Performance Evaluation of a RFID-Enabled Real Time Bus Dispatching System: Case study of the Bangkok bus system

Kriangsak Vanitchakornpong[1], **Nakorn Indra-Payoong**[2],
Agachai Sumalee[3], and **Wiroon Sriborrirux**[4], Non-members

ABSTRACT

This paper aims to present and evaluate the performance of one of the first real-time bus dispatching system in Bangkok, Thailand. The proposed bus dispatching system receives the real-time bus location data from the RFID sensor network. The paper provides the background and brief description of both the hardware and architecture of the RFID sensor network and the real-time bus dispatching system. The bus dispatching system continuously monitors the status of each bus and updates its expected arrival time at the depot using the real-time data from the RFID sensor network. If the expected number of vehicles falls below the required level, then the bus dispatching system will adjust the service headway and vehicle/driver assignments to minimize the impact on the service headway. The system is implemented on one of a bus lines in Bangkok. The main focus of the paper is to evaluate the performance of the implemented system by comparing the bus service qualities before and after the implementation of the real-time bus dispatching system. One month bus service data both before and after the system deployment are used in the evaluation of the bus level of service. The result illustrates the potential real-life benefit of the real-time bus dispatching system despite the simplicity of the timetable adjustment strategy.

Keywords: Real-Time Bus Dispatching System, RFID Based Services, Bus Level of Services, Bus Service Performance Evaluation, Intelligent Transport System

1. INTRODUCTION

Developing a convenient and highly utilized public transport system is one of the key strategies to tackle traffic congestion and ensure urban sustainability. However, the public transport mode is generally inferior to the private car in terms of its directness of journey, inconvenience, and reliability. Particularly, the issue of reliability of bus services can be a major obstacle to attract more travelers from the private cars. One of the crucial operational requirements of the bus service is to maintain a regular headway along the service route according to the announced schedule. This will allow the passengers to better plan their trip and arrival time to the bus stop which in turn will help reducing the passenger waiting time. To maintain the regular headway, bus dispatching systems have been proposed to adjust the crew and vehicle service plans to cope with any possible circumstance which may deviate from the plan. For instance, due to an unexpected incident (excessive traffic congestion or vehicle brake-down) the bus scheduled for the upcoming service may not be back to the depot on time for the dispatching. In this case, the bus dispatching system may decide to allocate a new vehicle (and driver) to the scheduled service.

In mega-cities, particularly in developing nations (e.g. Bangkok), the bus dispatching system has to deal with the high variability of traffic congestion and travel time. The current approach for accommodating this uncertainty is to introduce a buffer time into the scheduling process, e.g. introducing additional 30 minutes for the journey time of each bus run in the off-line scheduling process. This approach normally requires additional vehicles to maintain the service headway, since some buses may not return to the depot on time for the next scheduled service due to the high variability of journey time. In some circumstances, the fleet size may not be sufficiently large to maintain the service headway along the bus route under this dispatching strategy. To this end, the concept of real-time bus dispatching system has emerged in which one of the main components of this system is the real-time vehicle location information. The real-time information of the vehicle location along the route will help the operator to adjust and improve the service schedule as well as the dispatching strategy according to the updated traffic condition.

Recently, several applications of Intelligent Transportation System (ITS) have been employed to improve the efficiency of bus operation including

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[1,2] The authors are with Faculty of Logistics, Burapha University, Thailand, E-mail: kriangsv@buu.ac.th and nakorn@buu.ac.th

[3] The author is with Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, E-mail: ceasumal@polyu.edu.hk

[4] The author is with Department of Electrical Engineering, Burapha University, Thailand, E-mail: wiroon@buu.ac.th

Global Positioning System (GPS), Automatic Passenger Counting (APC), and E-Ticket system [3]. Similarly, the Automatic Vehicle Location (AVL) system has been used to provide the real-time location of the buses along the route. Dessouky *et al.* [4] applied the bus tracking technology or AVL in controlling and adjusting the schedule of bus transfer at bus terminals to minimize the transfer delay. They highlight the importance of the AVL system in a successful application to reduce the transfer delay. Chan *et al.* [2] evaluated the performance of the AVL technology at signalized junction for the bus priority scheme. The AVL system can be categorized into three different types including i) Fixed-base station, ii) GPS, and iii) Radio navigation [9]. The GPS is probably one of the most widely used systems for the AVL particularly for the freight vehicles. However, the application of GPS as a reliable source of the real-time AVL in a mega-city may face the problem with the lack of satellite signal when the vehicle is travelling underneath an expressway or in the corridor with high-rise buildings (e.g. the canyon effect in Hong Kong). In some cities, the AVL system is implemented through the fixed-based station system using the RFID technology. For instance in several cities in Sweden and Denmark, the city authorities installed the RF-Receivers or RFID readers at different locations along the roadsides (e.g. signpost or streetlight pole). Each bus is then equipped with an RFID tag in which an appearance of the RFID tag as detected by the RFID reader will provide the current location of the bus along the service route. The main advantage of the RFID system for the AVL is its reliability and accuracy. The cost of data transfer can also be lowered since the transmission of the data is normally carried out through the land-line communication system (since the RFID reader is normally attached to a roadside equipment). In addition, the location data obtained from the RFID system can be used straightaway whereas the location data from the GPS must be processed through the data filtering and map matching algorithms first.

