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Integer programming model for optimizing bus timetable using genetic algorithm

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Abstract. Bus timetable gave an information for passengers to ensure the availability of bus services. Timetable optimal condition happened when bus trips frequency could adapt and suit with passenger demand. In the peak time, the number of bus trips would be larger than the off-peak time. If the number of bus trips were more frequent than the optimal condition, it would make a high operating cost for bus operator. Conversely, if the number of trip was less than optimal condition, it would make a bad quality service for passengers. In this paper, the bus timetabling problem would be solved by integer programming model with modified genetic algorithm. Modification was placed in the chromosomes design, initial population recovery technique, chromosomes reconstruction and chromosomes extermination on specific generation. The result of this model gave the optimal solution with accuracy 99.1%.

1. Introduction

Bus timetable is the information which is provided by transportation provider for the passenger to give a service certainty time in term of departure/arrival bus schedule. Bus transportation service provider which is usually use timetable in giving the schedule information to the customer is the road based mass transit (*bus rapid transit*/BRT), shuttle bus and the other scheduled bus service transportation.

The consequences of using timetable is the bus should be deployed on schedule without waiting for a full passenger on the bus. As a result, service providers must be able to determine the number of optimum bus departure/frequency from the place of origin to the destination (optimal trip number) so that a timetable is made in accordance with passenger demand conditions and existed constraints, with regard to passenger service. It means in the off-peak time, the amount of trip will be less compared with the amount of trip during rush hour and vice versa. If it's not be calculated well, when the trips frequency is too small, there will be accumulation of passengers (unserved passenger) or vice versa, when the trips frequency is too much, it will waste the operating costs.

Making a timetable with the optimal number of trips (optimal timetable) without the computer programming, requires high accuracy and long processing time. The time required to achieve optimal working timetable is 2-7 working days, depends on the availability of data, tools, precision and expertise of the timetable maker. In providing services, service providers often face the changes of passenger demand and operational constraints that make the existing timetable to be improved. The long processing time in making timetable would create delays to anticipate the situation changing which will affect the services quality or operational costs.

Some studies related to the development of optimal bus scheduling model already made, some of them are Ceder *et al.* who already described timetables synchronization problems at transit stops by maximizing the number of arrival bus simultaneously [1]. Fu *et al.* modelling real time model nonlinear programming with using GPS. This model has the advantage in term of giving departure information to the passengers [2]. Kidwai develops genetic algorithm to solve the bus scheduling. On his article, scheduling models was made in two phases, the first phase is finding out the minimum frequency and the other phase is to find out the optimization model for the assignments in the services route [3]. Chuanjio *et al.* focus in developing model to find out the optimal headway and solve it using genetic algorithm. The developed model that has been made was in the form of nonlinear programming and also with considering the departure time and arrival time among shelters in the route. Chuanjio also did sensitivity analysis of his developed model [4]. Kidwai *et al.* and Chuanjio *et al.* haven't considering the bus worker aspect on their model. Wihartiko already modelling the number of trip problem with using integer programming. His model already considered the working hours of employees but has not considered the minimum service standards and it's limitations in finding the optimal number of trips on one route in one day [5]. Furthermore, Wagale *et al.* have developed Demand Travel-time Responsive model for scheduling problems [6]. Most of the research developed in the scope of bus scheduling are done by modelling the problem to find the optimum headway. Headway can be sought from the amount of frequency/route has been found. The differences amongst models were in the term of assumptions, indicator that be used and the method of solving problem.

This research is the development of integer programming model by Wihartiko [5], which will be designed by modelling a model that can accommodate a minimum service standards and overcome the limitations of the previous model by using genetic algorithm. Integer programming model can be solved using genetic algorithms [7]. Genetic algorithm is an evolutionary and numerical technique to find the optimal solution by using the principles of genetics theory [8]. Modifications with using genetic algorithm in this article was taken place in the chromosomes design which is the representations of bus operational time, chromosome generation techniques in feasible area, chromosome reconstruction techniques and population extermination on specific generation. The objective of this research is to model the optimal timetable problem into the form of integer programming, which then be solved by using a genetic algorithm. This research is limited to the manufacture of optimal timetable which contains the bus departure time schedule at the starting point and at the end point. Timetable explanations, bus arrival time schedule, departure schedules in each shelter along the trip, the making of "conditional" timetable, schedules synchronization at the transit, determination of the optimal number of officers, determination of the optimal number of buses, timetable evaluation method to predict the number of passengers and the bus travel time is not part of this research

