Timetable Creation of BRT Trans Musi Palembang on AAL Ampera Route

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Abstract. Timetable creation is an integer linear programming in transportation scheduling. In this study, we used primary and secondary data of BRT Trans Musi Kota Palembang on AAL-Ampera route for bus operation time in each of the 2 periods in the morning (i. e. at 6 to 8 am) and afternoon (i.e. at 4 to 6 pm). The aim of this timetable creation is to find the optimal departure time of the bus in minimizing the density of passengers in the bus and in a halte (or tranfer node). We solved the problem by Branch and Bound method. Based on the results, headway in the morning is higher than afternoon time, especially for Ampera - AAL route. This means that passengers are transported on the route AAL - Ampera in the morning more than the afternoon. Conversely passengers for the route Ampera - AAL in the afternoon more than the morning. In the morning, the required number of buses for AAL - Ampera route is more than the Ampera - AAL route. By contrast, in the afternoon, the required number of buses for Ampera - AAL route is more numerous. The start time of operation on both routes in each period is relatively the same.

Keyword: Timetable, headway, branch and bound method, BRT Trans Musi.

1. Introduction

Trans Musi type Bus Rapid Transit (BRT) is one of the mass transportation in Palembang City. Trans Musi operates in a specified zone or route. Likewise, passengers get into and out of the bus at predetermined stops (commonly called halte), so that people become more orderly and orderly. In this transportation system, it also known as the transit system, where passengers change other vehicles to continue their journeys, passengers are only charged a one-time fee, so it feels more economical in terms of cost. Existing facilities such as air conditioning, music, and the presence of bus conductor who are ready to serve passengers are also the excellence of Trans Musi.

In addition to the excellence of Trans Musi there are also shortcomings, including the accumulation of passengers at the halte due to the arrival of bus is very long time or uncertain arrival intervals. Passenger density can also happen on the bus. Many passengers crowded so that the atmosphere became uncomfortable. The preparation of the departure time list must be arranged in such a way that there will be no accumulation of passengers at the halte or on the bus. There are several Trans Musi commuting routes including Sako - PIM, AAL - Ampera, AAL - OPI mall, Plaju - PS, Kertapati-Pusri, and Pusri-PS.

Timetable preparation aims to maximize vehicles that come simultaneously at a halte that assumes that the vehicle used is not limited [1]. Trans Musi is limited in number, so it is necessary to minimize the density of passengers with a limited number of vehicles. Timetable preparation can be done by using the Branch and Bound Method. The Branch and Bound method is one method for generating optimal solutions for a linear program that generates integer decision variables. This method works in such a way that to limit the optimum completion which will produce fractions by creating upper and lower branches for each decision variable that is worth a fraction to be integer so that each restriction will generate a new branch.

Timetable preparation for Trans Musi cases was also carried out by [2] on the Sako-Pasar Gubah route and vice versa at 08.00 - 10.00 am. In this study, the timetable was arranged for AAL - Ampera route (in the morning and evening) and Ampera - AAL (in the morning and evening) using the Branch and Bound method. The AAL - Ampera route is the main route that passes the protocol road from the large terminal (Alang-Alang Lebar; AAL) to the city center (Mesjid Agung) so that it is one of the most important routes for passengers to go to work and go home or other activities.

Based on the data in in 2016, Trans Musi has a timetable of departure with headway for 20 minutes. But in fact, the hour of departure bus does not correspond to the timetable properly. Bus departures are only adjusted to the bus queue at the terminal, not tailored to the needs of passengers on the bus at any given time interval.

The purpose of this study was to conduct timetable to schedule the departure of Trans Musi vehicles from Ampera to AAL and vice versa in each of the 2 periods in morning and afternoon by using the Branch and Bound Method. This timetable is adjusted by the average number of passengers in a period of time.

The result of Branch and Bound method is the same as the result of dynamic programming in MCKP [3]; [4].

Limitation of problems in this study are: (1) Trans Musi timetable preparation is carried out only on Monday to Thursday at 06.00 - 08.00 WIB and 16.00 - 18.00 WIB on the AAL - Ampera route and the opposite route; (2) The passenger density level on Monday - Thursday is assumed relatively the same compared to Friday, Saturday, and Sunday; (3) The time taken by Trans Musi from the AAL halte to Ampera and from the Ampera halte to AAL is assumed to be fixed for each departure; (4) The conditions of a number of Trans Musi operating are assumed to have no interference during operation; and (5) Road conditions and traffic jams are ignored.

