JURNAL ILMIAH TEKNIK INDUSTRI
ISSN: 1412-6869 (Print), ISSN: 2460-4038 (Online)
Journal homepage: http://journals.ums.ac.id/index.php/jiti/index
doi: 10.23917/jiti.v20i2.15639

Developing Bus Rapid Transit's Schedule using Max Load Method (Trans Metro Bandung Corridor 2 Case Study)

Dionisius Aldwin[1a], Fran Setiawan[1b◆], Loren Pratiwi[1c]

Abstract. *Congestion is one of problems that must be solved by the Government of Bandung City. One of the projects are improving the public transport sector. Trans Metro Bandung (TMB) is one of public transport at Bandung. People's interest to use TMB is very low. This happens because TMB does not have a reliable bus schedule. The focus of this study is to build a TMB's corridor 2 schedule with headway based on the current passenger condition. The headway is determined using the max load method. This study will compare the current headway target set by TMB with the headway based on the passenger arriving pattern. After that, the schedule which is made from the choosen headway will be simulated. This study shows that the current headway set by Trans Metro Bandung management is better. Simulation shows that schedule can reduce passenger average waiting time quite significant.*

Keywords: *bus rapid transit; headway; max load method; simulation; trans metro bandung.*

I. Introduction

Bandung is one of metropolitan city in Indonesia. As a big city in Indonesia, one of problems which is faced by Bandung is congestion. In 2017, the average speed of vehicle in Bandung is 14.1 km/hour (Mauludy, 2019). Moreover, Bandung is also stated as the most congested city in Indonesia at the end of 2019 (Asian Development Bank, 2019). There are many causes of congestion in Bandung. One of them is the behaviour of inhabitans. In 2019, Statistics Indonesia, through its research which titled "Bandung in Numbers", states that the number of private cars in Bandung reach 392,000 units and private motorcycles is 1,244,433 units. 78.28% of Bandung's inhabitans choose to use their own vehicle to transport from one point to other point rather than use public transport (Statistics Indonesia, 2017).

In order to cope with congestion, the government of Bandung had done some of initiatives. One of initiative is to encourage people to use public transports. One of public transport that wants to be improved is Trans Metro Bandung (TMB)/Bandung's Bus Rapid Transit. The government is also made a policy that only Rp 1,- fare for teacher, labor and veteran (Ichsan, 2019). Nevertheless, these policies can increase the number of TMB's passengers only 17%. The government also has a plan to improve the quality of TMB by conducting a study for the implementation of international standard Bus Rapid Transit system.

According to Vuchic (2005), there are 6 elements that must be possessed in a BRT system. However, TMB has not fulfilled the 6 elements of BRT. Some of elements which are not fulfilled are TMB does not have its own path, it does not have regular schedule and headway, and the height of platform for passenger substitiution's is still not good. There are some reasons why many citizens do not willing to use TMB. Based on small survey, 6 from 10 respondents said that there is uncertainty in departure time and traveling time. Direct observation is also carried out and it its obtained that TMB's bus does not stop at every bus stop. It was also found several times that if the bus stop is empty and there is no passenger want to stop there, then the bus will not stop at that bus stop. Based on observation, there is no information about the schedule of TMB.

Schedule is a good link between rapid transit service providers and passengers seeking reliablity service. Inaccurate schedule can confuse

[1] Department of Industrial Engineering, Faculty of Engineering, Universitas Katolik Parahyangan, Jl. Ciumbuleuit 94, Bandung, 40141

[a] email: dion.aldwin98@gmail.com
[b] email: fransetiawan@unpar.ac.id
[c] email: lorenp@unpar.ac.id
◆ corresponding author

Submited: 31-08-2021 Revised: 10-12-2021
Accepted: 20-12-2021

users and give a bad image for the service users (Ceder, 2007). One of the causes of unreliable schedule is the assumption that the passsengers must adjust and follow the schedule developed by the schedule developer. The schedule designer should adjust the design to the arrival of passengers (Ceder, 2007). In order to make a good schedule, it is necessary to pay attention to the headway used. Improvement at headway usually reduce the waiting time between passengers. Based on study which was conducted by Salek and Machemehl (1999), it is consistently shows an increase in passenger waiting time, especially if the headway is more than 30 minutes. The conventional policy that is usually used is that the waiting time for passengers is the half of the headway if the headway is less than 15 minutes (Ceder, 2007). One way to produce an appropriate headway is to use passenger frequency as a basis.

Currenlly, TMB has had 5 corridors over the Bandung City. The fifth corridor is the newest, begin to operate in November 2019. The route which is served by each corridor are Corridor 1 (Cibiru – Cibeureum), Corridor 2 (Cicaheum – Cibereum), Corridor 3 (Cicaheum – Sarijadi), Corridor 4 (Antapani – Leuwi Panjang), Corridor 5 (Antapani – Stasiun Hall). Corridor 1 and 2 is the oldest Corridor. This research focus on corridor 2. Corridor 2 is chosen because the route is long enough, it passes through tourism area such as Jalan Asia Afrika and Braga. Corridor 2 also passes many centers of economic in Bandung city. In addtion, corridor 2 has the biggest number of passengers than the others corridor. At the end of 2019, the number of passengers at corridor 2 each day is 380. This number has grown 16.88% from the previous year (Prasatya, 2019). Corridor 2 consists of 27 permanent bus stops and 9 semi-permanent bus stops (Lati, 2018).

