Optimizing University Shuttle Buses to Reduce Students' Waiting Time Using a Discrete Event Simulation Technique

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***Abstract*— Shuttle buses replacing private transports have long been used to reduce traffic congestion in a university campus. However, to estimate the optimal number of buses taking into account human behaviour using a manual method to provide a better service is very difficult. This is especially true when the shuttle buses have multiple routes and are significantly affected by unpredictable human behaviour such as their stochastic arrival at the available bus stops. This paper thus employs modelling and simulation methodologies specifically a Discrete Event Simulation (DES) technique to observe the effects of various configuration of bus number to student waiting time. For this, a DES model for bus transportation in a university using various available modules in Arena software was first developed. The simulation model was then fed with relevant data; e.g., the total number of students having classes at certain time periods, the current allocation of the buses for each bus stop, etc. The model was later used as a test bed for various configurations and analysis of the number of buses and their effects on students' waiting time including their optimal number. The simulation results show that the current number of used buses can be reduced to its optimal number while maintaining student waiting time. This simulation model employs a new approach of using a "transport" module to transport a huge amount of entities to multiple stations as opposed to its traditional usage to only transport a single entity to a particular station.**

Keywords*— *Discrete Event Simulation, Shuttle Bus, Waiting Time, University, Transportation

1. Introduction

Providing an adequate and appropriate transportation service is one of the common challenges encountered in almost every city in the world [1]. This includes universities; i.e., places for tertiary education. In most universities in Malaysia especially its public universities, the distance between one place to another place is relatively far. To commute between these locations, transportation is a must. Allowing students to bring their own transports will significantly cause traffic congestion in the universities and create the problem of parking spaces. To cater this problem, the management of the universities typically provides shuttle buses for the students. A shuttle bus service has been seen as a better alternative since it can transport a large number of students from location to location at a time. The main locations are residential halls and lecture halls.

In a public university in the northern area of Malaysia, the residential halls are divided into four clusters. To transport the students from the residential halls to lecture halls, shuttle buses have been used. Shuttle buses are routed from the residential halls based on relevant routes named as Route A, Route B, Route C and Route D. The lecture halls are meanwhile named as DKG 2 (which transport the students from the residential halls to DKG 1, 2, 3), DKG 4, DKG 5, DKG 6 and DKG 7. All of these routes have their own paths connecting the respectively assigned residential halls and lecture halls. The shuttle buses begin their operation as early as 7.30 am and end at 12.00 am. Each route has its own number of residential halls. Route A and B shares the same pathways.

This paper is an extended version of Zulkepli et al. [2] whereby the problem and system definition, conceptual model formulation and data collection were discussed thoroughly. These are the crucial steps involved in the modelling process of a real-life system using a Discrete Event Simulation (DES) approach. This paper continues the remaining steps of DES in optimizing the total number of buses for route A and B needed at the peak hour of the bus operation, which is from 8:00 to 8:30 am. The main reason why these two routes were chosen is that both routes share the same route from the residential halls to the lecture halls and have multiple residential halls and bus stops, making the system complicated. This complication has made our study interesting

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especially in determining the optimal number of buses that should be allocated at each residential hall during the peak hour in order to ease traffic movement and ensure the students' waiting time and queue length are in a tolerable limit.

2. Problem Statement

The buses move from the terminal to the assigned residential halls around 7.30 am. As the time approaches 8.00 am, the problem then arises. At this time, the number of students increases tremendously which significantly increases their queue length. During this period of time, the bus drivers who have completed their assigned routes have to decide to either take the students at the bus stops along their routes or to directly go to the bus stops that they have been assigned. There are two cases to be considered.

The first case is that the assigned bus stops could have many students in queue and if they are ignored, then their waiting time and length in queue at the bus stops will increase. The second case is that the assigned bus stops could have short queues or the waiting students are being handled by other buses and there have been many waiting students at other bus stops which have not been handled by any buses, then the waiting time and length in queue at the bus stops will increase. The times for students to wait for a bus and time taken for the bus to complete the assigned routine routes should be considered to ensure that the simulation system really replicates the real system. In our model, the bus speed is assumed to be around 40 km/h. This assumption is based on the regulation of United States Federal Transit Administration (FTA) [3] mentioning that buses travel on average at only around 60 percent of the speeds of other automobiles and other private vehicles using the same streets due to the cumulative effects of traffic congestion, traffic signals, and passenger boarding.