Regardless of the AVL technology adopted, the general framework of the real-time bus dispatching system involves the update of the timetable to reflect the current and predicted traffic condition and the generation of the vehicle and crew rosters for the updated service timetable. The bus dispatching system must also consider various practical constraints involving the resource availability (on both the drivers and vehicles) and other operation constraints (e.g. maximum working hour for each driver or lunch-break period). The main objective of the real-time bus dispatching system is to maintain the regular headway according to the announced timetable. There are several previous studies attempting to improve the efficiency of the bus operation through a better service scheduling. Sun [12] investigated an approach to determine an appropriate time interval for the bus dispatching problem using the data on the service revenue and passengers' characteristics (e.g. waiting time and wiliness to pay for travel). Vanitchakornpong *et al.* [13] proposed a constrained local search algorithm for designing a bus timetable with multi depots and line change (swap of the vehicles serving different lines) to minimize the operating cost. Dessouky *et al.* [4-5] proposed strategy to determine bus dispatching using the real-time vehicle tracking data to decrease the passenger waiting time at the terminal. Yin [14] developed a real-time expert system (based on the past experiences of the operation) to provide guidance on the best strategy to handle the abnormality in the service headway. Pangilinan *et al.* [10] utilized the real-time AVL data in the bus dispatching strategy to reduce the gap between the actual and planned schedules. Fu *et al.* [6] proposed a real-time stop-skipping and vehicle holding strategy for the bus dispatching control to reduce the passenger waiting and trip times.

This paper aims to evaluate the performance of a recently developed RFID enabled real-time bus dispatching system for the Bangkok bus network. The proposed system can adjust the service operation/schedule according to the updated bus/driver availability and the current traffic condition. The real-time bus location data provided by the RFID sensor network is a central component of the proposed system to determine the current traffic condition and the bus availability for the subsequent services. The practicality of the system especially for the application to a developing country like Thailand is fully addressed and illustrated in the paper through the case study. The paper also presents the hardware architecture of the successful RFID system for providing the real-time bus location data as a part of the real-time bus dispatching system. The paper then evaluates the performance of this practical real-time bus dispatching system in term of the improved level of bus service compared to the existing manual operational procedure. The evaluation is based on one bus route in Bangkok which is equipped with the proposed RFID system using one month service data on two service routes. The result should provide a tangible judgment on the potential benefit of the real-time bus dispatching system.

The remainder of this paper is organized as follows. Section 2 introduces the proposed RFID-based AVL system which is successfully implemented in Bangkok. Then, Section 3 explains the simple real-time bus dispatching framework based on the real-time bus location and travel time data obtained from the RFID AVL system. Section 4 presents the real case study of the application of the proposed RFID AVL and real-time bus dispatching system. The case study involves two service lines of a bus company called Premier Metro Bus in Bangkok. The section compares the performance of the proposed system with the current manual operation of bus dispatching. The final section concludes the paper and discusses the results.

2. RFID SENSOR NETWORK FOR BUS LOCATION IDENTIFICATION

This section briefly presents the architecture of the proposed RFID sensor network for detecting the buses equipped with an RFID-tag [11]. The proposed RFID system for the AVL consists of a network of 150 RFID readers whose function is to detect the RFID-tag installed on a bus passing through a specific location in the road network. The four main components of the system are:

(i) Base stations or RFID readers are installed at different public telephone booths at road-sides, and the distance between base stations ranges from to 3 km. The installation of the 500 m. RFID readers at the public telephone booths provides a sufficient housing of the reader protecting the electrical parts from the climate/weather. The setup will also allow the transfer of the real-time data from the reader through the land-line ADSL of the public telephone booths. Note that in this study, the RFID with 433MHz operating frequency is used as it operationally works well in the congested traffic area.Fig. 1 shows the installation of the RFID reader at a telephone booth for the case study.