Moreover, there are some previous research on corridor 2. The previous research were focused in looking for distributions or patterns that may occur during corridor 2 operations such as distribution of time between bus arrival (headway), distribution of time passenger arrivals at the shelter and distribution of waiting time of passengers for buses. However, to the best of our knowledge, there has been no research which studied on bus scheduling in corridor 2. Therefore, in this research, we will develop the schedule for corridor 2.

From previous research, we can know about the current operational parameter in TMB's corridor 2. Currently, it is known that the average time between bus arrival (headway) is 27 minutes with the standard deviation is 12 minutes (Ramdhan, 2014). However, currently the headway target from TMB administrator is 20 minutes (Ramdhan, 2014). This condition made the average of waiting time of passengers in bus stop is 12.624 minutes where it follows the exponential distribution (Rahmadiensyah, 2014). This means that a passenger at average should waiting for 12 minutes from arriving at bus stop until he can enter the bus.

Passengers of TMB's corridor 2 have several tendencies. Passengers usually come to the shelter one by one or passengers can also come to the shelter with a group of people (in batch) (Stefani, 2014). Based on the knowledge in bus arrival time, there are passengers who know the bus arrival time and some of them are not. Passengers who know the bus arrival time, usually come to bus stop 5 minutes before they enter the bus (Rahmadiensyah, 2014).

In developing a schedule for Bus Rapid Transit, it is important to determine the frequency of bus arrivals so that the required headway can be determined. Headway is an important thing to be known in advance in developing a schedule. This is because the headway is used to provide a pause between bus departures.

In this research, headway will be determined using Max Load Method. The schedule is developed based on the headway. Then, this schedule is simulated to know the performance of the schedule and it will be evaluated based on the waiting time of passengers. This evaluation will be conducted by comparing our suggesstion with the current condition.

II. RESEARCH METHOD

The first step after doing literature review is to get the data on interarrival time of passengers, distance between shelters and the average velocity of TMB. Interarrival time of passengers determines the number of passengers arriving in a certain time unit. The number of passengers will be one input to develop the schedule. Since our research is conducted in pandemic situation, then we cannot obtain the "actual data". In pandemic situation, the government encourage its citizen to have their activity from their home. This condition causes the operational of TMB in unnormal condition.

Distance and travel time between shelters and the average velocity of bus are used to determine the time which is needed by bus to travel from shelter n to shelter n+1. This time will be a basis to determine the departure time of bus at the shelter other than the first shelter. The list of shelter in corridor 2 is obtained from Department of Transportation Bandung. The distance is obtained from Google Map platform. The average velocity is approximate from the average velocity of vehicle in Bandung according to Mauludy (2019). According to Mauludy (2019), the average velocity of vehicle in Bandung is 14.1 Km/hour. Again, we do not use the real TMB average velocity since in the pandemic, the traffic condition of Bandung city is not in normal condition.

Then, we determine the frequency of bus and the headway of TMB. The purpose of buses scheduling is to ensure that there is adequate interarrival bus time to accommodate the maximum number of passengers along the route that will hop on and off over a certain period (Ceder, 2007). This research uses max load method to determine the frequency of bus. According to Ceder (2007), the formulation of max load method can be seen in equation (1).

$$F_j = \frac{\bar{p}_{mj}}{\gamma_j \cdot c}$$

$$X = \beta(-\ln(1-U))^{\frac{1}{\alpha}}$$

$$\gamma_j \cdot c = d_{oj} \quad (1)$$

where

Fj = The frequency of bus for period j

$\bar{p}_{mj}$ = Average maximum number of passengers (max load) observed on-board in period j.

c = the capacity of a bus (number of seats plus the maximum allowable standees)

γ_j = the load factor during period j $0 < \gamma_j \leq 1$

d_{oj} = desired fraction of the capacity (e.g. number of seats).

After headway is determined, then it will be used as a foundation in schedule development. The schedule which is developed is the schedule of bus departure from each of shelter. There are some components which is needed to develop the schedule. First is headway, second is travel time between shelters and third is dwell time. Dwell time is a duration of a bus to stop at the shelter to pick up and drops passengers.

Dwell time is obtained from analyzing the mininum service standards of BRT in several other cities, such as BRT in Semarang City and TransJakarta in the Capital Jakarta. By doing an observation on its characteristics, BRT in Semarang City has the similar characteristics with TMB. Therefore, dwell time which is used in TMB is the same with the dwell time of BRT in Semarang city which is 30 seconds.

After the schedule has been developed then it will be simulated to know the performance of the schedule. The parameter of evaluation is the average waiting time of passengers and whether there are buses which do not carry passengers at all during the trip.

Data Collection

Since this research is done during the pandemic situation, then we cannot use the actual data. So, we collect the data from previous research and generate some data based on the result from previous research. First data that we generate is the number of passengers in each time interval. In this research, the time interval used is 60 minutes. We generate the data from 05.00 to 17.00 in accordance with the daily operational time of TMB. To generate the number of passengers in each time interval, we used the research from Stefani (2004). This research studied about the interarrival time probability distribution of passengers of TMB's corridor 2. The result was the interarrival time of passengers is following Weibull distribution which the parameter of distribution is depend on the headway of the bus. The probability distribution of interarrival time of passengers of corridor 2 according to Stefani (2004) can be seen in Table 1.

Currently, the average headway of TMB's corridor 2 is 27 minutes while the target from TMB's management is 20 minutes. Based on this condition, in this research, the probability distribution of interarrival time of passengers of TMB's corridor 2 is following Weibull distribution with the shape parameter (α) value is 0.46 and scale parameter (β) is 6.12.