Long waiting time will cause dissatisfaction among the students. Requests have been made to the top management to provide more buses or better bus drivers' schedules to help improve the service. On the contrary, cutting down the number of buses will worsen the current system as the buses will be overcrowded and this leads to safety issue among students.

3. Literature Review

When dealing with a transportation problem, most researchers opt to use operational research approaches especially linear programming, optimization, computer simulation or hybrid techniques where operations research is combined with computer simulation. Such problems using linear programming are to determine the shortest route through a network to minimize the total distance travelled [4]-[5]. This technique involves Vogel's approximation method (VAM), the modified distribution method (MODI), the stepping-stone method (SSM), northwest corner method, and least cost method whose solution is capable of minimizing the costs reflecting the transportation optimization. Hlayel and Alia [5] formulated a transportation optimization problem for solving the linear programming using a technique called 'The Best Candidates Method'. The objective of the method was to minimize the total weight of the costs by adding a dummy row to make supply equal to the demand. Hence, the transportation costs in this row was assigned to zero during the calculation. In addition, the optimal solution or the closest to the optimal solution could also be obtained.

Planning of transits can be divided into two types depending on their time taken. The first one is called operational planning for the short term and the other one is for the medium-to-long term called strategic planning. Jaramillo-Alvarez, Gonzalez-Calderon and Gonzalez-Calderon [6] argued that the design of bus routes, frequencies and scheduling of the vehicles are short-term problems. This technique is usually solved using an operation research method since it allows us to integrate a large number of mathematical tools including optimization and simulation to model various complex problems of transport planning to support decision making. Cotfas and Diosteanu [7] utilized hybrid genetic algorithm based on heuristics techniques to improve the time required for generating a solution by determining the best route from the stations closer to the user`s location. The algorithm used two heuristics techniques considering the number of transfers with the remaining distance to the destination station in order to improve the convergence speed. The interface of the system used web technologies to offer both portability and advanced functionality during the solution development.

The computer simulation technique can also help in reducing transportation problems. Such problems using the computer simulation were the problems dealing with how to transport items with the minimum cost [8]-[9]. Zhang and Ren [8] used a DES technique to optimize the routes of buses so that the buses can use alternative routes with low congestion. The result showed that using the alternative routes with low congestion segments minimizes the bus delay and also improve in the continuity of the bus transportation system. In addition, the optimized bus route can also provide stability and continuity which can satisfy the customer`s need by decreasing the waiting time and waiting line. Additional buses would only be provided at the busy bus stops. Güler [9] studied how to improve the management of a train system and equipment in order to assure comfortable, economical, and safe transportation for people of

Izmir using Arena software. Based on the output, the energy cost of operating the train can be reduced by decreasing the number of coaches. However, this would increase the waiting in queue and cause coaches to be more crowded which eventually make the customer feel uncomfortable with the services. This research successfully determined the optimal number of coaches and trips to reduce waiting queue and increase satisfaction among customers.

3.2 Justification for Using a DES Technique

There are two types of computer simulation which have widely been used to solve real-life problems, i.e. System Dynamics which focuses more on a holistic view of a problem and DES which focuses more on individual entities moving through a series of processes and competing a limited number of resources in a system. Both techniques have their own advantages and drawbacks [10] in solving transportation problems. Since our considered transportation problem focuses on the individual effect of buses on students' waiting time at each available station, this paper employs a DES technique. Besides that, the changes of the number of buses assigned at each residential hall in every semester due to the changes in the students' schedules require appropriate techniques for the allocation process. Currently, the management team has not had any specific techniques to solve the transportation process which delay the implementation of a better system. Our proposed technique for allocating the buses is the simulation technique since:

a. Simulation only requires us to change parameter values in the module and rerun the simulation to get the solution while any additions or reductions of variables in other techniques require us to reformulate and recalculate the model to get its new solution.
b. Simulation only requires users to change parameters or structures of a model which needs little tasks while linear programming and genetic algorithm techniques require a specialist for obtaining the solution every time the variable is changed
c. Simulation's learning curve is easier compared to the other techniques
d. Simulation does not require specialists to do the hard coding to find another best solution compared to heuristic techniques which require specialists to perform iterative methods to search the other best solution

