Developing a New Activity Pollution Index for Emissions Quantitative Assessment in Projects Construction Phase: Case Study of an Administrative Building, Egypt

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Abstract. Quantitative assessment of emissions related to construction projects should be performed during the planning phase of the projects. This is significant to spot the high values of pollution during the construction phase. In this study, a model is developed to estimate pollution resulting from Buildings construction activities. The model calculates the generated pollution for each activity involved in the project as a result of dust, gases and noise emissions. A new index is developed namely Activity Pollution Index (API) which expresses the amount of total pollution for each activity during the project construction phase. Also, the developed model is able to display the resulted total pollution distribution throughout the project life that corresponding to the planned scheduling. An actual case study in an administrative building construction in Egypt is selected to demonstrate the practical use of the proposed model. The results show that the peak and minimum values of total pollution were occurred during the excavation activity and the formwork erections and steel fixing of the second segment of the building with values of API equal to 69 and 2, respectively.

1. Introduction
Air pollution has been and remains to be seen as a serious problem that affects human health and welfare. Construction industry carries a major threat to the environment as it has various impacts on the environment. Construction of buildings in Egypt is considered as one of the large sectors of the construction industry. Integrated environmental protection at the project planning phase should be performed to avoid or minimize pollution. To minimize the generated pollutants, construction
engineers and planners need to evaluate and optimize their resource utilization decisions and selections. For each activity in the project, these decisions include: a) selecting construction methods and raw materials, and b) identifying equipment’s and labors’ configurations and size. For example, using more productive equipment or using high engine power machines may save time, but it often increases air pollution. Construction equipment contributes a significant portion of air pollutants in urban areas during construction works such as site preparation, foundation works, road construction and maintenance [1].

The main types of emissions in building construction are direct and indirect emissions. Direct emissions are defined as those emissions that produced from the major process considered while indirect emissions are emissions at upstream processes of the major process [2].

A lot of research studies have performed that are concerned with environmental issues. For instance, Chen et al. [3] proposed an approach for quantitative assessment during the planning phase; this approach is based on the calculation of a “Pollution Index” for each of the construction activities. The index is simply a multiplication of the impact magnitude by the duration of the activity. In another study, Soderman [4] concluded that the quantitative risk analysis provides an assessment of environmental safety, the link between quantitative risk analysis and environmental management is fundamental for mitigating environmental impact. Chen et al. [5] used an analytic network process (ANP) to construct two decision models for environmental construction planning. Guggemos et al. [6] used the usage hours of the construction machines to estimate their emissions.

Hummer et al. [7] presented an optimization model for selecting construction equipment fleets that minimize total equipment cost and total emissions, or that minimize total equipment cost while limiting emissions. In another study, Arocho et al. [8] made a study on four street and utility construction projects and calculate emissions from the utilized non-road equipment. This study revealed that demolition and earthwork activities have a major effect on the total emissions during street construction. Baratia and Shen [9] developed a model to reduce the quantity of emissions produced per travelled distance for on-road construction equipment. They considered in their study three main operational factors that effect on emission rate. These factors are speed, road slope and payload.

This paper focuses on estimating emissions generated from buildings construction projects. The proposed environmental model aims at estimating the amount of pollution produced from construction activities. This model mitigates construction pollution by calculating the pollutants released from each project activity due to dust, harmful gases and noise, further it calculates the overall activity pollution index.

2. Methodology

The Activity Pollution Index model is developed to calculate the amount of air pollution generated from each activity in Building construction project. Further, it calculates the overall pollution of the project. Figure 1 illustrates the procedures followed to calculate the Activity Pollution Index (API). The proposed environmental model is divided into three sub-modules: dust, gases and noise.

Emission factors published by United States Environmental Protection Agency (US EPA) is used to estimate emissions from construction equipment usage. The major reason for applying US EPA emission factors for emissions estimating is that these factors are established according to the machine power and its deterioration and hence, give real emission pattern. This provides a unique emission factor for every machine which reflects the practical emission pattern better.