Table 1. Parameter of probabilty distribution of interarrival time of TMB's corridor 2

Headway (in minutes)	Shape Parameter (α)	Scale Parameter (β)	Mean (μ)
<20	0,32	1,72	3,06
20-30	0,46	6,12	1,32
30-40	0,29	4,44	1,61
40-50	0,36	5,08	1,46
>50	0,26	9,05	1,28

After knowing the probability distribution of interarrival time of passengers of TMB's corridor 2, then the number of passengers in each interval time is generated using the algorithms below (Law, 2015).

1. Generate the number which has uniform distribution U (0,1).
2. Return a number which has Weibull distribution with the following equation

$$X = \beta(-\ln(1-U))^{\frac{1}{\alpha}} \quad (2)$$

In order to generate random number in step 1, we use the Linear Congruential Generator (LCG) method. This method is widely used to generate the number which follow uniform probability distribution (Law, 2015). According to Law (2015), the equation 5 and 6 below are used in LCG method to generate random number.

$$Z_i = (aZ_{i-1} + c)(mod\ m) \quad (3)$$

$$U_i = \frac{Z_i}{m}$$

where,

Z_i = integer number

U_i = Uniform random number [0,1]

a = the multiplier

c = the increment

m = the modulus

The value of a, c, and m must be considered carefully. In this research, we want to generate 100 random numbers in 1 dataset. Therefore, the value of a, c, and m used are 21, 11 and 100 respectively. Next step is converting the uniform random number (0,1) to the Weibull distribution number using equation (3). After this step, the interarrival time of passengers have been generated.

III. Result and Discussion

Headway Determination

The interarrival time of passengers which has been generated will be used in determining the number of passengers in each interval time (each 60 minutes). Every multiple 60 minutes will be counted how many passengers want to use TMB Corridor 2 service. The number of passengers in one interval time 60 minutes (1 hour) will be calculated based on the cumulative of interarrival time of passengers. If the cumulative is still within time interval (60 minutes) than the passenger will be included in that time interval. The calculation is done for every shelter of corridor 2 (route Elang Cicaheum and vice versa Cicaheum-Elang). As an illustration, we only show the calculation for Elang shelter in Table 2 for the time between 5-10.

From Table 2, we can see that 5 a.m. is a start point (the value is set 0), first passengers is come to the Elang shelter 0.084 minutes later, second passenger is come to Elang shelter 22.836 minutes later which gives the cummulative 22.921 minutes, third passenger is come to Elang shelter 12.449 minutes later which gives the cummulative 35.370 minutes, fourth passenger is come to Elang shelter 26.609 which gives the cummulative 61.979 minutes. We can see that the fourth passenger is already pass the first 60 minutes (5 a.m. – 6 a.m.). It means that he is included the second interval (6 a.m. – 7 a.m.) and so on. So we obtain that the number of passengers in the first time interval (5 a.m. – 6 a.m.) are 3. We do this until all time interval is done (until 5 p.m.).

Table 2. Calculation example of the number of passengers in one-time interval

Time Interval	Passenger interarrival time	Cumulative of passenger interarrival time	Cumulative number of passengers
5-6	0.084	0.084	1
	22.836	22.921	2
	12.449	35.370	3
6-7	26.609	61.979	1
	0.159	62.137	2
	8.128	70.265	3
	1.323	71.588	4
	0.651	72.239	5
	1.524	73.764	6
	10.342	84.106	7
	0.331	84.437	8
7-8	57.989	142.426	1
	24.621	167.047	2
8-9	77.706	244.753	0
9-10	77.706	244.753	1
	0.496	245.249	2
	15.080	260.329	3
	2.590	262.919	4
	1.421	264.340	5
	2.937	267.277	6
	19.766	287.043	7
	0.837	287.880	8
	0.006	287.886	9

The number of passengers in each interval time (each hour/60 minutes) then will be used as input to max load method using equation 1. We divide maximum number of passengers on each interval (Pmj) by the capacity of bus (d0j). Then, in order to get the best value of bus frequency, we compare the frequency yielded from equation 1 to the frequency currenly set by TMB management according to equation (3). The best frequency is the biggest one. The Headway which used by TMB management is 20 minutes. It means that the bus frequency from TMB management is 3 buses per hours. The result of frequency according to max load method is shown in Table 3.

Based on Table 3, TMB only need 1 bus in each time interval in both routes. Next, based on this frequency, we can get the headway based on the equation……. Then, the headway from max load method is compared with the target from TMB management. The smallest TMB will be chosen in the schedule generation. The headway from TMB management is chosen since its value is 20 minutes compared to from max load calcutation (60 minutes). This headway will be used in bus scheduling at all time intervals.

Table 3. Frequency Calculation using max load method

Jam	Elang - Cicaheum		Cicaheum - Elang	
	P_{mj} (orang)	P_{mj} / d_{oj} (bus)	P_{mj} (orang)	P_{mj} / d_{oj} (bus)
5-6	16	0,533	14	0,467
6 -7	8	0,267	9	0,3
7 -8	13	0,433	10	0,333
8 -9	15	0,5	12	0,4
9 -10	11	0,367	11	0,367
10 -11	12	0,4	12	0,4
11 -12	7	0,233	10	0,333
12 -13	10	0,333	10	0,333
13 -14	11	0,367	12	0,4
14 -15	14	0,467	14	0,467
15 -16	12	0,4	17	0,567
16 -17	10	0,333	10	0,333

Schedule Generation

Based on the previous section, headway of 20 minutes is used. In this section, the schedule is generated based on the even headway. Even headway ensures each time interval has the same headway and frequency. The schedule generated is the bus departure schedule from each shelter. There are three inputs which is needed to generate the schedule, namely headway, travel time between shelters and dwell time (stop time) to pick up and drop off the passengers.

