Unit processes identification of maintenance on rigid and flexible pavement of local road

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Abstract. Maintenance and rehabilitation as part of pavement’s life cycle become more important since it’s an effort to restore the road condition as planned. This process will produce the emission of greenhouse gases that give an impact to the environment. The Live Cycle Assessment (LCA) was used to estimate the GHG’s emissions. With LCA we could identify the unit process that will produce the GHG’s emissions during maintenance and rehabilitation of road pavement. This research aimed to identify the unit processes of the maintenance and rehabilitation of rigid and flexible pavement and to analyse the amount of GHG emitted during this process. Four local roads in Indonesia were investigated as case studies. The result indicated the amount of energy of the unit processes as well as the GHG amount. This will lead to the identification of the hotspot of flexible and rigid pavement maintenance process. In rigid pavement maintenance activities, the hotspots included the asphalt transport process to asphalt mixing plant, cement transportation to the batching plant, and cement processing. Meanwhile, in flexible pavement maintenance activities, the hotspots were the asphalt transportation to asphalt mixing plant, transportation aggregate, and transportation to site.

1. Introduction
Maintenance and rehabilitation are stages in the life cycle of flexible pavement which contribute to the impact on the environment. The stages of maintenance and rehabilitation activities produce emissions. Some can be produced through the fuel combustion process in the mode of transportation or equipment used, the processing of raw materials, the mixing of materials used and the transportation of materials used to the project location. The regular maintenance process produces fewer emissions that have environmental impacts than the road rehabilitation process because additional processing units are needed, such as processing raw materials, transportation, mixing and laying out the final products for flexible road surfaces [1].

The stage of maintenance and rehabilitation is one of the biggest contributors to emissions in infrastructure development [2]. The decision for choosing road maintenance such as Hot Mix Asphalt thin overlay (the thin layer of hot asphalt) and chip seal on flexible pavement was because the impact to the environment was less than other maintenance activities such as crack seals and slurry seals, and from another point of view the selection of road maintenance activities will also reduce costs incurred [3].
Decisions taken to reduce the environmental impact resulting from road maintenance and rehabilitation activities have an impact on energy consumption and emissions produced. The use of recycled materials such as Reclaimed Asphalt Pavement (RAP) for highway maintenance case studies in Italian highway will reduce about 34% of energy consumption and 30% of pollutant emissions produced compared to the use of ordinary or natural materials for road maintenance [4]. Policies taken from the stages of selecting road pavement construction and the selection of ways to maintain the pavement will also affect the environmental impact. Based on previous research, road pavements in France with continuously reinforced concrete (CRC) and bituminous asphalt concrete types with different maintenance policies will produce different environmental emission impacts [5].

To identify and estimate the impacts resulting from the road maintenance and rehabilitation process, an analysis or approach is needed to calculate how much energy consumption and emissions produced, which hotspots, process units produce the most emissions. The results obtained later can be used for decision making from implementing party or government policies to reduce the environmental impact.

This paper aimed to identify the unit processes of the maintenance and rehabilitation of rigid and flexible pavement and to analyze the amount of GHG during this process. One approach to estimate emissions produced was the life cycle assessment (LCA) approach. Life Cycle Assessment is an approach to find out the impact that results from a particular product [6].

This research was carried out based on a case study of the maintenance of a rigid and flexible road construction. The Life Cycle Assessment method was applied to find out the hotspot point in each process unit that produces the most greenhouse gas emissions. The data used in the life cycle assessment method consisted of primary data obtained from direct observations in the field and secondary data obtained from the related official database and the official website of the database provider. The primary data needed by this research included the location data of raw materials, mixing plant location, quarry location, construction equipment, transportation equipment, and maintenance stage. Secondary data needed included general data and project volume, TRACI 2.1 conversion data [7], and database life cycle inventory from previous researches. After the data were obtained, the stages of rigid and flexible pavement maintenance were compiled, starting from the supply of raw materials to the stages of maintenance. For each stage, the process was reformulated on what happens and what materials are needed to do that stage. After all the processes and material needs of each stage were formulated, it could be determined that greenhouse gas emissions were generated using a database obtained from EcoInvent [8]. The output of greenhouse gas emissions generated from each process from each stage was then converted to kg CO2 eq units using TRACI 2.1 conversion data. From the value of these emissions, it can be concluded the processes and stages of construction which produced the highest emissions (hotspots).

2. Result and discussion
In this research, there were 4 roads maintenance activities, namely 2 case studies of rigid road maintenance (case study 1 and 2) and 2 case studies of flexible road maintenance (case study 3 and 4). Maintenance activities carried out were routine maintenance of rigid and flexible pavements.