The benefits of this study are the presence of a timetable is expected to minimize passenger density in Trans Musi vehicles on the route of Ampera to AAL and vice versa; we can get the optimal Trans Musi departure time schedule on Ampera-AAL route and vice versa for each of 2 periods in morning and afternoon; and wecan see the optimal comparison of scheduling and Trans Musi frequencies in the morning (when people start the activity) and in the afternoon (when people come home from activities).

2. Research Methods

This research is a case study. The data used are primary and secondary data that obtained from PT. Sarana Pembangunan Palembang Jaya (SP2J) Kota Palembang, namely the average length of travel on both routes, the time of departure, the number of passengers transported, and the number of vehicles used.

The steps taken in this study are as follows:

1. Formulate optimization model in timetable preparation.

1.1 Defining data becomes the decision variables:

$BA(k)$ is the number of public transport vehicles needed from terminal k.

$x^F(.)$ is a variable that states the frequency value in the jth period for the route from terminal k_1 to terminal k2.

1.2 Establish an objective function to minimize passenger density in the bus.

1.3 Form constraint functions.

2. Completing timetable using the Branch and Bound Method.

3. Analyze the optimization results of the preparation of Trans Musi timetable for each route in 2 periods in morning and afternoon.

4. Complete the Branch and Bound Method by Lingo Software.

5. Arrange timetable based on headway obtained.

3. Results and Discussion

Timetable preparation in this study was divided into four cases, namely:

1. AAL - Ampera route in period 1 and period 2 (in morning).
2. Ampera - AAL route in period 1 and period 2 (in morning).
3. AAL - Ampera route in period 3 and period 4 (in afternoon).
4. Ampera - AAL route in period 3 and period 4 (in afternoon).

Bus departure schedule data is obtained from PT. Sarana Pembangunan Palembang Jaya (SP2J). Data on the number of passengers is obtained from observations in Monday through Thursday at 06.00 - 08.00 WIB and at 16.00 - 18.00 WIB. Observation data can be seen in Table 1.

Table 1. Data needed in timetable preparation of Trans Musi.

Route	Travel Length (Minutes)	Period	Time	Passenger		
				Average	Max.	Occupancy
AAL – Ampera	60	(1) 06.00 – 07.00	Morning	21	147	65% = 22
		(2) 07.00 – 08.00		20	120	70% = 23
	60	(3) 16.00 – 17.00	After-noon	17	119	55% = 18
		(4) 17.00 –18.00		16	64	45% = 15
Ampera – AAL	60	(1) 06.00 – 07.00	Morning	11	77	55% = 18
		(2) 07.00 – 08.00		15	90	60% = 20
	60	(3) 16.00 – 17.00	After-noon	27	189	85% = 28
		(4) 17.00 – 18.00		28	168	90% = 30

Notes: Period in WIB (Waktu Indonesia Barat). For example: 07.00 WIB means 7:00 am, 16.00 WIB means 4:00 pm, etc.

Based on Table 1, the average number of passengers on the AAL - Ampera route in the morning period is higher than the Ampera - AAL route. Instead the number of passengers on the Ampera - AAL route for 2 afternoon periods is higher than the AAL - Ampera route.

3.1. Defining Notation and Value

Ceder [5] states that the minimum number of public transport vehicles needed to serve the set of terminal T is formulated systematically, namely:

$$N = \sum_{k \in T} D(k) = \max \sum_{k \in T} d(k,t); t \in [t_1, t_2] \quad (1)$$

where N: The minimum number of vehicles needed to serve the terminal set T during the operational period $[t_1,t_2]$

$D(k)$: The minimum number of vehicles needed for departure from terminal k

If there are N_0 public transport vehicles that can be used to serve the terminal set T during the operational period $[t_1, t_2]$, then there are constraints:

$$\{d\ (k,t) \text{ is determined by } x^F(.)\} \leq BA\ (k);\ t \in T_k\ ; k \in T \quad (2)$$

where $d(k,t)$: The total number of departures is reduced by the number arrival of vehicles at terminal k at time $t \in [t_1,t_2]$;

T : The terminal set

T_k : The set of vehicle departure times from terminal k during the operational period $[t_1,t_2]$, with $T_k \subseteq [t_1, t_2]$.