4. METHODOLOGY

Figure 1 depicts the steps involved in conducting the simulation study of a real-life system and analyzing its performance using a DES technique. It begins with the problem statement of the system and finishes with its implementation and documentation. These crucial steps were suggested by Maria [11] to help the modeler to design and develop a simulation model and to ensure that the model really mimics a considered system. In our case, ARENA software was used to ease the modelling process of the shuttle buses moving from station to station.

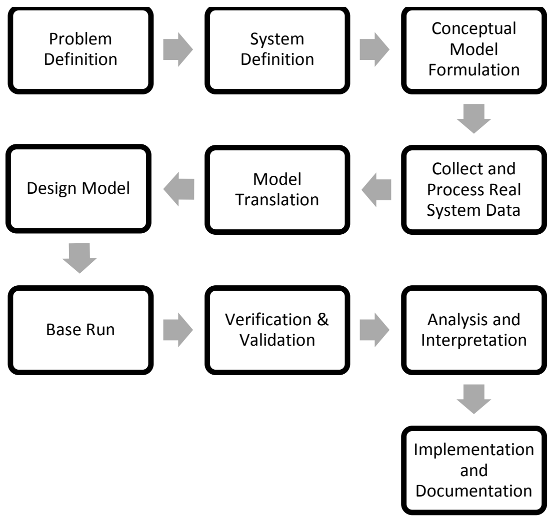

Figure 1: Steps Involved in Developing a Simulation Model and Performing Simulation Analysis. Adapted from Maria [11].

As shown in Figure 1, one of the crucial steps is collecting and processing real system data. For our bus shuttle problem, the data about the total number of students having classes at 8.30 am from various residential halls to their respective lecture halls were collected from the university's academic department. The information about the current setting of the allocation of the buses for each bus stop was meanwhile gained from the interview sessions conducted with the bus service provider. All of the collected data were then input into Arena Software. The details about the processes starting from the problem definition up to real system data collection and process have been explained thoroughly in [2]. The previous paper has also discussed the methodology used up to the model translation part.

4.1 Model Translation

To ease the management of the model, the "divide and conquer" concept has been used, where the model was divided into several sub-models. Figure 2 depicts a bus stop station where a "create" module is used to represent the arrival of students at each residential hall. To transport the students to other stations, a "transporter" module is used to transport a single student during the process. Thus, to include a single student into a group of students so that they can be transported in a group, a "batch" module is used. The students are therefore batched at their respective residential hall`s bus stop. A "decide" module is used to differentiate the requests from the students at the current bus stop to transport them to the other bus stops. On the other hand, the another "transporter" module named `transport bus` only transports other students from other bus stop to their assigned destinations

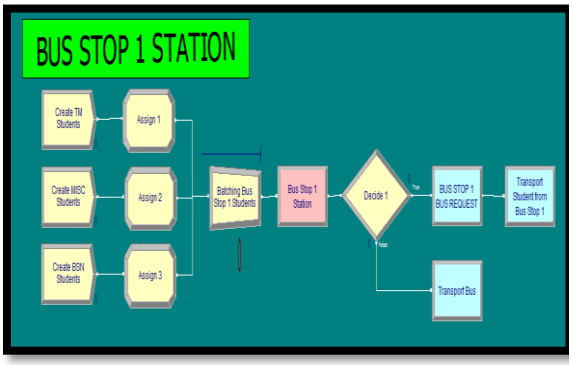

Figure 2. The Process of Creating and Batching the Entities and Handling their Requests

