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Bus Scheduling in The City Of Surabaya Using Smooth Transition Method and Equal Average Load

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***Abstract*—The Surabaya city's government has experienced several problems regarding their transportation scheduling system that is still planned manually and does not meet passengers' needs. Another issue that arises from the customer side is the lack of information on the public transportation schedule. The government is then developing a smart city project to reform the public transportation system, namely the Surabaya Intelligent Transport System (SITS). However, current system has not addressed the problem of resource management that makes bus scheduling less efficient. Therefore, this study aims to support SITS's success and cope with the transportation problems by developing an application to automate bus schedule using the smooth transition method which works based on repetition of the same departure interval in each time, and average load method that consider the number of passengers in a period. The findings show that the proposed methods could generate bus timetable automatically and more efficiently compared to the existing timetable, e.g., reduce 50% of the number of buses.**

Keywords— public transport schedules, smart city, smooth transition, equal average load

I. INTRODUCTION

Congestion has caused problems for several regions, including the city of Surabaya. Various solutions are then proposed and implemented to overcome such issues, one of them is to revitalize public transportation in Surabaya. However, one of the obstacles in restoring public transportation is the lack of public interest in using public transport for daily trips, especially for city buses. That issue occurs due to the lack of optimal service in city buses, such as uncertain arrival schedules and the absence of schedule information for public transportation if passengers travel using google maps direction. In contrast, such information is prominent for passengers to increase their interest in using public transportation. Another problem with the community's low interest in using public transportation is the lack of integration between public transit that cannot serve all areas in Surabaya with a definite arrival time [1]

Surabaya needs a system that can perform resource management well to overcome those issues and establish good public transport empowerment. Therefore, the government is currently developing a Smart City project to reform a better public transportation system, namely the Surabaya Intelligent Transport Systems (SITS).

A literature review related to the development of public transportation was carried out to succeed in the achievement of SITS. In general, the public transportation development process is divided into four processes, namely route design, schedule development, vehicle scheduling, and employee scheduling [2]. Some of the previous studies are route design and optimization for both city buses and Surabaya city transportation [3]–[6]. Therefore, this research aims to carry out one of the four existing processes, namely the development of a bus arrival schedule in Surabaya, i.e, Transportation Timetabling. The main contribution or novelty of this research is that this is the first study investigating the application of Smooth Transition Method and Equal Average Load Method with the case study of public transport in Indonesia, and the study show that the proposed method could generate bus timetable automatically and more efficiently compared to the existing manually generated timetable. In addition, we provide a new dataset that may attract interest of researchers in timetabling problems.

II. LITERATURE REVIEW

A. Scheduling

Scheduling is a combinatoric optimization problem investigated by the researcher for some purposes, such as job scheduling [4], [7], facility allocation [8], and transportations such as rail [9], [10] and green logistics [11]. Lawler [4] defined scheduling as a mathematical study to find optimal solutions in arranging, grouping, sorting, or selecting discrete objects that are usually finite number. In this study, the used procedure follows Ceder's theory [2] to determine the frequency (Fig. 1). In addition, similar with previous study for bus scheduling such as in [12]–[16].

B. Maximum Load Method

According to Ceder [2], [3], the preparation of public transportation schedules can be built using the maximum load method. The maximum load is the value of the highest passenger load on a route. The value of the load at each bus stop will be different. To determine which load value to use, the highest load value is chosen to represent the maximum number of passengers that must be carried by the bus. Furthermore, this load value will be used to calculate the frequency and delay of departures.

