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Artificial Immune System for Optimizing Public Bus Transportation Route During Peak and Off-Peak Hour

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ABSTRACT

The increasing private car ownership has led to an overwhelming amount of vehicles on the road and has resulted in bad traffic conditions. The most effective way to reduce the number of vehicles on the road is to increase the use of public transport such as the bus. However, public trusts towards public transport have mostly been diminished due to poor punctuality and efficiency of the public transports to reach their destinations on time. There are several artificial intelligence approaches that have been proposed in the past by other researchers using optimization techniques such as Genetic Algorithm, Ant Colony Optimization, and Artificial Immune System to increase the efficiency of the public transportation route. In this study, we propose an efficient artificial intelligence approach to come out with an efficient transportation route. The Artificial Immune System (AIS) approach is chosen due to its adaptive and efficient characteristics which have been demonstrated in many problem domains, including transportation route optimization problems. Although there are few literatures available that focus on using AIS as a routing optimization technique, the results obtained from their studies have demonstrated that AIS is able to achieve better results than other methods. The algorithm will be tested with the Traveling Salesman Problem (TSP) benchmark dataset to validate its quality versus existing techniques. Moreover, the proposed AIS is conducted on a real case study of public bus transportation routes during peak and off-peak hour in Penang, Malaysia. The result of this study is expected to contribute towards the improvement of public bus transportation efficiency which would, in turn, encourage public usage as well as reduce the amount of vehicles on the road, thus minimizing bad traffic.

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INTRODUCTION

Increasing the private car ownership in Penang, Malaysia over the past 10 years, has caused traffic congestion since the roads that were built years ago can no longer cater to the amount of vehicles on the road. The utilization of public transport is the most effective way to overcome the congestion caused by the trend of the increasing vehicles on the road compared to increasing the road capacity due to the space limitation on the island. However, most people prefer to take their own vehicles compared to public transportation. In a study, it was found that the main factor that caused people to choose private vehicles over public bus transport was due to its reliability and traveling time (Kamba *et al.* 2007). As the number of motor vehicles on the road grows with the increasing population within the country, it is observed that Penang is no exception to the phenomenon. There are 1,551,650 registered motor vehicles in Penang, averaging to about 1.06 cars per person for a population that totals to 1,468,800. The registration rate of motor vehicles in the state is increasing at an average of 9.5% a year compared to the increase of 7.2% for the country. A survey conducted by the Japan International Cooperation Agency (JICA) shows that the main transportation problems are traffic congestion due to the rapid increase of car ownership, high accident rate and lack of parking spaces (Madhoun *et al.* 2008). Thus, the need to encourage the public to accept public transportation relies on the efficiency of the public transport itself.

According to the feedback from the questionnaire distributed to both private and public transport users, the respondents' greatest factor that encourages the use of private cars is travel time (44.1%), the high traffic congestion and the delay imposed when using public transport (36.6%), and likely factors to switch from public transport to privately owned vehicles is the ability to arrive on time (37.2%). It is clear that punctuality and traveling time play an important role in determining the mode of transport (Kamba *et al.* 2007). Therefore, to

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achieve desirable punctuality and travelling time, an efficient route optimization technique for public transportation, such as the bus, is required.

The public bus transportation route optimization is the ordering of visits (stops) the bus requires in order to achieve the most efficient route and uses the least amount of travelling time. Optimizing the bus transportation routes will help to improve their overall reliability and travelling time, thus enabling the bus to be punctual and on-time as well as encourages public usage.

The objective of this paper is to propose the optimization of public bus transportation route using Artificial Immune System (AIS). For years, AIS has been adopted by many researchers, mainly performed by imitating the natural immune system to take advantage of the fairly new concept in real world application (Zheng *et al.* 2010). AIS is an adaptive system, inspired by theoretical immunology and observes immune functions, principles and models, which explore, derive and apply distinct biologically inspired immune mechanisms to solve the real world problem (Darmoul *et al.* 2006). In addition, AIS has also shown to be able to solve constrained global optimization problems (Cruz-Cortés *et al.* 2005), which is particularly important for route optimization problem. The AIS area has shown continuous evolution of methods to solve optimization problems, as well as to tackle other complex computational problems showing an improvement in performance in the overall result. Thus, the potentials demonstrated by the performance of AIS have motivated its adoption for optimizing the public bus transportation route.

