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CARBON DIOXIDE EMISSION EVALUATION IN CONSTRUCTION OPERATIONS USING DES: A CASE STUDY OF CARWASH CONSTRUCTION

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ABSTRACT

This study aims to assess the carbon dioxide emission of carwash construction operation by applying computer-based simulation modeling. Discrete event simulation (DES) serves as an effective way to functionally evaluate carbon dioxide emission of a typical carwash construction. The DES model makes it possible to efficiently simulate and analyze carbon dioxide emission factors. This in turn requires project participants to find ways to decrease inverse environmental effects of the projects to respond to the increasing concern on such issues. This study is carried out by studying the process, data analysis, and simulation of the construction operation using Visio, Excel, and EZStrobe computer software. This simulation tool is practical for project participants and will offer them an idea of carbon dioxide emission in more realistic scenarios during construction operation.

1 INTRODUCTION

1.1 Motivation

The construction phase of any facility is a major contributor to the environmental pollutants during the life cycle of many industrial projects (Sharrard, Matthews, and Ries 2008). Different industries try to reduce the amount of environmental pollutant production in the life cycle of their facilities in order to meet sustainability criteria set forth by local, state, and federal agencies. The carwash industry is a huge consumer of water and producer of pollutants including oil, phosphorous, ammonia, surfactants, and solid wastes (Orscheln 2011). While recent environmental conservation movements such as the “Lexington County’s Green Car Wash Campaign” coordinated by the Clemson University (Orscheln (2011), solved waste water issues to a large extent, the construction process of a typical carwash facility unit remains as a big concern in the life cycle emission analysis. According to the Bureau of Economic Analysis (2016), the automobile unit sale dropped approximately 30% during the United States financial crises from 2007 to 2009. As of 2009, however, there was a significant rise in vehicle unit sale (BEA, 2016). From 2009 to 2015, the vehicle unit sales grew nearly 39% and the number is expected to rise in subsequent years (BEA 2016). With the growth of automobile sales volume, the demand for carwash construction increased.

1.2 Problem Statement & Research Method

The lack of a clear understanding of carbon dioxide emission during industrial processes and the shortage of standard measurement tools drew governments’ pace on creating a lower carbon footprint (Pearson and Foxon 2012). Simulation is a powerful tool for supporting the decision making process in construction management, which helps compare alternatives and choose a better construction process (AbouRizk and

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Mohamed 2000). This research project evaluates the construction phase of a carwash facility as a case study and measures the carbon dioxide emission using an integrated simulation framework. The evaluation framework developed in this study uses discrete even simulation (DES) to model the carbon dioxide emission during carwash constructions.

1.3 Research Background

DES, as a major tool used in this research, is a simulation paradigm which focuses on modeling system behaviors as discrete events that can be viewed as a queuing network (Nouman, Anagnostou, and Taylor 2013). The state of an entity, drawn from a resource pool, changes by execution of an activity. In this study, EZStrobe is used as a simple but advanced computer simulation system that is designed with specific attention to construction processes modeling (Halpin and Riggs 1992). The simulation platform is based on activity cycle diagram (ACD) that uses a graphical network to outline, among others, the resources and activities (Halpin and Riggs 1992; Martinez 1996).

2 METHODOLOGY

2.1 Simulation-Based Environmental Impact Assessment

For the estimation and evaluation of carbon dioxide emission from carwash construction, DES provides the carbon dioxide emission model and helps calculate the carbon dioxide emission from the construction process. Referring to the definition of the International Standards Organization (ISO), four main steps are required to assess the environmental impacts of products or services (ISO 2009a). These four steps include "goal and scope definition", "inventory analysis", "impact analysis", and "result interpretation" as shown in Figure 1 (ISO 2009a).

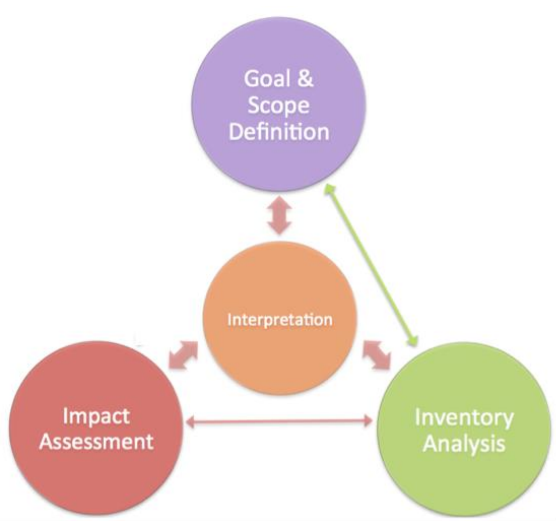

Figure 1: Life cycle assessment framework (adopted from ISO 2009a).