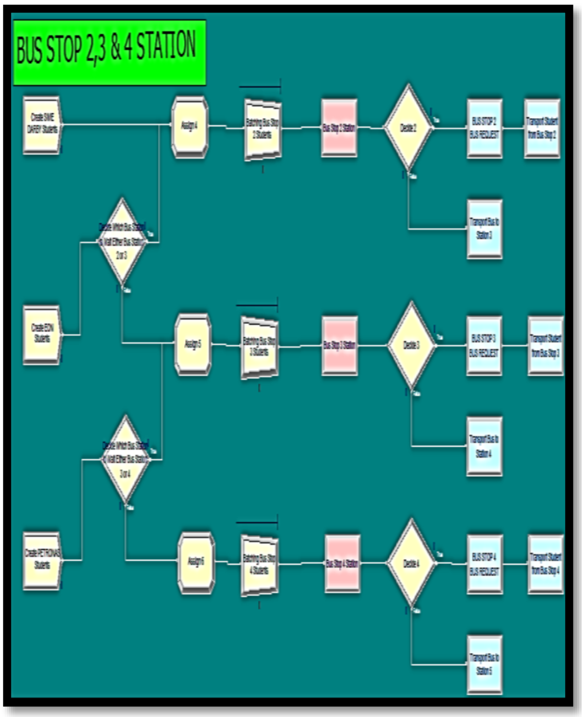

Figure 3. Process of Entity Deciding Which Stations to Wait the Bus and Its Flow

Bus stops 3 and 4 have "decide" modules after the "create" modules. Their main function is to distribute the students at the EON residential hall, Sime Darby residential hall and Petronas residential hall to the nearby bus stops where the distances between the three residential halls' bus stops are close to each other. Students tend to choose a bus stop closer to their rooms. The model is depicted in Figure 3.

The "free" module is used to free the requested transporter while the "separate" module is used to separate the batched students at the end of the process. This is the reason of using these two modules at the end of the process.

Route A and B have been modelled to drop students at DKG 5 and DKG 2. The process of dropping off students is the same at each bus stop. Figure 4 depicts that the bus being set in the "transport" module reaches its destination which is the DKG 5 bus stop. The "search" module is then used to search the students at the bus with drop destination at DKG 5. The "drop off" module is later used to set the students to leave the bus. As the student leaves the bus, the bus continues to move towards another bus stop.

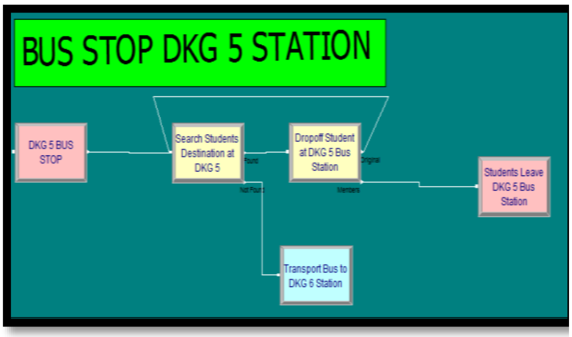

Figure 4. Process of Searching the Students Who Will Be Dropped Off at the DKG 5 Station

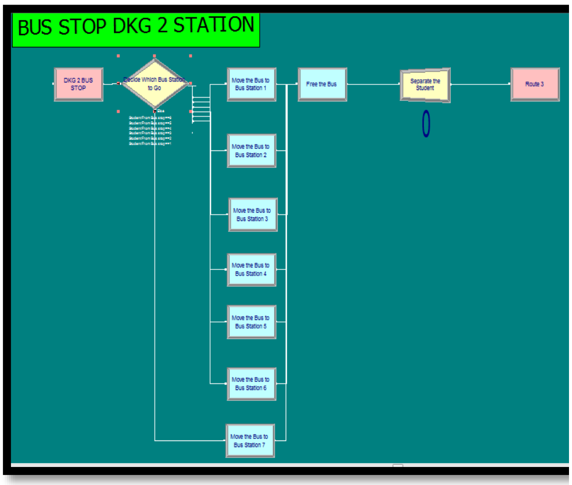

Figure 5. Process of Dropping Students at DKG 2 Station and Moving the Bus at the Assigned Station

As the bus arrives at the last bus stop which is the bus stop at DKG 2, the module is different than before as depicted in Figure 5 because buses moving freely do not need to go to any specific bus stop. These buses will return to the station and wait for the next request. The "move" module is used to execute the task of moving the free bus while the "decide" module is used to first find which bus stop they have taken the student before. As there is other assigned bus at the station that the free bus just visited before, then the free bus can go to any bus stop requested by students.