(ii) Active RFID tags (transponder) are attached to buses and other types of vehicles (e.g. private cars or taxis). Once the vehicle with an RFID tag approaches the detecting zone of the RFID reader the vehicle ID will then be transmitted to the RFID reader. This transaction then registers the appearance of this vehicle at this location and time. Fig. 2 shows the RFID tag, which was developed in-house, in which the RFID tag is powered by the vehicle electrical system.

(iii) The control center will then collect all real-time data transmitted from the RFID readers as well as operate and monitor the status of all RFID readers through the network of the fixed IP VPN or Dynamic DNS of the RFID readers. Fig. 3 shows the schematic diagram of the connectivity between the control center and the sensor network.

(iv) The software application will filter and process data for different applications, e.g. data for bus dispatching system or tracking system.

The proposed RFID AVL system is based on the typical RFID system but the two-way communication functionality between the RFID reader and tag is introduced to increase the accuracy and reliability of the data transaction. Thus, the proposed RFID sensor network can be categorized as V2I system (Vehicle-to-infrastructure system) in which the communication between the road-side infrastructure and

(a)

(b)

Fig.1: *(a) Public telephone booth in Bangkok and (b) installation of the RFID reader inside the booth*

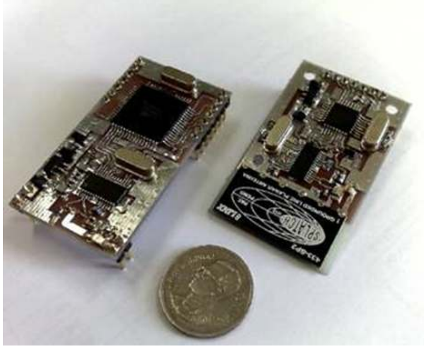


Fig.2: *Examples of the developed active RFID tags.*

the vehicle is under CALM standard [1]. Note that the detecting zone of the RFID reader was developed to cover both sides of the road (both direction) in which only one RFID reader is requires to be installed at each location. This will help reducing the infrastructure cost of the system.

The proposed system also involves an innovative communication protocol between the RFID reader and vehicle tag. The proposed communication protocol involves three stages:

- The regular beacon signal which is called ACK (Acknowledge) is broadcasted from the RFID reader to detect the RFID tags within the detecting zone.
- The signal is then transmitted from the RFID tag to the RFID reader to inform the ID of the tag during the beacon signal cycle of the RFID reader.
- The final phased involves the verification of the IDs of all RFID tags detected by the RFID reader. After the verification a signal will be sent back to each RFID tag to confirm the successful transmission of the vehicle ID.

Fig. 4 illustrates the communication framework of the proposed RFID system. From Fig. 4, the base station (RFID reader) broadcasts the beacon signal every cycle of t1 interval which is 700 milliseconds. The beacon signal will cover the area of around 200 meter radius. The RFID tag will operate under two modes 1) listen mode and 2) transmit mode which is related to the second phase of the communication protocol explained earlier. Once the vehicle with a RFID tag enters the detecting zone of the RFID reader the RFID tag (which is under the listen mode now) will detect the ACK signal from the RFID reader. Then, the RFID tag will switch to the transmit mode to prepare the data in the packet format under a particular encryption scheme. This data will then be transmitted to the RFID reader. The design of the communication protocol in our RFID system can cope with the speed of vehicle up to 120 km/hr with the maximum number of 100 vehicles in the detection zone during the same transaction period [11].

The proposed RFID sensor system allows the bus operator to monitor the location of each vehicle on the real-time basis from the bus tracking module. The location data of each bus between each pair of the RFID reader can then be used to calculate the travel time or speed profile of that road section. The location data of each bus from the RFID readers can then be used to generate the time-space diagram of the vehicles. The information from the time-space diagram can then be used to adjust the timetable and bus dispatching strategy as well as evaluating the overall performance of the bus system (this will be illustrated in the case study section later).

3. REAL-TIME BUS DISPATCHING FRAMEWORK

The design of bus timetable or service schedule for each period is based on the potential travel demand and expected bus journey time in each time period. After the timetable is finalized the vehicle and driver will then be assigned to each of the service run (i.e. bus and driver scheduling process) considering the available resources. In this paper, we consider the daily operations of the bus service to handle the deviation of the service headway from the original schedule. From the preliminary analysis of the service data and travel time data in Bangkok the main reasons for the deviation of the service headway are i) the break-down of bus due to the engine or other problems, and ii) the delays of the service and arrival time to the depot due to the traffic accident (or other unexpected incidents on the road) and traffic congestion. For the first type the break-down vehicle may no longer be used in the subsequent runs of the service on that day. On the other hand, the delayed vehicles in the second case can be considered as available fleet for the later services in which the expected arrival time of the vehicle back to the depot must be calculated. To adjust the timetable (or bus dispatching interval time), the number of vehicles and crews available during that time period must be considered in which the adjustment of the bus dispatching time or service timetable can also be made at the bus terminal (depot). In theory it is possible to adjust the service schedule en-route (e.g. using the vehicle holding or stop-skipping strategy). However, this strategy may not be practical and requires a two-way in-vehicle communication system between the drivers and the control center which may be costly and distracting. Fig. 5 shows the flow chart of the real-time (or reactive) timetable adjustment process considered in this paper.