2. Research Method

2.1. *Problem formulation in the form of Integer Programming*
In achieving optimal bus timetable, it be done by complementing the optimum trip/rit determination model [5] by considering minimum service standard and also by finding out the optimum rit for every route in the specific time period. The assumptions that be used:
1. Passengers distributed uniformly in one scheduling partition.
2. The same headway for each partition.
3. Make the bus journey happened from the starting point to the final destination repeatedly. Thus, the bus departure frequency (bus trip number) from the starting point to the final destination equals with a number of bus trips from the final destination to the starting point.

Bus timetable can be made according to the available routes, the passengers movement pattern in a time period, and the rush hour in a day. For example defined:
- $R = \{1, 2, \ldots, r | r \in \mathbb{N}\}$, is a set of routes, paths or corridors served by the service provider.
- $V_r = \{1, 2, \ldots, v_r | v \in \mathbb{N}, r \in R\}$, is a set of schedule variations imposed in a specific period on a route r∈R.

- $P_{r,v} = \{1,2,\dots,p_{v,r}|p \in \mathbb{N}, v \in V, r \in R\}$, is a set of partition or time division of the applicable timetable in a schedules variations $v \in V$ dan $r \in R$.

To formulate the problem of determining the optimal number of trips in integer programming, defined:

- $q_{r,v,p}^{psgr}$:   Average number of passengers on the route $r \in R$ in schedule variations $v \in V$ on partition $p \in P$.
- $q_{bus,r}$:   The numbers of vehicles that can be operated at route $r \in R$
- q_{cty} :   Bus capacity in the term of passengers
- q_{emp} :   Number of drivers employed
- $t_{r,v,p}$:   Departure time of the bus n on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $T_{r,v,p}$:   Bus travel time (minutes) in one rit/trip at route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $h_{r,v,p}$:   Bus *headway*, is the time differences (minutes) between one departure and the next departure ($h_{r,v,p} = t_{r,v,p,n+1} - t_{r,v,p,n}$). Headway can be found using the following equation:

$$h_{r,v,p} = \frac{2T_{r,v,p}}{q_{bus,r}} \tag{1}$$

- $h_{std,r,v,p}$:   *headway based on the minimum service standard*
- LF :   *Load Factor* defined as the percentage between the numbers of passengers and the bus capacity.
- K_{emp} :   Maximum working hour of the bus operation employee per day, added by the maximum overtime hour in minutes along 1 variation periods.
- K_{emp} :   Minimum working hour of the bus operation employee per day, in minutes along 1 variation periods.
- $k_{LF_{r,v,p}}$:   Number of passengers that be expected to be served on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $k_{r,v}$:   Number of schedule repetition during $v \in V_r$ on route $r \in R$
- $M_{r,v,p}^{Rit}$:   Maximum rit/trip number that should be fulfilled for journey on route $r \in R$ in schedule variation $v \in V_r$ on partition $p \in P_{r,v}$

$$M_{r,v,p}^{Rit} = \frac{\Delta t_{r,v,p}}{h_{r,v,p}} = \frac{t_{r,v,p,n_{max}} - t_{r,v,p,n_0}}{h_{r,v,p}} \tag{2}$$

- $m_{r,v,p}^{Rit}$:   Minimum rit/trip that possible to be fulfilled for journey on route $r \in R$ in schedule variation $v \in V_r$ on partition $p \in P_{r,v}$

$$m_{r,v,p}^{Rit} = \frac{\Delta t_{r,v,p}}{h_{std,r,v,p}} \tag{3}$$

- $x_{r,v,p}$:   Amount of Rit or bus departure frequency on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $inc_{r,v,p}$:   Average bus income for every rit/trip on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $outc_{r,v,p}$:   Average operational costs for every rit/trip on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$
- $c_{r,v,p}$:   Average profit/loss in every rit/trip on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$

$$c_{r,v,p} = inc_{r,v,p} - outc_{r.v,p} \tag{4}$$

The result of developing the optimum rit/trip determination model with using integer programming is as Model (5) follows:

Maximize $$z(x) = \sum_{r \in R} \sum_{v \in V_r} \sum_{p \in P_{v,r}} c_{r,v,p} . x_{r,v,p} \tag{5.1}$$