The first and basic step is to define goal and scope in the carwash construction. It is worth mentioning that generally project participants pay more attention to completing construction projects within agreed costs and intended schedule and are less concerned with the amount of carbon dioxide emitted during construction period. Therefore, the goal of this study is to utilize EZStrobe computer software to develop a computer simulation model for simulating carbon dioxide emission during carwash constructions. Also, its scope covers developing an evaluation method for carbon dioxide emission of carwash construction integrated by DES to respond to the increasing demand of carbon dioxide reduction and governmental commitments.

The next step following goal and scope definition is inventory analysis. The inventory analysis process can be categorized into three parts, extracting duration of activities from video data, gathering construction flow chart related to concrete construction operations, and system boundary. Brio, a Canadian carwash company, published their carwash construction video showing the time it takes for construction equipment construction to finish a task. The activity cycle diagram (ACD) of the simulation model is developed using the observations from the video representing construction processes. The DES model is built based on the ACD. To estimate and evaluate carbon dioxide emission from carwash construction, a DES model is built by EZStrobe software which simulates the construction functions relating to concrete. Using DES, the carbon dioxide emission is accurately evaluated by multiplying the duration of operation and idling of construction equipment with a coefficient for each type of equipment. The proposed approach provides carbon dioxide emission performance on actual duration of the equipment operation and idling duration (non-operation) making the carbon dioxide emission evaluation more precise.

2.2 Evaluating and Calculating Carbon Dioxide Emission

The concrete mixer truck, concrete pump truck, and concrete vibrator are chosen as the major machinery equipment used in analysis. The concrete mixer truck activities include loading, hauling, unloading, pouring concrete, and returning to concrete loading site. Concrete pump truck activity also includes safety inspection before pouring concrete and pouring concrete. The function of the concrete vibrator is to vibrate after pouring concrete in the mold. Screeding tool is used to flatten out the wet concrete. According to each activity process from the equipment, the DES model can be built as in Figure 2.

After completing the simulation, the results of the duration of machinery equipment and activities have been assessed by DES model. The key to the evaluation of carbon dioxide emission is the duration of machinery activities. The actual operating time of each activity can be calculated by multiplying n and d, as shown in Equation 1.

$$Time_{operating} = n \times d \tag{1}$$

where n is the number of occurrences of each equipment activity; and d equals the average duration of equipment activity. Another important consideration is that the amount of carbon dioxide emission is based on the equipment operation duration and equipment idling duration.

The total amount of carbon dioxide emission for machinery equipment is calculated as $Time_{operating} \times EF_{operating} + Time_{idling} \times EF_{idling}$. Therefore,

$$Emission_{total} = \sum Time_{operating} \times EF_{operating} + Time_{idling} \times EF_{idling} \tag{2}$$

where $Time_{operating}$ is represented by equation (1); $EF_{operating}$ is carbon dioxide emission coefficient per unit operating time; $Time_{idling}$ is the idling time of each equipment activity; EF_{idling} is carbon dioxide emission coefficient per unit idling time.

A study of idle and non-idle fuel use rates and CO_2 emission rates indicates that a value of γ is in the range from 0.2 to 0.3 (Lewis, Leming, and Rasdorf, 2012). In applying $EF_{operating}$, the equation for carbon dioxide emission coefficient of idling time is below:

$$EF_{idling} = \gamma \times EF_{operating}, \quad \text{where } \gamma = 0.2. \tag{3}$$

where γ is used as an adjustment factor for calculating carbon dioxide emission of idling time of the equipment.