From Fig. 5 after receiving the vehicle real-time location data and travel time data from the RFID system, the first step is then to check the number of available vehicles. The algorithm will use the real-time travel time estimation based on the RFID data of the previous buses along the same route and historical data to estimate the arrival time of each bus to the depot. The number of buses at the depot and the expected number of arriving buses before the dispatching of the next batch of services can then be estimated. The vehicles and drivers are categorized as fixed and float vehicles/drivers. The fixed vehicles are those assigned to a particular service route whereas the float vehicles are available for dispatching to any service route as needed. The system will continuously monitor the location and expected arrival time of each bus, and evaluate if the number of available vehicles can serve the planned schedule. If the number of vehicles is sufficient, the algorithm will then call the vehicle and crew scheduling module

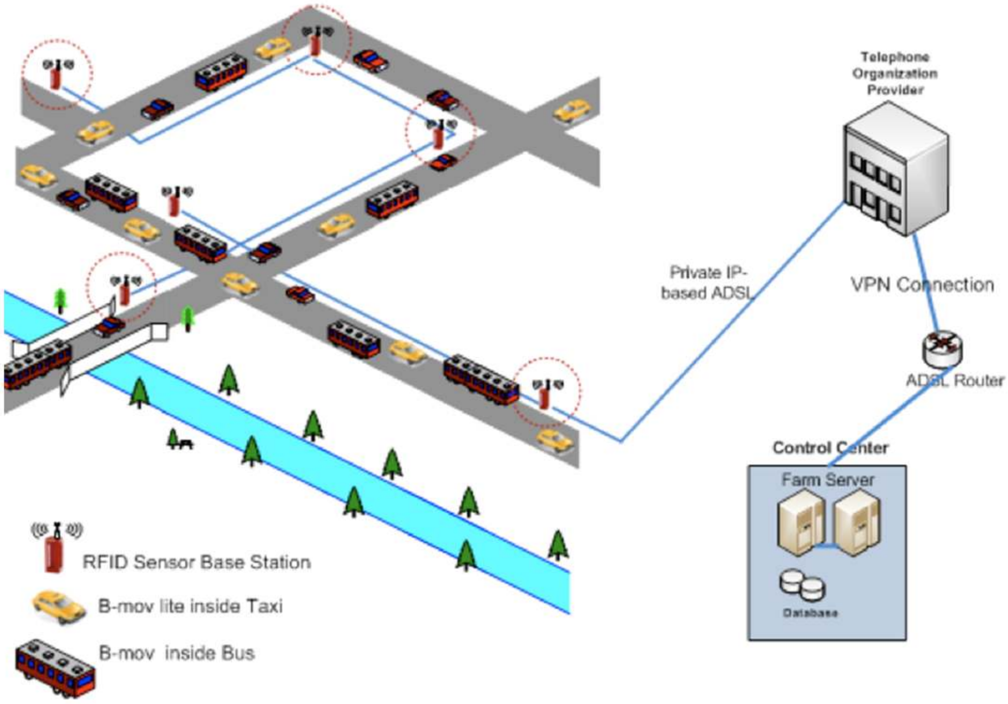


Fig.3: *RFID reader (B-Base) architecture and connection layers.*

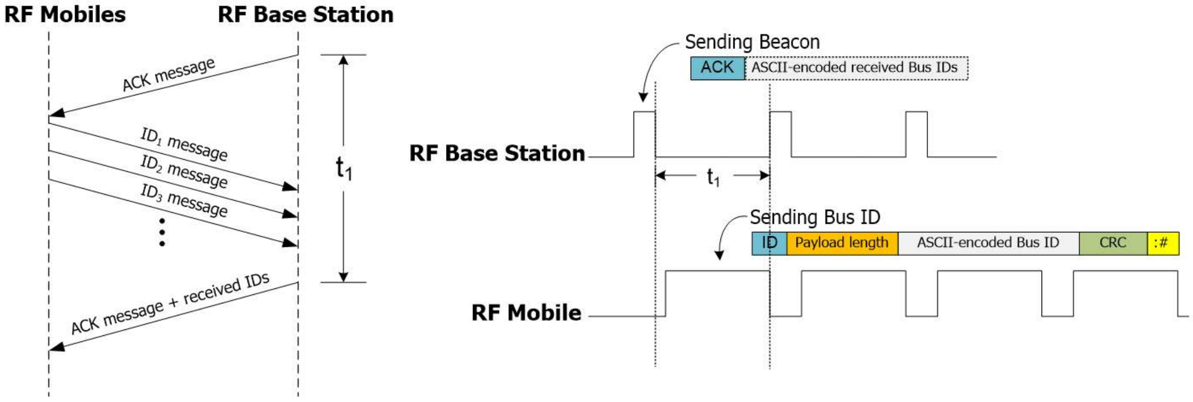


Fig.4: *Message and time diagram of the communication between RFID reader and tag.*

to assign a vehicle and driver to each scheduled run. However, if the number of vehicles is insufficient to cope with the original schedule, the system will then adjust the timetable for bus dispatching during that time period (dispatching adjustment module). The adjustment process will consider several factors including desired service headway, the number of available vehicles, the number of runs which may be cancelled due to the lack of vehicles, and the trip time. The timetable adjustment will be carried out for the services during the affected time period only to address mainly the service runs which are expected to deviate from the original schedule. The main aim of the timetable adjustment is to maintain the original service schedule as much as possible. After adjusting the timetable and dispatching strategy, the vehicle and crew scheduling modules will then be invoked to assign vehicles and drivers to the service runs in the updated timetable.

