Externalities aspects of freight distribution through the urban consolidation center

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Abstract. This study is also intended to analyze how the traffic parameter is taken into account in the determination of distribution routes and schedules. The analysis is based on the data produced by one of the Urban Consolidation Center (UCC) operators in the form of their freight vehicles’ travel diary. The results show that the average CO₂ emissions produced by the delivery activity through the UCC are 0.0196 kg CO₂/item. By dispatching an average number of items of 2139.70 within one trip, each truck is responsible for the external costs of CO₂ emissions as Rp16,614,- (based on International standards of external costs of CO₂ emissions) or Rp4,131,- (based on Indonesian standard). Regarding the traffic consideration on the distribution trips, most of the trips go into class II, i.e., UCC serves retail stores with a fairly wide coverage area but has not too many stops. In terms of tour efficiency, distribution trips through UCC are considered to be quite efficient. However, they can still be more optimized by increasing the average travel speed of vehicles per stop, reducing mileage between delivery points, or reducing service time in each delivery point without reducing service quality.

1. Introduction

In the goods movement flow, the products need to pass through several segments. The products begin at the manufacturer and then shipped by heavy-duty truck to the wholesale warehouse. Those products sit in the warehouse until they are distributed to fulfill the retail stores’ demand so that consumers will be able to buy the products directly [1]. In that flow, the distribution segment is a segment that has several problems, such as the large amount of CO₂ emissions produced and the inefficient use of truck capacity. Emissions are one of the four main problems that are often found in the goods distribution system [2]. The high emission is caused by the inadequate utilization of the truck’s capacity - low load factor - which causes trucks to often find delivery in conditions that are not full, even empty. This condition, by Zhou, Hui, and Lian [3], is assessed as a waste of transportation capacity.

Rizet, Cruz, and Mbacké [4] proposed a method to increase the load factor to reduce CO₂ emissions without reducing the mobility of shipments. The method is referred to as consolidation, which, according to Çetinkaya and Lee [5], is a combination of many small-volume shipments so that a larger, more economical loads can be dispatched on the same vehicle. Further application of the consolidation system is to create logistics facilities used to combine loads of various operators and produce more economical shipping plans or provide more services [6]. The facility is known as the Urban Consolidation Center (UCC).

This research was conducted to see how much CO₂ emission is generated from shipment via UCC and its external costs. In addition, this research also looks at how the traffic parameter is taken into account in the determination of distribution routes and schedules.

2. Literature review
The distribution segment is a segment that has several problems, such as the high contribution of emissions generated to the inefficient use of truck capacity in the delivery process. As the most widely used mode in this activity, trucks contribute to $\frac{1}{3}$ NO$_x$, $\frac{1}{4}$ of CO$_2$ emissions, and $\frac{1}{2}$ of PM, which are components of air pollution. An example of a low load factor can be seen in Europe, where more than 20% of truck movements carry completely empty space, and the remainder is almost never full [7].

To answer this problem, a consolidation system has emerged, whose further application is manifested in the form of a logistics facility, known as the Urban Consolidation Center (UCC). UCC is a facility to combine loads of various operators and produce more economical delivery plans or provide more services [6]. In its implementation, the impact of externalities certainly will be generated.

Externalities are impacts that do not want to be held by other parties – who are not involved in logistical activities – but are still charged indirectly [8]. Types of externalities are water pollution, air pollution, congestion and accidents, and noise. This research will focus on CO$_2$ emission externalities.

According to Williams, Kemp, Coello, Turner, and Wright [9], there are levels of emission externality calculations that are compiled based on the accuracy of the calculation results. As shown in figure 1, the last tier – the one at the very bottom level – is the most specific calculation that produces the least uncertain result, and vice versa. This research uses the third level to calculate emissions.

![Figure 1. Levels of emission calculation methods.](image-url)

### 3. Research methods

The data used in this study are delivery truck trip data in 7 days duration with six active delivery days and one holiday. From existing data, information is obtained in the form of the delivery date, Vehicle Kilometers Traveled (VKT), number of items, location of delivery points, type of vehicle, and type of fuel used.

