The Trip Distribution Analysis of Water Trucks as Heavy Vehicles with PTV Visum Application

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Keywords: Trip Distribution, Visum, DCGR Model.

Abstract: Water is the basic need of people and it supports the basic activities of the community in Kupang City. Therefore, in order to meet the need for clean water, communities purchase water that is delivered by water trucks and sold by private sectors. These heavy vehicles pass through public roads, increase the traffic volume and affect the road capacity. This study aims to determine the trip distribution of heavy water trucks using the Origin-Destination Matrix (ODM). The method used in analyzing the trip distribution is the Double Constrained Gravity (DCGR) model with a negative exponential impedance function, which is then used to assign the road network traffic in the PTV Visum Application. The resulting trip distribution model is Tid = Oi.Dd.Ai.Bd.exp(-0,6181.Cid) and the total trip distribution of water trucks is at the rate of 131 vehicles/day. The prediction of trip distribution shows that the highest traffic assignment is found on the Liliba village to Oepura village route.

1 INTRODUCTION

Transportation difficulties, especially in developing countries, continue to increase as the needs of adequate transportation grow. Thus, in order to be better prepared in fulfilling the need for transportation infrastructure in the future, it is necessary to study the trip patterns (Suthanaya and Maulidawati, 2019). The acceleration of digital system also enhances the opportunity to create a high-quality transportation system (Maget et al., 2019).

A research conducted in Denpasar, Bali predicts that the trip distribution will reach the total number of 28,873,490 people/day by 2033 (Suthanaya and Maulidawati, 2019). In order to describe the trip distribution of travelers in an area, it is necessary to generate the Origin-Destination Matrix (ODM) through conducting the Origin-Destination Survey. Previous studies have also produced approximations of trip distribution in West Java Province based on the results of statistical tests using the Double Constrained Gravity (DCGR) model with a negative exponential impedance function, Tid = Oi.Dd.Ai.Bd.exp$^{(-0,014159.Cid)}$. (Aprilliansyah and Herman, 2015).

This study aims to determine the trip distribution of water trucks using the Origin-Destination Matrix (ODM). The data is based on a survey of the water trucks' trip distributions starting from the water sources, as the origin zones, to the points of delivery, as the destination zones. Moroever, a research in the City of El Paso, the United States, offers a model for transportation planners to calculate the total trip distribution (Bencomo, 2018). PTV Visum application is an example of the utilization of computerized traffic model and it provides modelling of transport networks and transport demand, including trip production-attraction and spatial trip distribution (Jacyna, 2017).

2 LITERATURE REVIEW

2.1 Origin-Destination Matrix

In the transportation system, trip patterns are often described in terms of the trip flow of vehicles, passengers, and goods that move from the origin zone to the destination zone within a certain area and over a certain period of time. The Origin-Destination Matrix is often utilized by transport planners to describe these trip patterns.

Origin-Destination Matrix is a two-dimensional matrix that contains information of trips between

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zones in a certain area. The row denotes the origin zone, the column represents the destination zone, thus the cells represent the amount of trip from the origin zone to the destination zone. In this case, the notation T_{id} states the amount of trip flow (vehicles, passengers, or goods) from the origin zone i to the destination zone d during a certain time interval. Trip patterns can be generated if the Origin-Destination Matrix is utilized in a transport network system. By examining the trip patterns, the transport problems can be identified and solutions may be immediately generated.

The Origin-Destination Matrix plays a pivotal role in transport planning and management as it provides a detailed explanation of the trips. The number of zones and the value of each cell are two most important elements in Origin-Destination Matrix, as the number of zones indicates the total number of cells that can be obtained. Each cell requires information on distance, time, cost, or a combination of these three, which is used as a measure of accessibility. The general form of the Origin-Destination Matrix can be seen in Table 1.

2.2 Trip Distribution

Trip distribution is the flow of trip production from one zone to a number of other zones, known as zone-to-zone trip. Several methods can be used to generate the trip distribution, including the Synthetic Method.

