical model, Section 5 discusses the analysation of the models by comparing the total cost of the models and finally section 6 concludes this paper.

3. MATHEMATICAL MODEL:

3.1 ABBREVIATIONS:

Some of the abbreviated terms are used here. They are listed as follows: CWM : Construction Waste Management

TC : Total Cost

RU : Reused

RC : Recycled

EM : Emission

3.2 NOTATIONS:

X : Pay rate (wages) per month

Y : No. of labors required

TC : Total cost of CWM with reusing and recycling processes

TC^* : Total cost of CWM without reusing and recycling processes

L_C : Labor Cost

C_C : Cost of collected waste

S_C : Cost of sorted waste

RU_C : Cost of reused waste

RC_C : Cost of recycled waste

D_C : Cost of disposed waste for with reusing and recycling processes

D^*_C : Cost of disposed waste for without reusing and recycling processes

T_C : Transportation cost for with reusing and recycling processes

T^*_C : Transportation cost for without reusing and recycling processes

E_C : Environmental cost for with reusing and recycling processes

E^*_C : Environmental cost for without reusing and recycling processes

EM_C : Cost of emission caused by dumping of waste illegally for with reusing and recycling processes

EM^* : Cost of emission caused by dumping of waste illegally for without reusing and recycling processes

W_C : Amount of collected waste

W_S : Amount of sorted waste

W_{RU} : Amount of reused waste

O_1 : Amount of waste omitted as non-reused

W_{RC} : Amount of recycled waste

O_2 : Amount of waste omitted as non-recycled

EM : Amount of emission caused by dumping of waste illegally for with reusing and recycling processes

EM^* : Amount of emission caused by dumping of waste illegally for without reusing and recycling processes