$BA(k)$: The amount of public transport needed for departure from terminal k.

$$c^F(.) = \text{maximum } \{P_m(.) - F.d_0(.),0\} \quad (3)$$

where

$(.)$: In the jth period for the route from terminal k_1 to terminal k_2, $j \in J; J =$ the set of periods..

$c^F(.)$: Crowding in the jth period for the route from terminal k_1 to terminal k_2 when frequency F is selected (number of passengers crowded; for the capacity of Trans Musi bus is 58 passengers).

$P_m(.)$: Maximum of the average number of passengers in the jth period for the route from terminal k_1 to terminal k_2.

F : The predetermined frequency in the jth period for the route from terminal k_1 to terminal k_2; with $F = L(.), L(.)+1, L(.)+2, \ldots, U(.)-1, U(.)$

$L(.)$: Minimum frequency allowed; and

$U(.)$: The maximum frequency that is determined based on the calculation of the coefficient of the objective function.

$d_0(.)$: Occupancy (comparison between the number of passengers and available seating capacity) desired in the jth period for the route from terminal k_1 to terminal k_2.

$x^F(.)$: frequency value F for a period; which is a binary variable; worth 1 if F departure is selected in the jth period.

$(.) \in J$: the period from terminal k_1 to terminal k_2; with J is period set.

Example: $J = \{1, 2\}$ means period 1 for 6:00 am – 7:00 am and period 2 for 7:00 am– 8:00 am; $J = \{3, 4\}$ means period 3 for 4:00 pm. - 5:00 pm. and 4th period for 5:00 pm. - 6:00 pm.

$$\sum_{F=L(.)}^{U(.)} x^F = 1, \forall (.) \in J ; J = \{1,2,\ldots,n\} \quad (4)$$

The constraints of the total number of vehicles needed for all terminals at the terminal set T are:

$$\sum_{k \in T} BA(k) \le N_0 \quad (5)$$

where N_0 : The number of vehicles that can be used to serve the terminal set T during the operational period.

Variable constraints that meet are:

$$x^F(.) \in \{0,1\}; \forall F; (.) \quad (6)$$

with $F \in [L(.), U(.)]$

$$BA(k) \ge 0; BA(k) \in Z; \forall k \in T \quad (7)$$

[5]; [1]

Based on Equation (3), $c^F(1)$ can be determined in period 1 for the AAL - Ampera route (in 06:00 – 07:00), so $c^2(1)$ =maximum {147-2 (22), 0} = 103; $c^3(1)$ = maximum {147-3 (22), 0)} = 81, and so on until for $F = 7$, we get $c^7(1)$ = maximum {147-7 (22), 0} = 0.

The same calculation was also carried out for $c^F(2)$ in period 2 (in 7:00 – 8:00), $c^F(3)$ in period 3 (in 16:00 – 17:00), $c^F(4)$ in period 4 (17:00 – 18:00), and also for $c^F(1)$, $c^F(2)$ $c^F(3)$, $c^F(4)$ on the Ampera-AAL route, so that Table 2 is obtained.

Table 2. Decision variables x^F and coefficients of objective function $c^F(.)$.

Route	AAL – Ampera (6:00-8:00 o'clock)			
Period	1 (6:00–7:00)		2 (7:00–8:00)	
Frequency	$c^F(.)$	$x^F(.)$	$c^F(.)$	$x^F(.)$
$F = 2$	103	x_1	74	x_7
$F = 3$	81	x_2	51	x_8
$F = 4$	59	x_3	28	x_9
$F = 5$	37	x_4	5	x_{10}
$F = 6$	15	x_5	0	x_{11}
$F = 7$	0	x_6		
Route	Ampera – AAL (6:00-8:00 o'clock)			
Period	1 (6:00–7:00)		2 (7:00–8:00)	
Frequency	$c^F(.)$	$x^F(.)$	$c^F(.)$	$x^F(.)$
$F = 2$	41	x_1	50	x_5

$F = 3$	23	x_2	30	x_6
$F = 4$	5	x_3	10	x_7
$F = 5$	0	x_4	0	x_8

Route	AAL – Ampera (16:00-18:00)			
Period	3 (16:00–17:00)		4 (17:00–18:00)	
Frequency	c^F (.)	x^F (.)	c^F (.)	x^F (.)
$F = 2$	83	x_1	34	x_7
$F = 3$	65	x_2	19	x_8
$F = 4$	47	x_3	4	x_9
$F = 5$	29	x_4	0	x_{10}
$F = 6$	11	x_5		
$F = 7$	0	x_6		
Route	Ampera – AAL (16:00-18:00)			
Period	3 (16:00–17:00)		4 (17:00–18:00)	
Frequency	c^F (.)	x^F (.)	c^F (.)	x^F (.)
$F = 2$	133	x_1	108	x_7
$F = 3$	105	x_2	78	x_8
$F = 4$	77	x_3	48	x_9
$F = 5$	49	x_4	18	x_{10}
$F = 6$	21	x_5	0	x_{11}
$F = 7$	0	x_6		

Table 2 is obtained by calculating the number of passengers crammed for each route in each period if a frequency value is selected.