The survey on the condition of the project location was an initial stage in road maintenance and rehabilitation activities. This activity was carried out to determine the level of road damage and its corrective actions. This survey activity used transportation equipment in the form of passenger cars. The use of this transportation equipment will require energy and fuel which will produce greenhouse gases (GHG) emissions.

Processing and procurement of road maintenance materials are the processing of raw materials carried out in quarry or at the factory. These materials include aggregates, sand, asphalt, and cement. The use of tools to process raw materials will produce greenhouse gases (GHG) emissions.

The material transportation stage includes 3 activities, namely transportation of material from quarry to the mixing plant, transportation from the mixing plant to the project location, and transportation of materials from the quarry directly to the project location. This transportation process usually uses a dump truck. The use of this dump truck fuel will result in the release of greenhouse gas emissions.
The mixing process on the Asphalt Mixing Plant (AMP) or batching plant (BP) requires energy and fuel consumption which will later release greenhouse gases (GHG) emissions.

The last process unit was work at the project site. The work used several transportation equipment and heavy equipment that require fuel and released greenhouse gases (GHG) emissions during its operation.

2.1. Rigid pavement
Routine maintenance work in case studies 1 and 2 is an improvement of expansion joints repairs, mudjacking, local fillings, and in site reconstruction.

The main material used in joint repairs expansion work is rubberized asphalt. This work requires the assistance of heavy equipment in the form of asphalt sprayers, air compressors, and dump truck. Each of these machines will produce GHG emissions in operation. Greenhouse gas emissions generated in this activity are presented in table 1.

Table 1. GHG emission release on expansion joint repairs.

| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
|-----------------------------|------------------------|----------------|
| Site condition survey       | 11.62                  | 40.59          | 0.60-1.64  |
| The production of Asphalt   | 0.19                   | 0.19           | 0.01-0.01  |
| The production of Kerosene  | 0.00                   | 0.00           | 0.00-0.00  |
| Transportation of Asphalt to AMP | 1,426.01             | 1,598.32       | 64.65-73.81 |
| Transportation of Kerosene to AMP | 485.71              | 544.40         | 22.02-25.14 |
| Transportation to site       | 8.39                   | 288.84         | 6.88-0.26  |
| Usage of Asphalt Sprayer    | 0.01                   | 0.01           | 0.00-0.00  |
| Usage of Air Compressor     | 0.01                   | 0.01           | 0.00-0.00  |
| Usage of Dump Truck         | 0.01                   | 0.01           | 0.00-0.00  |
| Sum of GHG emission         | 1,931.95               | 2,472.37       |              |

Mudjacking work was carried out to improve the slab reduction in the joint. The mudjacking carried out with the main ingredient was filler cement. This work required the assistance of heavy equipment in the form of air compressors and mudjacking machines. Each of these machines will produce GHG emissions in operation. The overall GHG calculation results are presented in the table 2.

Table 2. GHG emissions release on mudjacking.

| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
|-----------------------------|------------------------|----------------|
| Survey of Site condition    | 11.62                  | 40.59          | 0.63-5.41   |
| The production of cement    | 449.48                 | 449.48         | 24.30-59.87 |
| Transportation of Cement to BP | 595.95               | 245.68         | 32.22-32.73 |
| Transportation to site       | 102.64                 | 14.59          | 1.94-5.55   |
| Usage of Air Compressor     | 0.01                   | 0.01           | 0.01-0.01   |
| Usage of Mud jacking Machine| 0.36                   | 0.36           | 0.03-0.05   |
| Sum of GHG emission         | 1,160.06               | 750.71         |              |

Patching work was done to repair chipped or chipped concrete slabs. The main material used in this work is generally a mixture of concrete/epoxy. This work required the assistance of heavy equipment in the form of air compressors and concrete mixers. Each of these machines will produce GHG emissions in operation. The calculation results of GHG patchwork are presented in table 3.