U_C : Unit cost of collected waste

U_S : Unit cost of sorted waste

U_{RU} : Unit cost of reused waste

U_{RC} : Unit cost of recycled waste

U_T : Unit cost of transportation

U_L : Unit landfill charge

U_E : Unit environmental cost of illegal dumping of waste

U_{EM} : Unit cost of emission caused by dumping of waste illegally

3.3 MODEL-I (FOR FINDING THE TOTAL COST OF CWM WITH REUSING AND RECYCLING PROCESSES):

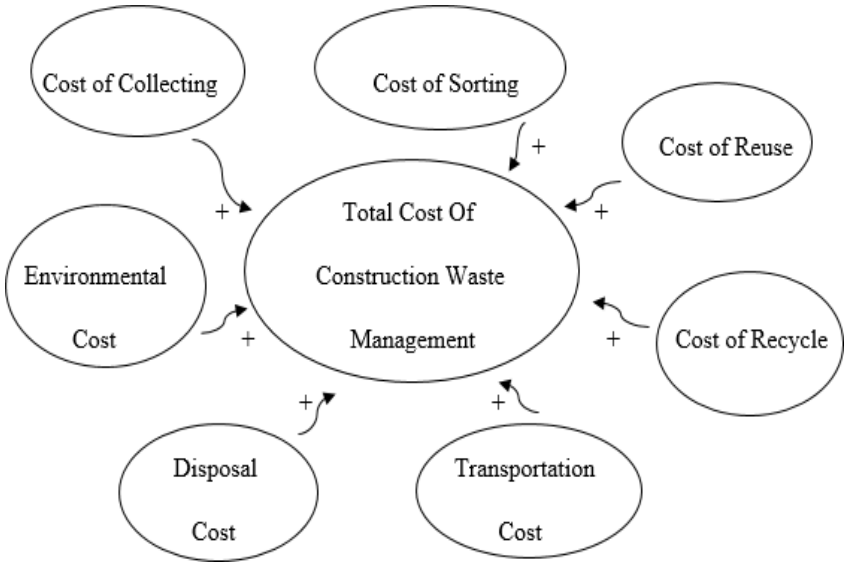

Figure-1

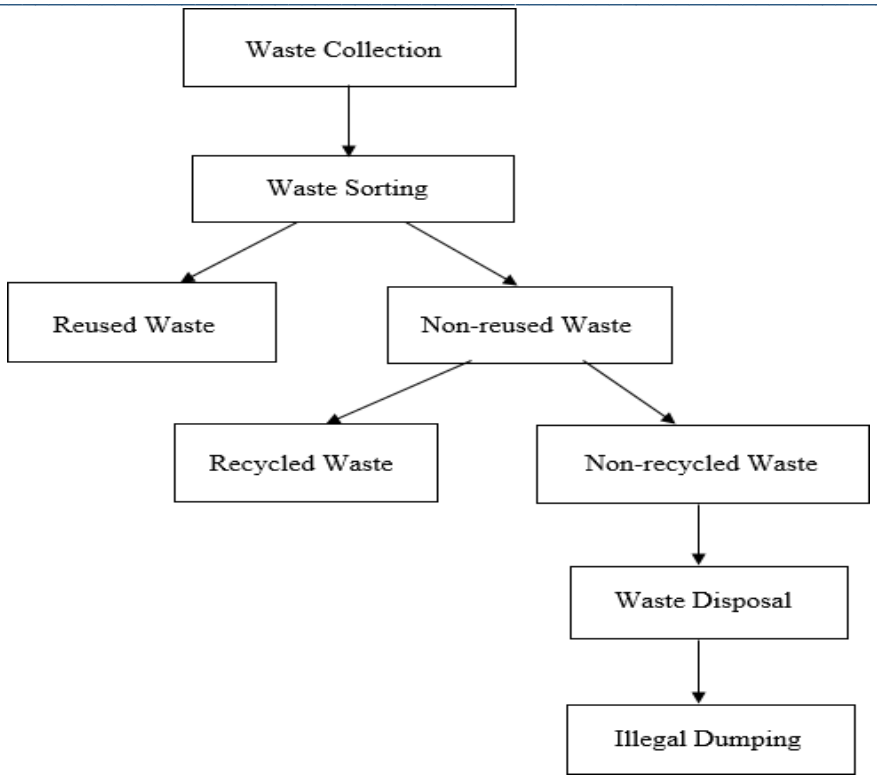

Figure-2

Total Cost:

Total cost (TC) = Labor cost + Cost of collected waste + Cost of sorted waste

+ Cost of reused waste + Cost of recycled waste + Cost of disposed waste + Transportation cost + Environmental cost + Cost of emission caused by dumping waste illegally

$TC = L_C + C_C + S_C + RU_C + RC_C + D_C + T_C + E_C + EM_C$

$TC = (X \times Y) + (W_C \times U_C) + (W_S \times U_S) + ((W_S - O_1) \times U_{RU})$

$+ ((O_1 - O_2) \times U_{RC}) + (O_2 \times U_L) + (O_2 \times U_T)$

$+ (O_2 \times U_E) + (EM \times U_{EM})$ (1)

Hence, this is the equation for finding the total cost of CWM with reusing and recycling processes.

3.4 MODEL-II (FOR FINDING THE TOTAL COST OF CWM WITHOUT REUSING AND RECYCLING PROCESSES)

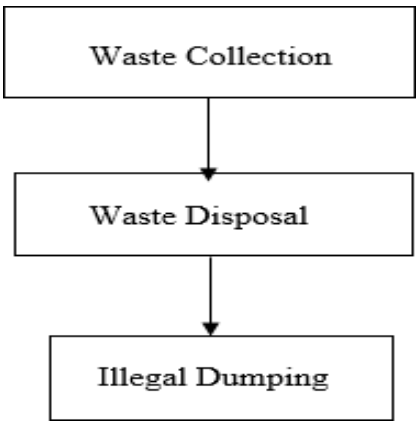

Figure-3

Total Cost:
Total cost (TC^*) = Labor cost + Cost of collected waste + Cost of disposed waste + Transportation cost + Environmental cost + Cost of emission caused
by dumping waste illegally

$TC^* = L_C + C_C + D^* + T^* + E^* + EM^*$
$C \quad C \quad C \quad C$

$TC^* = (X \times Y) + (W_C \times U_C) + (W_C \times U_L) + (W_C \times U_T)$

$+ (W_C \times U_E) + (EM^* \times U_{EM})$ ---------- (2)

Hence, this is the equation for finding the total cost of CWM without reusing and recycling processes.

