Determination of Location and Numbers of Monorail Stops in Surabaya with Max Covering Problem Model

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Abstract. The Surabaya City Government plans to develop Mass Rapid Transit (MRT). The selected MRT is trams and monorails. The MRT procurement is expected to attract public attention to using public transportation so that it can reduce the use of private vehicles. With the reduction of private vehicles, it is expected to reduce congestion and traffic accidents. For the operation of the MRT, supporting facilities are needed, namely the stop for the monorail. So, the author intends to conduct research to determine the location and number of monorail stops. In this study, the determination of the location and number of monorail stops was determined by the Max Covering Problem model when there was a limit in the number of monorail stops established so as to maximize the number of passengers served, which was preceded by calculating the optimal number of monorail stops with the Set Covering Problem model. The results of calculations using the Set Covering Problem model indicate that there are 62 locations for monorail stops in order to serve the point of demand, totaling 151 locations along the route. If it turns out the government has budget constraints in the construction of monorail stops in 62 predetermined locations, then the calculation using the Max Covering Problem model is obtained by choosing 50 locations for monorail stops.

1. Introduction
In this era of globalization, we know that technology is growing. This results in humans being encouraged to do everything quickly and precisely. Because of this, it is necessary to have adequate transportation facilities. The higher human population and human activities result in the need for transportation facilities to increase significantly. As a solution to this problem, the Government plans to develop Mass Rapid Transit (MRT). The selected MRT is trams and monorails.

The City Government intends to allocate monorails on the east-west route, while the trams are allocated to the north-south line [1]. The MRT procurement is expected to attract public attention to using public transportation so that it can reduce the use of private vehicles. With the reduction of private vehicles, it is expected to reduce congestion and traffic accidents. For the operation of the MRT, supporting facilities are needed, namely the stop for the monorail. So, the author intends to conduct research to determine the location and number of monorail stops. The establishment of shelters that are less than optimal can increase transportation problems, this is due to the many people who intend to use this mode but become lazy to use it. This happens because there are difficulties when intending to take advantage of available facilities.

In this study, the determination of the location and number of monorail stops was determined by the Max Covering Problem model when there was a limit in the number of monorail stops established.
so as to maximize the number of passengers served, which was preceded by calculating the optimal number of monorail stops with the Set Covering Problem. In the first phase the research was examined regarding the data needed to determine the location of the monorail stop. The data includes secondary data about the location of the trip generated from the C-map and Google map. Furthermore, from the data, the location of monorail user requests is determined. From the point of request, the location of the candidate monorail stops is chosen that meets the criteria for building a monorail stop.

Then the distance between the candidate monorail stops and the requested point is measured. The next step is to determine the location and number of monorail stops with the Set Covering Problem model. Furthermore, an analysis of the location of the monorail stop was carried out when the government had limited budget for the construction of monorail stop (consideration of the cost of establishing monorail stop) with the Max Covering Problem model. To simplify the calculation, the problem is done with the help of Lingo 13.0 software. From this calculation, the location and number of monorail stops can serve the maximum number of passengers.

Before this research was conducted, there had been research on determining the location and number of monorail stops which were subsequently used as literature studies. Research has been carried out by determination of location and numbers of tram stops in surabaya with model set covering problem written by Ardiansyah, A. and Mardlijah [2].

2. Monorail stop locations criteria
Criteria for determining the bus stop in this study include:

- The definition of the point of request in this study is the location that is likely to cause a fairly high number of passengers [3].
- The location of the candidate bus stop with a crossing must be more than 50 meters [4] so as not to cause congestion. There are two factors that are taken into consideration in determining stops near the intersection. If the flow of the vehicle turns right, the location of the bus stop is built before the intersection. If the vehicle turns left solid, the stop is built after the intersection.
- Distance of candidate bus stops with hospitals and places of worship must be more than 100 meters, so that the construction of shelters does not disturb the peace of hospitals and places of worship [4].
- The distance of pedestrians to get to the bus stop is a maximum of 400 meters [5].