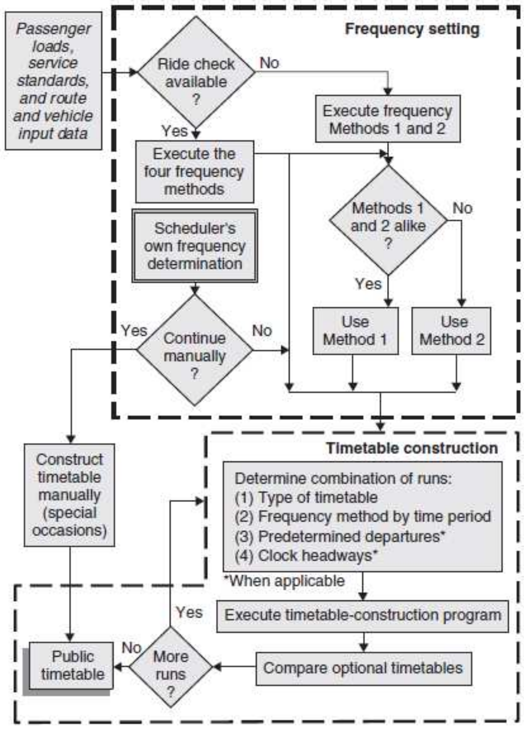


Fig. 1. Scheduling procedure

1) Frequency. Frequency is the value of bus departures every hour in the form of real numbers, calculated based on the number of passengers divided by the total bus cap (1) each period (1). The frequency value will be used to calculate the departure interval. Hence, the value does not represent the number of bus departures directly. The frequency is calculated using the maximum load method by taking the highest load value (Fig. 1)

$$f = \frac{x_i}{c} \tag{1}$$

In which:
f = frequency
x_i= the average number of passengers in period i in hours
i = bus departure period (hour) according to the bus schedule every day (1, 2, 14)
c = bus load capacity

2) Departure Interval. Departure interval represents the departure distance between successive buses. The value of the departure interval is calculated from the value of the bus departure frequency. There are two departure breaks: normal and transition. The normal departure delay interval obtained from 60 minutes divided by the frequency (2).

$$h = 60/f \tag{2}$$

Meanwhile, the average value of the normal departure interval between two consecutive periods forms a transitional departure interval [4].

C. Smooth Transition Method

Some researchers have revealed smooth transition model as one of the most effective method to optimize bus scheduling problems, such as in [17]–[20]. One of the characteristics of scheduling with the smooth transition method is a repetition of the same departure interval in each time period *j*. Departure interval within periods will be static, so the bus will depart at a regular time. The known intervals are the departure breaks per one hour. If the bus departure is between two periods or two hours, the new departure interval is calculated, and it is called transitional departure interval between the two periods. Thereby, the next departure time will be calculated from the previous departure time plus the transitional departure time. The rules for defining a schedule with smooth transitions are as follows [4]:

- If the last departure + departure interval is still at the same period (same hour), then the next departure time is the last departure + departure time.
- If the last departure time + departure delay enters the next hour, then the next departure time is the last departure time + transitional departure time.

D. Equation method of average load

The characteristic in the next scheduling is to pay attention to the number of passengers in a period. The bus departure schedule will adjust to the estimated time at which the number of passengers at the stop corresponds to the average maximum load and the bus capacity. The departure times between buses will not be arranged the same.

There will be two departure tables used in calculating the departure interval: normal departure interval and the transitional departure interval. The main principle of scheduling using this method is to divide the number of passengers carried on each bus evenly, so the data used to form the table is the average value of passengers' addition per minute. The estimated data on the number of additional passengers will be updated every time there is data on the new passengers. Here are some rules for scheduling the equal average load [2]:

- Set the first departure schedule according to the standard bus operating hours. In this case, because the bus operating time within in Surabaya is 05.00 am, by default the first departure will always be at 05.00 am.
- Determine the average number of additional passengers.
- Determine the second and subsequent departures with the headway value calculated by bus capacity divided by the average number of additional passengers.
- Suppose at the current departure there is a difference between the seats available and the estimated number of passengers (capacity exceeds passenger requirements), then the difference will be added to the next departure.

III. Methodology

This research is carried out through the methodology as shown in **Error! Reference source not found.**. The study is started by having the initial problems as observed in Surabaya's public transport. Those issues then are confirmed by conducting interviews with the department of transportation in Surabaya and reviewing several studies from various sources, such as articles, interviews, previous research, and related documents. Therefore, the study literature's output is information gap among real cases and literature to determine the need for research.