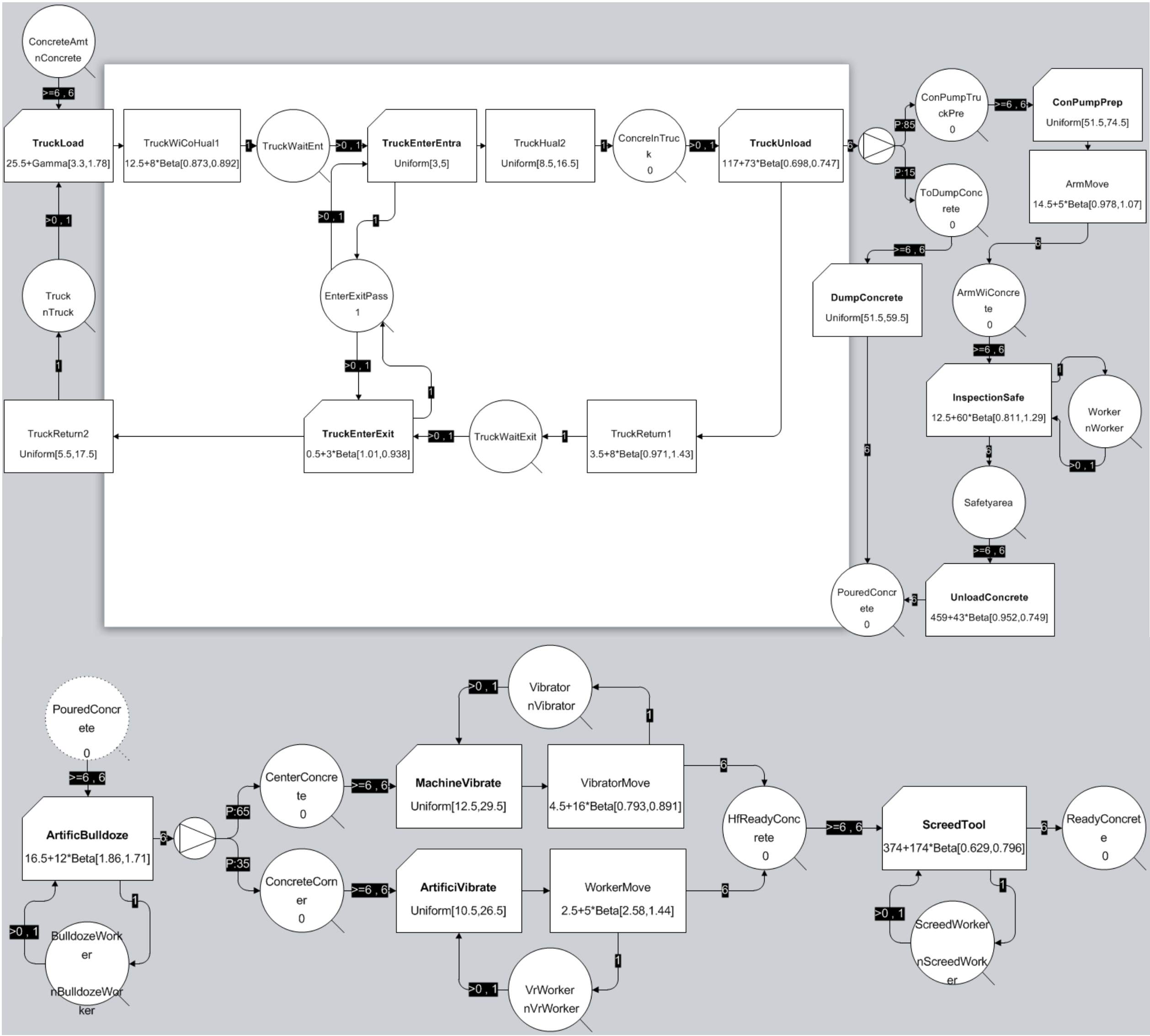

Figure 2: DES model for pouring concrete in carwash construction.

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$$Time_{operating} = n \times d \tag{4}$$

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where $Time_{operating}$ is represented by equation (1); $EF_{operating}$ is carbon dioxide emission coefficient per unit operating time; $Time_{idling}$ is the idling time of each equipment activity; EF_{idling} is carbon dioxide emission coefficient per unit idling time.

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$$EF_{idling} = \gamma \times EF_{operating}, \quad \text{where } \gamma = 0.2. \quad (6)$$

where γ is used as an adjustment factor for calculating carbon dioxide emission of idling time of the equipment.