2.1. Estimating Dust Emissions

Dust arises from mechanical disturbance of granular material exposed to the air. It is termed fugitive because it isn't discharged to the atmosphere in confined flow stream (EPA). The main sources of fugitive dust in Buildings construction are; traffic on unpaved roads, materials handling, bulldozing and grading. Dust sub-module uses the empirical equations that presented by EPA ([10]–[13]). Figure 2 shows the flowchart for dust sources and factors affecting each one.
2.2. Estimating Gas Emissions

Construction vehicles and plant machinery are the main sources of harmful gases emissions. This module covered most major pollutants released from combustion engines of equipment’s during the buildings construction. These pollutants are Carbon monoxide (CO), Hydrocarbon (HC), nitrogen Oxides (NOX), sulfur oxides (SOX) and Particulate matter less than 10µm in aerodynamic diameter (PM10), Carbon dioxide (CO2), Methane (CH4) and nitrous oxide (N2O). Methane (CH4) and nitrous oxide (N2O) are neglected in this study due to unavailability of data which is required to calculate them.

Gas emission from each equipment (Ei) can be evaluated using the general equation given below:

\[
E_i = EFi \times P \times LF
\]  

(1)

Where: \( EFi \) is the emission factor for the emission i in g/(hp-hr); \( P \) is the power of the considered equipment in HP; \( LF \) is the operation load factor of the considered equipment.
2.3. Estimating Noise Emissions

The main source of noise in buildings construction projects is construction equipment. In addition, some activities cause noise during their execution. By determining the manufacturer, model type and power of equipment, noise component estimates the noise level. Noise is measured with a sound level meter and usually in terms of Decibels (dB). When two or more pieces of construction equipment are producing sound simultaneously, the total sound level isn’t the summation of sound produced from each equipment. Because Decibels are geometric values, they can’t be added or multiplied directly, but that can be done by calculating the equivalent sound level (Leq) from equation (2).

\[
Leq = 10 \log \frac{\sum_{i=1}^{N} 10^{L_i/10}}{N}
\]

Where: \(Leq\) is the equivalent sound level; \(L_i\) is the sound level for source i and \(N\) is the total number of sources.

2.4. Calculating Activity Pollution Index (API)

Total activity pollution index is calculated by normalizing the amount of dust, gases and noise emissions for each considering activity. The normalization process is done by determining the maximum threshold limit of pollutant. Such maximum threshold limits can be determined from environmental regulations and Acts in Egypt such as Law No.9 (Promulgating the Environmental Law 2009) [14]. Activity Pollution Index (API) can be estimated according to the following equation:
Where:

\[ API_i = \frac{E_{i \text{dust}}}{E^m_{\text{dust}}} + \sum \frac{E_{i \text{gases}}}{E^m_{\text{gases}}} + \frac{E_{i \text{noise}}}{E^m_{\text{noise}}} \]  

\[ (3) \]

\[ C_x = \frac{Q}{\pi x U \sigma_x \sigma_z} \left[ e^{-\frac{u^2}{2\sigma_x^2}} \right] \]

\[ (4) \]

Where: \( C_x \) is the ground level concentration at distance \( x \) downwind (g/m³); \( Q \) is the quantity of pollutant (g/sec); \( U \) is the mean wind speed (m/sec); \( \sigma_x \) and \( \sigma_z \) are the horizontal and vertical standard deviations of wind direction respectively (m) and \( H \) is the source height (m) (the value utilized by the pollution module is 1m as default value).

### Table 1

The environmental law applied in Egypt law No. 9 (2009)

| Pollutant | Harmful Gases | Dust | Noise |
|-----------|---------------|------|-------|
|           | CO | NO2 | PM10 | SO2 | HC | CO2 |
| Maximum Limit (µg/m³) | 30000 | 400 | 400 | 350 | 600 | 35000 | 10000 | 90 (dB) |

2.5. **Model Implementation**

The developed API model is coded and implemented using Visual Basic for application (VBA) on Microsoft Excel software. Friendly user interfaces are designed to facilitate entering data, sorting data, calculating the gases, dust and noise emissions for each activity and hence, calculating API and generating output reports. Therefore, the user enters each activity involved in the project. The equipment required for each activity can be added. The gas, dust, and noise emissions are defined for each equipment which required for an activity. Finally, after entering the parameter required for each emission, the results will appear in output interface.

2.5.1. **Gas sub-module.** All the machines utilized by the construction activities should be defined. Gas sub-module estimates the emissions of six main pollutants, carbon monoxide (CO) sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), Hydrocarbons (HC) and carbon dioxide (CO2). The total gas emissions for all equipment utilized by each construction activity can be calculated.

2.5.2. **Dust sub-module.** Dust Sub-Module calculates the dust emissions generated from four sources, material handling, traffic on unpaved roads, bulldozing and grading.