Based on the data obtained from Table 2, then we define the following decision variables:

a. Variable $x_{12a} = BA$ (AAL) is the number of public transport vehicles needed by route *a* (from the AAL halte to the Ampera halte) in the morning.
b. Variable $x_{9b} = BA$ (Ampera) is the number of public transport vehicles needed by route *b* (from the Ampera halte to the AAL halte) in the morning.
c. Variable $x_{11c} = BA$ (AAL) is the number of public transport vehicles needed by route *c* (from the AAL halte to the Ampera halte) in the afternoon.
d. Variable $x_{12d} = BA$ (Ampera) is the number of public transport vehicles needed by route *d* (from the Ampera halte to the AAL halte) in the afternoon.

To facilitate completion with the Branch and Bound method, suppose the variable x^2 (1, AAL, Ampera) is replaced by the variable x_1. Likewise, for $x_7 = x^2$ (4, AAL, Ampera) is a variable that states the frequency value is 2 in the 4th period for the route from the AAL halte to the Ampera halte in the afternoon, and so on.

3.2 *Timetable Preparation of the AAL - Ampera Route (Morning)*

The objective function is to minimize the passenger density of the Trans Musi based on the amount of passenger density.

Minimum $Z_1 = 103x_1 + 81x_2 + 59x_3 + 37x_4 + 15x_5 + 0x_6 + 74x_7 + 51x_8 + 28x_9 + 5x_{10} + 0x_{11} + 0x_{12}$

Constraints based on determining the departure frequency of the bus are defined as follows:

a. Because for the AAL - Ampera route in period 1 (in the morning) only one value is taken for *F*, the constraint is $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 1$
b. Because for the AAL - Ampera route in period 2 (morning) only one value is taken for *F*, the constraint is $x_7 + x_8 + x_9 + x_{10} + x_{11} = 1$

AAL - Ampera Departure Route in Period 1 (Morning)

At the maximum F value assuming that the value of $x_1 = 2$, $x_2 = 3$, $x_3 = 4$, $x_4 = 5$, $x_5 = 6$, $x_6 = 7$, so

a. in 8th minute there is no vehicle departing.

b. Possible values for F in the 16th minute are x_4 and x_5, assumed by the constraints $x_4 + x_5$.

c. Possible values for F in the 24th minute are x_2, x_3, and x_6. Based on the addition of possible values for F in the 16th and 24th minutes, it is assumed that the constraints are $x_2 + x_3 + x_4 + x_5 + x_6$.

d. Possible values for F in the 32nd minute are x_1, x_3, x_4, and x_6. Based on the addition of possible values for F in the 16th, 24th, and 32nd minutes, it is assumed $x_1 + x_2 + 2x_3 + 2x_4 + x_5 + 2x_6$..

e. Possible values for F in the 40th minute are x_2 and x_5. Based on the addition of possible values for F in the 16th minute, 24th minute, 32nd minute, and 40th minute, it is assumed $x_1 + 2x_2 + 2x_3 + 2x_4 + 2x_5 + 2x_6$.

f. Possible values for F in the 48th minute are x_1, x_4, and x_6. Based on the addition of possible values for F in the 16th minute, 24th minute, 32nd minute, 40th minute, and 48th minute, it is assumed $2x_1 + 2x_2 + 2x_3 + 3x_4 + 2x_5 + 3x_6$.

g. Possible values for F in the 56th minute are x_2, x_3, x_4, and x_5. Based on the addition of possible values for F in the 16th minute, 24th minute, 32nd minute, 40th minute, 48th minute, and 56th minute, it is assumed $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6$.