Travel time between shelters is obtained by dividing the distance between shelters and the average velocity. Distance between shelters is obtained using Google Maps and the avarage velocity of vehicle in Bandung City is obtained based on the survey which conducted by Mauludy in 2019 which is 14,1 km/hour. Dwell time is obtained by comparing the other bus rapid transit which has the similar characteristic to

TMB. Dwell time bus rapid transit in Semarang City is considered like TMB because there is no special lane for bus rapit transit, therefore dwell time of 30 minutes is used.

Then, the schedule is generated. The schedule is based on the departure time of the buses on each shelter. Although TMB has been operating since 5.00 a.m, the first departure will start at 5.30 a.m The first departure at 5.30 a.m departs from the first shelter on each route. In this paper, we only show the schedule for Elang shelter. It can be seen in Table 4.

It can be seen from Table 4 that there are 36 trips in Elang Shelter. It begins from 5.30 a.m to 5.10 p.m. The time lapse between one trip to the next is 20 minutes. This is based on a predetermined headway. Although the operational hours of TMS is end at 5.00 p.m, but in this schedule, we make a trip at 5.10 p.m. This trip will serve the passengers arriving between 4.50 p.m and 5.00 p.m. In each day, TMB will finish operating if the passengers before the last schedule have been served.

Table 4. Bus Schedule of *Elang* Shelter

Trip number	Departure Time	Trip number	Departure Time
1	05:30:00	19	11:30:00
2	05:50:00	20	11:50:00
3	06:10:00	21	12:10:00
4	06:30:00	22	12:30:00
5	06:50:00	23	12:50:00
6	07:10:00	24	13:10:00
7	07:30:00	25	13:30:00
8	07:50:00	26	13:50:00
9	08:10:00	27	14:10:00
10	08:30:00	28	14:30:00
11	08:50:00	29	14:50:00
12	09:10:00	30	15:10:00
13	09:30:00	31	15:30:00
14	09:50:00	32	15:50:00
15	10:10:00	33	16:10:00
16	10:30:00	34	16:30:00
17	10:50:00	35	16:50:00
18	11:10:00	36	17:10:00

The trip at 5.10 p.m causes the entire TMB corridor 2 ends at 6.00 p.m. This because the length of journey from the first shelter to the last shelter is about 1 hour. In addition, this last trip makes each shelter have a different service time for the last passengers.

Schedule Simulation Arrangement

The schedule which has been generated then will be simulated to see three performance measures namely the average waiting time for passengers, the daily average number of passengers and the number of empty passenger incidents. The latter is to ensure that there is no bus operates without passengers after the schedule is implemented. Simulation is done using Microsoft Excel and each simulation will be replicated 30 times. There are 2 objects to be simulated, which are bus and passengers.

The first object of simulation is passenger. The simulation describes when passenger come to a shelter. If the bus is available when the passenger come, then it will depart, otherwise it will wait until the next bus is available. The scheme of simulation of passenger is shown in Figure 1.

The second object of simulation is bus. There are two schemes to be examined. First scheme shows when the bus arrives to shelter whether there is any passenger or not. Second scheme also shows whether there is bus which does not carry passengers during the schedule. The second scheme is done in all shelters except for the first and the last shelter. It because the departure time of both follow the schedule which has been generated. The scheme of simulation of passenger is shown in Figure 2.