The widely known, and frequently used, synthetic method (spatial interaction) is the gravity model (GR) as it is rather simple and easy to understand. This model follows the concept of gravity introduced by Newton in 1686. This method assumes that the production and attraction of trips are related to several parameters of the origin zone, such as population and accessibility, including distance, time, or cost. The accessibility is regarded as an impedance and is calculated using a negative exponential function.

Table 1: The general form of Origin-Destination Matrix.

Zona	1	2	3	…	N	O_i
1	T_{11}	T_{12}	T_{13}	…	T_{1N}	O_1
2	T_{21}	T_{22}	T_{23}	…	T_{2N}	O_2
3	T_{31}	T_{32}	T_{33}	…	T_{3N}	O_3
.	.	.	.	…	.	.
.	.	.	.	…	.	.
.	.	.	.	…	.	.
N	T_{N1}	T_{N2}	T_{N3}	…	T_{NN}	O_N
D_d	D_1	D_2	D_3	…	D_N	T

The β parameter is obtained from the quotient between the value of K which ranges from 2~3 with C_{id} , which is the average of the impedance value (Aprilliansyah and Herman, 2015).

$$f_{(cid)} = e^{-\beta(Cid)} \quad (1)$$

Double-constrained Gravity Model (DCGR) is used in the equation (1) (Tamin, 2000).

$$T_{id} = O_i . D_d . A_i . B_d . f_{(cid)} \quad (2)$$

Dimana:

T_{id} = number of trips between zone i and d (trips/day)

O_i = number of trips from origin zone i (trips/day)

D_d = number of trips from destination zone d (trips/day)

A_i = production balancing constant

B_d = attraction balancing constant

$f_{(cid)}$ = impedance function

With the boundary conditions can be seen in equation (3) and equation (4).

$$B_d = \frac{1}{\sum_{d=1}^{N}(A_i . O_i . f_{(cid)})} \quad (3)$$

$$A_i = \frac{1}{\sum_{d=1}^{N}(B_d . D_d . f_{(cid)})} \quad (4)$$

2.3 PTV Visum

PTV Visum is a world's leading software for macroscopic modelling of transportation and is currently used by more than 1,000 organizations. It provides transportation modelling of the traffic network, as well as a feature to analyze the external effects of traffic, such as air pollution and noise levels (AR, 2021).

The traffic assignment can be modelled in the PTV Visum application and the result can be used as the measurement for the road segment and the road network. This stage involves three components, namely the trip matrix, the road network, and the assignment mechanism, including the route selection and the road restriction for goods transport vehicles (Citra et al., 2019).

Trip distribution is part of four sequential transportation modelling steps. Trip production and attraction are calculated by determining the impedance matrix from the total requested trip. The elements of the matrix itself are calculated under the trip distribution procedure. On the one hand, the trip distribution from the destination zone to the origin zone is based on the attraction of the trip, on the other hand the trip distribution from the origin zone to the destination zone is measured by the matrix of travel time, fares and other general costs (Visum 15, 2015).

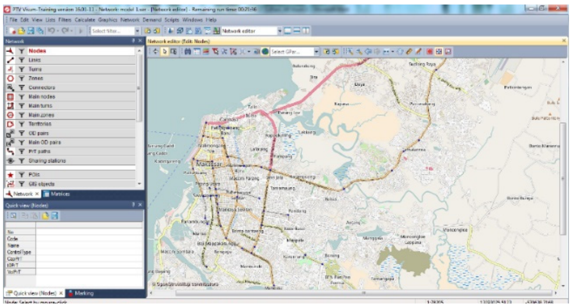

Figure 1: Example of an observation points map in the VISUM Program (AR, 2021).

3 RESEARCH METHOD

This study begins with a preliminary research on the volume of heavy vehicles, specifically of water trucks in Kupang City. After conducting the preliminary survey, it is necessary to identify how the volume of the water trucks affects the road capacity. Thus, a reference matrix is developed based on the topic and research objectives. Following this, the data collection process is conducted through direct surveys, such as observations and interviews, as well as filling a survey form at the origin zone and the destination zone. The survey is conducted within five working days, as the research location consists of five zones, namely zone 1 (Oebobo), zone 2 (Kayu Putih), zone 3 (Liliba), zone 4 (Oepura), and zone 5 (Oesapa).