3.1 Bus dispatching adjustment strategy

This section presents a simple adjustment strategy for the bus dispatching schedule. The adjustment of the bus dispatching time is to respond to the insufficient number of vehicles to serve all scheduled services during that time period and to cope with the failure of the vehicles to operate following the original schedule. As discussed, the proposed system will continuously update the status of each vehicle (its location and expected arrival time at the depot). From this real-time update, the system can estimate the number of avail-

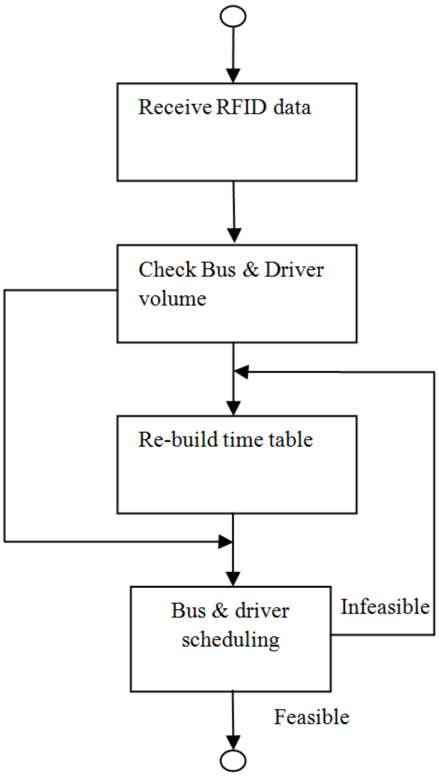


Fig.5: *Reactive bus scheduling flow chart.*

able buses/drivers within each time interval (T_r). In the case that the number of vehicles/drivers may not be sufficient to serve the original scheduled headway (H_{Tr}), the adjustment of the headway (and hence the timetable) will be carried out within that time interval. Each time interval, T_r, is defined by the beginning and end times denoted by s_{T_r} and e_{T_r}. The adjustment of the timetable within each time period is carried out by calculating the new headway (denoted by $H_{T_r}^{new}$) for that time period considering the expected number of available vehicles, b_{T_r}, i.e.

$$H_{T_r}^{new} = \frac{e_{T_r - \max(s_{T_r}, ct)}}{b_{T_r}} \tag{1}$$

where ct is the time epoch during the time interval. Note that since this update will only be triggered when the expected number of available buses at the depot is lower the minimum number of buses required (to maintain the original headway). Thus, definitely $H_{T_r}^{new} > H_{T_r}$. During this adjustment the remaining floating buses will already be considered as the available buses for the services.