Simulation Validation

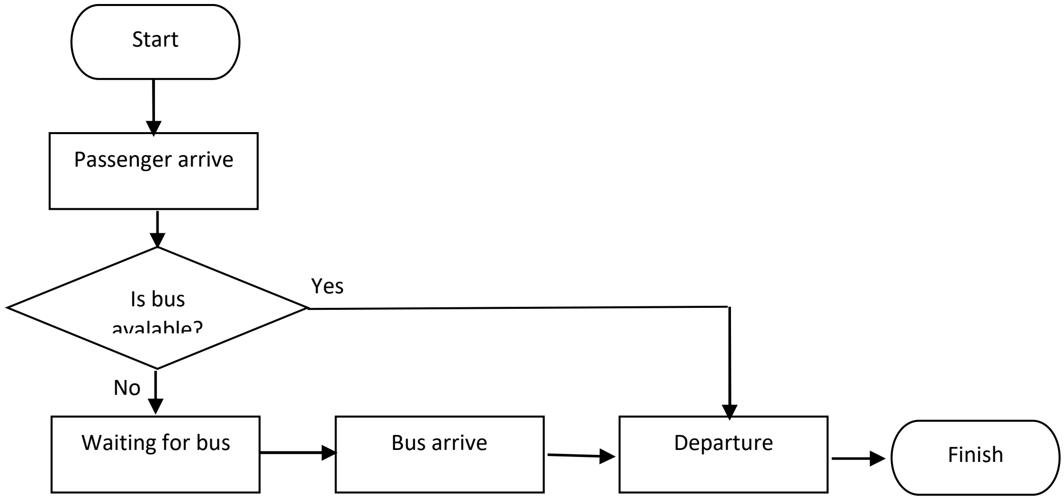

Figure 1. Flowchart of passenger process in simulation

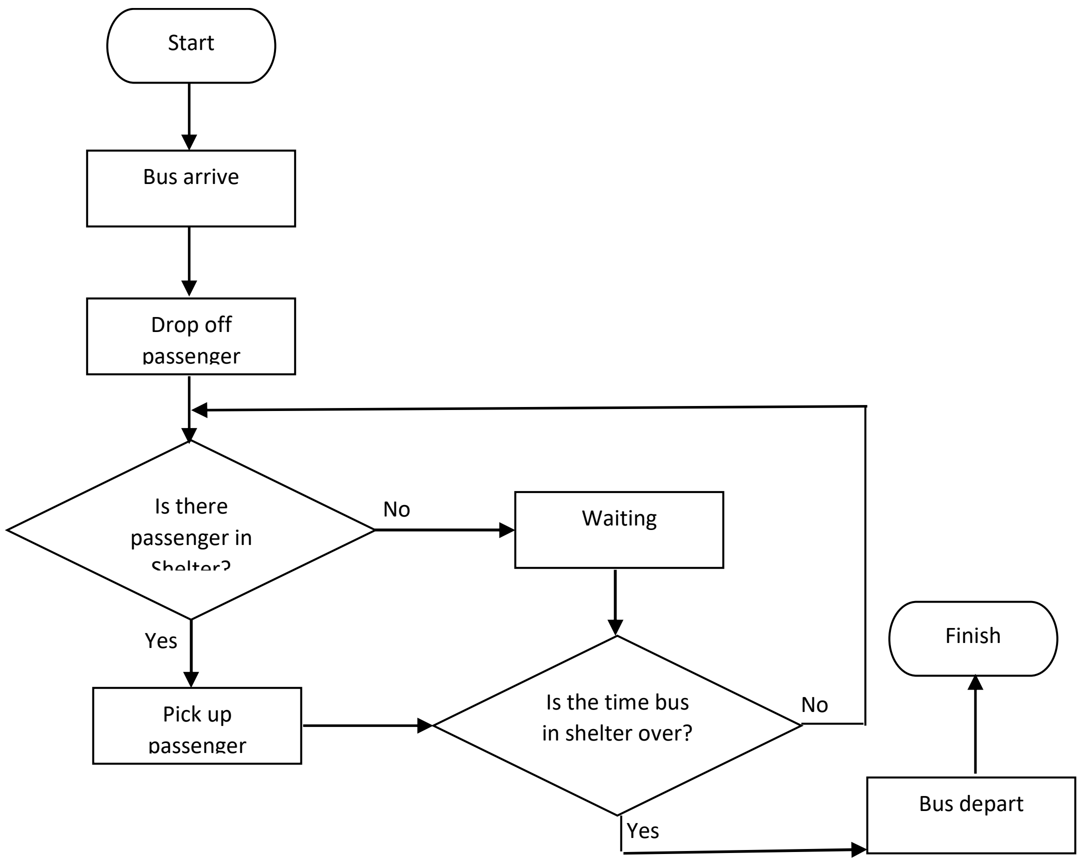

Figure 2. Flowchart of bus process in simulation

In order to get the good simulation in which the simulation can be a good representative of a real-world system, we do a validation. In this step, we examine whether the simulation results differ from the real world statistically. We will check if there is any difference on the passengers waiting time between simulation and real world. We use F test for the variance and t test for the mean. All these tests are performed using Microsoft Excel. In F test we get the P value of 0.340. It means that there are no significant differences of the variance of passenger waiting time between simulation and real world. In t test, we get the P value of 0.327. It means that there are no signifant

Table 5. The maximum, minimum and average passenger waiting time of elang shelter

Replication	Maximum	Minimum	Average
1	00:29:55	00:00:06	00:10:20
2	00:29:53	00:01:04	00:11:16
3	00:30:00	00:00:22	00:11:20
4	00:29:52	00:00:13	00:08:32
5	00:19:51	00:00:11	00:11:39
6	00:29:01	00:00:38	00:11:05
7	00:26:28	00:00:00	00:09:02
8	00:27:34	00:00:05	00:12:04
9	00:19:56	00:00:29	00:11:56
10	00:29:59	00:00:59	00:11:20
11	00:19:38	00:00:38	00:11:00
12	00:20:00	00:00:15	00:09:26
13	00:30:00	00:00:26	00:08:56
14	00:29:21	00:00:58	00:11:45
15	00:29:10	00:00:21	00:08:33
16	00:19:44	00:00:07	00:10:18
17	00:20:50	00:00:08	00:09:52
18	00:29:36	00:00:41	00:10:19
19	00:29:14	00:00:26	00:08:36
20	00:19:36	00:00:03	00:08:53
21	00:29:57	00:00:08	00:11:22
22	00:29:40	00:00:25	00:10:00
23	00:21:52	00:00:04	00:09:29
24	00:29:06	00:00:19	00:10:04
25	00:24:38	00:00:02	00:10:45
26	00:19:26	00:00:11	00:11:29
27	00:29:46	00:00:26	00:11:45
28	00:22:47	00:02:20	00:10:53
29	00:20:16	00:00:10	00:11:26
30	00:23:12	00:00:55	00:09:58

differences of the means if passenger waiting time between simulation and real world.