AAL - Ampera Departure Route in Period 2 (Morning)

At the maximum F value assuming that the number of values $x_7 = 2$, $x_8 = 3$, $x_9 = 4$, $x_{10} = 5$, $x_{11} = 6$, so

a. The 64th minute there is no vehicle departing, so based on the constraints in the 56th minute, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6$.

b. Possible values for F in the 72nd minute are x_9, x_{10}, and x_{11}. Based on the addition of possible values for F in the 64th minute and 72nd minutes, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_9 + x_{10} + x_{11}$.

c. Possible values for F in the 80th minute are x_7, x_8, and x_{11}. Based on the addition of possible values for F in the 64th minute, 72nd minutes, and 80th minutes, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + x_8 + x_9 + x_{10} + 2x_{11}$.

d. Possible values for F in the 88th minute are x_8 and x_9. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute and 88th minute, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + 2x_8 + 2x_9 + x_{10} + 2x_{11}$.

e. Possible values for F in the 96th minute are x_7, x_{10}, and x_{11}. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute and 96th minute, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 2x_8 + 2x_9 + 2x_{10} + 3x_{11}$.

f. Possible values for F in the 104th minute are x_8 and x_{10}. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, and 104th minute, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 2x_9 + 3x_{10} + 3x_{11}$.

g. Possible values for F in the 112th minute are x_9 dan x_{11}. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, 104th minute, and 112th minute, it is assumed that the constraint is $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 3x_9 + 3x_{10} + 4x_{11}$.

h. Possible values for F in the 120th minute are x_7, x_8, and x_{10}. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, 104th minute, 112th minute, and 120th minute, then assumed with constraint $2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 3x_7 + 4x_8 + 3x_9 + 4x_{10} + 4x_{11}$.

AAL – Ampera Arrival Route in Period 2 (Morning)

At the maximum F value with the assumption that the number of values $x_1 = 2$, $x_2 = 3$, $x_3 = 4$, $x_4 = 5$, $x_5 = 6$, $x_6 = 7$, so

a. Possible values for F in the 64th minute are x_3, x_4, and x_6, assumed with the constraint $-x_3 - x_4 - x_6$.

b. Possible values for F in the 72nd minute are x_1, x_2, x_4, and x_5. Based on the addition of possible values for F in the 64th minute and 72nd minutes, it is assumed by the constraint $-x_1 - x_2 - x_3 - 2x_4 - x_5 - x_6$.

c. Possible values for F in the 80th minute are x_1 and x_5. Based on the addition of possible values for F in the 64th minute, 72nd minutes, and 80th minutes, it is assumed by the constraint of $-2x_1 - x_2 - x_3 - 2x_4 - 2x_5 - x_6$.

d. Possible values for F in the 88th minute are x_3 and x_6. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, and 88th minute, it is assumed by the constraint $-2x_1 - x_2 - 2x_3 - 2x_4 - 2x_5 - 2x_6$.

e. Possible values for F in the 96th minute are x_2, x_3, and x_5. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, and 96th minute, it is assumed by the constraint $-2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 2x_6$.

f. The possible value for F in the 104th minute is x_6. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, and 104th minute, the constraint is assumed by $-2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 3x_6$.

g. Possible values for F in the 112th minute are x_1 and x_4. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, 104th minute, and 112th minute, it is assumed by constraint $-3x_1 - 2x_2 - 3x_3 - 3x_4 - 3x_5 - 3x_6$.

h. The possible value for F in the 120th minute is x_3. Based on the addition of possible values for F in the 64th minute, 72nd minute, 80th minute, 88th minute, 96th minute, 104th minute, 112th minute, 120th minute, it is assumed by constraint $-3x_1 - 2x_2 - 4x_3 - 3x_4 - 3x_5 - 3x_6$.

Based on the above calculation, the constraints are obtained in Table 3.

Table 3. Constraints of the number of buses used in the morning.