Every maintenance and rehabilitation activity produces process units, GHG emissions and different hotspot, this is due to several factors such as work volume, materials needed, construction equipment used, as well as the distance of materials transportation and mixing plant to the project location.
GHG emissions from rigid pavement road maintenance work in case studies 1 and 2 ranged from 1,000 to 2,500 kg CO₂ e per each unit for routine maintenance work. In this rigid pavement maintenance case study, there were 3 process units that released the highest greenhouse gas emissions, namely cement transportation to the batching plant, which was in the range from 27.57 to 32.73%, asphalt transport to AMP locations which was 64.65-73.81%, and cement processing that was equal to 24.55-59.87%.

| Table 3. GHG emissions release on patching work. |
|--------------------------------------------------|
| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
| Case study 1 | Case study 2 | Case study 2 |
| Site condition survey | 449.48 | 40.59 | 0.63-4.55 |
| The production of cement | 10.09 | 449.48 | 24.55-50.43 |
| The production of aggregate | 595.95 | 10.09 | 0.55-1.13 |
| Transportation cement to BP | 676.22 | 245.68 | 27.57-32.22 |
| Transportation aggregate to BP | 51.32 | 112.62 | 12.64-36.56 |
| Transportation to site | 102.64 | 29.20 | 3.28-5.55 |
| Usage of Air Compressor | 0.01 | 0.0119 | 0.00-0.00 |
| Usage of Mud jacking Machine | 0.35 | 3.5814 | 0.40-0.19 |
| Sum of GHG emission | 1,886.06 | 891.25 |

2.2. Flexible pavement

Routine maintenance work for flexible road pavement includes routine crack filling, hot asphalt mixture work, cold asphalt mix work, and macadam penetration work.

Crack filling is routine maintenance work carried out to fill small cracks in flexible pavements. In addition to requiring asphalt materials, cracking filling work also requires the assistance of heavy equipment in the form of asphalt sprayers, air compressors, and dump truck. Each of these machines will produce GHG emissions in operation. The results of the calculation of GHG emissions from each unit of the crack filling process are presented in table 4.

| Table 4. GHG emissions of the crack filling process. |
|--------------------------------------------------|
| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
| Case study 1 | Case study 2 | Case study 2 |
| Survey of site condition | 0.22 | 17.43 | 0.38-0.74 |
| The production of Asphalt | 0.18 | 0.19 | 0.01 |
| The production of Kerosene | 0.00 | 0.00 | 0.00 |
| Transportation of Asphalt to AMP | 1592.38 | 1580.50 | 67.31-67.99 |
| Transportation of Kerosene to AMP | 542.37 | 538.33 | 22.93-23.16 |
| Transportation to site | 183.37 | 211.54 | 8.46-9.01 |
| Usage of Asphalt Sprayer | 0.01 | 0.01 | 0.00 |
| Usage of Air Compressor | 0.01 | 0.01 | 0.00 |
| Usage of Dump Truck | 0.02 | 0.2 | 0.00 |
| Sum of GHG emission | 2318.56 | 2348.21 |

Hot asphalt mixture for routine maintenance is carried out to cover holes in the pavement. This method is often done in Indonesia, commonly referred to as patching. Hot asphalt mix work requires the help of heavy equipment such as wheel loaders, pedestrian rollers, and dump truck. Each of these machines will produce GHG emissions in operation. The results of the calculation of GHG emissions from each unit of the asphalt hot mix process are presented in table 5.
Table 5. GHG emissions release on hot asphalt mixture process.

| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
|-----------------------------|-------------------------|----------------|
| Survey of site condition    | 0.22                    | 17.43          |
| The production of Asphalt   | 0.98                    | 0.03-0.04      |
| The production of aggregate | 0.57                    | 0.02           |
| The production of cement    | 1.72                    | 0.06-0.07      |
| Transportation of Asphalt to AMP | 1592.38              | 53.68-66.64   |
| Transportation of aggregate to AMP | 338.11              | 14.29-14.44   |
| Transportation of cement to AMP | 367.90                | 21.60-27.81   |
| Mixing process in AMP       | 8.94                    | 30.30-30.37    |
| Transportation to site      | 7.56                    | 2.96-3.16      |
| Usage of wheel loader       | 0.11                    | 0.00           |
| Usage of pedestrian roller  | 0.71                    | 0.02-0.03      |
| Usage of Dump Truck         | 2.34                    | 0.08-0.10      |
| Sum of GHG emission         | 2389.60                 | 2944.50        |

Cold asphalt mixture for routine maintenance is carried out to cover holes in the pavement. This method is almost the same as the hot asphalt mixture, only different when mixing asphalt is done without a hot temperature. Cold asphalt mix work requires the help of heavy equipment in the form of a concrete mixer, pedestrian roller, and dump truck. Each of these machines will produce GHG emissions in operation. The results of the calculation of GHG emissions from each unit of the asphalt cold mix process are presented in table 6.