Simulation Result

There are two outputs in this simulation. The first output is the average waiting time of passengers and the second is the number of passengers boarding to the bus. We do 30 times replication. Table 5 shows the average of passenger waiting time in elang shelter for 30 replications.

Based on the simulation result, it is obtained that the average of passenger waiting time ranging from 7 minutes to 18 minutes for all shelters on TMB corridor 2. However, there are still some incidents where passengers wait for the bus for up to 1 hour. This happens a lot in early trip schedule. The average waiting time for each replication has a small variance. This means that

Table 6. The average number of daily passengers of all shelters

Shelter	Maximum number of daily passengers	Minimum number of daily passengers	The average
Elang	71	49	59,93
Garuda	69	50	57,37
BCA Rajawali	71	51	59,53
RS. Kebon Jati	72	50	58,97
RS. Santosa	68	49	58,77
Perintis Kemerdekaan	69	50	58,33
Telkom	72	49	60,50
Pasar Kosambi	72	53	61,53
Segitiga Mas	73	50	60,17
Disdik	72	50	60,83
Bengawan	72	50	60,50
Ahmad Yani	73	51	60,53
Cikutra	70	55	60,63
Cimuncang	73	53	62,33
Cicaheum	73	55	61,73
Padasuka 1	66	50	58,00
BCA	69	50	57,23
Ibrahim Adji	71	51	59,30
Jembatan Pelangi	71	49	58,60
Simpang banten	67	49	58,40
STIMIK AMIK	69	50	57,77
Bengawan	72	49	59,60
Lap. Persib	72	53	60,40
Jaya Plaza	72	50	59,60
Pos Giro	70	50	59,63
Katapang	69	50	59,33
Panin	70	50	59,43
Alun-alun	70	50	58,83
Pasar Baru	72	49	60,87
Gardu Jati	71	50	60,33
Andir	73	51	62,30
SDN. Raya Barat	72	53	60,50
Jend. Sudirman 1	72	55	61,47
Jend. Sudirman 2	74	56	62,73
Jend. Sudirman 3	75	53	63,13

on average, passengers waiting at a shelter do not have a large enough difference between one passenger and another.

Next, the average number of daily passengers from all shelters based on simulation result is shown in Table 6 below. The number of daily passengers describes how many passengers are carried by TMB from one shelter.

Next, the simulation also shows the frequency of the no passengers will board to the bus when the bus arrives at shelters. Based on the schedule that has been generated in the prevous section, there are 36 trips. The simulation result

Table 7. The frequency of empty passenger at Elang shelter

Trip no	Frequency	Trip no	Frequency
1	4	19	2
2	15	20	10
3	12	21	10
4	22	22	14
5	12	23	13
6	14	24	19
7	18	25	18
8	15	26	14
9	12	27	12
10	18	28	13
11	13	29	18
12	16	30	16
13	15	31	16
14	15	32	10
15	8	33	15
16	13	34	18
17	12	35	17
18	8	36	16

Table 8. New schedule of Elang-Cicaheum route at Trip 1 and 2

Shelter	Trip 1	Trip 2
Elang	5:30	5:50
Garuda	5:35	5:55
BCA Rajawali	5:39	5:59
Kebon Jati	5:44	6:04
RS. Santosa	5:46	6:06
Perintis Kemerdekaan	5:30	5:50
Telkom	5:33	5:53
Pasar Kosambi	5:39	5:59
Segitiga Mas	5:40	6:00
Disdik	5:43	6:03
Bengawan	5:45	6:05
Ahmad Yani	5:49	6:09
Cikutra	5:52	6:12
Cimuncang	5:55	6:15
Padasuka 2	5:58	6:18

show that on every trip, there are still events where when the bus comes but there are no passengers in shelters at that time. The frequency of empty passengers on every shelter when the bus come to that shelter does not mean that bus is operating without any passengers. This may happen when the bus arrives at a shelter, there is no passenger in that shelter. This condition indicates that there are no additional passengers will be on the bus. After a further examination on the simulation result, there are no buses operating with empty passengers on both routes. Table 7 shows the frequency of empty passenger in the shelter when the bus arrives for Elang shelter from 30 replications

As we can see from Table 7, there are incidents of empty passenger on the shelter when the bus arrives at Elang shelter at 36 trips from 30 replications. Based on the simulation, the incidents of empty passenger are the least at the first trip in all shelters in both routes. This means that the first trip is the busiest trip.

By generating and implementing a schedule, it is expected that it can minimize the passenger waiting time. Moreover, one indicator to good performance of bus rapid transit system is the minimum passenger waiting time. However, based on the simulation, there are still passenger waiting time more than 1 hour mainly in the first trip. This case happens at some shelters on both routes. Therefore, we generate new schedule in order to minimize the passenger waiting time.

After we do a further examination on the simulation result of the first schedule, it is found that the waiting time more than 1 hour starts to appear at the shelter which is about 30 minutes from the first shelter. This happens because passengers can start to come to the shelter at 5.00 a.m but the first departure of that shelter is at 6.00 a.m. In order to minimize the passenger waiting time, the schedule is made by considering the duration between the TMB starts to operate and the first departure. Therefore, it will be proposed that 1 trip will be served by 2 buses. In this case, 1 trip will be served by 2 buses does not mean that there are 2 buses departing from the same shelter.