From this information, externality can be calculated using the formula at the third level of figure 1, namely calculated activity data, which is VKT and the number of items, fuel consumption assumptions, and emission factors according to the type of vehicle. With the result of emission externalities' calculation, external costs can be obtained by multiplying the externalities with the unit cost.

$$EC_{Item} = \frac{VKT_{trip}}{n_{trip}} * F_F * F_{CO2} * F_{UC}$$  \hspace{1cm} (1)

- $EC_{Item}$: External cost per item (Rp/item)
- $VKT_{trip}$: VKT in one trip (km)
- $n_{trip}$: Number of items in one trip (items)
- $F_F$: Fuel factor (liter/km)
- $F_{CO2}$: Emission factor (kg CO$_2$/liter)
- $F_{UC}$: Unit Cost (Rp/kg CO$_2$)
Vehicle Kilometers Traveled (VKT) is the total distance traveled in each truck trip expressed in kilometers. The number of items represents the total items carried by each truck on each trip.

For the type of diesel truck vehicle (CDE-L) used in this study, the fuel consumption factor is 0.125 liters/km, which means that for every 1 liter of fuel – in this study, it is diesel fuel – the delivery truck is able to travel distances of up to 8 km. The emission factor is the amount of carbon emission produced based on the type of vehicle fuel. National Development Planning Agency [10] describes the amount of CO₂ emission factors used for the Indonesian region (table 1).

| Fuel type | Emission Factor (kg CO₂/liter Fuel) |
|-----------|-------------------------------------|
| Diesel Oil| 2.2                                 |
| Fuel Oil  | 26                                  |

The unit cost for emissions can be determined by a carbon tax [11]. Unit costs are adjusted to the conditions of each country. For international standards, the unit cost applied is €30 per tonne CO₂, while Indonesia itself has a unit cost below that figure, along with Brazil and Russia. For Indonesia, a unit fee of €7.46 is applied for each tonne of CO₂ generated from vehicle emissions.

Prior to the calculation of external costs, the Euro currency was converted into Rupiah, which according to Bank Indonesia was the same as Rp15,879.79 as of Jun, 19 2020. With this, the conversion factor for the unit cost in Rupiah for international standards is Rp476.39/kg of CO₂ and Indonesia as much as Rp118.46/kg of CO₂.

4. Results and discussion

Data is obtained from one company retail in Indonesia, namely company X, with the scope of activities engaged in the trading of convenience stores or supermarkets to meet daily needs.

With various types of goods, this company has a shipping flow, represented in figure 2, that applies a consolidation system and uses a consolidation center as the intermediary. Thus, it is unnecessary for the suppliers to distribute goods to the retail stores, but only to the consolidation center directly.

![Figure 2. Consolidation process at distribution stage [12].](image_url)

The process starts with the supplier delivering a number of items – in this study limited to grocery items – to the consolidation center. The consolidation center will receive various variants of goods from several suppliers to be put together in one truck with the number of each type of goods that have been adjusted to the needs of the retail store. The final stage of this process is the distribution from the Consolidation Center to a number of retail stores.

During each trip, each truck distributes goods to more than one delivery point. The delivery point in question is a retail store whose locations are spread across several regions, such as DKI Jakarta, West
Java, and Banten. The consolidation center, which is the reference for this research, serves more than 350 retail stores. In graph 1, the distribution of the number of retail stores in each region can be seen.

Graph 1. Distribution of the number of retail stores in each region.

Location of the consolidation center from company X is in the Tangerang area. The retail stores served are scattered in various regions, with South Jakarta and Tangerang being the regions with the largest number of retail stores, while in Banten and West Java (Depok and Bogor), the number of retail stores tends to be small.

The data obtained were grouped based on the number of kilometers traveled by each truck on each trip. The groupings are divided into the following ranges:
- Close: <134 km
- Moderate: 135 - 194 km
- Far: 195 - 314 km
- Very far: >315 km

Table 2. Data grouping based on mileage travel

| Mileage                | Number of trips |
|------------------------|-----------------|
| Close (<135 km)        | 101             |
| Moderate (135 - 194 km)| 7               |
| Far (195 - 314 km)     | 8               |
| Very Far (> 314 km)    | 5               |

After grouping the data, as shown in table 2, it is known that most of the distribution trips made by company X’s UCC traveled less than 134 km. In this study, there is a dependent variable, which is a variable viewed from the existing data sample. The dependent variables include vehicle kilometers traveled, number of delivery items, vehicle kilometers traveled per item, and CO₂ emissions. Data processing was carried out with the help of SPSS software.