3 DATA COLLECTION

3.1 Tool

Three common tools are used for the data collection and simulation in BRIO carwash construction:

1. MPlayerX computer software to replay the entire BRIO carwash construction in order to obtain observational data from the video, especially the duration of equipment and activities;
2. Input Analyzer computer software to find statistical distributions that best fit the duration of each equipment activity; and
3. EZStrobe to develop a DES model for outcomes in the durations of each of equipment activity.

The EZStrobe software is a key tool in this project. The computer software uses seven symbols on the toolbar "EZStrobe Stencil" to build an ACD network diagram which represents the flow of the carwash construction. The seven symbols are "Queue," "Conditional Activity," "Normal Activity," "Fork," "Draw Link," "Release Link," and "Branch Link."

3.2 Results of Video Observations

The video data is converted to a table of activity duration for probability distribution fitting. As shown in Table 1 below, activity duration of each of equipment activity comes from video data that is collected in BRIO carwash construction site. The equipment's activity duration, including predecessor activity duration, beginning time, successor activity duration, and finishing time are determined from the video data. Each activity is observed at least 35 times, making the time distribution more precise.

3.3 Distribution Fitting Results

The settled activity duration from the video data are put into the Input Analyzer software to automatically generate a distribution that best simulates the actual data. As an example, Figure 3 and 4 show two major graphical results of activity duration distribution in the carwash construction. Furthermore, all activity duration distributions are tested by Square Error, Chi-Squared, and Kolmogorov-Smirnov (K-S) tests to measure the goodness of fit. Square Error, Chi-Squared, and K-S are used to estimate parameters from the sample data and makes sample data more conservative. The time distribution table based on the construction site is shown in Table 2.

The simulated results of the duration of equipment activities is assessed from the DES model. After completion of the simulation, test verification and validation of the DES model is required. The verification and validation test is to ensure the accuracy and reliability of the computational simulation. The purpose of verification is to compare the simulated and observed duration of activities of the concrete mixed truck and validation ensures that the construction process in DES model is the same as the real construction process.

Table 1: Activity duration for each equipment.