Subject To $$k_{emp} . \frac{q_{emp}}{2} \leq \sum_{r \in R} \sum_{v \in V_r} \sum_{p \in P_{r,v}} T_{r,v,p} k_{r,v} . x_{r,v,p} \leq K_{emp} . \frac{q_{emp}}{2} \tag{5.2}$$

$$m_{r,v,p}^{Rit} \leq x_{r,v,p} \leq M_{r,v,p}^{Rit} \qquad ; \forall r \in R, \forall v \in V_r, \forall p \epsilon P_{r,v} \tag{5.3}$$

$$x_{r,v,p} \geq \frac{q_{r,v,p}^{psgr}}{k_{LF_{r,v,p}}} \qquad ; \forall r \in R, \forall v \in V_r, \forall p \epsilon P_{r,v} \tag{5.4}$$

$$x_{r,v,p} \in \mathbb{Z}^+ \cup \{0\} \qquad ; \forall r \in R, \forall v \in V_r, \forall p \epsilon P_{r,v} \tag{5.5}$$

Objective function (5.1) states to find out the rit/trip numbers in order to maximize profits or minimize losses. Constraint (5.2) ensures that all of departure can be served by employees of the company with also considering the minimum employee working hour. Constraint (5.3) ensures that the number of trips being served does not exceed the amount of the existing fleet and in accordance with the minimum service standards. Constraints (5.4) to ensure that passengers can be served according to expectations of the company. Constraint (5.5) ensures that the solution result is nonnegative integers.

2.2 Optimal timetable creation with using genetic algorithm
John Holland introduced the concept of Genetic Algorithm in the early decades of 1970. Genetic Algorithm is a numerical optimization method inspired by the theory of natural selection and genetics. This algorithm contains stages sequential procedure that processes a population of artificial chromosome (artificial) into other new populations [8]. There are five main processes used in the genetic algorithm such as the initial population, the fitness value calculation, selection, crossover and mutation [9]

Optimal timetable creation by using GA was done by modifying the representation model of Huy *et al.* [7], especially in the process of the chromosomes design which is the representations of bus operational time, chromosome generation techniques in feasible area, chromosome reconstruction techniques and population extermination on specific generation. Result of optimal timetable representation to GA is as follows:

1. Establishment of Initial Population Chromosomes.
   The established chromosomes are the representation of the time on all variables $x_{r,v,p}$.
   Each variables is coded with using genes with the length of time (in minutes) on route $r \in R$ in schedule variations $v \in V_r$ on partition $p \in P_{r,v}$. In this case, the numbers of genes for variable $x_{r,v,p}$ is $\Delta t_{r,v,p}$ (or equal $\Delta t_{r,v,p} + 1$ if $x_{r,v,p}$ placed on the end of operational time). Each genes on chromosomes has values:

   $$\text{gene}(n) = \begin{cases} 1 & \text{, if } t_{r,v,p,n} \text{ selected on timetable} \\ 0 & \text{, if } t_{r,v,p,n} \text{ unselected on timetable} \end{cases} \tag{6}$$