3. Set covering problem model
The Model Set Covering Problem has the aim of minimizing the number of monorail stop locations but can serve all points of demand. Where the general form of the Set Covering Problem model is as follows [6]:

Objective function:

$$ \min Z = \sum_{j \in J} x_j + \frac{1}{d_j} x_j $$

And constraints function:

$$ \sum_{j \in H_i} x_j \geq 1 \ \forall \ i \in I $$

$$ x_j \in \{0,1\} \ \forall \ j \in J $$

With $Z$ is objective function, $I$ is point of request with index $i$, $J$ is candidate monorail stop with index $j$, $p_{ij}$ is distance between point of request $i$ and candidate monorail stop $j$, $P_k$ is fulfillment distance, $d_j$ is the number of potential demand / passengers at alternative locations $j$, $H_i$ is $\{j | p_{ij} \leq P_k\}$ which is all candidate monorail stops that can cover point of request $i$. Where,
the alternative stops location \( j \) is picked

\[ x_j = \begin{cases} 1, & \text{if the alternative stops location } j \text{ is picked} \\ 0, & \text{else} \end{cases} \]

Objective (1) to minimize the number of monorail stops. The \( \frac{1}{d_{ij}} \) term is included in the model to avoid alternate solutions (ensuring that there will be more candidates for the monorail stop). The constraint function (2) for each point of request can be covered by at least one candidate monorail stops, and , the constraint function (3) to determine the location of the monorail stop chosen or not. The Set Covering Problem model was solved with the help of Lingo 13.0 software.

4. Max covering problem model

The Max Covering Problem model aims to maximize the number of point of requests that are served by limiting the number of location points of service facilities that can serve those points of request [2]. Where the general form of the Max Covering Problem model is as follows [7]:

Objective function:

\[
\text{max } M = \sum_{i \in I} g_i y_i
\]

(4)

And constraints function:

\[
\sum_{j \in H_i} x_j \geq 1 \forall i \in I
\]

(5)

\[
\sum_{j \in H_i} x_j - y_i \geq 1 \forall i \in I
\]

(6)

\[
x_j \in \{0,1\} \forall j \in J
\]

(7)

\[
y_i \in \{0,1\} \forall i \in I
\]

(8)

With \( M \) is objective function, \( g_i \) is the number of potential requests / passengers who can served at the point \( i \), \( q \) is the number of location limits for monorail stops that can be built, \( I \) is point of request with index \( i \), \( J \) is candidate monorail stop with index \( j \), \( p_{ij} \) is distance between point of request \( i \) and candidate monorail stop \( j \), \( P_k \) is fulfillment distance, \( H_i \) is \( \{j | p_{ij} \leq P_k\} \) which is all candidate monorail stops that can cover point of request \( i \). Where:

\[
x_j = \begin{cases} 1, & \text{if the alternative stops location } j \text{ is picked} \\ 0, & \text{else} \end{cases} \\
y_i = \begin{cases} 1, & \text{if the alternative location of bus stop } j \text{ can serve the point } i \text{ selected} \\ 0, & \text{else} \end{cases}
\]

In this problem, objective function (1) to maximize total demand that can be fulfilled. Constraint function (2) to determine that the fulfillment of demand at point \( i \) is not counted, except in one alternative location that can meet point \( i \), the constraint function (3) to determine that there are restrictions on the number of locations of stops to be built. Constraint function (4) to determine that the location of the location is chosen or not as the location of the establishment of the monorail stop. Constraint function (5) to determine that a point of request \( i \) can served by candidate monorail stop \( j \) or not. The Max Covering Problem model was solved with the help of Lingo 13.0 software.

5. Simplex method and branch and bound method

The methods that will be used for calculation in Lingo are simplex method and branch and bound method, and can be explained as follows:

- Simplex method is one of the settlement techniques in a linear program that is used as a decision-making technique in problems related to the optimal allocation of resources. [8].
- The Branch and Bound method is a feasible solution approach used in solving linear program problems, especially integers [8], by dividing the feasible solution area into smaller subset, then systematically evaluating the subset to find the best solution. This method consists of node diagrams and branches (branches) as a framework in the process of finding the optimal
solution. In this study the Branch and Bound method is used together with the Simplex method. Examples of node and branch diagrams (branch) are shown in Figure 1.