The data summary and data processing steps are completed through the Origin-Destination Matrix with the help of Microsoft Excel. Furthermore, the DCGR Model is used to calculate the trip distribution and then the results are assigned into the road network by the PTV Visum application. Once the trip distribution data is obtained, the future policy on traffic management may be formulated based on this finding.

3.1 Trip Distribution Survey

The trip distribution survey is delivered by collecting five types of data, namely the total number of heavy vehicles, travel time, travel distance, and travel cost.

3.1.1 Heavy Vehicles Survey

This survey is conducted in five research zones, from 07 AM to 06 PM for five days, namely Oebobo village, Sikumana village, Liliba village, Oepura village, and Oesapa village which can be seen in Table 2. The survey is carried out by identifying water trucks in each origin zone (water collection points) and the destination zone (end-consumer delivery points). This study ensures each truck is available to participate in the survey, recorded based on the vehicle number, and shadowed by the surveyor to the destination zone.

Table 2: Trip distribution zone.

Zone	Village
1	Oebobo
2	Sikumana
3	Liliba
4	Oepura
5	Oesapa

3.1.2 Travel Time Survey

Travel time records the time needed for the water trucks to arrive at the destination zone from the origin zone. The travel time survey utilizes a basic, smartphone-based timer application and the data is taken from each zone and for each water truck.

3.1.3 Distance Survey

This survey records the distance from the origin zone to the destination zone. The distance survey utilizes a basic, smartphone-based distance tracker application and the data is taken from each zone and for each water truck.

3.1.4 Travel Cost Survey

This survey directly interviews water truck drivers on the transportation cost needed to travel from the origin zone to the destination zone. The data is taken in each zone and for each water truck.

4 RESULTS AND DISCUSSION

The result of Origin-Destination Matrix (ODM) as the output of the survey can be seen in Table 3. Based on the matrix, the origin zone with the highest traffic is zone 3 (Liliba village), which it records the rate of 38 vehicles/day. Meanwhile, zone 1 (Oebobo village) is the origin zone with the second highest record of trips at 29 vehicles/day. Furthermore, Zone 5 (Oesapa village) is the third highest origin zone with a trip rate of 25 vehicles/day.

On the other hand, Zone 5 (Oesapa village) is the destination zone with a highest trip record of 34 vehicles/day. The second position is held by zone 3 (Liliba village) with the value of 29 vehicles/day. Moreover, zone 4 (Oepura village) is the third busiest destination zone with a record of 24 vehicles/day.

The origin zone with the least trip distribution is zone 4 (Oepura village), with a record of 18 vehicles/day. While the destination zones with the least trip distributions are zone 1 (Oebobo village) and zone 2 (Sikumana village), both record the value of 22 vehicles/day.

Meanwhile, the number of trips from the origin zone to the destination zone with the highest number of trips (Oesapa village) is 23 vehicles/day. The rate of 1 vehicle/day from the origin zone to the destination zone with the least trip distribution, is shown by Oebobo to Sikumana and Liliba village; Sikumana to Oebobo, Liliba, Oepura and Oesapa village; Liliba to Sikumana and Oepura; Oepura to Liliba village; and Oesapa to Oebobo and Sikumana village.

Table 3: The result of Origin-Destination Matrix (ODM) of water trucks.

Zone	1	2	3	4	5	O_i
1	6	1	1	15	6	29
2	1	17	1	1	1	21
3	3	1	23	1	10	38
4	11	2	1	2	2	18
5	1	1	3	5	15	25
D_d	22	22	29	24	34	131

The table shows that Liliba village has a high trip distribution, as the result of abundant water resources in this particular zone and adequate road accessibility. Meanwhile, Oesapa village shows that the community has a high demand for clean water, although the demand originates internally or from the same zone.

4.1 Impedance Function Analysis

Distance, as one of the accessibility functions, is regarded as an impedance function that will illustrate the longest and shortest distance taken by the water trucks. As seen from the table 4, the shortest distance is recorded between zone 2 (Sikumana village) to zone 1 (Oebobo village) because the road access is adequate enough. On the contrary, the longest distance is recorded between the zone 2 (Sikumana village) to zone 5 (Oesapa village) as both points are far apart.