For example, Elang shelter is the first shelter on the Elang-Cicaheum route. At 5.30 a.m, a bus will depart from Elang shelter. Another bus will depart at 5.30 a.m as well but from another shelter. Another shelter which will be served by departure at 5.30 a.m is a shelter which is 20 minutes away from the first shelter (from Elang shelter) namely Perintis Kemerdekaan shelter. Therefore, the Perintis Kemderkaan shelter will start the departure of its first trip at 5.30 a.m. The selection of shelter which 20 minutes away from the first shelter is based on the headway of 20 minutes so that all shelters will have a consistent headway.

For illustration, Table 8 shows the schedule for the first and the second trips for all shelters for some shelters at Elang-Cicaheum route.

Based on Table 8, we can see that there are 2 buses in one trip which differentiate based on the colour. In trip 1, the grey colour shows that schedule is serve by bus 1, while the orange colour shows that the schedule is serve by bus 2. At 5.50 a.m, the bus which departed at 5.30 a.m would serve the second trip at Perintis Kemerdekaan shelter, then at the same time there would be a depature with the third bus from the Elang shelter which point out by a green colour. There are 37 trips in the new schedule. The 37th trip is a continuation of the 36th trip which departs from the first shelter.

After the new schedule is generated then it is simulated using the same procedure with the first schedule. Based on the simulation result, the average of passenger waiting time is 11 minutes for both of routes and there is no passenger waiting time which more than 1 hour. The daily number of passengers is in range between 57 to 63.

Comparison between Current Condition and After Schedule Implementation

In this section, the performance of schedule implementation through simulation is compared to the current condition (without schedule) also through simulation in terms of the average of passenger waiting time. The condition of current condition (without schedule) is based on the bus interarrival time from Ramdhan (2014) which has the probability distribution of Gamma (4.83, 5.58). The bus interarrival time after schedule implementation is based on the new schedule which has been generated in previous section. The graph which shows the average passengers waiting time before and after schedule implementation for both routes are shown in Figure 3 and 4 below.

Modified two sample t confidence interval or welch interval is used to test whether there is a statistically significant difference between before and after schedule implementation. Null hypothesis of the test is there is no significant differences between two samples. The alternative hypothesis is there is significant differences between two samples. This test is done for all shelters. The rejection criteria are if the interval is not passing the 0. The welch interval test is done using Microsoft Excel. The result of the test is shown in Table 9.

From Table 9, there is significant difference between the passenger waiting time before and after schedule implementation. The schedule generate can minimize the passenger waiting time significantly. Other differences are TMB has schedule on all shelters while currently the schedule is only on Cicaheum shelter and the headway alter from 27 minutes to 20 minutes.

Schedule Implementation

In implementing the schedule, the TMB management should pay attention on the speed of bus. This is because the schedule is generated using a deterministic bus speed (14 km/hour). However, in fact, the bus speed can change

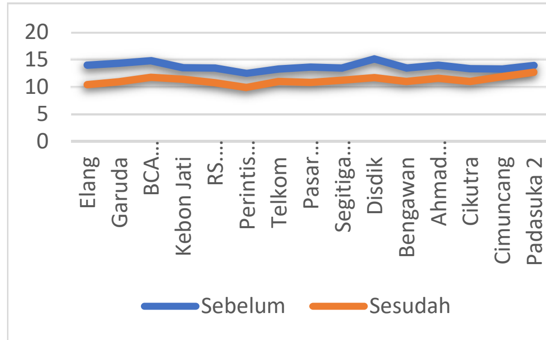

Figure 3. Average passenger waiting time before and after schedule implementation for Elang-Cicaheum route

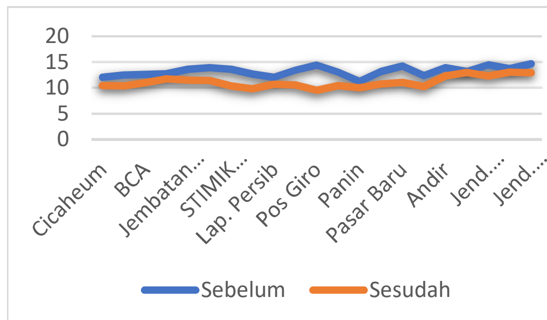

Figure 4. Average passenger waiting time before and after schedule implementation for Cicaheum-Elang route

Table 9. Welch interval test for the passenger waiting time before and after the schedule implementation

Shelter	Lower bound	Upper bound	Conclusion
Elang	0.002505	0.002472	Reject H0
Garuda	0.002393	0.002359	Reject H0
BCA Rajawali	0.002165	0.002127	Reject H0
Kebon Jati	0.001514	0.001477	Reject H0
RS. Santosa	0.001898	0.001859	Reject H0
Perintis Kemerdekaan	0.001822	0.001789	Reject H0
Telkom	0.001579	0.001545	Reject H0
Pasar Kosambi	0.002141	0.001799	Reject H0
Segitiga Mas	0.001564	0.001528	Reject H0
Disdik	0.002412	0.002375	Reject H0
Bengawan	0.00174	0.001703	Reject H0
Ahmad Yani	0.001694	0.001656	Reject H0
Cikutra	0.001646	0.001606	Reject H0
Cimuncang	0.000987	0.000944	Reject H0
Padasuka 2	0.000888	0.000838	Reject H0
Cicaheum	0.001116	0.001085	Reject H0
Padasuka 1	0.001483	0.001448	Reject H0
BCA	0.001133	0.001102	Reject H0
Ibrahim Adji	0.000701	0.000665	Reject H0
Jembatan Pelangi	0.00149	0.001451	Reject H0
Simpang banten	0.001727	0.001692	Reject H0
STIMIK AMIK	0.002272	0.002234	Reject H0
Bengawan	0.002002	0.00197	Reject H0
Lap. Persib	0.000967	0.000936	Reject H0
Jaya Plaza	0.001992	0.001957	Reject H0
Pos Giro	0.003437	0.003399	Reject H0
Katapang	0.001826	0.001789	Reject H0
Panin	0.000891	0.000853	Reject H0
Alun-alun	0.001691	0.001651	Reject H0
Pasar Baru	0.002192	0.002153	Reject H0
Gardu Jati	0.001479	0.001438	Reject H0
Andir	0.001134	0.00109	Reject H0
SDN Raya Barat	0.000131	0.0000864	Reject H0
Jend. Sudirman 1	0.001519	0.001472	Reject H0
Jend. Sudirman 2	0.000505	0.000454	Reject H0
Jend. Sudirman 3	0.001222	0.001172	Reject H0