Table 3. VKT and number of items on delivery via UCC

| Mileage      | VKT (km) Mean | SD | Number of items Mean | SD |
|--------------|--------------|----|----------------------|----|
| Close (<135 km) | 102.58       | 14.2 | 2194.82              | 813.44 |
From all data on distribution trips through the Urban Consolidation Center, the mean (average) and standard deviation are 126.82 km and 67.86 km, respectively. The average value and standard deviation of each mileage category can be seen in table 3. The amount of VKT in each calculated data group is normally distributed (p > 0.05), homogeneous, which means that the data grouping is uniform (p > 0.05) and has a significant difference in mean value (p < 0.05).

The number of items on the distribution trip through the Urban Consolidation Center has an average of 2139.7, with a standard deviation of 803.97. Based on the results of the Kruskal-Wallis test, there is a significant influence between the distance traveled on the number of items (p < 0.05).

In the course of distribution, VKT per item is the result of the total distance traveled by truck in each trip divided by the total number of items carried by truck.

Table 4. VKT per item and external costs per item on UCC shipments

| Mileage            | VKT per Item (km/item) | External Cost per Truck (Rp) |
|--------------------|------------------------|-----------------------------|
|                    | Mean   | SD     | Indonesia | International |
| Close (<135 km)    | 0.0537 | 0.0224 | 3,341.70  | 13,438.72     |
| Moderate (135 - 194 km) | 0.0864 | 0.0301 | 4,821.32  | 19,389.07     |
| Far (195 - 314 km) | 0.1060 | 0.0341 | 7,126.11  | 28,657.84     |
| Very far (>314 km) | 0.3030 | 0.0728 | 12,493.09 | 50,241.28     |

VKT per item of all distribution trip data through UCC has an average value of 0.07 km/item and a standard deviation of 0.062 km/item. The average value and standard deviation of each mileage category are shown in table 4.

The dependent variable obtained is then multiplied by the emission factor as referred to in table 1. Because the vehicle under review uses diesel fuel, this means that the emission factor used is 2.2 kg CO$_2$/liter of fuel. Multiplying this will produce the externality which is then multiplied by the unit cost to get the external cost.

Overall, the external costs generated by each truck on each trip to transport the average number of items of 2139.7 can be seen in table 5. These external costs will be compared with a similar company.

Table 5. External emission costs per truck (company X)

| Conversion standards | The average number of items per truck | External cost per truck |
|----------------------|---------------------------------------|-------------------------|
| International        | 2139.7                                | 16614.1                 |
| Indonesia            |                                       | 4131.29                 |

To assess the productivity of company X, a comparison of external costs was performed with similar companies that are also engaged in the grocery sector. Table 6 is comparative data from a similar company named company Y.

Table 6. Comparative data with the similar company (company Y)

| Transportation type | Average International Cost/Truck (Rp) | Average Indonesia Cost/Truck (Rp) |
|---------------------|--------------------------------------|----------------------------------|
| Diesel Engkel       | 14478.2                              | 3600.17                          |
| Diesel Double       | 20279.9                              | 5042.84                          |

A comparison of the two external costs for each type of vehicle produces a ratio in table 7 below.
From this table, it can be seen that for deliveries using a diesel engkel truck, company X generates 14% more external costs than company Y. As for the different vehicles, company X generates 18% less external costs compared to company Y.

For the same type of vehicle, namely diesel engkel, company X does generate 14% higher external emissions costs, but if seen from the average mileage traveled, company X has an average VKT of 127 km, while for company Y the average VKT taken is only 104.2 km. It can be said that with higher emissions, company X covers a farther area and is more productive. So, it can be concluded that the resulting emissions will be directly proportional to the productivity of the delivery truck. With company X emission which is bigger than company Y, it means company X is more productive.