Table 6. GHG emissions release on the asphalt cold mix process.

| Unit process of GHG release | GHG emission (kg CO₂ e) | Percentage (%) |
|-----------------------------|-------------------------|----------------|
| Survey of site condition    | 0.2                      | 17.43          |
| The production of Asphalt emulsion | 17.11                | 0.78-0.81      |
| The production of sand      | 10.35                   | 0.47-0.49      |
| Transportation of Asphalt to AMP | 1592.38              | 71.82-75.34    |
| Transportation of sand to AMP | 267.87                 | 12.67-14.37    |
| Mixing process in AMP       | 8.94                    | 0.41-0.42      |
| Transportation to site      | 216.08                  | 10.22-11.32    |
| Usage of concrete mixer     | 1.94                    | 0.09-0.09      |
| Usage of pedestrian roller  | 0.80                    | 0.04-0.04      |
| Usage of Dump Truck         | 6.99                    | 0.32-0.33      |
| Sum of GHG emission         | 2113.72                 | 2200.58        |

Macadam or penetration layer for routine maintenance is carried out to cover holes or bumpy roads that are on the pavement to return to steady road conditions. This macadam penetration work requires the help of heavy equipment in the form of a wheel loader, three wheel rollers, dump truck, and an asphalt sprayer. Each of these machines will produce GHG emissions in operation. The results of the calculation of GHG emissions from each macadam penetration process unit are presented in table 7.

GHG emissions from flexible pavement road maintenance work in case studies 3 and 4 ranged from 2,000-3,000 kg CO₂ e per each unit for routine maintenance work. The process unit for transporting asphalt material to AMP, transportation sand to AMP and transportation to site are unit processes that release the highest GHG emissions at the flexible pavement maintenance stage. The percentage of the total greenhouse gas emissions released by transportation asphalt to AMP, transportation aggregate to AMP and transportation to site in this case study were in the range from 53.68 to 75.34%, from 12.67 to 14.37%, and from 10.22 to 11.32% respectively.
Table 7. GHG emissions release on macadam process.

| Unit process of GHG release                        | GHG emission (kg CO$_2$ e) | Percentage (%) |
|---------------------------------------------------|-----------------------------|----------------|
| Case study 1                                      | Case study 2                |                |
| Survey of site condition                          | 0.22                        | 17.43          |
| The production of Asphalt                         | 18.77                       | 18.77          |
| The production of aggregate                       | 17.64                       | 17.64          |
| Transportation of Asphalt to AMP                  | 1592.38                     | 1580.50        |
| Transportation of aggregate to AMP                | 626.36                      | 217.70         |
| Mixing process in AMP                             | 8.94                        | 8.94           |
| Transportation to site                            | 324.12                      | 373.89         |
| Usage of three wheel roller                       | 0.24                        | 0.24           |
| Usage of dump truck                               | 0.14                        | 0.14           |
| Usage of asphalt sprayer                          | 0.13                        | 0.13           |
| Sum of GHG emission                               | 2579.98                     | 2226.44        |

3. Discussion
The fact is that after its construction the road pavement still has many processes until its service life ends, e.g. operation, maintenance & rehabilitation and so on. This is then brought to question; what about the GHG on the next process after its construction? Maintenance and rehabilitation as parts of pavement’s life cycle become more important since it’s an effort to restore the road condition as planned.

The results of the calculation of GHG emissions from this case study were GHG emissions were produced for a period of road maintenance, which ranges from 1,000 to 2,000 kg CO$_2$ e for rigid pavements, and 2,000 to 3,000 kg CO$_2$ e for flexible pavements.

In contrast to the emissions at the construction stage which is only done once, total emissions at the maintenance stage need to be taken into account during the service life. The availability of road conditions models will greatly support decision making, when a pavement needs to be maintained.

Pramono in 2016 conducted research on road maintenance modelling based on the value of surface distress index (SDI) on city roads. The modelling results showed that there were 8 routine maintenance activities in 10 years [9]. Considering that 2 case studies of flexible pavement were also local road with similar type of maintenance, the similar model can be developed providing that the SDI data of these two roads are available. Furthermore, the total emissions at the maintenance stage during their service life can be determined.

4. Conclusion
Unit processes of GHG emission release of maintenance on rigid and flexible pavement are site condition survey, the production of material, transportation material to mixing plant, processing in the mixing plant, transportation to site, and usage of equipment for each maintenance activity. From the results of the analysis that has been carried out in rigid pavement maintenance activities, there were 3 processes units which released the highest GHG emissions, namely the asphalt transport process unit to AMP, transport of cement to batching plans, and cement processing. In flexible pavement maintenance activities, the process unit that released the highest GHG emissions were unit of the process of transporting asphalt material to AMP, transportation aggregate to AMP, and transportation to site.

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