Table 4: Accessibility matrix (C_{id}).

Zone	1	2	3	4	5
1	1,93	5,40	3,40	0,88	2,13
2	0,45	1,53	5,45	0,88	12,60
3	3,43	2,90	1,54	5,50	0,96
4	2,86	2,55	4,10	0,98	5,60
5	5,40	3,00	2,83	2,34	2,26

Table 5 displays the value of the impedance function for each zone of origin and destination using a negative exponential function with a value of $\overline{C_{id}}$ of 3.236 and β with the value of 0.6181.

Table 5: Accessibility function matrix ($f_{(cid)}$).

Zone	1	2	3	4	5
1	0,3027	0,0355	0,1223	0,5817	0,2675
2	0,7572	0,3880	0,0344	0,5823	0,0004
3	0,1198	0,1666	0,3862	0,0334	0,5542
4	0,1706	0,2068	0,0793	0,5474	0,0314
5	0,0355	0,1566	0,1736	0,2354	0,2474

4.2 DCGR Model Analysis

The Origin-Destination Matrix (ODM) is then analysed with the DCGR model by entering the calculated distance as the impedance function. The data is processed using the value of A_i and B_d alternately for each origin and destination zone. The iteration process starts by assuming the values of B_1, B_2, B_3, B_4, dan B_5 = 1. The iteration is repeated 14 times until the values of each A_i and B_d reach convergence, or static, including in the next iteration.

The results then act as the input for the Origin-Destination matrix using Equation (2). Hence, the water trucks' trip distribution in the form of DCGR model can be seen in Table 6.

The Origin-Destination Matrix, generated from the DCGR model, illustrates the trip distribution of water trucks with a distance factor. The results show that there is a difference between the ODM based on the preliminary calculation and the ODM based on the DCGR model. A significant change is seen in zone 1 (Oebobo village) with a decrease from 15 vehicles/day to 8 vehicles/day due to the long distance between Oebobo village and Oepura village.

Additionally, zone 2 (Sikumana village) also experiences a change with a decrease from 17 vehicles/day to 6 vehicles/day. This is because the trip distribution is more evenly generated based on the distance.

Table 6: Origin-Destination Matrix of water trucks generated from DCGR model.

Zone	1	2	3	4	5	o_i	O_i	A_i	E_i
1	7	1	5	8	8	29	29	0,0330	1,00
2	9	6	1	5	0	21	21	0,0256	1,00
3	2	5	14	0	16	38	38	0,0240	1,00
4	3	5	3	7	1	18	18	0,0442	1,00
5	1	5	7	4	8	25	25	0,0415	1,00
d_d	22	22	29	24	34	**131**			
D_d	22	22	29	24	34		**131**		
B_d	1,0226	1,3871	1,3686	0,6334	0,9589				
E_d	1,00	1,00	1,00	1,00	1,00				**1,00**

Furthermore, zone 3 (Liliba village) also experiences a change of trip distribution due to the distance factor between zones, from 10 vehicles/day to 16 vehicles/day.

The largest change occurs in the destination zone 1 (Oebobo village) with a decreasing value from 11 vehicles/day to 3 vehicles/day due to a long distance between these two zones. Also, the most significant trip distribution value change in zone 5 (Oesapa village) occurs inside the destination zone 5 itself where the value of 15 vehicles/day decreases to 8 vehicles/day. This is because the trip distribution is more evenly generated based on the distance.

The comparison of the Origin-Destination Matrix based on the preliminary calculation and the one generated by the DCGR model can be seen in Figure 2. The results of the comparison then create the equation Y = 3.074 + 0.413X with a correlation coefficient value (r) = 0.629. This illustrates that the Origin-Destination Matrix based on the preliminary calculation and the origin-destination matrix based on the DCGR model has a fairly close correlation.