In the process of delivering goods through UCC, there are a number of aspects that affect the speed and efficiency of delivery, one of which is congestion. To see the effect of congestion on the delivery of goods, the variables to be reviewed are travel time and distance between delivery points.

Graph 2. Travel time and distance between delivery points.

It can be seen that the graph shows a regression equation that represents all the data. The equation is $y = 2.296x + 9.6679$. In addition, $R^2$ is also obtained to describe whether the regression equation is sufficient to represent all available travel data. It can be seen in the graph that the $R^2$ value is almost close to 1, which is 0.918. This shows that the regression equation is quite good in representing all travel data. In accordance with its function, which is to see the distribution of the average travel speed, it can be seen that the average travel speed is 0.33 km/minute or 20 km/hour. By looking at most of the points that converge around the line, it can be said that the trip data has little spread, which means that the average travel speed is fairly uniform.

Points above or below the average speed of most trips indicate that there are still trips affected by congestion, so routes and scheduling need to be fixed. However, because most of the data is gathered around the regression line, it means that route and schedule design are considered optimal.

In this study, distribution trips are grouped into three classes. Class division is based on travel efficiency or Percentage of Time Driving (PTD) which is a function of the average distance traveled...
between delivery points for each trip. To obtain the PTD figure, the following calculation formula is applied:

\[
P_{TD} = \frac{\bar{d}}{\bar{d} + t_c \bar{s}}
\]  

(2)

\(\bar{d}\): The average distance traveled between delivery points per trip

\(t_c\): Service time or the time required for loading/unloading goods at each retail store (30 minutes)

\(\bar{s}\): Average vehicle speed

**Graph 3.** Trip classification based on PTD and average mileage between delivery points.

By looking at the graph of the PTD relationship with the average distance traveled between delivery points, the company will be able to see that most of the trips fall into class I, II, or III. Class I was a trip with many stopping points and a short driving time. This illustrates a condition where the density of retail stores on this route is fairly high.

Operationally, class I is the most efficient condition for distributors, because with a short trip, distributors can still serve many retail stores. Class II is a condition in which less retail stores are served than class I, but the coverage area is farther away. For conditions in class III, a high PTD rate cannot be said to have high efficiency. It is because the average mileage traveled tends to be longer and can only serve a few retail stores [13].

The farther the distance between the consolidation center and a retail store, the further it will reduce the efficiency of the trip. This is because the distance of the retail store from the consolidation center increases the likelihood of vehicles going through main roads (highways) which are more easily affected by congestion. Congestion will have an impact on reducing the average speed of the vehicle, which makes the percentage of time on the trip bigger. This condition describes low efficiency.

As shown in graph 3, most of the distribution trips fall into class II, which means the consolidation center of company X serves retail stores with a wide coverage area, but does not have too many stopping points. That result represents company X’s condition, where the consolidation center serves retail stores in a fairly wide area, covering Jakarta, Tangerang, and Banten with an average of 9 stop points for each trip. The small average distance between stop points on trips in class II indicates that both the distance between the consolidation center and retail stores and the distance between retail stores is quite close, and the density of retail stores in that area can also be said to be relatively high.

5. Conclusion
For each truck in each trip, by transporting an average of 2139.70 items, a CO$_2$ emission externality of 34.87 kg CO$_2$ was produced. The result of conversion to the unit cost resulted in an external cost of Rp 16,614.1 based on international standards and Rp 4,131.29 based on Indonesian standards.

To assess productivity, a comparison was made with the externalities of similar companies, which resulted in the conclusion that company X is considered quite productive.

Regarding the consideration of congestion aspects in shipping operations, it can be concluded that the route and schedule design is quite optimal because only a few points are far below or above the regression line.

Most of the distribution trips are in class II, which means the consolidation center of company X serves retail stores with a wide coverage area and not too many stop points. This indicates the distribution activities of company X is quite efficient.

For trips that are far scattered from the regression line, it can be fixed by planning an optimal route and schedule to avoid congestion. To increase the efficiency of trips in class III, things that can be done are increasing average speed, reducing the distance between stop points, or being able to control service time without reducing service quality.

For further research, it will be optimal if the externalities of distribution activities with and without UCC can be compared to see the effectiveness of UCC.

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