Activity	Concrete Mixer Truck Loading	Concrete Mixer Truck Hauling #1	Concrete Mixer Truck Entering Work Space	Concrete Mixer Truck Hauling #2	Concrete Mixer Truck Unloading	Concrete Pump Truck Preparation	Dump Concrete	Concrete Pump Truck Arm Move	Safty Inspection	Concrete Pump Truck Concrete Unloading	Concrete Pump Truck Arm Remove	Concrete Mixer Truck Return #1	Concrete Mixer Truck Exiting Work Space	Concrete Mixer Truck Return #2	Artifical Bulldozer	Machine Vibrate	Vibrator Move	Artificial Vibrate	Worker Move	Screeding Top of Concrete
Duration (second)																				
1	38	14	4.6	9	161	60	54	15	72	501	16	7	1	14	18	21	10	17	5	515
2	30	14	3.8	16	158	57	53	18	16	473	15	9	3	17	25	19	14	17	5	434
3	31	14	3.4	11	179	71	58	15	24	482	15	11	1	12	23	25	18	23	6	487
4	34	14	4.7	13	173	74	58	17	46	497	18	7	3	10	21	18	10	11	6	548
5	29	20	3.7	13	149	74	52	16	58	464	16	7	1	13	28	21	13	15	6	426
6	32	17	3.9	14	135	63	58	15	15	469	14	8	1	12	22	22	17	18	5	404
7	30	13	3.2	15	117	58	52	18	38	480	14	6	1	14	23	28	5	12	5	444
8	28	13	4.8	10	122	66	52	15	28	477	17	5	2	11	27	29	18	12	6	493
9	28	16	4.2	11	117	72	53	16	24	481	16	5	3	6	18	13	20	25	6	511
10	33	13	4.6	12	125	68	57	19	19	476	14	4	1	12	25	16	9	26	7	374
11	31	17	3.4	12	178	52	52	18	36	500	14	6	3	9	21	15	10	11	7	542
12	26	20	4.7	10	163	56	58	17	47	499	18	5	3	10	26	15	5	15	5	409
13	38	15	3.6	10	127	60	55	18	52	501	15	8	1	13	25	26	7	25	4	499
14	33	13	4.2	15	189	64	53	15	18	489	18	4	2	6	23	18	15	14	7	441
15	31	17	4.3	13	118	70	56	18	24	479	17	4	1	16	17	20	17	15	5	432
16	26	13	4.2	13	181	60	53	19	43	489	17	4	3	6	18	26	14	23	6	387
17	27	16	4.7	15	183	52	58	19	38	493	16	6	1	12	25	27	15	22	6	424
18	31	14	4.2	11	143	52	56	15	62	459	14	10	3	15	22	22	18	25	3	383
19	31	16	4.4	16	160	74	59	16	18	499	18	5	3	15	24	14	10	16	7	537
20	28	18	3.2	14	150	56	59	19	13	491	18	11	1	10	23	26	19	15	5	425
21	33	20	4.9	15	137	59	57	17	26	470	17	6	2	8	24	17	5	14	6	505
22	26	20	3.0	13	167	66	58	19	39	491	14	5	2	9	21	16	5	17	4	407
23	35	16	3.7	14	133	69	55	15	50	495	17	7	1	10	18	27	20	18	7	388
24	33	16	3.9	9	140	69	53	17	32	491	14	4	3	10	24	22	6	13	6	466
25	32	19	4.0	11	117	70	55	15	21	485	15	6	2	15	25	29	5	14	3	518
26	32	20	4.5	9	154	58	57	17	37	465	16	9	3	8	25	28	11	12	6	423
27	37	20	3.6	15	139	60	55	17	19	484	18	4	3	15	27	17	12	25	5	397
28	37	17	3.9	13	159	52	58	17	37	492	17	5	2	16	19	15	20	19	7	374
29	29	19	3.7	9	163	70	55	16	63	492	16	11	2	8	17	29	7	13	7	374
30	27	18	4.5	16	161	72	55	16	55	471	15	7	2	11	18	20	9	25	6	513
31	33	16	3.1	9	139	73	58	16	14	468	15	5	3	6	18	13	19	17	6	445
32	26	17	3.2	13	184	60	54	16	26	460	14	9	3	15	28	21	7	22	7	406
33	31	19	4.9	14	187	57	57	19	68	493	14	4	3	11	25	26	7	26	6	413
34	38	17	4.3	13	121	63	52	18	31	461	15	10	1	16	23	24	12	18	7	511
35	34	15	3.1	15	183	73	53	18	40	473	14	7	2	7	27	14	10	13	7	522

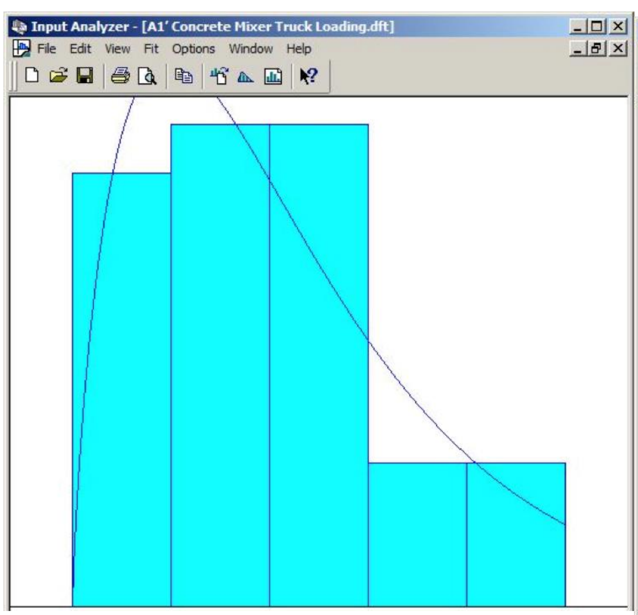

Figure 3: Probability distribution of concrete mixer truck loading duration.