2.5.3. **Noise sub-module.** The user selects the equipment and enter the manufacturer, type, power and the noise level of each different equipment utilized by each activity. Once the user enters these data, the noise sub-module calculates the total noise for all equipment utilized by the construction activity.

3. **Case Study**

3.1. **Case Description**

This case example considers the construction of the new administrative building of Egypt Japan University for Science and Technology (EJUST) in new Burg Alarab city-Alexandria Governorate in
Egypt. It is a three-story building in four segments with a total area of 2500 m². Table 2 lists the main activities and the associated utilized equipment of the case study.

**Table 2.** The main activities and utilized equipment of the case study

| Activity                        | Utilized Equipment                        | Number |
|--------------------------------|-------------------------------------------|--------|
| Excavation                     | Loader (Caterpillar 966H (6 m³))          | 2      |
|                                | Truck (Mercedes Actros 4040 (18 m³))     | 4      |
| Backfilling                    | Loader (Caterpillar 966H (6 m³))          | 1      |
|                                | Truck (Mercedes Actros 4040 (18 m³))     | 2      |
| Soil Replacement-Compaction    | Loader (Caterpillar 966H (6 m³))          | 1      |
|                                | Truck (Mercedes Actros 4040 (18 m³))     | 4      |
|                                | Compactor (Caterpillar CS533E)            | 1      |
| Formworks                      | Truck (Mercedes Actros 4040)             | 1      |
| Reinforcement                  | Truck (Mercedes Actros 4040)             | 1      |
| PC pouring for foundation      | Truck mixer (Volvo FM400 (8 m³))         | 7      |
|                                | Pump (Schwing S43SX)                     | 2      |
| RC pouring for foundation      | Truck mixer (Volvo FM400 (8 m³))         | 7      |
|                                | Pump (Schwing S43SX)                     | 2      |
|                                | Vibrator (Honda)                        | 4      |
| RC pouring for columns         | Truck mixer (Volvo FM400 (8 m³))         | 3      |
|                                | Pump (Schwing S43SX)                     | 1      |
|                                | Vibrator (Honda)                        | 2      |
| RC pouring for Beams & slabs   | Truck mixer (Volvo FM400 (8 m³))         | 3      |
|                                | Pump (Schwing S43SX)                     | 1      |
|                                | Vibrator (Honda)                        | 2      |

4. Results and Discussion

The daily emissions generated from the main activities as a result of dust, gases noise and activity pollution index per each considered. It is worth to note that the factors that influence the activity pollution index (API) are: the construction method, the number of utilized equipment, the equipment percentage of usage and their power. Using the developed modules above, we can get the emissions generated from main activities as shown in Table 3.

**Table 3.** Calculated emissions generated from main activities

| Activity                        | Pollution Rate (gm/hr) | Dust (gm) | Noise (dB) | API   |
|--------------------------------|------------------------|-----------|------------|-------|
| Excavation                     | 342.04                 | 1171.4    | 424.76     | 5171.4| 424.76 | 580.36 | 632743.64 | 41672.9 | 9.82 |
| Backfilling                    | 158.22                 | 2084.9    | 2044.9     | 3045.51 | 245.14 | 347.51 | 378873.22 | 93616.23 | 109  |
| Soil Replacement-Compaction    | 214.31                 | 1391.96   | 3045.51    | 245.14 | 347.51 | 378873.22 | 93616.23 | 109  |
| Formworks                      | 4.4                    | 117       | 6.4        | 9.8   | 10693.6 | 8158.45 | 90  | 1.16 |
| Reinforcement                  | 4.4                    | 117       | 6.4        | 9.8   | 10693.6 | 8158.45 | 90  | 1.16 |
| PC pouring for foundation      | 259.2                  | 1559.84   | 3770.56    | 245.14 | 347.51 | 378873.22 | 93616.23 | 109  |
| RC pouring for foundation      | 264.32                 | 1493.09   | 3801.22    | 281.7 | 734.3 | 801501.79 | 14574.12 | 103  |
| RC pouring for columns         | 133.2                  | 801.66    | 1911.01    | 156.45 | 367.15 | 400747.78 | 14574.12 | 105  |
| RC pouring for Beams & slabs   | 133.2                  | 801.66    | 1911.01    | 156.45 | 367.15 | 400747.78 | 14574.12 | 105  |

As shown in Table 3, the maximum value of API is calculated from reinforced and plain concrete pouring for foundation to be 10.16 and 10.09, respectively as there are huge number of equipment utilized in this activities with high usage percentages. The reason that excavation generates considerable pollution (API 9.82) as it uses 2 loaders with high Hp (260 Hp) and high usage
percentage (90%). In addition to that the soil has high percentage of silt that produce a lot of dust during execution of this activity.