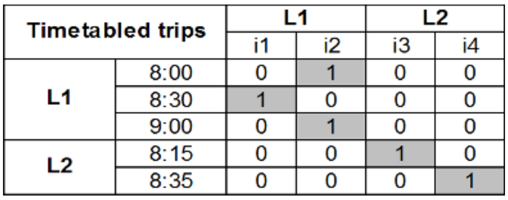
With the adjusted headway, the number of service runs during the service time interval T_r can be determined as

$$n_{T_r}^{new} = \frac{e_{T_r - \max(s_{T_r}, ct)}}{H_{T_r}^{new}} \tag{2}$$

The bus dispatching system will then generate new service runs (trips). This is considered as a new timetable for this service interval. The vehicle and crew scheduling algorithms will then be invoked to assign appropriate vehicles and drivers to the new service runs according to the adjusted timetable. Both of the algorithms for vehicle and crew scheduling are based on Vanitchakornpong *et al.* [13] and Indra-Payoong *et al.* [8]. Below a brief description of the bus (vehicle) and crew (driver) scheduling problems are provided.

3.2 Bus scheduling module

The bus scheduling module is invoked by the proposed system once the headway or bus timetables are adjusted. The vehicle scheduling problem for bus systems involves assigning different buses to different scheduled trips so as to minimize the total operating costs whilst satisfying several practical constraints including (i) only one bus is assigned to a scheduled trip, and (ii) other constraints (e.g. time-window or route restriction). The problem is modeled as the set partitioning type formulation as shown in Fig. 6. Each row represents a timetabled trip, and column represents a bus.



Timetabled trips		L1		L2	
		i1	i2	i3	i4
L1	8:00	0	1	0	0
	8:30	1	0	0	0
	9:00	0	1	0	0
L2	8:15	0	0	1	0
	8:35	0	0	0	1

Fig.6: *Set partitioning formulation for bus scheduling process.*

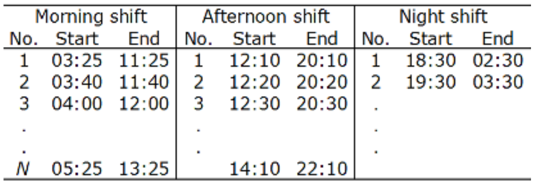
In Fig. 6, there are five scheduled trips with two different service lines: L1 and L2. Vehicle i1 and i2 belong to L1, and i3 and i4 belongs to L2. A feasible solution is shown in Fig. 6 in which for L1 bus i2 departs at 8:00 and 9:00, and i1 departs at 8:30; for L2, bus i3 and i4 depart at 8:15 and 8:35 respectively. The bus vehicle scheduling problem can be considered as a constraint satisfaction problem in which the violation of hard constraints (operational constraints) is prohibited, and the objective function is converted into a soft constraint. In general, the constraint violation (v) can be written as:

$$Ax \leq b \Rightarrow v = \max(0, Ax - b) \tag{3}$$

where A is coefficient value, x is decision variable, and b is a bound. A solution for the problem is achieved when i) the hard violation (H) equals to zero, and ii) the soft violation (S) is minimized. The hard constraints are further categorized into the basic and side constraints. The basic constraints are mainly concerned with the consistency of the solution, e.g. one trip should be assigned to one vehicle. On the other hand, the side constraints are related to additional operational constraints considered, e.g. time-window constraint on arrival time of the vehicle back to the depot. For the soft constraints, these are mainly for route-time constraint, line change and vehicle transfer operations, and relaxed hard time windows. In general, the route-time constraint may be associated with vehicle range (due to fuel limit), maintenance period, and maximum driver's working hours. The problem stated in (3) is a complete NP-Hard problem. In the system the constrained local search algorithm as proposed by Vanitchakornpong *et al.* [13] is adopted to find a feasible and efficient fleet assignment.

3.3 Driver scheduling module

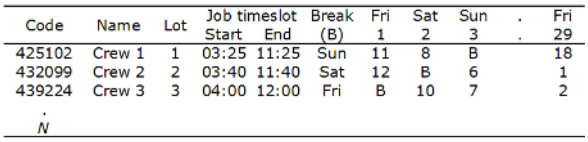
Driver scheduling module involves an assignment of a number of drivers to different scheduled bus services. The main aim of the system is to assign the jobs scheduled to different drivers in optimal sequences so as to minimize the total costs whilst satisfying several constraints (e.g. job timeslots, work-shift allocation, job sequencing, duty spread-over). According to a bus line operation in Bangkok, bus and driver scheduling are carried out separately few weeks prior to its operations. However, for the case study considered the company has implemented the fixed and floating drivers which introduces the flexibility into the real-time driver scheduling. Prior to bus driver scheduling, job timeslots for each bus line on each day are normally determined as shown in Fig. 7.