   Below is the ilustration of genes & chromosomes from Model (5).
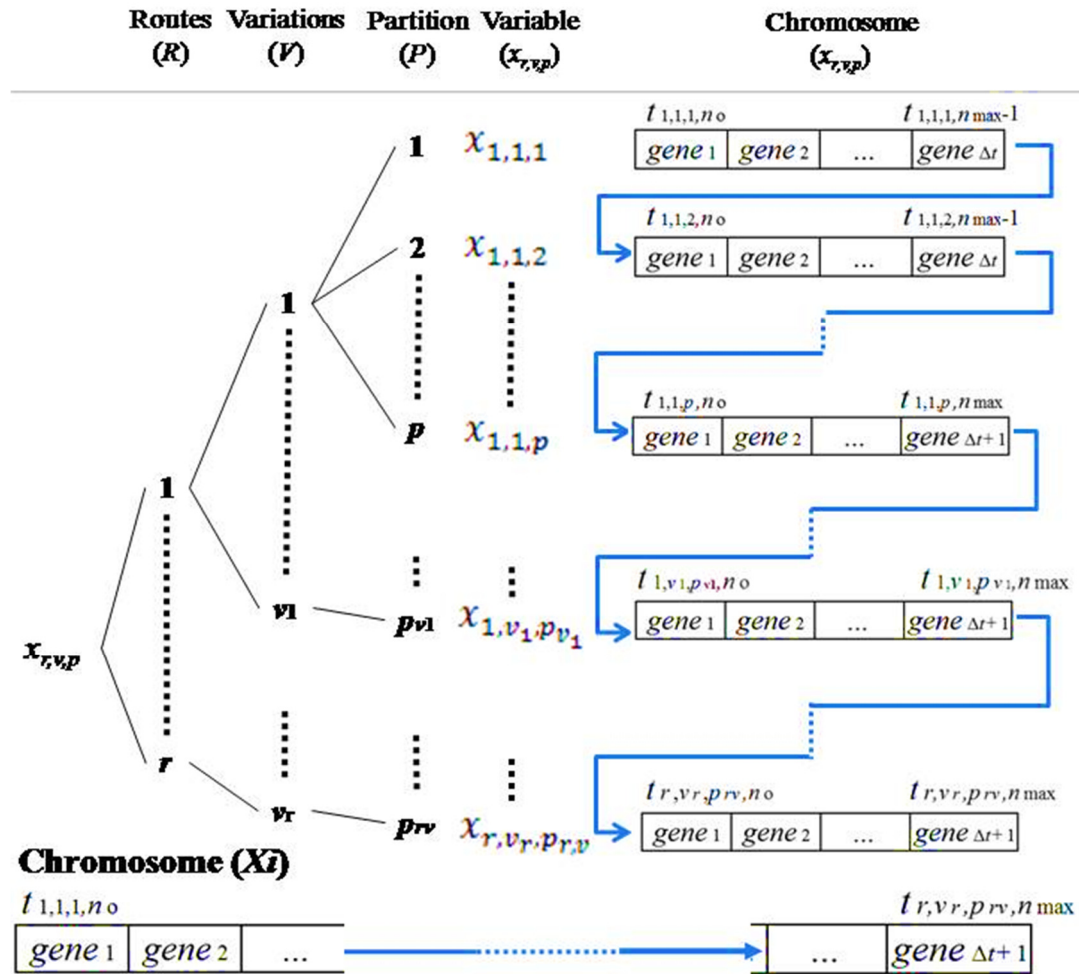
Figure 1. Design of chromosome

Each chromosome represent all variables on Model (5). Numbers of chromosomes was determined with the amount of N that will be raised randomly, limited, and arranged well to become first population. The early chromosomes was formed based on the random establishment from the value that is possible as result from one variable. In this case, the randomized variable value should

fulfilled the constraints in Model (5), which is the integer ranging between Max $(\dfrac{q_{r,v,p}^{psgr}}{k_{LF_{r,v,p}}}, m_{r,v,p}^{Rit})$

until $M_{r,v,p}^{Rit}$ and fulfilled Constraints (5.1).

The value that be obtained randomly then will be represented in the form of chromosomes which is also the representations of timetable.

2. Fitness function.

To find out the fitness values for each chromosomes (Xi), it is done with using formula below:

$$f(X_i) = z(X_i) - \sum_{j=1}^{m} |MC_j.VC_j| ; i = 1,2,\dots N \qquad (7)$$

Where $z(X_i)$ is the objective functions value from model (8) for chromosome X_i. The number of variable $x_{r,v,p}$ is as large as all genes in part of chromosomes which representing the variable $x_{r,v,p}$.

MC_j value is the constanta to measures the constraints interest j. VC_j is the variable value which is not suitable with constraints j. In this case, the value of VC_j for individu I is as follows:

$$VC_j = \begin{cases} A(X_i) - b & ; A(X_i) > b \\ 0 & ; \text{otherwise} \end{cases} \quad j = 1, 2, \ldots m \tag{8}$$

Assumption that be used in calculating the fitness values is each chromosome which is the result of genetic algorithm operator is an irregular chromosome and there is no checking for the chromosome regularity.