No	Minute to	Terminal	Constraints
1	8	AAL	there is no vehicle departing
2	16	AAL	$x_4 + x_5 \leq x_{12}$
3	24	AAL	$x_2 + x_3 + x_4 + x_5 + x_6 \leq x_{12}$
4	32	AAL	$x_1 + x_2 + 2x_3 + 2x_4 + x_5 + 2x_6 \leq x_{12}$
5	40	AAL	$x_1 + 2x_2 + 2x_3 + 2x_4 + 2x_5 + 2x_6 \leq x_{12}$
6	48	AAL	$2x_1 + 2x_2 + 2x_3 + 3x_4 + 2x_5 + 3x_6 \leq x_{12}$
7	56	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 \leq x_{12}$
8	64	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 - x_3 - x_4 - x_6 \leq x_{12}$
9	72	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_9 + x_{10} + x_{11} - x_1 - x_2 - x_3 - 2x_4 - x_5 - x_6 \leq x_{12}$
10	80	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + x_8 + x_9 + x_{10} + 2x_{11} - 2x_1 - x_2 - x_3 - 2x_4 - 2x_5 - x_6 \leq x_{12}$
11	88	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + 2x_8 + 2x_9 + x_{10} + 2x_{11} - 2x_1 - x_2 - 2x_3 - 2x_4 - 2x_5 - 2x_6 \leq x_{12}$
12	96	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 2x_8 + 2x_9 + 2x_{10} + 3x_{11} - 2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 2x_6 \leq x_{12}$
13	104	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 2x_9 + 3x_{10} + 3x_{11} - 2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 3x_6 \leq x_{12}$
14	112	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 3x_9 + 3x_{10} + 4x_{11} - 3x_1 - 2x_2 - 3x_3 - 3x_4 - 3x_5 - 3x_6 \leq x_{12}$
15	120	AAL	$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 3x_7 + 4x_8 + 3x_9 + 4x_{10} + 4x_{11} - 3x_1 - 2x_2 - 4x_3 - 3x_4 - 3x_5 - 3x_6 \leq x_{12}$

The next constraint is the limited number of bus that operate for 2 periods to serve the AAL - Ampera route and vice versa, so that constraints are obtained:

For the AAL - Ampera route in the morning: $x_{12} \leq 4$.

Because of the limitations of the allowed variable values, based on Equation (4) the constraint is obtained $x_j \in \{0, 1\}, \quad j = 1, 2, 3, \ldots, 11$

Based on Equation (5), it is obtained $x_j \geq 0,\ x_j \in Z,\ j = 12.$

Model Form of Timetable Problem on BRT Trans Musi for AAL - Ampera Route (Morning)

Minimum $Z_1 = 103x_1 + 81x_2 + 59x_3 + 37x_4 + 15x_5 + 0x_6 + 74x_7 + 51x_8 + 28x_9 + 5x_{10} + 0x_{11} + 0x_{12}$

with constraints

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 1 \quad (8)$$

$$x_7 + x_8 + x_9 + x_{10} + x_{11} = 1 \quad (9)$$

$$x_4 + x_5 \leq x_{12} \quad (10)$$

$$x_2 + x_3 + x_4 + x_5 + x_6 \leq x_{12} \quad (11)$$

$$x_1 + x_2 + 2x_3 + 2x_4 + x_5 + 2x_6 \leq x_{12} \quad (12)$$

$$x_1 + 2x_2 + 2x_3 + 2x_4 + 2x_5 + 2x_6 \leq x_{12} \quad (13)$$

$$2x_1 + 2x_2 + 2x_3 + 3x_4 + 2x_5 + 3x_6 \leq x_{12} \quad (14)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 \leq x_{12} \quad (15)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 - x_3 - x_4 - x_6 \leq x_{12} \quad (16)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_9 + x_{10} + x_{11} - x_1 - x_2 - x_3 - 2x_4 - x_5 - x_6 \leq x_{12} \quad (17)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + x_8 + x_9 + x_{10} + 2x_{11} - 2x_1 - x_2 - x_3 - 2x_4 - 2x_5 - x_6 \leq x_{12} \quad (18)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + x_7 + 2x_8 + 2x_9 + x_{10} + 2x_{11} - 2x_1 - x_2 - 2x_3 - 2x_4 - 2x_5 - 2x_6 \leq x_{12} \quad (19)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 2x_8 + 2x_9 + 2x_{10} + 3x_{11} - 2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 2x_6 \leq x_{12} \quad (20)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 2x_9 + 3x_{10} + 3x_{11} - 2x_1 - 2x_2 - 3x_3 - 2x_4 - 3x_5 - 3x_6 \leq x_{12} \quad (21)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 2x_7 + 3x_8 + 3x_9 + 3x_{10} + 4x_{11} - 3x_1 - 2x_2 - 3x_3 - 3x_4 - 3x_5 - 3x_6 \leq x_{12} \quad (22)$$

$$2x_1 + 3x_2 + 3x_3 + 4x_4 + 3x_5 + 3x_6 + 3x_7 + 4x_8 + 3x_9 + 4x_{10} + 4x_{11} - 3x_1 - 2x_2 - 4x_3 - 3x_4 - 3x_5 - 3x_6 \leq x_{12} \quad (23)$$

Solution of Timetable Preparation Problems Based on the Branch and Bound Method

Completion of the linear relaxation program can be done by supporting Lingo Software (version 11.0), which can be seen in the following Table 4:

Table 4. Output of Lingo software for AAL - Ampera route (morning).