The remainder of this paper is organized as follows: the problem background section discusses previous studies conducted in the same problem domain. The problem description section elaborates the scopes and assumptions imposed within the domain of the problem under consideration. The following section emphasizes the proposed approach specific to the problem in consideration. In the next section, the optimization results are obtained and the analysis highlighted. Finally, the last section will conclude the paper.

Problem Background:

The transportation network problem can be divided into two main components: 1) the transportation routing problem and 2) the transportation scheduling problem (Chakroborty 2003). Generally, the public bus transportation routing problem is included in the former, which is based on the currently available road network with pre-determined bus stops. This scenario is similar to the well-known traveling salesman problem (TSP) which is widely used to illustrate and study the bus transportation route optimization problem. On the other hand, the latter involves assigning suitable schedules for the buses. These two components are fundamental in representing the real world situation in the transportation network problem. In practice, these two components are usually implemented sequentially (or iteratively), with the routes determined in advance of the schedules. A well designed route will not only be able to operating economically but will be able to provide a reasonable service to the passengers using the public transport (Lampkin and Saalmans 1967). Therefore, the need for an efficient route design is essential for the transportation network advancement.

The route design is part of the public bus network design which contributes an important part in the public transportation operational planning process. Thus, it is no surprise that the transportation route design, also known as the transit route network design problem (TRNDP), has been drawing quite some attention since the late 1960s. The optimal design of the bus route was first discussed in 1979, where the relevant findings is analyzed to identify the significant features of the TRNDP as demand characteristics, objective functions, constraints, passenger behavior, solution techniques, and computational time for solving the problem (Kepaptsoglou and Karlaftis 2009). Generally, the transportation route problem is similar to the classical traveling salesman problem (TSP) whereby each of the bus stops needs to be visited once before the bus returns to its original stop. However, there are several variants of the TRNDP. Some of the more common variants are the vehicle routing problem with backhauls (VRPB), vehicle routing problem with time windows (VRPTW), time-dependent vehicle routing problem (TDVRP), and pick-up and delivery problem (PDP) (Potvin 2009). In this paper, the focus will be on the TDVRP since time of the day will affect the determination of optimized public bus transportation route.

The optimization of the public bus transportation route has been one of the important factors affecting the efficiency of the overall transportation route design. There are several researches on the natural immune system which harvest the advantage of the adaptive nature of the system to be used to solve various real world problems (Zheng *et al.* 2010). The AIS area has shown its potential to be used in other complex problems with its evolution property which has improved performance.

AIS has been adapted into various transportation routing problems from public transports such as school buses to the delivery of agri-fresh products. For instance, the AIS approach has been adopted to solve the delivery of agri-fresh products, which is a vehicle routing problem with time windows (VRPTW) (Shukla and Jharkharia 2013). An experiment was carried out with the algorithm based on the real-life instances extracted from the Azadpur wholesale market in New Delhi, India. The result was then compared to other optimization algorithms such as the genetic algorithm (GA) and simulated annealing (SA) by performing some tests. It was discovered that AIS performed better in terms of quality and rate of convergence compared to the other

approaches (Shukla and Jharkharia 2013). Considering its performance potential in the application of other domains, AIS is chosen to optimize the public bus transportation routing problem.

Problem Description:

In TDVRP, the solution is based on the time of the day. In this case, time is categorized as either peak or off-peak hours as this plays an important role to determine the different conditions of the traffic at different times of the day. A different route may be faster to reach the same destination although the distance may seem further. This is due to the amount of vehicles on that particular road on that time of the day or even due to the number of traffic lights along the way.

AIS will efficiently optimize the order of bus stops assigned to a particular bus. However, the start and end destination are fixed. The scope of the study is listed below:

- i. This study focuses on improving the transportation route efficiency in terms of the traveling time needed since it is the main reason people dislike taking the public bus.
- ii. The algorithm determines the order of the bus stops to be visited in the most efficient manner to suit the passenger but does not relocate, add or dismiss a bus stop entirely.
- iii. The research is carried out based on the data collected during peak and off-peak hours for the bus routes that travel to the working area where the congestion occurs.
- iv. The research is carried out based on the data collected from public buses, namely the Rapid Penang bus, which is based in Penang Island, Malaysia.

The problem is subjected to the following assumptions:

- It is assumed that the same bus route will only pass through the same bus stop once.
- The peak hours are defined as 6.30am-9.30am and 5.00pm-8.30pm while the other times are off-peak hours.
- The stopping time to pickup/drop off passengers at each bus stop is disregarded as it usually takes less than a minute.
- The starting and ending bus stops of the route are fixed.
- The bus stops that are more than 5km from each other are considered too far apart to be efficient and thus, are disregarded.