3. Reconstruction, Extermination of Chromosome and Elitism.
   Chromosome with the bess fitness value will be reconstructed, so it will produce the regular chromosome. The regularity of chromosomes was needed in order to create the timetable with the well-ordered headway. Extermination of chromosomes done when the population is considered to be no longer able to produce a better generation. In this extermination process, only the chromosomes with the best values ($X_{i_{best}}$) that will be maintained and will be included with the new population (elitism process [9]). For example, $g \in \mathbb{Z}^+$ is the generation in one genetic algorithm. In this case, the extermination of chromosomes done when the best fitness values in generation g equals the best fitness values on generation $g+w$ ($f(X_{i_{best,g}}) = f(X_{i_{best,g+w}})$). It means the extermination process will happen if the best fitness values equals along w generations consecutively ($w = 50$). The new population that will be used to replace the exterminated population, is the early population when first time raised. Every W generation, the new population will be raised, will and replace the early population.

4. Selection, crossover and mutation.
   On this research, it will use rank selection in the selection process [10], *crossover* 2-points on *crossover process* and mutation operator to find the optimal solutions.

5. Chromosome representation on timetable
   The best chromosomes will be combined with departure time vector and then it will be arranged becomes 10 columns matrices.

6. Parameter choice
   The number of chromosomes ($n = 50$), the probability of mutation ($p_m = 0.001$), the probability of crossover ($p_c = 0.6$) [11], the number of generations ($g = 6000$), the extermination of chromosomes ($w = 50$) and the new population ($W = 0, 2000, 4000$).

2.3 Error Analysis

Absolute Error (E) is the absolute value of the difference approximation solution with the exact solution ($E = |z - \hat{z}|$). While the relative error (E_R) is the value of Absolute Error (E) compared with the absolute value of the exact solution, in this case $E_R = |z - \hat{z}|/|z|$ [12]. Accuracy is calculated based on the proximity to the optimal value which is defined as:

$$\text{Accuracy} = (1 - E_R) \times 100\% \tag{9}$$

3. Results and Analysis

Based on the experiment result that has be done (Table 1), the initial population generation techniques in the feasible area, regular chromosome arrangement techniques, and chromosomes extermination techniques in the specific generation could improve the genetic algorithm performance in finding out the optimal solution in the case of arranging timetable. On each table, it can be seen that in this case, the improvement of crossover possibility 0.1 and mutation possibility (from 0.001 becomes 0.01) will not significantly increases the accuracy of fitness values.

Table 1. Preliminary Experiment Results Search Solutions with Genetic Algorithm

No	Initial Population		Pc	Pm	reconstruction	extermination		generation	Best Position	accuracy
	Random	Feasible				w=50	W=2000			
1	√		0.6	0.001	x	x	x	1000	70	-388.10%
2		√	0.6	0.001	x	x	x	1000	103	87.52%
3		√	0.7	0.001	x	x	x	1000	103	88.27%
4		√	0.6	0.01	x	x	x	1000	29	83.38%
5		√	0.7	0.01	x	x	x	1000	39	89.04%
6		√	0.6	0.001	√	x	x	1000	108	90.38%
7		√	0.6	0.001	√	√	x	1000	732	96.81%
8		√	0.6	0.001	√	√	x	3000	1418	97.98%
9		√	0.6	0.001	√	√	√	4000	3524	99.41%

Settlement of the Model (5) be done with using initial population generation techniques in feasible areas, chromosomes arrangement techniques and chromosomes extermination techniques in specific area. The Model (5) is implemented on the existing BRT service in Bogor, Indonesia. Recapitulation of the optimal solution search using genetic algorithms to 9 repetitions can be seen in Table 2. From the solution results,it shows that the fitness value that is obtained equals with the objective functions values for every repetition. Based on Formula (7), it means that the entire solution produced by the genetic algorithm is a feasible solution.