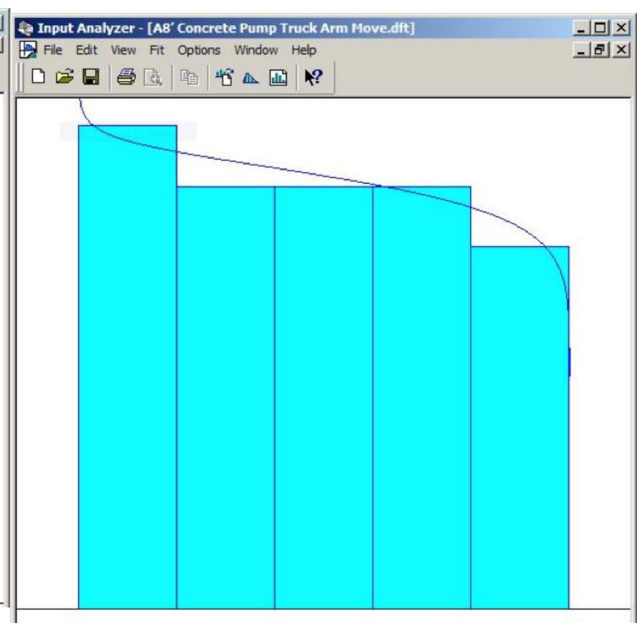

Figure 4: Probability distribution of concrete pump truck arm move duration.

Table 2: Probability distribution of activity durations.

Activity	Time Distribution	Alpha	Beta	Min	Max	Standard Deviation	Chi Squared	K-S
Concrete Mixer Truck Loading	25.5 + GAMM(3.3, 1.78)	3.3	1.78				1.85	
Concrete Mixer Truck Hauling #1	12.5 + 8 * BETA(0.873, 0.892)	0.873	0.892				0.0367	
Concrete Mixer Truck Entering Work Space	Uniform(3, 5)			3	5		1.43	0.0859
Concrete Mixer Truck Hauling #2	Uniform(8.5, 16.5)			8.5	16.5		1.63	
Concrete Mixer Truck Unloading	117 + 73 * BETA(0.698, 0.747)	0.698	0.747				3.11	
Concrete Pump Truck Preparation	Uniform(51.5, 74.5)			51.5	74.5		2.31	
Dump Concrete	Uniform(51.5, 59.5)			51.5	59.5		0.771	
Concrete Pump Truck Arm Move	14.5 + 5 * BETA(0.978, 1.07)	0.978	1.07	15	19	1.43	0.0423	
Safety Inspection	12.5 + 60 * BETA(0.811, 1.29)	0.811	1.29	13	72	16.6	1.83	
Concrete Pump Truck Concrete Unloading	459 + 43 * BETA(0.952, 0.749)	0.952	0.749				0.622	
Concrete Pump Truck Arm Remove	13.5 + 5 * BETA(1.07, 1.28)	1.07	1.28	14	18	1.48	1.16	
Concrete Mixer Truck Return #1	3.5 + 8 * BETA(0.971, 1.43)	0.971	1.43	4	11	2.24	0.937	
Concrete Mixer Truck Exiting Work Space	0.5 + 3 * BETA(1.01, 0.938)	1.01	0.938	1	3	0.873	0.808	
Concrete Mixer Truck Return #2	Uniform(5.5, 17.5)			5.5	17.5		0.771	
Artifical Bulldozer	16.5 + 12 * BETA(1.86, 1.71)	1.86	1.71				0.154	
Machine Vibrate	Uniform(12.5, 29.5)			12.5	29.5		0.133	
Vibrator Move	4.5 + 16 * BETA(0.793, 0.891)	0.793	0.891				1.74	
Artificial Vibrate	Uniform(10.5, 26.5)			11	26		2.16	
Worker Move	2.5 + 5 * BETA(2.58, 1.44)	2.58	1.44	3	7	1.11	0.6240	
Screeding Top of Concrete	374 + 174 * BETA(0.629, 0.796)	0.629	0.796			55.5	3.62	0.0994

3.4 Verification of the Model

As an example of the activity of a concrete mixer truck, the settled activity duration from the video data is compared to the simulated activity duration from DES model, as shown in Table 3.

Table 3: Activity duration for concrete mixer truck.