Proposed Artificial Immune System Algorithm For Optimizing The Public Bus Transportation Route:

Natural Immune System Metaphor:

The Artificial Immune System is inspired by the human natural immune system. The natural immune system is the body's defense system against harmful foreign substances. The foreign substance, or the stimuli known as the antigen (such as bacteria, viruses, or infected cells) within the immune system, is detected by the antibodies which will then adapt and destroy them in response. Similarly in the TDVRP domain, the optimized route (antibody) responds to the traveling time between bus stops depending on the time of the day (stimuli).

AIS is naturally used in pattern recognition, fault detection, diagnosis, and a number of other fields, including optimization of the transportation routing problem (Keko *et al.* 2003). Recently, there has been an increasing trend in adapting the concept behind the natural immune mechanism to solve optimization problems (Timmis *et al.* 2003). AIS is an evolutionary bio-inspired algorithm, which means that it is inspired by nature and evolves to adapt to the problem.

The natural immune system only responds to antigens by identifying them when the affinity threshold is exceeded. The natural immune system also uses the affinity measure to determine if the encounter has reoccurred in order to respond either with the previous response or to adapt and change to a response which is more effective in order to eliminate the antigens. In the case of TDVRP, affinity is used to determine the quality of the solution route generated. With the affinity measure, AIS is able to measure the quality of the solution and hence, continuously improve the solution until either the best solution is obtained or the stop criterion is reached.

Solution Representation Scheme and Population Initialization:

Since the AIS algorithm is inspired by the natural immune system of the human body, the elements in the natural immune system are bound to be mapped and represented to tailor to the specific problem of TDVRP. The following describes the mapping of the elements onto AIS in the public bus transportation route domain:

- **Antigen:** Travelling time between bus stops.
- **Antibody:** Solution route.
- **Affinity:** Total travelling time.

In order to generate a feasible route that adheres to the constraints imposed by the public bus transportation route; the first population solution is generated randomly. The first and last stops are fixed while other stop orders are generated randomly according to the bus stops that the bus needs to visit. Algorithm parameters such as the population size, clonal selection percentage and the generation number are initialized. The definitions of the terms used in the context of this study are as follows:

- **Population Size:** The number of solutions within each generation.
- **Clonal Selection Percentage:** The percentage of the population size that will undergo further AIS processing.
- **Generation Number:** The number of cycles of the overall AIS process before it ends.

Mutation (Improvisation Process):

Mutation is conducted to improve the route solution generated. The AIS proposed will use a simple swapping mechanism to mutate the antibody, or swap the stops of the solution route. The number of mutations that happen depends on the clonal selection percentage determined in the initialization stage. The AIS will sort the generated solutions in ascending order and mutate them according to the clonal selection percentage to generate the next generation of solutions. An example of the simple swapping mechanism is shown in Fig. 1. The bus stops needed to be visited are represented with numbers in the figure and are then swapped to generate a new order of bus stops that gives the new solution route.

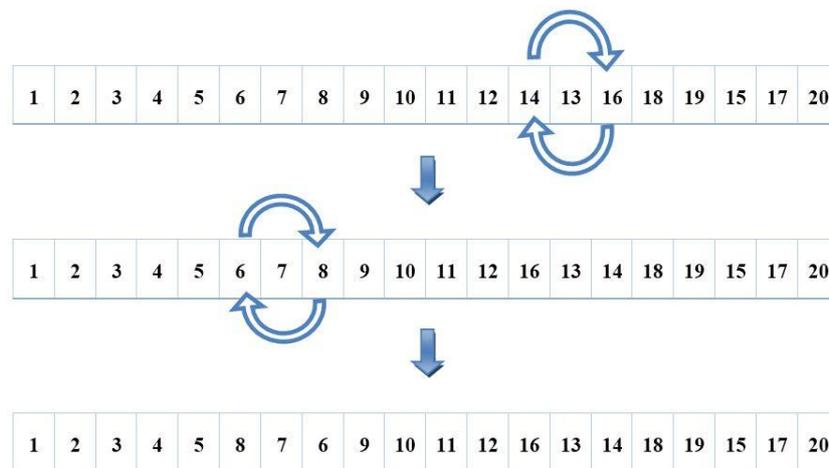


Fig. 1: Illustration of the simple swapping mechanism.