Table 2. Optimal Solutions Search Repetition Results

Repetition	Variable																		Best Position	Fitness Value	Objective Value	Condition	Accuracy
	X_{111}	X_{112}	X_{113}	X_{114}	X_{115}	X_{121}	X_{122}	X_{123}	X_{124}	X_{131}	X_{132}	X_{133}	X_{134}	X_{211}	X_{212}	X_{311}	X_{312}	X_{313}					
verification	4	31	16	41	5	6	15	60	6	15	15	8	35	18	18	7	56	3			-73334054		
1	4	32	18	41	5	6	17	60	6	15	15	8	35	18	18	7	50	3	5186	-74029219	-74029219	feasible	99.05%
2	4	31	16	43	6	6	15	60	6	15	15	8	35	18	18	7	50	3	4560	-73489285	-73489285	feasible	99.79%
3	4	32	16	44	5	7	17	60	6	15	15	8	35	18	18	7	48	3	5645	-74267919	-74267919	feasible	98.73%
4	4	32	17	41	5	7	15	60	6	15	15	8	35	18	18	7	52	3	4640	-73753009	-73753009	feasible	99.43%
5	5	31	16	41	5	8	16	61	7	15	15	8	35	18	18	7	53	3	5175	-74636165	-74636165	feasible	98.22%
6	4	34	16	42	5	6	17	60	6	15	15	8	35	18	18	7	48	3	5222	-73935336	-73935336	feasible	99.18%
7	4	31	16	41	5	6	15	60	6	15	15	8	35	18	18	7	56	3	5342	-73334054	-73334054	optimal	100.00%
8	4	31	16	42	5	8	15	60	6	15	15	8	35	18	18	7	53	3	5625	-73918832	-73918832	feasible	99.20%
9	4	32	16	44	5	8	17	60	6	15	15	8	35	18	18	7	48	3	5422	-74586206	-74586206	feasible	98.29%
																	Average		5201.89		-73994447		99.10%

The examination results of solution optimization show that genetics algorithm could find the optimum solution on the 7th repetition with the fitness values -73,334,054 on the 5,342 generation in accordance with Figure 2. Chromosome resulting from such solution is presented in the form of timetable as in the Table 3. Analysis result of towards the generated error shows that the solution which is produced by using genetic algorithm has the optimal value with the average of errors (0.009) or having the accuracy 99,10%. Total fitness value calculation performed in the genetic algorithm is $(50 \times 6000) \leq 2^{19}$ which is much smaller when compared with the search space for 2^l ($l =$ the chromosome length, in this case $l = 4340$). Efficiency of the genetic algorithm usage towards the search space reaches 99.99%.
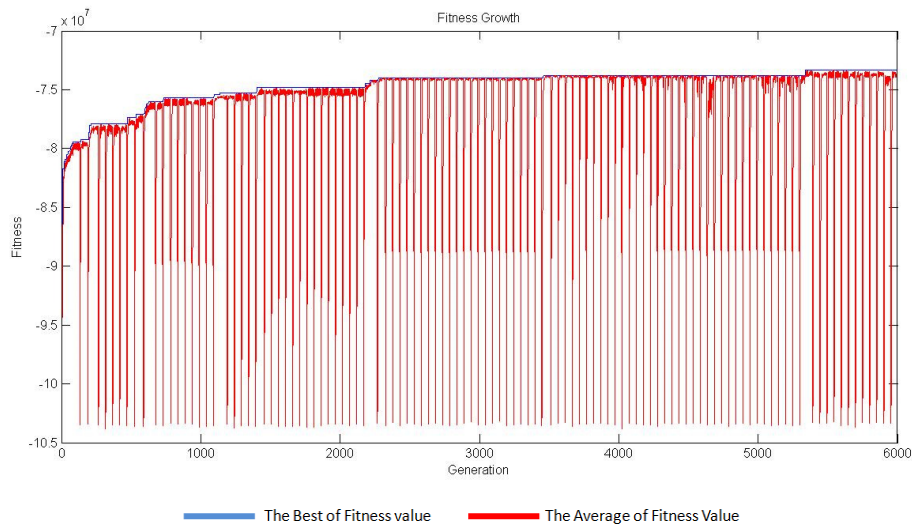
Figure 2. Fitness Values of Graphical Implemented Model (5)

Table 3. The Optimal *Timetable* on BRT service in Bogor, Indonesia.

Bubulak - Baranang Siang									
5.00	5.08	5.15	5.23	5.30	5.38	5.46	5.54	6.02	6.10
6.18	6.26	6.35	6.43	6.51	6.59	7.07	7.15	7.23	7.31
7.39	7.47	7.55	8.03	8.11	8.19	8.27	8.35	8.44	8.52
9.00	9.08	9.16	9.24	9.32	9.40	9.52	10.04	10.16	10.28
10.39	10.51	11.03	11.15	11.27	11.39	11.51	12.03	12.14	12.26
12.38	12.50	12.59	13.08	13.17	13.26	13.35	13.44	13.53	14.02
14.11	14.20	14.29	14.38	14.47	14.56	15.05	15.14	15.23	15.32
15.41	15.50	16.00	16.09	16.18	16.27	16.36	16.45	16.54	17.03
17.12	17.21	17.30	17.39	17.48	17.57	18.06	18.15	18.24	18.33
18.42	18.51	19.00	19.15	19.31	19.46	20.00	-	-	-