![Figure 1. Example Node and Branch Diagram.](image)

6. Defining point of request
In this research, which included the point of request were schools and universities, workplaces (factories and government offices), sports venues, shopping centers and traditional markets, locations of formal housing, tourism objects, and several other places where there might be large movement activities. The point of request includes: East Coast Center (factories and government offices), sports venues, shopping centers and traditional markets, locations...
7. Determining candidate stops point that meets the criteria

The point of request to be the candidate bus stop must be in accordance with the criteria discussed earlier. The candidate for the monorail stops are: East Coast Center M. (x_1 ), PPNS (1) (x_2 ), Graha ITS (1) (x_3 ), ITS (1) (x_4 ), H. Mandiri Mansion (1) (x_5 ), Galaxy M. (1) (x_6 ), Unair. K. C (1) (x_7 ), Zoom. H. Darwinhusada (1) (x_8 ), Sambal Bu Rudy (1) (x_9 ). SMKN 5 S. / Halte SMKN 5 S. (2) (x_10 ), H. Kassanda (2) (x_11 ), SMK Berdikari 1 S. (1) (x_12 ). SMAN 4 S. (1) (x_13 ), H. Sahid (1) (x_14 ), H. Gubeng (1) (x_15 ), Galaxy H. (x_16 ), Sriwijaya Mess (x_17 ), Marvel C. (1) (x_18 ), Transmart Ngagel (1) (x_19 ), Novotel S. (1) (x_20 ), SDN Ngagel 1 (1) (x_21 ). S. Wonokromo (1) (x_22 ), M. DTC Wonokromo (1) (x_23 ), SMA Khadijah S. (x_24 ), Terminal Joyoboyo (1) (x_25 ), KBS (1) (x_26 ), Oval H. (1) (x_27 ), Richeese F. Adityawarman (1) (x_28 ), Universitas 45 S. (1) (x_29 ), Ciwo M. S. (1) (x_30 ), Shangri-La H. S. (1) (x_31 ), Java Paragon H. (1) (x_32 ), Sumbi H. (1) (x_33 ), LIPIA S. (1) (x_34 ), Vasa H. (1) (x_35 ), SDN P. K. Kendal 1 (1) (x_36 ), SMPK Petra 1 (1) (x_37 ), Lenmarc M. (1) (x_38 ), McD’ Graha Family 1 (1) (x_39 ), SMK Petra 1 S. (1) (x_40 ). P. Graha Family (1) (x_41 ), Ranch M. (1) (x_42 ), Unesa K. Lidah Wetan (1) (x_43 ), SMP Labschool Unesa Lidah (1) (x_44 ), Citraland (x_45 ), SMP Labschool UNESA Lidah (2) (x_46 ), Unesa K. Lidah Wetan (2) (x_47 ), Ranch M. (2) (x_48 ), P. Graha Family (2) (x_49 ), SMK Petra 1 S. (2) (x_50 ), McD’ Graha Family (2) (x_51 ), Lenmarc M. (2) (x_52 ), SMPK Petra 1 (2) (x_53 ), SDN P. K. Kendal 1 (2) (x_54 ), Vasa H. (2) (x_55 ), LIPIA S. (2) (x_56 ), Sumi H. (2) (x_57 ), Java Paragon H. (2) (x_58 ), Shangri-La H. S. (2) (x_59 ), Ciwo M. S. (2) (x_60 ), Universitas 45 S. (2) (x_61 ), Richeese F. Adityawarman (1) (x_62 ), Oval H. (2) (x_63 ), KBS (2) (x_64 ), Terminal Joyoboyo (2) (x_65 ), M. DTC Wonokromo (2) (x_66 ), SDN Ngagel 1 (2) (x_67 ), Novotel S. (2) (x_68 ), Transmart Ngagel (2) (x_69 ), Marvel C. (2) (x_70 ), H. Santika (x_71 ), Taman Lansi (2) (x_72 ), H. Gubeng (2) (x_73 ). H. Sahid (2) (x_74 ), SMAN 4 S. (2) (x_75 ), SMK Berdikari 1 S. (2) (x_76 ), H. Kassanda (2) (x_77 ), SMKN 5 S. / Halte SMKN 5 S. (2) (x_78 ), Sambal Bu Rudy (1) (x_79 ), Zoom H. Darwinhusada (2) (x_80 ), Unair. K. C (1) (x_81 ), Galaxy M. (2) (x_82 ), H. Mandiri Mansion (2) (x_83 ), ITS (2) (x_84 ), Graha ITS (2) (x_85 ), PPNS (2) (x_86 ).