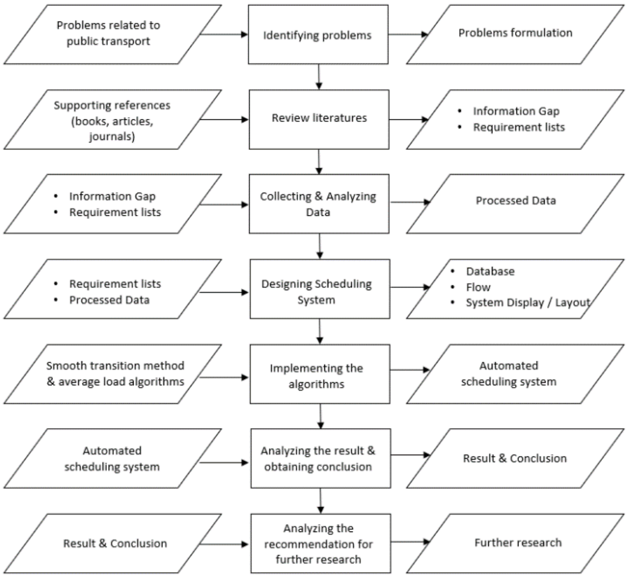


Fig. 2. Research Methodology

In order to get a wider insight of the problems, the secondary information are collected and analysed from several sources such as DAMRI's system and e-dishub, an information system used to manage public transport in Surabaya: 1) average number of passengers in one departure on odd and even rites, 2) load factor (i.e. load factor, calculating the utility value of the available load capacity of the mode of transport), 3) headway (distance or time lag between arrivals between buses at each stop), and 4) vehicle capacity. Those processed data are combined with the requirement list obtained from the literature review to design the scheduling system, including database, data and process flow, and layout design.

Once the system has been developed, two kinds of algorithms, which are the smooth transition method and equal average load that has been well-proven in recent studies, is selected as comparison method to automate the transportation schedule. Afterward, the results is evaluated to measure the algorithm's performance in terms of generating an effective and efficient schedule. The evaluation is conducted by comparing smooth transition and equal average load with current method, which manual calculation of bus scheduling without any algorithm applied. Finally, such evaluation leads to a recommendation for scheduling bus in a more effective and efficient way by reducing the number of bus departures.

IV. System Implementation

A. Getting an Average Number of Passengers

The number of passengers per hour per day is calculated based on the average bus passenger number accumulated from previous periods. This number will continue to be updated as the passenger number data is added, edited, or deleted. The value through codes as in Fig. 3.

```
$this->db->select("route_name, station_name,
time_id, time_day, day_rit,
passenger_hour, SUM(passenger_amount) AS
passenger_amount '");
```

Fig. 3. Getting an average number of Passengers

B. Calculate Frequency

The frequency is formulated from the number of passengers in the passenger table divided by the capacity that has been initiated. In this case, the bus capacity is 54. The frequency value will be updated and stored in the frequency column of the frequency table in Fig. 4.

C. Calculating Headway

The $headway value is derived from the period divided by the frequency. The period value is 60 minutes, while the frequency per hour is obtained from the frequency table. The $headway value is then stored in the headway column of the headway table in Fig. 5.

D. Scheduling with Smooth Transition

The implementation of the smooth transition method requires data on the average number of passengers, the headway from the headway table, and the transition from the transition table. Normally, a smooth transition schedule is derived from the last departure time plus the headway value. However, if the resulting schedule enters the next hour headway period, the headway value is replaced by a transition value. The headway value is obtained from the headway table and the transition value is obtained from the transition table in Fig. 6.