Baranang Siang - Bubulak									
5.31	5.39	5.46	5.54	6.14	6.22	6.30	6.38	6.46	6.54
7.02	7.10	7.19	7.27	7.35	7.43	7.51	7.59	8.07	8.15
8.23	8.31	8.39	8.47	8.55	9.03	9.11	9.19	9.28	9.36
9.44	9.52	10.00	10.08	10.16	10.22	10.34	10.46	10.58	11.10
11.21	11.33	11.45	11.57	12.09	12.21	12.33	12.45	12.56	13.08
13.20	13.40	13.49	13.58	14.07	14.16	14.25	14.34	14.43	14.52
15.01	15.10	15.19	15.28	15.37	15.46	15.55	16.04	16.13	16.22
16.31	16.40	16.50	16.59	17.08	17.17	17.26	17.35	17.44	17.53
18.02	18.11	18.20	18.29	18.38	18.47	18.56	19.05	19.14	19.23
19.32	19.41	19.50	20.05	20.21	20.36	20.50	-	-	-

Bubulak - Baranang Siang									
5.00	5.20	5.40	6.00	6.20	6.40	7.00	7.14	7.28	7.42
7.56	8.10	8.24	8.38	8.52	9.06	9.20	9.34	9.48	10.02
10.16	10.30	10.39	10.47	10.56	11.04	11.13	11.21	11.30	11.38
11.47	11.55	12.04	12.12	12.21	12.29	12.38	12.46	12.55	13.03
13.12	13.20	13.29	13.37	13.46	13.54	14.03	14.11	14.20	14.28
14.37	14.45	14.54	15.02	15.11	15.19	15.28	15.36	15.45	15.53
16.02	16.10	16.19	16.27	16.36	16.44	16.53	17.01	17.10	17.18
17.27	17.35	17.44	17.52	18.01	18.09	18.18	18.26	18.35	18.43
18.52	19.00	19.12	19.24	19.37	19.49	20.00	-	-	-

Baranang Siang - Bubulak									
5.35	5.55	6.15	6.35	6.55	7.15	7.40	7.54	8.08	8.22
8.36	8.50	9.04	9.18	9.32	9.46	10.00	10.14	10.28	10.42
10.56	11.20	11.29	11.37	11.46	11.54	12.03	12.11	12.20	12.28
12.37	12.45	12.54	13.02	13.11	13.19	13.28	13.36	13.45	13.53
14.02	14.10	14.19	14.27	14.36	14.44	14.53	15.01	15.10	15.18
15.27	15.35	15.44	15.52	16.01	16.09	16.18	16.26	16.35	16.43
16.52	17.00	17.09	17.17	17.26	17.34	17.43	17.51	18.00	18.08
18.17	18.25	18.34	18.42	18.51	18.59	19.08	19.16	19.25	19.32
19.36	19.41	19.53	20.05	20.18	20.30	20.41	-	-	-

Bubulak - Baranang Siang									
5.00	5.19	5.39	5.58	6.17	6.37	6.56	7.15	7.35	7.54
8.13	8.33	8.52	9.11	9.31	9.50	10.01	10.11	10.22	10.33
10.43	10.54	11.05	11.15	11.26	11.37	11.47	11.58	12.09	12.19
12.30	12.39	12.48	12.56	13.05	13.14	13.23	13.31	13.40	13.51
14.02	14.14	14.25	14.36	14.47	14.58	15.10	15.21	15.32	15.43
15.54	16.06	16.17	16.28	16.39	16.51	17.02	17.13	17.24	17.35
17.47	17.58	18.09	18.20	18.31	18.43	18.54	19.05	19.16	19.27
19.39	19.50	20.00	-	-	-	-	-	-	-