The logic is to make sure that the free bus returns to their original bus stop. If there are any requests from students and there are no specified bus at the current bus stop, the bus can take the requested students. On the other hand, if there are no requests from the students at that the bus stop, then the free bus can move to another bus stop which has demand from the students. The main function of the free bus is to support the specified bus transporting the students.

4.2 Model Design

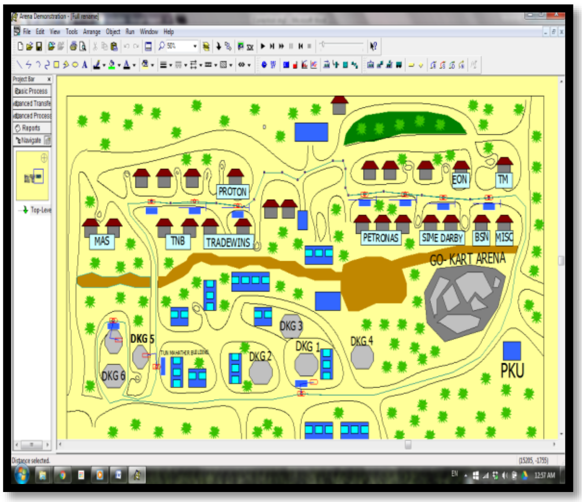

Figure 6. Model Representing the Real World Situation

Based on the conceptual model formulation and translation, the whole model was designed to represent the real system connecting all of the available bus stops. Figure 6 shows that all the bus stops along routes A and B are set and connected with specific distances as shown in Figure 7.

Stations

	Beginning Station	Ending Station	Distance
17	Station 1	Station 3	600
18	Station 1	Station 4	750
19	Station 1	Station 5	1450
20	Station 1	Station 6	1650
21	Station 1	Station 7	1800
22	Station 2	Station 4	450
23	Station 2	Station 5	1150
24	Station 2	Station 6	1350
25	Station 2	Station 7	1500
26	Station 3	Station 5	850
27	Station 3	Station 6	1050
28	Station 3	Station 7	1200
29	Station 4	Station 2	620
30	Station 4	Station 3	650
31	Station 4	Station 6	900
32	Station 4	Station 7	1050
33	Station 5	Station 1	5200
34	Station 5	Station 2	5500
35	Station 5	Station 3	5800
36	Station 5	Station 4	5950

Figure 7. The Distance between Each Bus Stop in Meter

To synchronize between simulation and the real system, the distances have to be set accurately to measure the total time required by the bus to complete one cycle trip (i.e., from the residential halls to the allocated DKGs). This is due to the fact that the mechanism of a transporter module in Arena has been designed to first satisfy the oldest request from any stations. In our case, if there is any request from the previous bus station, the bus will then be back to the station. For example, if the bus is already at station 3 and there is a request from station 1, the bus will automatically turn behind to station 1. This does not represent the real system. To cater this, the model sets the distance between each station to represent real world situation and forces the bus to make one whole cycle before it can entertain the request from its previous station.

Unstructured interviews with the management have also been conducted to understand how the total number of buses is located to each station. Based on the number of transports parked in the provided parking lot at residential halls, 5% of the students were assumed to use their own transport to attend their classes. Based on our observation, around 15% of the students were also assumed to arrive early in the morning (between 7.30am to 8.00 am) at the bus station. Another 80% meanwhile begin to queue at the bus stop during the time span of 8.00 am to 8.30 am. This scenario contributes to the waiting time problem.

The buses start to move to the assigned bus stations at 7.30 am. Thus, the interval length is one hour from 7.30 am to 8.30 am. The interval was then divided into 30 minutes; i.e., 7.30 am to 8.00 am to be the non-peak hour while 8.00 am to 8.30 am to be the peak hour. Table 1 shows the number of students having classes early in the morning. The replication length was set 30 minutes from 7.30 am to 8.00 am (non-peak hour) and the base time unit was set in minutes and the other 30 minutes repeat the same action.