E. Scheduling with Equal average load

The implementation of the average load equalization scheduling method is used to ensure that each bus transports passengers equally according to the number of passengers needs in Fig. 7.

```
foreach($data as $row)
{
  $update = array(
   ' time_id _frequency’ => $row[' time_id'],
   'frequency_hour' => $row['passenger_hour'],
   'frequency' =>
  $row['passenger_amount']/$this>capacity );
```

Fig. 4. Calculating frequency

```
foreach($data as $row)
{
$update = array(
              'time_id_headway' => $row['time_id'],
              'headway_hour' => $row['frequency_hour'],
              'headway' => ceil(60/$row['frequency'])
              );
$this->e_m->updateHeadway($update);
}
```

Fig. 5. Calculating headway

```
Get total_frequency
For i = 1 to total_frequency do
Get headway
Get transition
Set departure (first departure)
tmp_departure = departure + headway
If tmp_ departure > departure + 60 minutes then
New_departure = departure + headway
Else
New_ departure = departure + transition
```

Fig. 6. Scheduling with Smooth Transition

```
Initiation
Set capacity
Get value ‘average’ (additional passenger average)
leftover_capacity = {true, false}
Delete table
Get total_frequency
```

```
Set departure (as schedule)
leftover_chair = capacity – load
For i = 1 to total_frequency do
Get time_current
Get load
Get leftover_chair
If load < leftover_chair then
    a. leftover_chair - = load
    b. leftover_load = false
else
    a. headway = ceil(leftover_chair /average)
    b. departure = time_current + headway
    c. load  = leftover_chair
if load > 0 then leftover_load = true
else leftover_load = false
Set load = capacity – leftover_load
```

Fig. 7. Equal average load

V. RESULT & DISCUSSION

A. Final Results

This research has generated a php-based automatic bus scheduling system to run the smooth transition and the average load equalization algorithm on the PAC 1 bus line in Surabaya. The number of bus passengers is accumulated by the system into a span of an hour to create schedules, however the data required as input can be provided in any time frame.

The application leads to a more efficient schedule in terms of the number of required bus fleet which has an impact on operational costs. It takes as many as 42 bus departures on a manual schedule, whether it's busy or quiet. Meanwhile, by applying smooth transition and equal average load method, the number of departures become almost a half smaller on average compared to the manual method. However, that result still meets the needs of passengers who will board the bus. This reduces the operating costs of the bus fleet without reducing services and the number of passengers carried. Both of methods result in similar number of buses, except for some daily iteration where smooth transition made up smaller number of buses, especially when the RIT equals to Even. The results of the comparison of the number of buses required for each scheduling method can be seen in the Table 1. In addition to comparison with the manual timetable, Table 1 compares the performance of smooth transition and equal average methods. It shows that their performance is competitive. However, since the datasets used within this study is new, the comparison with other algorithms in the literature was not carried out.

TABLE I. COMPARISON OF THE NUMBER OF BUS DEPARTURES IN EACH SCHEDULING METHOD

Day	RIT	Manual	Smooth Transition	Equal average load
Monday	Odd	42	27	27
Tuesday	Odd	42	23	23
Wednesday	Odd	42	22	22
Thursday	Odd	42	25	25
Friday	Odd	42	24	24
Saturday	Odd	42	24	24
Sunday	Odd	42	20	20
Monday	Even	42	26	26
Tuesday	Even	42	23	23
Wednesday	Even	42	21	21
Thursday	Even	42	24	25
Friday	Even	42	23	23
Saturday	Even	42	23	24
Sunday	Even	42	20	20

B. Testing

To be able to analyse and draw conclusions on application performance, the results are tested with three scenarios.

1) Scenario 1: Change the number of passengers. In this scenario, the number of passengers is made, and the testing was conducted to see its effect on the resulting schedule. Fig. 8 displays the data to be changed by deleting the number of passengers on Monday at 05.11 where there are 40 passengers.

The resulting schedule shows that the number of bus departures decreases as the number of passengers decreases. Fig. 8 depicts the initial schedule, while Fig. 9 represents the schedule after the number of passengers is reduced. On the initial schedule, there are three bus departures from 05.00 to 06.00. Then on the schedule with the data already reduced, there are only two departures from 05.00 to 06.00. The greater the number of passengers, the more the number of bus departures during the crowded time will increase.

The same result is also found in the equal average load table. The number of bus departures decreases as the number of passengers decreases according to the time the number of passengers changes. Fig. 10 shows the initial schedule, while Fig. 11 displays the schedule after the data is modified. The number of bus departures between 05.00 and 06.00 was reduced to two after the data was modified.