Baranang Siang - Bubulak									
5.40	5.59	6.19	6.38	6.57	7.17	7.36	7.55	8.15	8.34
8.53	9.13	9.32	9.51	10.11	10.34	10.45	10.55	11.06	11.17
11.27	11.38	11.49	11.59	12.10	12.21	12.31	12.42	12.53	13.03
13.17	13.26	13.35	13.43	13.52	14.01	14.10	14.18	14.28	14.39
14.50	15.02	15.13	15.24	15.35	15.46	15.58	16.09	16.20	16.31
16.42	16.54	17.05	17.16	17.27	17.39	17.50	18.01	18.12	18.23
18.35	18.46	18.57	19.08	19.19	19.31	19.42	19.53	20.04	20.15
20.27	20.38	20.48	-	-	-	-	-	-	-

Baranang Siang - Ciawi									
6.00	6.20	6.40	7.00	7.20	7.40	8.00	8.20	8.40	9.00
9.20	9.40	10.00	10.20	10.40	11.00	11.20	11.40	12.00	12.21
12.42	13.04	13.25	13.46	14.07	14.29	14.50	15.11	15.32	15.54
16.15	16.36	16.57	17.19	17.40	18.00	-	-	-	-

Ciawi - Baranang Siang									
6.36	6.56	7.16	7.36	7.56	8.16	8.36	8.56	9.16	9.36
9.56	10.16	10.36	10.56	11.16	11.36	11.56	12.16	12.52	13.13
13.34	13.56	14.17	14.38	14.59	15.21	15.42	16.03	16.24	16.46
17.07	17.28	17.49	18.11	18.32	18.52	-	-	-	-

Baranang Siang - Sentul City (Bellanova)									
5.45	6.04	6.24	6.43	7.02	7.21	7.41	8.00	8.13	8.26
8.39	8.51	9.04	9.17	9.30	9.43	9.56	10.09	10.21	10.34
10.47	11.00	11.13	11.26	11.39	11.51	12.04	12.17	12.30	12.43
12.56	13.09	13.21	13.34	13.47	14.00	14.13	14.26	14.39	14.51
15.04	15.17	15.30	15.43	15.56	16.09	16.21	16.34	16.47	17.00
17.13	17.26	17.39	17.51	18.04	18.17	18.30	18.43	18.56	19.09
19.21	19.34	19.47	20.00	20.31	21.00	-	-	-	-

Sentul City (Bellanova) - Baranang Siang									
6.02	6.21	6.41	7.00	7.19	7.38	7.58	8.18	8.31	8.44
8.57	9.09	9.22	9.35	9.48	10.01	10.14	10.27	10.39	10.52
11.05	11.18	11.31	11.44	11.57	12.09	12.22	12.35	12.48	13.01
13.14	13.27	13.39	13.52	14.05	14.18	14.31	14.44	14.57	15.09
15.22	15.35	15.48	16.01	16.14	16.27	16.39	16.52	17.05	17.18
17.31	17.44	17.57	18.09	18.22	18.35	18.48	19.01	19.14	19.27
19.39	19.52	20.05	20.16	20.47	21.16	-	-	-	-

4. Conclusion

This research has successfully developed a model of optimal timetable by using a genetic algorithm. Model is prepared using timetable variation data, route, partition/time division, number of passengers, number of fleets, capacity of the bus, departure time, travel time, headway, load factor, employees working hours, bus revenues and bus operating costs. Solutions with using genetic algorithm is done by representing the chromosomes as the time in timetable. Searching for the optimal solution is done by using several operators in the genetic algorithm, such as selection, mutation, crossover and elitism. Several techniques are added to enhance the fitness value, such as initial population generation techniques in the feasible area, regular chromosome arrangement techniques and chromosomes extermination techniques in a particular generation. The output generated from the genetic algorithm is the timetable with optimum number of trips. It is shown that the developed model has an accuracy of 99.10% in terms of proximity to the optimal solution. The efficiency of genetic algorithms usage for this problem reaches 99.99%. Research related to the preparation of optimal timetable can be developed further by developing an application that starts from the stage of the evaluation, optimization of the number of trips, preparation of optimal timetable, optimization of the employee number, optimization of the number of buses, and the preparation of schedules and bus driver. In addition, the model can be improved by taking into account the distribution of passengers as well as its implementation for the other bus rapid transit. For the model with genetic algorithm, it can be improved by adding a regularity constraint in calculating the value of the fitness function. Examination of chromosomes regularity can be done by calculating the deviation of the distance of a gene (with value 1) with another gene (with value 1) in a partition. In addition, it is also necessary to repair or add another technique, so genetic algorithm able to find the optimal solution in each repetition.

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