From the above mathematical models I & II, the equations (1) & (2) are used to find the total cost of construction waste management with and without reusing and recycling processes.

NUMERICAL ILLUSTRATIONS:

3.5 EXAMPLE (FOR FINDING THE TOTAL COST OF CWM WITH REUSING & RECYCLING PROCESSES):

The data for the numerical example is listed below, Pay rate (wages) (X) = Rs.10,000/month
No. of labors required (Y) = 4

Amount of waste collected (W_C) = 495 ton/month Amount of sorted waste (W_S) = 495 ton / month Amount of reused waste (W_{RU}) = 90 ton/month
Amount of waste omitted as non-reused (O_1) = 405 ton/month Amount of recycled waste (W_{RC}) = 225 ton/month
Amount of waste omitted as non-recycled (O_2) = 180 ton/month

Amount of emission caused by dumping of waste illegally for with reusing and recycling processes (EM) = 900 ton/month
Unit cost of collected waste (U_C) = 170 Rs/ton Unit cost of sorted waste (U_S) =170 Rs/ton Unit cost of reused waste (U_{RU}) = 170 Rs/ton Unit cost of recycled waste (U_{RC}) = 227 Rs/ton Unit cost of transportation (U_T) = 284 Rs/ton Unit landfill charge (U_L) = 693 Rs/ton
Unit environmental cost of illegal dumping of waste (U_E) = 682 Rs/ton Unit cost of emission caused by dumping of waste
illegally (U_{EM}) = 795 Rs/ton

Solution:

Total Cost:

The total cost equation is,

Total cost (TC) = Labor cost + Cost of collected waste + Cost of sorted waste

+ Cost of reused waste + Cost of recycled waste + Cost of disposed waste

+ Transportation cost + Environmental cost + Cost of emission caused by dumping waste illegally
TC = $L_C + C_C + S_C + RU_C + RC_C + D_C + T_C + E_C + EM_C$

TC = (X × Y) + ($W_C \times U_C$) + ($W_S \times U_S$) + ((W_S - O_1) × U_{RU})

+ ((O_1 - O_2) × U_{RC}) + ($O_2 \times U_L$) + ($O_2 \times U_T$)

+ ($O_2 \times U_E$) + (EM × U_{EM}) Substituting the values in the above equation, then,
TC = (10000 × 4) + (495 × 170) + (495 × 170) +

((495-405) × 170) + ((405-180) × 227) + (180 × 693) + (180 × 284)

+ (180 × 682) + (900 × 795)

= 40,000 + 84,150 + 84,150 + 15,300 + 51,075 + 1,24,740

+ 51,120 + 1,22,760 + 7,15,500

TC = Rs. 12,88,795

Hence, the total cost for CWM with reusing & recycling processes is Rs. 12,88,795.

3.6 EXAMPLE (FOR FINDING THE TOTAL COST OF CWM WITHOUT REUSING & RECYCLING PROCESSES):

The data for the numerical example is listed below, Pay rate (wages) (X) = Rs.10,000/month.

No. of labors required (Y) = 4

Amount of waste collected (W_C) = 495 ton/month

Amount of emission caused by dumping of waste illegally for without reusing and recycling processes (EM^*) = 3200 ton/month

Unit cost of collected waste (U_C) = 170 Rs/ton Unit cost of transportation (U_T) = 284 Rs/ton Unit landfill charge (U_L) = 693 Rs/ton
Unit environmental cost of illegal dumping of waste (U_E) = 682 Rs/ton Unit cost of emission caused by dumping of
waste illegally (U_{EM}) = 795 Rs/ton

Solution:

Total Cost:

The total cost equation is,

Total cost (TC^*) = Labor cost + Cost of collected waste + Cost of disposed waste + Transportation cost + Environmental cost + Cost of emission caused
by dumping waste illegally