Concrete Mixer Truck State	Concrete Mixer Truck Operation Duration (second)		
	Observed Data	**Simulated Data (average value for 100 times simulation)**	**Relative Change**
Loading	31.20	31.48	0.90%
Idling	677.40	695.87	2.73%
Transfer	29.90	32.84	9.82%
Unloading	152.20	151.70	0.33%
Return	20.20	20.41	1.04%

According to Table 3, the DES model can accurately simulate the duration of various activities except the duration of hauling the concrete. Apart from the duration of hauling concrete, there is less than 1% difference of observed data and simulated data. The idling time from simulated results and observation has a small difference of about 2.73%. Thus, this test demonstrates that the process of building the DES model is accurate.

3.5 Validation the Model

Figure 5 shows the testing results to validate the DES model by comparing the simulated and actual duration of pouring 18 cubic meters (m^3) concrete for the BRIO carwash construction. The simulated result comes from the raw results of the simulated duration by running DES model 100 times. The actual duration comes directly from the video data.

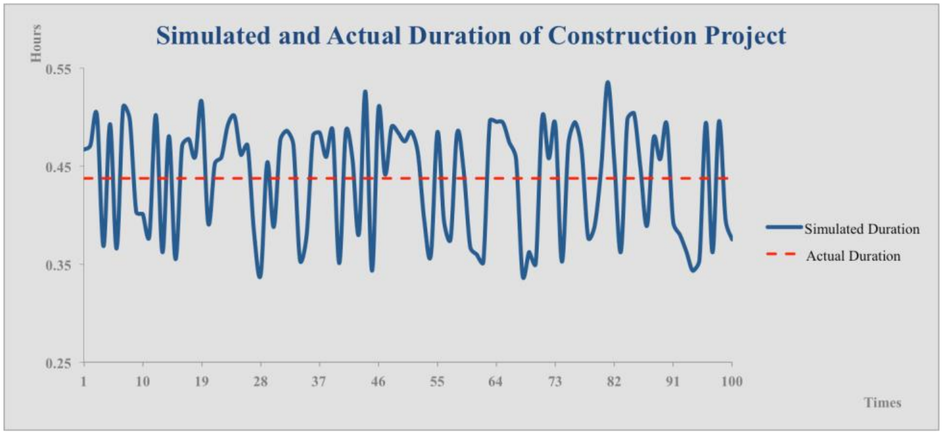

Figure 5: Simulated and actual duration of construction project for pouring concrete.

The DES model's output for pouring 18 m^3 concrete gives the average project duration with a relatively small standard deviation, which is about 0.44 hour and 0.0576 hour. From the video data, the actual project duration is 0.49 hour. It can be said that this test proves the validation of the DES model. After proving the verification and validation of DES model, the emission of carbon dioxide can be calculated based on the output of the DES model.

4 RESULTS AND ANALYSIS

The total mass of CO_2 emission for pouring 18 m^3 concrete in this study is 23,909 gram CO_2, obtained from the 100 runs of the simulation model. The results of the CO_2 emission calculation for the all the machinery equipment and activities are presented in Table 4. In terms of carbon dioxide emission intensity, pouring one cubic meter of concrete will generate around 1.3 kg of CO_2. The concrete pump truck accounts for the largest share in CO_2 emission, and the concrete mixer trucks are the second biggest contributor for CO_2 emission, as shown in Table 4.

Additionally, this study of the DES model provides project participants that carbon dioxide emission information from the carwash constructions is particularly essential. It is regarded as a cost-effective and time saving way to evaluate carbon dioxide emission.

5 CONCLUSION

Carwash construction will soon become a very large market in the U.S. and around the world. The presented study's goal was to use systematic calculations to evaluate and calculate carbon dioxide emission during carwash construction and to make effects to reduce carbon dioxide emission. R-world activity durations extracted from heavy equipment activities were used to develop a DES model. The model was validated and verified for fidelity assessment. Results indicate that around 24 kg of CO_2 is produced in the operation, the majority (around 15.5 kg) of which generated by the concrete pump truck.

6 FURTHER RESEARCH

This study has established a simulated framework to calculate and evaluate carbon dioxide emission during construction using a case study of carwash facility construction. Future directions of the presented work include using the results to improve equipment efficiency, reduce carbon dioxide emission, and optimize construction scheduling for less environmental impact.

Table 4: Emissions from various construction equipment.

Equipment	Emissions from Various Construction Equipment **CO2 (g)**
Concrete Mixer Truck	8190.25
Concrete Pump Truck	15535.12
Concrete Vibrator	176.35
Total	23901.72

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