Artificial Immune System Algorithm Implementation:

AIS first needs to be initialized with the population size, clonal selection percentage and generation number. It then randomly generates the first generation of feasible solutions. After making sure that the stopping criteria is not reached, it evaluates the affinity or quality of each of the solutions before sorting it in ascending order. The clonal selection percentage determines the number of solutions with the worst affinity to be mutated. The remaining better solutions, together with the improved mutated solutions, will be used as the initial population for the next generation. This process is repeated until the generation number or the stop criterion is reached. The flowchart of AIS is shown in Fig. 2.

Computational Result and Discussion:

Experimental Setups:

The objective of this study is to optimize the public bus transportation routes by minimizing the traveling time of the routes and satisfying the time constraint which is dependent on whether it is peak or off-peak hours. The proposed AIS is run 10 times independently with the parameters setup as shown in Table 1.

Table 1: Control parameters of the proposed AIS.

Control Parameters	Options			
Clonal Selection	0.25	0.45	0.65	0.75
Population Numbers	400	600	800	1000
Generation Numbers	500			

In Experiment 1, the proposed AIS is first tested with the public data of the Traveling Salesman Problem which is used by many literatures to test the performance of their optimization algorithms. The data used is the br17 from the TSPLIB (Reinelt 1991), which contains an asymmetric Traveling Salesman Problem with 17 cities with different distance instances for the different directions between cities. The asymmetric Traveling Salesman Problem is chosen to test the quality of the algorithm as it is similar to the actual data of the domain problem that we intend to apply as per the work in (Keko *et al.* 2003). The main objective of this experiment is to make sure that the proposed AIS is comparable with other optimization algorithms.

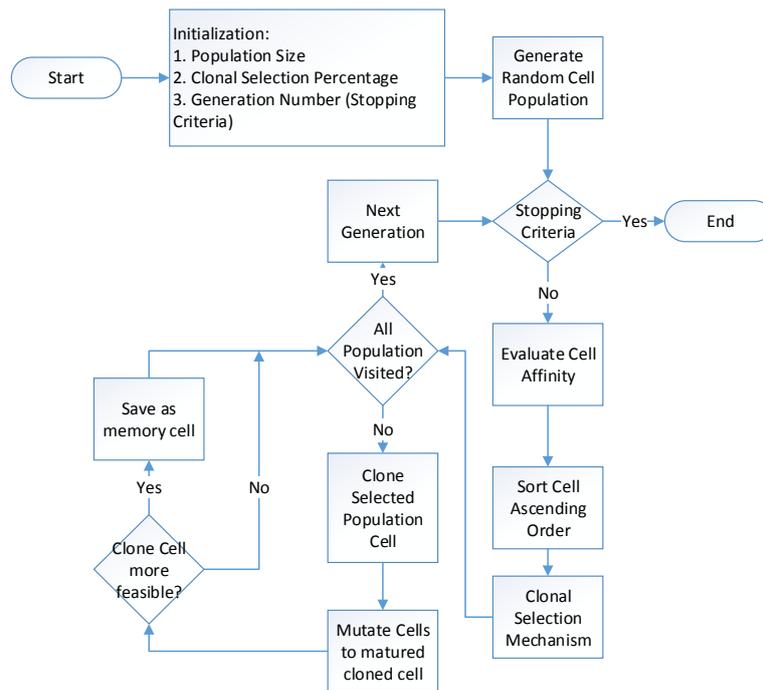


Fig. 2: Overall flowchart of AIS.

In experiment 2, the second set of data is obtained from the actual traveling time between the bus stops based on the Rapid Penang bus route 301. The current route and the bus stops used in this experiment are numbered in Table 2. For the experiments in this paper, route 301 from Lebu Relau to Pengkalan Weld during peak and off-peak hours will be used for comparison. The route consists of 20 bus stops along the blue line with different traveling times for peak and off-peak hours for the same path. The traveling time between two bus stops in the opposite direction is different due to some of the one-way road that connects the bus stops (Stop No. 13 to Stop No. 20), while others are the same in both directions (Stop No. 1 to Stop No. 12). This experiment aims to test the proposed AIS with the actual data of the public bus transportation route problem. The summary of the experiment setup is shown in Table 3.

Table 2: Rapid Penang bus route 301.