8. Distance measurement between stops candidate and fulfilled demand

Measurements are made in order to find out the location of the request point that can be fulfilled by the location of the candidate monorail stops. Distance measurement results were obtained with the help of C-map and Google Map. This stage is carried out in order to get a distance from one location to another, in order to find out the point of request that can be fulfilled by a candidate monorail stops.

9. Location and numbers of stops determination with set covering problem model

The next process is to determine the location and number of stops using the Set Covering Problem model. Objective function is to minimize the number of monorail stops.

The shape of the mathematical model is as follows:

\[ \min Z = \sum_{j \in J} x_j + \frac{1}{d_j} x_j \]

Where \( j = 1, 2, 3, ..., 86 \). In this problem, there are 86 candidates monorail stops, with syntax Lingo 13.0 is follows:

\[ \text{Min} = \sum \text{haltememenuhisyarat(j)}:X(j) \];

Where, \( x_j \) has 0 and 1 value. So, if the \( x_j = 0 \), then the candidate monorail stops will not be chosen. If \( x_j = 1 \), then the candidate will be chosen.

The first constraint function is each point of request can be covered by at least one candidate monorail stops. Where the shape of the mathematical model is as follows:

\[ \sum_{j \in H_i} x_j \geq 1 \forall i \in I \]
In this problem, the location of the request points 1, 2, 3, and 4 can only be fulfilled by the candidate bus stop 1, so that the equation model is $x_1 \geq 1$. The request point 5 can only be fulfilled by the candidate stop 2, so the equation model is $x_2 \geq 1$. For request points 6 can be fulfilled by candidates for stops 2 and 3, so the equation model is $x_2 + x_3 \geq 1$. This equation model is used at each request point, with syntax Lingo 13.0 is follows:

@for(permintaan(i):@sum(haltememenuhisyarat(j):x(j)*matrix(i,j))>=1);

The second constraint function is to determine the location of the monorail stop chosen or not (binary). Where the shape of the mathematical model is as follows:

$$x_j \in \{0,1\} \forall j \in J$$

With syntax Lingo 13.0 is follows:

@for(haltememenuhisyarat(j):@bin(x(j));

Optimization output of Lingo 13.0 result are shown in Figure 2.

**Figure 2.** Lingo 13.0 Optimization Output Result (Source: Data Processing, 2019).

From the calculation with the Set Covering Problem model, a monorail stop location is generated. these locations are: East Coast Center M. ($x_1$), PPNS (1) ($x_2$), ITS (1) ($x_4$), H. Mandiri Mansion (1) ($x_5$), Galaxy M. (1) ($x_6$), Unair K. C (1) ($x_7$), Sambal Bu Rudy (1) ($x_9$), SMKN 5 S./ Halte SMKN 5 S. (2) ($x_{10}$), SMK Berdikari 1 S. (1) ($x_{12}$), SMAN 4 S. (1) ($x_{13}$), H. Sahid (1) ($x_{14}$), Galaxy H. ($x_{16}$), Sriwijaya Mess ($x_{17}$), Marvel C. (1) ($x_{18}$), Transmart Ngagel (1) ($x_{19}$), Novotel S. (1) ($x_{20}$), SDN Ngagel 1 (1) ($x_{21}$), M. DTC Wonokromo (1) ($x_{23}$), SMA Khadijah S. ($x_{24}$), Terminal Joyoboyo (1) ($x_{25}$), Oval H. (1) ($x_{27}$), Richeese F. Adityawarman (1) ($x_{28}$), Ciwo M. S. (1) ($x_{30}$), Sumi H. (1) ($x_{33}$), LIPIA S. (1) ($x_{34}$), Vasa H. (1) ($x_{35}$), SDN P. K. Kendal 1 (1) ($x_{36}$), SMPK Petra 1 (1) ($x_{37}$), Lenmarc M. (1) ($x_{38}$), Mc D’ Graha Family (1) ($x_{39}$), P. Graha Family (1) ($x_{41}$), Ranch M. (1) ($x_{42}$), Citraland ($x_{45}$), Ranch M. (2) ($x_{46}$), P. Graha Family (2) ($x_{49}$), Mc D’ Graha Family (2) ($x_{51}$), Lenmarc M. (2) ($x_{52}$), SMPK Petra 1 (2) ($x_{53}$), SDN P. K. Kendal 1 (2) ($x_{54}$), Vasa H. (2) ($x_{55}$), LIPIA S. (2) ($x_{56}$), Sumi H. (2) ($x_{57}$), Ciwo M. S. (2) ($x_{60}$), Richeese F. Adityawarman (1) ($x_{62}$), Oval H. (2) ($x_{63}$), DTC Wonokromo (2) ($x_{66}$), SDN Ngagel 1 (2) ($x_{67}$),
10. Location and numbers of stops determination with max covering problem model