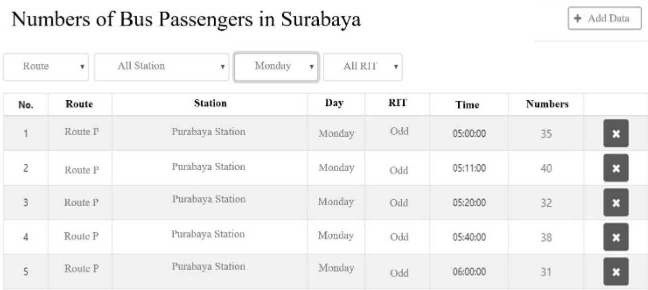


Fig. 8. Number of passengers for scenario 1

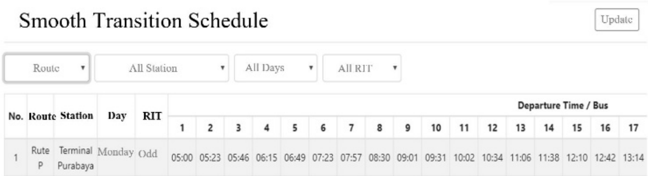


Fig. 9. Initial schedule of smoothing transition (Scenario 1)

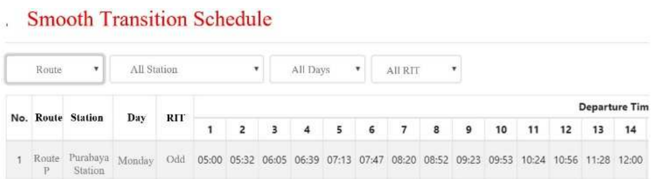


Fig. 10. Schedule of smoothing transition after decreased number of passengers (Scenario 1)

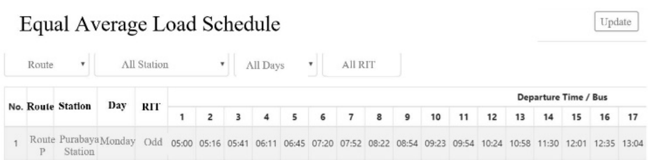


Fig. 11. Initial schedule of equal average load (Scenario 1)

Equal Average Load Schedule

Route | All Station | All Days | All RIT

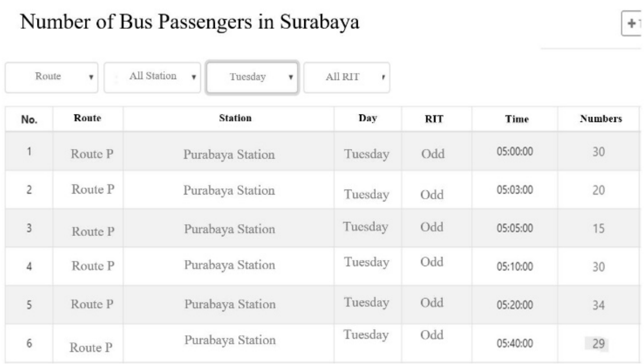
No.	Rute	Halte	Hari	RIT	Departure Time / B…														
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Route P	Purabaya Station	Monday	Odd	05:00	05:32	06:02	06:37	07:10	07:45	08:14	08:46	09:15	09:47	10:16	10:48	11:22	11:53	12:27

Fig. 12. Schedule of equal average load after adjusted

2) Scenario 2: Change the number of passengers. In this scenario, the passenger's number is modified and tested to see the effect of the time span of the data used as input on the schedule. (Fig. 13).

After the modification, the total passengers on Tuesday at between 5:20 a.m. and 5:40 a.m. at odd RIT online P accounts for 29 passengers. (Fig. 14)

The results show that the smooth transition schedule does not change the schedule between the initial conditions and after the modification. However, in the average load equalization schedule, there are differences in departure times. Fig. 15 is the initial schedule, and Fig. 16 is the modified schedule. It can be seen from figures that there is a time of departure which changes from 05.28 to 05.23. This is because the period of the data affects the value of additional passengers per minute used as the basis to form schedule with average load equalization method. The smaller the period, the more accurate the schedule will be.