$TC^* = L_C + C_C + D^* + T^* + E^* + EM^*$
$C \quad C \quad C \quad C$

TC^* = (X × Y) + ($W_C \times U_C$) + ($W_C \times U_L$) + ($W_C \times U_T$)

+ ($W_C \times U_E$) + ($EM^* \times U_{EM}$)

Substituting the values in the above equation, then the total cost equation becomes,

TC^* = (10000 × 4) + (495 × 170) + (495 × 693) + (495 × 284)

+ (495 × 682) + (3200 × 795)

= 40000 + 84150 + 343035 + 140580 + 337590 + 2544000

TC^* = Rs. 34,89,355

Hence, the total cost for CWM without reusing & recycling processes is Rs. 34,89,355.

4. ANALYSIS OF THE MODEL:

By comparing the values of total cost in both the models I & II, which we determined using the total costs equation in both the models, the value of total cost in the model-I is lower than the value of the total cost in the model- II (i.e., the value of the total cost in the model-I is Rs. 12,88,795 which is lower than the value of the total cost in the model-II is Rs. 34,89,355). We can say that the total cost value of CWM process is reduced by using the processes like reusing and recycling in the construction waste management processes. The following diagram explains the total costs values which we find out for the models I & II.

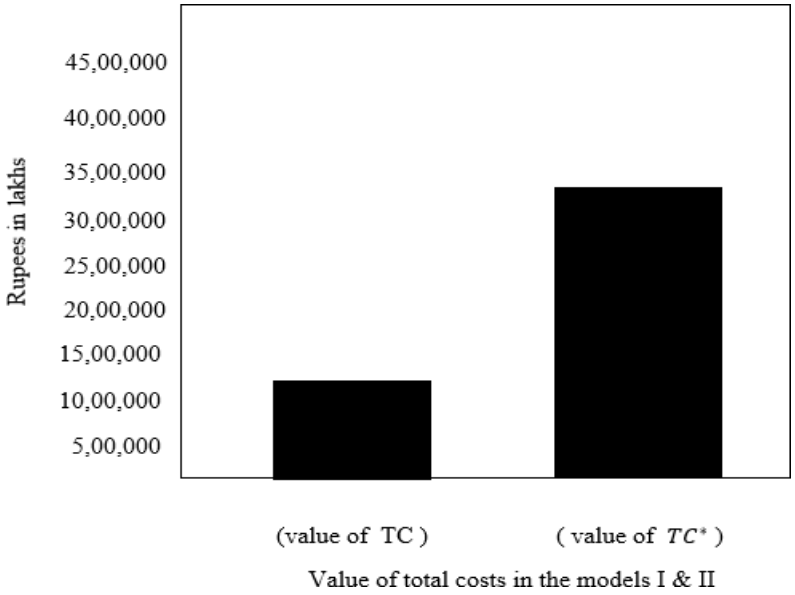

Figure-4

Here, TC: Total cost of CWM with reusing and recycling processes

TC^* : Total cost of CWM without reusing and recycling Processes

By the above diagram, we can say that the value of total cost in the model-I is lower than the value of the total cost in the model-II.

5. CONCLUSION:

In this study, the concept of construction waste management is discussed in the introduction part. The mathematical model to find the total cost of CWM with and without reusing and recycling is explained in the section 3. The proposed model is of two types model I & model II. Model I is for finding the total cost of CWM with reusing and recycling processes and also model II is for determining the total cost of CWM without reusing and recycling processes. In the section 4, the numerical illustrations for both the models I and II are discussed in a clear manner. Using the datas given in the both of the examples 1 & 2, the value of the total cost is find out for the models I &
II. Finally, in the section 5, the models I and II are analysed by comparing the values of the total cost and this is represented as a diagram.By analysing the models, we can conclude that the value of total cost of CWM in model I is lower than the value of the total cost of CWM in model II. Also, we can say that by using the process of reusing and recycling in CWM process, the total cost can be reduced in CWM process.

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