dynamically. If the speed is reduced, then there will be a delay in the bus departure. If the bus is late, the TMB may be lost its customer since the passengers can choose other modes of transportation. This delay is also possible because currently in Bandung there is no special lane for TMB.

When the bus speed increase, then the travel time of bus is shorter. In this case, the bus ideally can wait longer in a shelter. However, this is not possible to be applied in Bandung because again, there is no special lane for TMB in the Bandung road. It can cause the congestion to the road because of the TMB is stop longer in a shelter. Therefore, it is important to maintain the speed of the bus in order the schedule can be implemented optimally.

IV. Conclusion

The schedule is successfully generated to all shelters in TMB's corridor 2 (Elang-Cicaheum and Cicaheum-Elang route). This schedule can reduce the average passenger waiting time significantly compare to the current condition with the schedule is only on Cicaheum shelter through the simulation. The headway target from the TMB management of 20 minutes has already good. Therefore, there is no need for TMB management to change its headway's target. However, there is need for TMB to have a special lane in Bandung road. For further research, it can be good to build the schedule which consider the speed dynamicity and can try other method besides max load method.

References

Asian Development Bank. (2019). *Asian Development Outlook Update 2019*. September, 259.

Badan Pusat Statistik. (2017). *Statistik Komuter Bandung Raya* (*Hasil Survei Komuter Bandung Raya dan Gerbangkertosusila 2017*). Badan Pusat Statistik. https://www.bps.go.id/publication/2017/12/25/2017000000000000102367/statistik-komuter-bandung-raya--hasil-survei-komuter-bandung-raya-dan-gerbangkertosusila-2017-.html

Badan Pusat Statistik. (2019). *Kota Bandung Dalam Angka 2019*.

Ceder, A. (2007). Public Transit Planning and Operation (1st ed.). Butterworth-Heinemann. https://doi.org/10.1201/b12853

Hook, W., & Wright, L. (2017). The BRT Planning Guide. Itdp. https://www.sutp.org/files/contents/documents/resources/I_BRT-Planning-Guide/GIZ_SUTP_BRT-Planning-Guide_Complete_4th_EN.pdf

Lati, A. (2018). *Analisa tingkat nilai penting-kepuasan dan index kepuasan pengguna layanan TMB koridor 3 : Cicaheum-Sarijadi periode 2018* [Universitas Katolik Parahyangan]. http://repository.unpar.ac.id/bitstream/handle/123456789/8156/Cover - Bab1 - 3114024sc-p.pdf?sequence=1&isAllowed=y

Law, A. M. (2015). Simulation Modeling and Analysis. (5th ed., Vol. 78, Issue 383). Mc Graw Hill. https://doi.org/10.2307/2288169

Mauludy, M. F. (2019). Kecepatan Rata-rata di Kota Bandung Hanya 14,1 Kilometer per Jam - Pikiran-Rakyat.com. https://www.pikiran-rakyat.com/bandung-raya/pr-01307138/kecepatan-rata-rata-di-kota-bandung-hanya-141-kilometer-per-jam

Mengenal Bus Rapid Transit (BRT) - Dinas Perhubungan Provinsi Jawa Barat. (n.d.). Retrieved February 10, 2020, from http://dishub.jabarprov.go.id/artikel/view/566.html

Minat Masyarakat Gunakan Angkutan Umum Masih Minim. (n.d.). Retrieved February 10, 2020, from http://www.prfmnews.com/berita.php?detail=minat-masyarakat-gunakan-angkutan-umum-masih-minim

Program Trans Metro Bandung Rp 1 Belum Maksimal, Buruh, Guru, dan Veteran Tak Banyak yang Naik - Tribun Jabar. (2019). https://jabar.tribunnews.com/2019/08/12/program-trans-metro-bandung-rp-1-belum-maksimal-buruh-guru-dan-veteran-tak-banyak-yang-naik

Rahmadiensyah, R. H. (2014). Waktu tunggu penumpang berdasarkan waktu antara Bus Trans Metro Bandung. Universitas Katolik Parahyangan.

Ramdhan, B. P. (2014). Waktu antara bus Trans Metro Bandung koridor Cicaheum - Cibeureum.

Salek, M., & Machemehl, R. B. (1999). Characterizing Bus Transit Passenger Wait Times.

Stefani, F. (2014). Distribusi waktu kedatangan penumpang Trans Metro Bandung rute Cicaheum - Cibeureum. Universitas Katolik Parahyangan.

Vuchic, V. R. (2005). Urban Transit: Operations, Planning, and Economics. Wiley.