Number of Bus Passengers in Surabaya

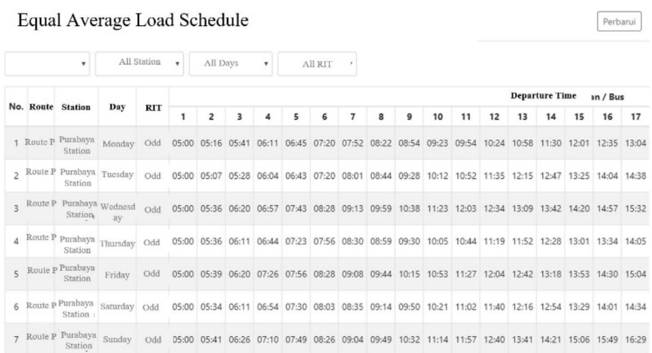
Route | All Station | Tuesday | All RIT

No.	Route	Station	Day	RIT	Time	Numbers
1	Route P	Purabaya Station	Tuesday	Odd	05:00:00	30
2	Route P	Purabaya Station	Tuesday	Odd	05:03:00	20
3	Route P	Purabaya Station	Tuesday	Odd	05:05:00	15
4	Route P	Purabaya Station	Tuesday	Odd	05:10:00	30
5	Route P	Purabaya Station	Tuesday	Odd	05:20:00	34
6	Route P	Purabaya Station	Tuesday	Odd	05:40:00	29

Fig. 13. Initial number of passengers (scenario 2)

Upda Route P	Purabaya Station	Tuesday	Odd	05:27:00	10
Route P	Purabaya Station	Tuesday	Odd	05:30:00	6
Route P	Purabaya Station	Tuesday	Odd	05:33:00	5
Route P	Purabaya Station	Tuesday	Odd	05:40:00	8

Fig. 14. Passenger's number after modification (Scenario 2)



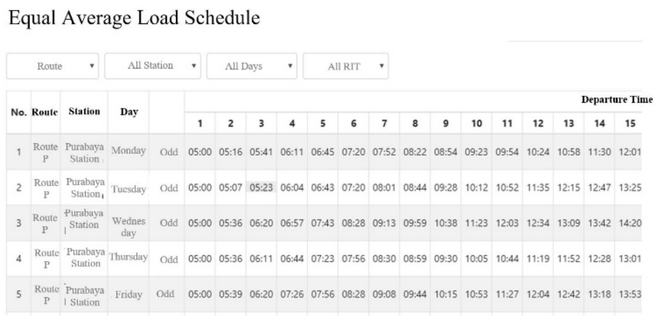
Equal Average Load Schedule

Perbarui

All Station | All Days | All RIT

No.	Route	Station	Day	RIT	Departure Time …an / Bus																
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Route P	Purabaya Station	Monday	Odd	05:00	05:16	05:41	06:11	06:45	07:20	07:52	08:22	08:54	09:23	09:54	10:24	10:58	11:30	12:01	12:35	13:04
2	Route P	Purabaya Station	Tuesday	Odd	05:00	05:07	05:28	06:04	06:43	07:20	08:01	08:44	09:28	10:12	10:52	11:35	12:15	12:47	13:25	14:04	14:38
3	Route P	Purabaya Station	Wednesday	Odd	05:00	05:36	06:20	06:57	07:43	08:28	09:13	09:59	10:38	11:23	12:03	12:34	13:09	13:42	14:20	14:57	15:32
4	Route P	Purabaya Station	Thursday	Odd	05:00	05:36	06:11	06:44	07:23	07:56	08:30	08:59	09:30	10:05	10:44	11:19	11:52	12:28	13:01	13:34	14:05
5	Route P	Purabaya Station	Friday	Odd	05:00	05:39	06:20	07:26	07:56	08:28	09:08	09:44	10:15	10:53	11:27	12:04	12:42	13:18	13:53	14:30	15:04
6	Route P	Purabaya Station	Saturday	Odd	05:00	05:34	06:11	06:54	07:30	08:03	08:35	09:14	09:50	10:21	11:02	11:40	12:16	12:54	13:29	14:01	14:34
7	Route P	Purabaya Station	Sunday	Odd	05:00	05:41	06:26	07:10	07:49	08:26	09:04	09:49	10:32	11:14	11:57	12:40	13:41	14:21	15:06	15:49	16:29