Morning shift			Afternoon shift			Night shift		
No.	Start	End	No.	Start	End	No.	Start	End
1	03:25	11:25	1	12:10	20:10	1	18:30	02:30
2	03:40	11:40	2	12:20	20:20	2	19:30	03:30
3	04:00	12:00	3	12:30	20:30	.		
.			.			.		
.			.			.		
N	05:25	13:25		14:10	22:10			

Fig.7: *Example of job timeslots.*

In Fig. 7, there are three shifts for job timeslots: morning, afternoon, and night shifts. Note that different shifts may be assigned with different sign-in/sign-off times for the drivers. In this example, each driver will have to work for around eight standard working hours per day. The drivers can then be assigned different patterns of the shifts as illustrated in Fig. 8.



Code	Name	Lot	Job timeslot Start	Job timeslot End	Break (B)	Fri 1	Sat 2	Sun 3	. .	Fri 29
425102	Crew 1	1	03:25	11:25	Sun	11	8	B		18
432099	Crew 2	2	03:40	11:40	Sat	12	B	6		1
439224	Crew 3	3	04:00	12:00	Fri	B	10	7		2
.										
N										

Fig.8: *Example of shift rotation for drivers.*

4. CASE STUDY OF BANGKOK BUS SYSTEM

The proposed RFID AVL system and the real-time bus dispatching algorithm (together with the vehicle and crew scheduling algorithms) are tested in a real-world case study of five bus routes of bus operators in Bangkok. In this case study, we will test the proposed RFID system and real-time bus dispatching system with line numbers 35, 4, 504, 554, and 558. In the test case, the bus dispatching system utilizes the data on vehicle locations and estimated travel times from the RFID network sensor to adjust the dispatching strategy. Fig. 9 shows the input data from the RFID system which is the trip time (or travel time) of five bus lines over the day.

Due to the uncertain travel time the number of available buses for the timetable may not be sufficient. For instance, from the operational plan at 10:00 there should be 4 buses available at the depot for this route, but due to an unexpected congestion the bus departing from the depot at 9:00 cannot return to the depot before 10:00. In this case, there will be only 3 buses available for dispatching until the late bus returns to the depot (which can be estimated from the real-time travel time). Based on this problem the operator allocates the vehicles and drivers into two groups: fixed service and floating service. Table 1 shows the actual allocation of the number of vehicles and drivers for bus lines. The vehicles and drivers from the fixed group will only run on the designated line. The allocation of the fixed vehicles and drivers to each line helps maintaining the service quality and robustness of the line operation. The floating vehicles/drivers will be in the ready states at the bus depot for filling up the service gap. The floating vehicle/drivers may be under the maintenance/ training during the stand-by period.

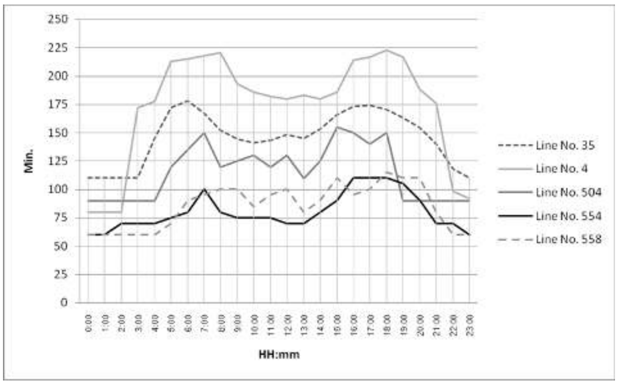


Fig.9: *Travel time profiles along bus lines from the RFID data.*

To evaluate the performance of the RFID enabled bus dispatching system, Tables 2 and 3 show the comparison of the utilized resources and service outputs from the manual operation and the proposed bus dispatching system (column Re-sch) of lines 35, 4, 504, 554, and 558 respectively. The results are compared in terms of (i) increase in the number of buses and drivers compared to the original plan (columns Bus and Driver), (ii) increase in the service headway during the whole operational period compared to the plan headway (column Headway), and (iii) reduction of the number of service runs compared to the original schedule (column Trip). Note that there is a slight difference in the implementation of the real-time bus dispatching system on these bus lines. For instance, for line number 35 and 504, 554, and 558 the real-time dispatching system is only implemented at the starting depot, only 554 and 558 running on the outer ring road of Bangkok with the intermediate transfer stop at Suvarnabhumi airport. On the other hand, the real-time dispatching system is implemented at both ends of the route for bus line number 4 since the route is considered as a long service route. In addition, for bus line number 4 the floating buses/drivers will be allocated at both ends.