Original Rapid Penang Route 301			
Stop No.	Stop Name	Stop No.	Stop Name
1	Lebu Relau	11	Jalan Penang (Komtar)
2	Jalan Dato. Ismail Hashim	12	Jalan Dr. Lim Chwee Leong
3	Jalan Tun Dr. Awang	13	Lebu Carnavon
4	Jalan Sultan Azlan Shah	14	Kampung Kolam
5	Jalan Sungai Dua USM	15	Jalan Masjid Kapitan Keling
6	Jalan Gelugor	16	Lebu Chulia
7	Jalan Jelutong	17	Gat Lebu Chulia (Little India)
8	Jalan Sungai Pinang	18	Jalan Pengkalan Weld
9	Jalan Patani	19	Perkarangan King Edwards
10	Jalan Dato Keramat	20	Pengkalan Weld (Jetty)

Table 3: Experimental setups summary.

Experiments	1	2
Aim	To justify the quality of the solution produced by AIS algorithm is up to standard	To justify the quality of the solution produced by AIS algorithm for public transportation route optimization
Dataset	<ul style="list-style-type: none"> The br17 dataset from TSPLIB Total number of bus stops: 17 	<ul style="list-style-type: none"> Travel time of Rapid Penang bus route 301, in peak and no-peak hours Total number of bus stops: 20
Result Observation	The best travel time in the 10 runs compared to best route of br17	The best travel time in the 10 runs compared to current route 301 used by Rapid Penang

Analysis of the Result:

The best known route of the br17 data that is done by an exhaustive search gives the optimum traveling time of 34 units of time. Based on the results obtained in Experiment 1, the best travel time obtained is 34,

which is also comparable to other algorithms in the literatures (Ahmed 2010; Liu *et al.* 2008). As shown in Fig. 4, the proposed AIS is able to achieve the best route with the dataset from the TSPLIB with the clonal selection of 0.45 and population size of 800, while the best average travel time is demonstrated by the clonal selection of 0.75 and population size of 600. Regardless of the results obtained, it is clear that the AIS algorithm is able to obtain optimum results using the br17 data of the TSPLIB, which is used as the benchmark data for many optimization algorithms to test their results within other domain problems.

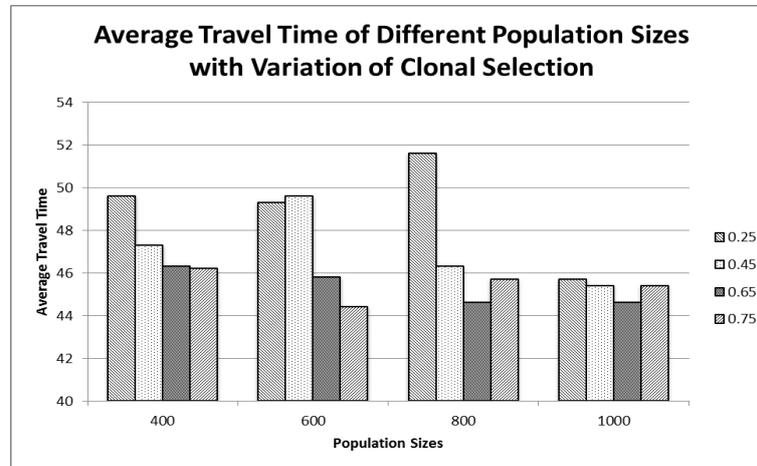


Fig. 3: Results of experiment 1.

The results of Experiment 2, obtained by the proposed AIS tested on the input from the real data from public bus transportation, i.e. the travel time between all the bus stops of the original bus route 301, is compared with the time for the new route suggested by AIS. Currently, the Rapid Penang bus follows the same route regardless of whether it is at peak hours or off-peak hours. However, the time needed to complete the route is different during peak and off-peak hours as there are factors (such as traffic condition during rush hour) affecting the travel time along the route at different times of the day.

The original route 301 used by the Rapid Penang bus takes 78 minutes to visit all of the bus stops in the current order during peak hours. The best AIS generated route takes only 61 minutes at peak hours, a reduction of 17 minutes using the clonal selection of 0.45 and the population size of 1000. The best average travel time is 68.1 minutes using the clonal selection of 0.75 and the population size of 1000. As shown in Fig. 5, even the worst and average times generated from every run is within 75 minutes, which is still better than the previous route used by the Rapid Penang bus.