Item	Value
Global optimal solution found	
Objective value	56.70000
Total solver iterations	3
Model Class	LP
Total variables	12
Nonlinear variables	0
Integer variables	0
Total constraints	17
Nonlinear constraints	0
Total nonzeros	132
Nonlinear nonzeros	0
Variable	*Value*
x_1	0.000000
x_2	0.700000
x_3	0.000000
x_4	0.000000
x_5	0.000000
x_6	0.300000
x_7	0.000000
x_8	0.000000
x_9	0.000000

x_{10}	0.000000
x_{11}	1.000000
x_{12}	4.000000

Based on Table 4, the upper limit obtained in determining the optimum solution for this problem is Z = 56.7 with the variable value obtained is $x_1 = 0$, $x_2 = 0{,}7$; $x_3 = 0$, $x_4 = 0$, $x_5 = 0$, $x_6 = 0{,}3$; $x_7 = 0$, $x_8 = 0$, $x_9 = 0$, $x_{10} = 0$, $x_{11} = 1$, $x_{12} = 4{,}7$. $x_1 = 0$, $x_2 = 0.7$; $x_3 = 0$, $x_4 = 0$, $x_5 = 0$, $x_6 = 0.3$; $x_7 = 0$, $x_8 = 0$, $x_9 = 0$, $x_{10} = 0$, $x_{11} = 1$, $x_{12} = 4.7$. In this solution an optimal integer number solution has not been obtained, so it needs to be branched. Branching continues to be carried out to find variables that have integer values and produce optimal solutions.

Furthermore, the calculation results of the Branch and Bound method on the problem of the Trans Musi BRT timetable preparation using Lingo Software can be seen in the following Table 5.

Table 5. Calculation result of Branch and Bound Method for AAL - Ampera route (morning)

Item	Nilai
Global optimal solution found	
Objective value	48.00000
Total solver iterations	3
Model Class	LP
Total variables	12
Nonlinear variables	0
Integer variables	0
Total constraints	17
Nonlinear constraints	0
Total nonzeros	132
Nonlinear nonzeros	0
Variable	*Value*
x_1	0.000000
x_2	0.000000
x_3	0.000000
x_4	1.000000
x_5	0.000000
x_6	0.000000
x_7	0.000000
x_8	0.000000
x_9	0.000000
x_{10}	0.000000
x_{11}	1.000000
x_{12}	4.000000

Based on Table 5, the output of the mathematical model obtained is as follows:
$x_1 = 0$, $x_2 = 0$, $x_3 = 0$, $x_4 = 1$, $x_5 = 0$, $x_6 = 0$, $x_7 = 0$, $x_8 = 0$, $x_9 = 0$, $x_{10} = 0$, $x_{11} = 1$, $x_{12} = 4$ and the optimal solution Z = 48. The Z value states that the total minimum number of passengers crammed is 48 passengers for 2 periods (AAL - Ampera route in the morning). In addition, based on these optimal solutions, it can be concluded as follows:

1. The values for variables x_1, x_2, x_3, x_5, x_6, x_7, x_8, x_9, x_{10} are 0. They mean that no bus is departed on the route and period to index of those variables.
2. The value for the variable $x_4 = 1$ where previously in the modeling stage has been explained that $x_4 = x^5$(1, AAL, Ampera), meaning that for the AAL - Ampera route in period 1, the frequency of the bus that must be departed is 5 buses, because of the frequency of bus in this series of trips is determined by the values x_1, x_2, ..., x_6.
3. The value for variable $x_{11} = 1$ where previously in the modeling stage has been explained that $x_{11} = x^6$(2, AAL, Ampera), meaning that for the AAL - Ampera route in period 2, the frequency of bus that must be departed is 6 because of the number of frequencies in this series of trips is determined by the values x_7, x_9, ..., x_{11}.

4. Value for variable $x_{12} = 4$, meaning that the number of bus needed for departure from AAL to Ampera is 4 buses.

Based on the results of determining the frequency, the headway can be determined by dividing 60 minutes with the frequency of buses every period in each route. It is shown in Table 6 below.