Table 1. Number of Students Having Classes Early in the Morning

Residential Halls	5% students moving by their own transports	15% students moving during 7.30 – 8.00 am	80% students moving during 8.00 – 8.30 am
BSN	19	56	299
EON	20	60	322
MAS	18	53	281
MISC	15	46	242
Petronas	20	60	322
Proton	9	26	135
Sime Darby	21	63	338
TM	19	57	302
TNB	15	45	238
Tradewinds	0	1	2

5. ANALYSIS AND FINDINGS

5.1 Base Run Setup for the Current Practices of the Bus Management

The solution from the current practices in managing the bus by the management is firstly translated into the simulation model with the number of the buses assigned at route A and B is 3 and 12 respectively. The capacity distribution of the buses is shown in Table 2.

Table 2. Number of Bus Assigned at Each Bus Stop.

Route	Bus Stop	Number of Bus Assigned	Total Number of the Buses
Route A	Bus Stop 5	1	3
	Bus Stop 6	1	
	Bus Stop 7	1	
Route B	Bus Stop 1	4	12
	Bus Stop 2	4	
	Bus Stop 3	3	
	Bus Stop 4	1	

The number of the replications is set to 30 replications to see the variation of performance results. Based on all of the replications, the performance measures are then averaged.

As our focus is to optimize the number of buses during the peak hours, the results of the 3rd phase are presented which are 80% of the students go to class from 8:00 am to 8:30 am. The current practice of the management is first set where the number of the allocated buses is 4, 4, 3, 1, 1, 1, 1 buses at bus stops 1, 2, 3, 4, 5, 6 and 7 respectively. A total of 15 buses that can move freely are assigned at all bus stops with no buses. Based on this bus allocation setting, the results show that student waiting time at all bus stops for the 30 replications, the average student waiting time is 8.96 minutes as depicted in Table 3. This simulation results were used as an indicator to verify and validate the model.

Table 3. Results for Each Replication (Rep) and its Waiting Time (WT)

Rep	WT	Rep	WT	Rep	WT
1	8.389	11	8.5619	21	8.907
2	8.9245	12	10.1697	22	8.2964
3	8.8795	13	8.4894	23	8.4368
4	9.8326	14	10.0056	24	8.5492
5	9.0472	15	8.9477	25	8.9265
6	9.8532	16	8.6628	26	8.5549
7	10.1856	17	8.6081	27	8.0051
8	10.5997	18	8.7659	28	8.4406
9	8.5459	19	8.6446	29	8.6084
10	8.0316	20	10.2409	30	8.7941
Average: 8.96348					

5.2 Model Verification and Validation

There are two ways to verify and validate the model as mentioned by Al-Sabban and Ramadan [12]:

a. *Verification of Input-output Transformations:* Comparing the outputs of the model with the outputs of the real system using the same input data set. If they approximately match, the model then represents the real system.
b. *Validation of Model Assumptions:* Structural assumptions related to how the system operates. On the other hand, data assumptions involve characteristics of system parameter data. In the model, structural assumptions were validated by the direct observation and comparison with the real system while the operational simulation model were validated by system domain experts. Data assumptions include the assumed statistical characteristics of model parameters such as the average bus loading and unloading times.

The verification and the validation of this research were done by informal interviews with the management and the students about the time taken for them to wait the bus. In addition, the management stated that the average waiting time for the students to wait the bus at all bus stations during 8.00 am to 8.30 am (peak hours) was 10 minutes. Carson [13] as in Nawawi et al. [14] stated that in order to achieve the level of sufficient accuracy, the differences between DES outputs and actual data must be within ±10%. The difference between DES output and the actual data is computed using the given formula:

$$Difference\ (\%) = \frac{|Simulation\ Output - Actual\ Data|}{Actual\ Data}\ x\ 100\%$$

The average waiting time obtained from the simulation output by running the model using the management`s preference number of bus assigned is shown in the Table 4. The difference is calculated using the formula.

$$\text{Difference } (\%) = \frac{|8.96 - 10.00|}{10.00}\ 100\% = \frac{|-1.04|}{10.00}\ x\ 100\% = 10.365\%$$

As the differences from the simulation and actual data obtained shows that the difference is within 10%, it proves that the developed model is valid. In addition, the management team has also verified the developed model and validated the average waiting time obtained from the base run. After the validation and verification processes, any alteration to the number of the assigned buses can be executed so that the desired result can be obtained from the simulation model which can later be put to the real practice.