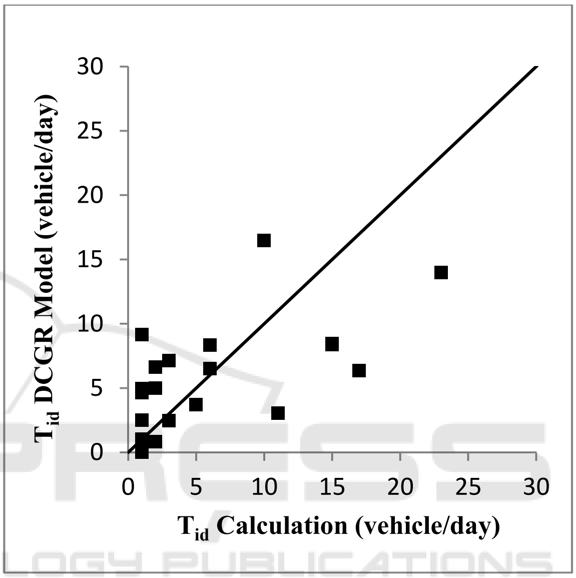

Figure 2: Comparison of ODM with preliminary calculation and ODM with DCGR model.

4.3 Assigning with PTV Visum

The origin-destination matrix based on the DCGR model is utilized to assign the trip distribution to the road network using the PTV Visum application. The data needed in the application is the zone data for each village which is stored as node, link, zone, and connector, as well as the Origin-Destination Matrix of the DCGR model. The traffic characteristics such as the initial capacity and initial speed is obtained from secondary data. Meanwhile, data on travel time is obtained from surveys.

The assignment of the Origin-Destination Matrix is calculated using the Equilibrium Assignment method. The map of water trucks' trip distribution, with a line of demand connecting the origin zone and the destination zone, can be seen in Figure 3.

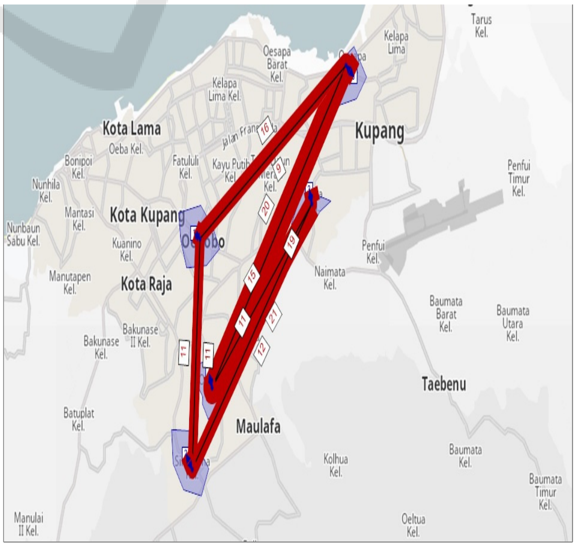

Figure 3: The results of assigning trip distribution with the PTV Visum Application.

In addition to the map of trip distribution, the PTV Visum application also generates the data of vehicles volume at each link that connects origin zone and destination zone. Based on Table 7, the largest volume is shown on the trip from origin zone 3 to the destination zone 4, which is from Liliba village to Oepura village, at the rate of 21 vehicles/day. Meanwhile, the smallest volume is located on the trip from origin zone 1 (Oebobo village) to destination zone 2 (Sikumana village), origin zone 2 (Sikumana village) to destination zone 1 (Oebobo village), origin zone 2 (Sikumana village) to destination zone 3 (Liliba village), at the rate of 11 vehicles/day.

Table 7: Vehicles volume for each origin zone and destination zone generated by the PTV Visum Application.

Origin Zone	Destination Zone	Volume (vehicle/day)
1	2	11
2	1	11
2	3	11
3	2	12
3	4	21
4	3	15
4	5	20
5	4	19
1	5	16
5	1	9

5 CONCLUSIONS

The total trip distribution of water trucks from all zones combined is at the rate of 131 vehicles/day. Furthermore, the origin-destination matrix calculation based on the DCGR model generate a trip distribution model Tid = Oi.Dd.Ai.Bd.exp$^{(-0,6181.Cid)}$. The prediction of trip distribution shows that the highest traffic assignment is found on the Liliba village to Oepura village route, at the rate of 21 vehicles/day. Furthermore, alternative options, in the form of modeling and traffic engineering, are crucial in order to anticipate the increasing number of heavy vehicles, such as water trucks, on certain routes.

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