Table 6. Frequency and headway for AAL-Ampera route in morning

Route	Period	Frequency	*Headway* (minute)
AAL – Ampera	1	5	12
	2	6	10

Based on Table 6, it can be seen that for the AAL - Ampera route in period 1 for 60 minutes, the number of bus that must be departed is 5 buses with a difference in departure time between bus one and the next bus is 12 minutes. In period 2 for 60 minutes, the number of bus that must be departed is 6 buses with a difference in departure time between bus one and the next bus is 10 minutes. Furthermore, the timetable obtained is shown in Table 7 below:

Table 7. Timetable of AAL - Ampera route (morning)

	AAL – Ampera Route
Departure to	Time (in WIB)
1	06:12:00
2	06:24:00
3	06:36:00
4	06:48:00
5	07:00:00
6	07:10:00
7	07:20:00
8	07:30:00
9	07:40:00
10	07:50:00
11	08:00:00

Based on Table 7, in the AAL - Ampera route, a headway was obtained for 12 minutes with 5 departures starting at 06:12 – 07:00 WIB for the 1st period, while at 07:10 – 08:00 WIB a headway was obtained for 10 minutes with 6 departures for the 2nd period.

Furthermore, in the same way as the timetable for the AAL-Ampera route in the morning, three other timetables can be obtained, namely for the AAL-Ampera route in the afternoon, the Ampera-AAL route in the morning and in the afternoon.

3.3 *Timetable of the AAL - Ampera Route (Afternoon) and Ampera-AAL Route*

In Table 8 and Table 9, we can see headway and timetable for three other routes.

Table 8. Frequency and headway for three other routes

Route	Period	Frequency	*Headway* (minute)
Ampera – AAL (Morning)	1	5	12
	2	5	12
AAL – Ampera (Afternoon)	3	5	12
	4	6	10
Ampera – AAL (Afternoon)	3	6	10
	4	6	10

Table 9. Timetable of three other routes

Departure to	Route		
	Ampera – AAL (Morning)	AAL – Ampera (Afternoon)	Ampera – AAL (Afternoon)
	Time	Time	Time
1	06:12:00	16:12:00	16:10:00
2	06:24:00	16:24:00	16:20:00

3	06:36:00	16:36:00	16:30:00
4	06:48:00	16:48:00	16:40:00
5	07:00:00	17:00:00	16:50:00
6	07:12:00	17:10:00	17:00:00
7	07:24:00	17:20:00	17:10:00
8	07:36:00	17:30:00	17:20:00
9	07:48:00	17:40:00	17:30:00
10	08:00:00	17:50:00	17:40:00
11		18:00:00	17:50:00
12			18:00:00

3.4 *Recapitulation of Comparison of Timetable Results on Both Routes for Each Period*

Based on the timetable obtained, it can be recapitulated as Table 10.

Table 10. Timetable comparison of AAL - Ampera and Ampera - AAL routes.

No		Period	Route	
			AAL – Ampera	Ampera – AAL
1	*Headway*	1	5	5
		2	6	5
		3	5	6
		4	6	6
2	Number of buses	1	12	12
		2	10	12
		3	12	10
		4	10	10
3	Start operating	1	06:12	06:12
		2	07:10	07:12
		3	16:12	16:10
		4	17:10	17:10

4. Conclusion

Based on the timetable obtained, it can be concluded:

1. For the morning time, the buses needed for period 1 of the AAL- Ampera route are 5 buses that operate with headway for 12 minutes, which starts at 06:12 – 07:00 WIB. In period 2, the required bus is 6 buses with a headway for 10 minutes, which starts at 07:10 – 08:00 WIB.
   On the Ampera - AAL route for period 1, there are 5 buses required to operate with headway for 12 minutes, starting at 06:12 – 07:00 WIB. In period 2, it takes 5 buses that operate with headway for 12 minutes, which starts at 07:12 – 08:00 WIB .
2. For the afternoon time, the buses needed on period 3 in AAL - Ampera route are 5 buses with headway for 12 minutes, starting at 16:12 – 17:00 WIB. In period 4, it takes 6 buses with a headway for 10 minutes, which starts at 17:10 – 18:00 WIB.
   On the Ampera-AAL route in period 3 it takes 6 buses with headway for 10 minutes, starting at 16:10 - 17:00 WIB. In period 4, it takes 6 buses that operate with headway for 10 minutes, starting at 17:10 - 18:00 WIB.

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