Figure 3. The resulted total pollution index distribution

Figure 3 shows the screen shot of the resulted total pollution index distribution throughout the project life that corresponding to the project planned scheduling. It is shown that total project duration is 76 weeks and the maximum pollution value is 69, which happened at 2nd and 3rd weeks (during excavation activity). In order to change the pollution distribution and minimize the peak points, we may change the construction methods, rescheduling project activities (by changing the relation amongst activities) or change crews' configuration

5. Summary and Conclusions

Air pollution has been and continues to be viewed as a serious problem that affects human health. This paper presented a pollution module that aims at assessing the air pollution generated from buildings construction projects during the planning and execution phases. Emissions resulting from building construction projects was divided into three main categories: dust, harmful gases, and noise. The Activity Pollution Index accounts for the three main categories by calculating their impacts individually. Further it calculates the overall project pollution histogram corresponding to a certain scheduling and hence, the planner can know the project pollution every week and see if there is a need to modify their plan, for example, by rescheduling, by changing the construction methods or crew configurations to reduce the pollution resulted from the activities construction. Visual Basic for Application (VBA) is used to facilitate data entry and to perform interim calculations of the designed API. Construction authorities and environmental bodies can utilize this research to assure that the total pollution of building construction projects is within the permissible threshold. Also, construction contractors can utilize the model to follow the environmental regulations.

6. References

[1] Fan H 2017 A Critical Review and Analysis of Construction equipment emission factors Procedia Eng. 96 351–58
[2] Sandanayake M, Zhang G, Setunge S, Li C, and Fang J 2016 Models and method for estimation and comparison of direct emissions in building construction in Australia and a case study Energy Build. 126 128–38
[3] Li H, Wong T and Chen Z 2000 Environmental management of urban construction projects in China J. Constr. Eng. Manag. 136 320–4
[4] Soderman M 2006 Environmental management in the construction industry - a comparative analysis of Skanska’s environmental risk assessment Dep. Econ. thesis
[5] Chen Z, Li H, and Wong T 2005 Environmental planning : analytic network process model for environmentally conscious construction planning J. Constr. Eng. Manag 131 92–10
[6] Guggemos A, Asce A and Horvath A 2006 Decision-support tool for assessing the
environmental effects of constructing commercial buildings J. Archit. Eng. 12 187–95
[7] Hummer J, Asce F, Arocho I, ASCE A and Rasdorf W 2017 Approach to assessing tradeoffs between construction equipment fleet emissions and cost J. Constr. Eng. Manag. 143 1–10
[8] Arocho I, Rasdorf W, Hummer J, and Lewis P 2017 Time and cost characterisation of emissions from non-road diesel equipment for infrastructure projects Int. J. Sustain. Eng. 10 123–34
[9] Barati K and Shen X 2017 Optimal Driving Pattern of On-Road Construction Equipment for Emissions Reduction Procedia Eng. 180 1221–28
[10] USEPA (United states environmental protection agency) 2009a Emiss. Factor Heavy Constr. Oper. US Environ. Prot. Agency, Washington, DC available www.epa.gov/ttn/chief/ap42/ch13/final/c13s02-3. pdf (accessed 19 May 2017)
[11] USEPA (United states environmental protection agency)2009b Emiss. Factor Fugitive Dust Sources.US Environ. Prot. Agency available www.epa. gov/ttn/chief/ap42/ch13/final/c13s02.pdf (accessed 19 May 2017)
[12] USEPA (United states environmental protection agency) 2009c EPA Emiss. factor for unpaved Road available www.epa.gov/ttn/chief/ap42/ch13/final/c13s0202. pdf (accessed 19May 2017)
[13] USEPA (United states environmental protection agency) 2009d Emission factor for aggregate handling and storage piles US Environmental Protection Agency, Washington, DC available at www.epa.gov/ttn/chief/ ap42/ch13/final/c13s0204.pdf (accessed 19 May 2017)
[14] Egyptian Promulgating Law No.9 2009 Maximum threshold limit of pollutant according to environmental regulations in Egypt

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