The Model Max Covering Problem has the aim of to maximize total demand that can be fulfilled. Objective function is to maximizing the number of request points that are served by limiting the number of location points of service facilities that can serve those points of request. Where the shape of the mathematical model is as follows:

\[ \text{max } M = \sum_{i \in I} g_i y_i \]

with \( i = 1, 2, 3, \ldots, 151 \). In this problem, there are 151 locations for request points. With syntax Lingo 13.0 is follows:

Max=$@\text{sum(Permintaan(i):}g(i)\text{)*y(i)}$

For each \( y_i \) has 0 and 1 value. So, if the \( y_i = 0 \) then the candidate stops will not be chosen. If \( y_i = 1 \), then the candidate will be chosen.

Constraint function is a form of constraints that will be allocated optiM.y into the purpose function. There are five constraints function in this research.

The first constraint function is to determine that the fulfillment of demand at point \( i \) is not counted, except in one alternative location that can meet point \( i \). Where the shape of the mathematical model is as follows:

\[ \sum_{j \in H_i} x_j - y_i \geq 0 \forall i \in I \]

In this problem, point of request 1 only could be fulfilled by candidate stops 1, do the equation model is \( x_1 - y_1 \geq 0 \). While point of request 2 only could be fulfilled by candidate stops 1, do the equation model is \( x_1 - y_2 \geq 0 \). For point of request 3 could be fulfilled by stops candidate 1, so the equation model is \( x_1 - y_3 \geq 0 \). This equation model used on every point of request. With syntax Lingo 13.0 is follows:

@for(permintaan(i):@sum(haltememenuhisyarat(j):x(j)*matrix(i,j))-y(i)>=0);

The second constraint function is to candidate monorail stops at the East Cost Center M., they are always chosen. This location is always chosen because it is the location of the initial departure and final destination of the monorail. Where the shape of the mathematical model is as follows:

\[ x_1 = 1 \]

With syntax Lingo 13.0 is follows:

init :  
x1 = 1;
endinit;

The third constraint function is to determine that there are restrictions on the number of locations of stops to be built. Where the shape of the mathematical model is as follows:

\[ \sum_{j \in J} x_j = q \]

With syntax Lingo 13.0 is follows:

@sum(Haltememenuhisyarat(j):x(j))= q;

In this analysis the value of \( q \) is determined as 50.

The fourth constraint function is to determine that the location of the location is chosen or not as the location of the establishment of the monorail stop (binary). Where the shape of the mathematical model is as follows:
\[ x_j \in \{0,1\} \forall j \in J \]

With syntax Lingo 13.0 is follows:
@for(haltememenuhisyarat(j):@bin(x(j));

The fifth constraint function is to determine that a point of request \( i \) can served by candidate monorail stop \( j \) or not (binary). Where the shape of the mathematical model is as follows:

\[ y_i \in \{0,1\} \forall i \in I \]

With syntax Lingo 13.0 is follows:
@for(Permintaan(i):@bin(y(i)))

Optimization output of Lingo 13.0 result are shown in Figure 3.

Figure 3. Lingo 13.0 Optimization Output Result (Source: Data Processing, 2019).