5.3 Intervention to the Current Practice

The number of bus distribution of each bus stop was changed to see which type of distribution would give the best result, i.e., the minimum waiting time. The suggestion of the bus distribution has also been suggested by the management. Our task is to implement the "*if then*" analysis. For example, configuration 11 shows that the bus is now allocated to be 1, 1, 1, 1, 1, 1 and 1 at bus stops 1, 2, 3, 4, 5, 6 and 7 respectively whilst the other 8 buses are set to move freely in order to pick up any students where the buses will deliver the students to their locations when there is a demand for it. For this setting, the students' waiting time based on 30 replications is 4.69 minutes. Other configurations were then used and the results obtained are shown in Table 5. A total of 12 configurations have been tested to search the best result. Table 4 depicts the number of bus distribution for each bus stop for each configuration.

Table 4. Summary of the Average Waiting Time

Configuration N	Number of Buses Assigned at Bus stop 1, 2, 3, 4, 5, 6 and 7	Number of Assigned Buses	Number of Buses moving	Total Buses	Average Waiting Time (Minutes)
1	3, 4, 3, 1, 1, 1, 1	14	1	15	4.369067
2	4, 3, 3, 1, 1, 1, 1	14	1	15	4.283003
3	5, 3, 3, 1, 1, 1, 1	15	0	15	4.264127
4	6, 3, 2, 1, 1, 1, 1	15	0	15	4.223133
5	3, 5, 3, 1, 1, 1, 1	15	0	15	4.358323
6	5, 2, 3, 1, 1, 1, 1	14	1	15	4.236213
7	5, 3, 2, 1, 1, 1, 1	14	1	15	4.264127
8	3, 3, 3, 1, 1, 1, 1	13	2	15	4.302853
9	2, 1, 1, 1, 1, 1, 1	8	7	15	4.202783
10	2, 2, 1, 1, 1, 1, 1	9	6	15	4.499577

11	1, 1, 1, 1, 1, 1, 1	7	8	15	4.694643
12	1, 2, 1, 1, 1, 1, 1	8	7	15	4.545030

The lowest average waiting time can be achieved using configuration 9, i.e., 2, 1, 1, 1, 1, 1, 1 buses allocated at stations 1, 2, 3, 4, 5, 6 and 7 respectively. 8 buses are assigned buses and the other 7 buses are the free moving buses. The average waiting time is 4.20 minutes which is the lowest average waiting time. This is the best configuration of the buses to be implemented compared to the current configuration by the management. To make this new system behave properly, one of the staff should be assigned to wait at the route to control which bus stop has the highest request so that the unassigned buses can stop and transport the students.

6. CONTRIBUTION, CONCLUSION AND FUTURE RESEARCH

The simulation model of the shuttle bus services can simulate whether certain implementation can improve the system or not. It considers the total students attending classes at the peak hour, i.e. 8:30 am which is different for every semester. Practical contribution can be seen when using the model. Various configurations of the number of buses and their effects on the students' waiting time can be analyzed. The development of the model itself has provided us a better vision for making a proper strategy to handle the recurring transportation problem. In term of theory contribution, a new approach of using the "transport" module in Arena software has been explored. Before this, the module is only used to transport a single entity to a single station. In this paper, a new method of using the transporter which can be assigned as a bus to carry a huge amount of entities at a time and to free the entities at many assigned destinations has been implemented.

However, the model only considered two routes. During the interview with the bus provider, the arrival rates of the students significantly change during a rainy season. Therefore, this condition should be considered in the model. Besides that, since the total buses owned by the provider is fixed, it is suggested in the future that this model can be extended to include full day of the bus operations.

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