Fig. 15. Initial schedule before modified (Scenario 2)



Equal Average Load Schedule

Route | All Station | All Days | All RIT

No.	Route	Station	Day		Departure Time														
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Route P	Purabaya Station	Monday	Odd	05:00	05:16	05:41	06:11	06:45	07:20	07:52	08:22	08:54	09:23	09:54	10:24	10:58	11:30	12:01
2	Route P	Purabaya Station	Tuesday	Odd	05:00	05:07	05:23	06:04	06:43	07:20	08:01	08:44	09:28	10:12	10:52	11:35	12:15	12:47	13:25
3	Route P	Purabaya Station	Wednesday	Odd	05:00	05:36	06:20	06:57	07:43	08:28	09:13	09:59	10:38	11:23	12:03	12:34	13:09	13:42	14:20
4	Route P	Purabaya Station	Thursday	Odd	05:00	05:36	06:11	06:44	07:23	07:56	08:30	08:59	09:30	10:05	10:44	11:19	11:52	12:28	13:01
5	Route P	Purabaya Station	Friday	Odd	05:00	05:39	06:20	07:26	07:56	08:28	09:08	09:44	10:15	10:53	11:27	12:04	12:42	13:18	13:53

Fig. 16. Passenger's number after modification (Scenario 2)

TABLE II. SPECIFICATION FOR THE 1ST DEVICE

Hardware	Specification
Type	Asus K46CM
Processor	Intel(R) Core™ i5-3317U
RAM	8.00 GB
Hard Disk Drive	500 GB

TABLE III. SPECIFICATION FOR THE 2ND DEVICE

Hardware	Specification
Type	Asus X450CC
Processor	Intel(R) Celeron(R) CPU 1007U
RAM	2.00 GB
Hard Disk Drive	500 GB

TABLE IV. TESTING RESULT FROM DIFFERENT DEVICES

Weekly Number	1st Device	3rd Device
1	00:55:08	02:00:00
2	00:40:04	01:55:31
3	00:29:09	01:52:41
4	00:28:00	02:06:28
5	00:30:02	01:45:37
6	00:27:01	01:55:44
7	00:27:01	01:55:00
8	00:25:06	01:36:86
9	00:26:5	01:44:90
10	00:25:02	01:41:84

3) Scenario 3: Test Other Devices The testing is also done with other devices which have specifications as in Table II & III.

The trials were carried out through ten iterations by calculating the running time needed to generate a new schedule, as shown in Table IV. Applications can run on both devices at the speed of generating a schedule, depending on the hardware's RAM. Furthermore, the ratio of the time needed to create a schedule is linear to the ratio of the RAM.

CONCLUSIONS

The most obvious finding to emerge from this study are as follows. First, compared to manual schedules that make buses depart randomly, this study proposed automated bus timetabling using smooth transition model and equal average that result in more efficient timetable requiring 50% a smaller number of buses and in turn could minimize operational cost. Second, this study provides new datasets in timetabling problem that may attract interest of other researcher in the field of timetabling and optimization. Third, in terms of the number of required buses, the experimental results show that the performance of smooth transition method and the average load are competitive. However, the benefit of average load method compared to smooth transition is that the departure time is more in line with the estimated additional passengers.

Lastly, this study provides new datasets in timetabling problem that can nurture new investigation. Since the dataset is new, the comparison with other algorithms in the literatures were not carried out.

Recommendation

These findings provide the following insights for future research: Smooth transition and the equal average load method were included in the analytical or exact optimization. Those methods still have many weaknesses including the computation process which is not as efficient as algorithmic optimization. Further research could investigate a more optimal value in a more efficient way by using more advanced methods or algorithms. This scheduling is carried out using the assumption that the bus capacity is of the same value, so a greater focus on using variations in bus capacity could produce other interesting findings that account more realistic and lead to more optimum solution.

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