From the calculation with the Max Covering Problem model, a monorail stop location is generated. these locations are: East Coast Center M. (1), PPNS (1), ITS (1), Galaxy M. (1), Unair K. C (1), SMKN 5 S./ Halte SMKN 5 S. (2), SMK Berdikari 1 S. (1), SMAN 4 S. (1), H. Sahid (1), Marvel C. (1), Transmart Ngagel (1), S. Wonokromo (1), SMA Khadijah S., Terminal Joyoboyo (1), Oval H. (1), Richeese F. Adityawarman (1), Ciwo M. S. (1), Sumi H. (1), Vasa H. (1), SDN P. K. Kendal 1 (1), SMPK Petra 1 (1), Lemnarc M. (1), Mc D’ Graha Family (1), SMAK Petra 1 S. (1), Ranch M. (1), Citraland, Unesa K. Lidah Wetan (2), P. Graha Family (2), Mc D’ Graha Family (2), Lenmarc M. (2), SMPK Petra 1 (2), SDN P. K. Kendal 1 (2), Vasa H. (2), Sumi H. (2), Ciwo M. S. (2), Richeese F. Adityawarman (1), Oval H. (2), M. DTC Wonokromo (2), SDN Ngagel 1 (2), Transmart Ngagel (2), Marvel C. (2), H. Santika , H. Gubeng (2), SMAN 4 S. (2), SMK Berdikari 1 S. (2), H. Kassanda (2), Unair K. C (1), Galaxy M. (2), ITS (2), PPNS (2).

11. Simulation with limits on the number of different monorel stop
The location of the bus stops selected from the calculation using the Set model Covering Problems as many as 65 stops. So this analysis will be tried simulation by providing input variations limiting the number of stops 20, 25, 30, 35, 40 and 45. The simulation results show that:
Table 1. Simulation results by providing variations in input limits on the number of stops.

| Number of Monorail Stop | Underserved passengers | Percentage |
|------------------------|------------------------|------------|
| 20                     | 2453747                | 68.96%     |
| 25                     | 2845517                | 79.97%     |
| 30                     | 3105258                | 87.27%     |
| 35                     | 3279672                | 92.17%     |
| 40                     | 3377472                | 94.92%     |
| 45                     | 3438532                | 96.64%     |
| 50                     | 3482354                | 97.87%     |

12. Conclusion
From calculations using the Max Covering Problem model, it can be concluded that the number of monorails chosen to be built when the government has a limited budget for the construction of shelters with a limit of 50 stops are East Coast Centre M. (1), PPNS (1), ITS (1), Galaxy Mall (1), Unair Kampus C (1), SMKN 5 Surabaya/ Halte SMKN 5 Surabaya (2), SMK Berdikari 1 Surabaya (1), SMAN 4 Surabaya (1), Hotel Sahid (1), Marvel City (1), Transmart Ngagel (1), Stasiun Wonokromo (1), SMA Khadijah Surabaya, Terminal Joyoboyo (1), Oval Hotel (1), Richeese Factory Adityawarman (1), Ciwo Mall Surabaya (1), Sumi H. (1), Vasa Hotel (1), SDN Pradah Kali Kendal 1 (1), SMPK Petra 1 (1), Lenmarc Mall (1), Mc Donalds Graha Family (1), SMAK Petra 1 Surabaya (1), Ranch Market (1), Citraland, Unesa Kampus Lidah Wetan (2), Plaza Graha Family (2), Mc Donalds Graha Family (2), Lenmarc Mall (2), SMPK Petra 1 Surabaya (2), SDN Pradah Kali Kendal 1 (2), Vasa Hotel (2), Sumi H. (2), Ciwo Mall Surabaya (2), Richeese Factory Adityawarman (1), Oval Hotel (2), Mall DTC Wonokromo (2), SDN Ngagel 1 (2), Transmart Ngagel (2), Marvel City (2), Hotel Santika, Hotel Gubeng (2), SMAN 4 Surabaya (2), SMK Berdikari 1 Surabaya (2), Hotel Kassanda (2), Unair Kampus C (1), Galaxy Mall (2), ITS (2), PPNS (2).

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