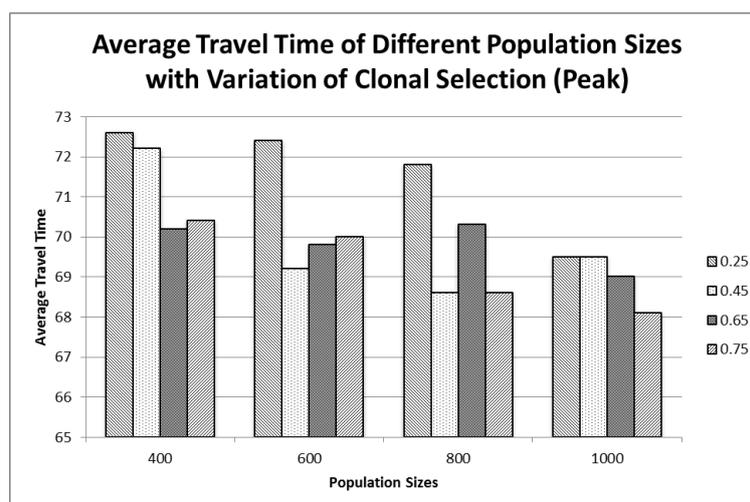


Fig. 4: Results of experiment 2 (Peak time).

Using the same route 301, the time needed for the bus to visit all the bus stops is 67 minutes during off-peak hours. The best time generated by AIS is 60 minutes for the bus to visit all the bus stops during off-peak hours using the clonal selection of 0.65 and the population size of 800, whereas the best travel time is 62.7 minutes

using the clonal selection of 0.65 and the population size of 600. This shows an improvement of 7 minutes compared to the current route. The solution with the longest time to travel the route generated by AIS is within 70 minutes, which still shows an improvement of 3 minutes compared to the original route. This indicates that even the worst result generated is still feasible and able to improve the original route 301 of the Rapid Penang bus.

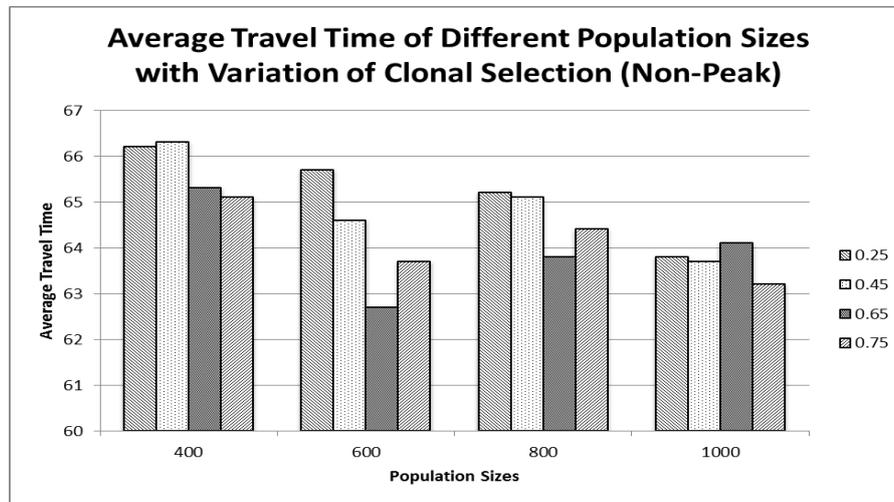


Fig. 5: Results of experiment 2 (Off-peak time).

In summary, Table 4 shows the improvement in the travel time needed to visit all the required bus stops, especially in the case of peak hours, using AIS-generated routes compared to the original route 301 of the Rapid Penang bus.

Table 4: Travel time comparison of route 301 and AIS-generated route.

	Route 301 (min)	Best AIS-generated route (min)	Best AIS generated route	Improvement (%)
Peak Hour	73	61	1-2-3-4-5-6-7-8-9-10-11-12-14-13-16-18-19-15-17-20	21.79
Off-Peak Hour	67	60	1-2-3-4-5-6-7-8-9-10-11-12-14-19-16-15-13-17-18-20	10.45

Conclusion:

In conclusion, this paper proposed the AIS approach to solve the optimization problem in public bus transportation route. The parameters and techniques of the AIS are presented together with its comparison with the standard TSPLIB and actual data of route 301 of Rapid Penang bus. The best result generated by the proposed AIS has shown potential of solving the problem in public bus transportation route optimization and also complex real world problems. However, further improvement is needed by considering other affecting factors other than the time factor defined as peak and off-peak hours. In addition, the solution should cover many other factors that also contribute to the delay or change in travel time to reach a certain destination such as revisiting, dynamic origins and destinations, among others. Future work encompasses factors that might also influence the outcome of the best route, such as the route distances, the capacity, and travel costs to make the generated solution more comprehensive.

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