We use the data over one month period before and after the implementation of the automatic bus dispatching system. The results are compared by different days of week as well. From the table, in general the real-time bus dispatching system outperformed the manual operation in all cases. For the short route (line number 35, 554, 558), the number of additional buses and drivers from the bus dispatching system are slightly lower than the manual plan in average. On the other hand, with the long route (line number 4, 504) the reduction of the required number of buses with the real-time dispatching is significantly lower than that required by the manual operation. For line number 35, the increase in the service headway from the manual operation almost doubles that from the bus dispatching system, Similarly, with the manual operation around seven service trips per day were cancelled whereas only around 3.5 runs were cancelled under the real-time bus dispatching operation. Also headway improvement is relatively obvious for line number 504. The result of other lines in terms of the change in headway and number of trips provided is similar to the case of line number 35 and 504 but with a smaller level of improvement. This may be due to the operation procedure of bus line number 4 which allocates the reserved (float) vehicles/drivers at both ends, and in case of line number 554 and 558 having an intermediate transfer stop. This provides a more buffer to the manual operation to maintain the regular headway despite the delay arrival of the service buses. For the line number 554 and 558 servicing on a less congestion area results the headway of the bus dispatching system slightly better than the manual plan. Nevertheless, the results from test cases illustrate the potential resource saving to maintain the scheduled headway services.

Table 1: *Allocation of float and fixed vehicles/drivers on bus lines.*

	Total	Fixed	Float
Line No. 35			
Bus	16	14	2
Driver	34	27	6
Line No. 4			
Bus	25	21	4
Driver	52	42	10
Line No. 504			
Bus	26	22	4
Driver	54	44	10
Line No. 554			
Bus	30	26	4
Driver	64	54	10
Line No. 558			
Bus	13	11	2
Driver	28	22	6

Fig. 10 shows an example of the operation of the automatic bus dispatching system based on the real-time RFID data. The figure shows the actual time-space trajectory of a bus serving line number 35. The first inclined line in this figure is the trajectory of the vehicle according to the planned schedule based on the historical travel time data. According to the plan, this vehicle should depart from the depot at around 8:30 and return to the depot at around 12:40 just in time to depart for the subsequent service run at 12:45. The second inclined line shows the actual trajectory of this vehicle on that day based on the real-time data from the RFID system. On that day, the traffic condition was slightly worse than the expected situation on the outbound trip in which the vehicle arrived at the destination of the run slightly behind the schedule. The main problem occurred on the inbound leg of the vehicle (heading back to the depot) in which the bus experienced a serious delay from around 12:00 onward. This resulted in the delay of the vehicle arrival time at the depot. The bus dispatching system received the location of the vehicle during each updating interval. The expected late arrival of the running bus was detected at around 12:15 which triggered the adjustment of the timetable and vehicle/crew scheduling. A new dispatching strategy was then defined by the proposed system in which the new vehicle was dispatched at 12:45 instead. The late arrival bus was shifted to serve the other scheduled run at 13:00.

To further evaluate the performance of the real-time bus dispatching system, we adopt the bus level of service scheme as proposed by Pangilinan et al. [10] as shown in Table 4. Level of service A refers to the service that can meet the original schedule perfectly whereas Level of service F represents the operation with an excessive deviation from the original plan in terms of the service headway. The deviation of the

Table 2: *Reactive bus dispatching output of bus line number 35.*

	Bus		Driver		Headway		Trip (85)	
	Manual	Re-sch	Manual	Re-sch	Manual	Re-sch	Manual	Re-sch
Monday	2	2	2	2	16.5	10.5	8.25	5
Tuesday	2	1.75	2	1.5	11.25	5.75	6.25	2.75
Wednesday	2	1.5	2	1.5	9.5	5.5	6.5	2.75
Thursday	2	1.75	1.5	1.5	12	6.25	7.75	3.25
Friday	2	2	2	2	18.75	12.25	9.25	6.5
Saturday	1.75	1.5	1.75	1.25	8.25	4.5	5	2
Sunday	1.75	1.75	1.5	1.5	9.5	6	5	2.75
Avg.	1.93	1.75	1.82	1.61	12.25	7.25	6.86	3.57

Table 3: *Reactie bus dispatching.*

	Bus		Driver		Headway		Trip	
Line #	Manual	Re-sch	Manual	Re-sch	Manual	Re-sch	Manual	Re-sch
4	3.21	2.36	3.18	2.21	9.64	7.18	5	3.39
35	1.93	1.75	1.82	1.61	12.25	7.25	6.86	3.57
504	2.89	2.68	2.96	2.36	6.75	5.54	2.75	2.00
554	3.11	2.79	3.39	3.00	11.36	9.54	2.82	2.14
558	1.64	1.46	1.75	1.54	7.29	6.36	1.75	1.39

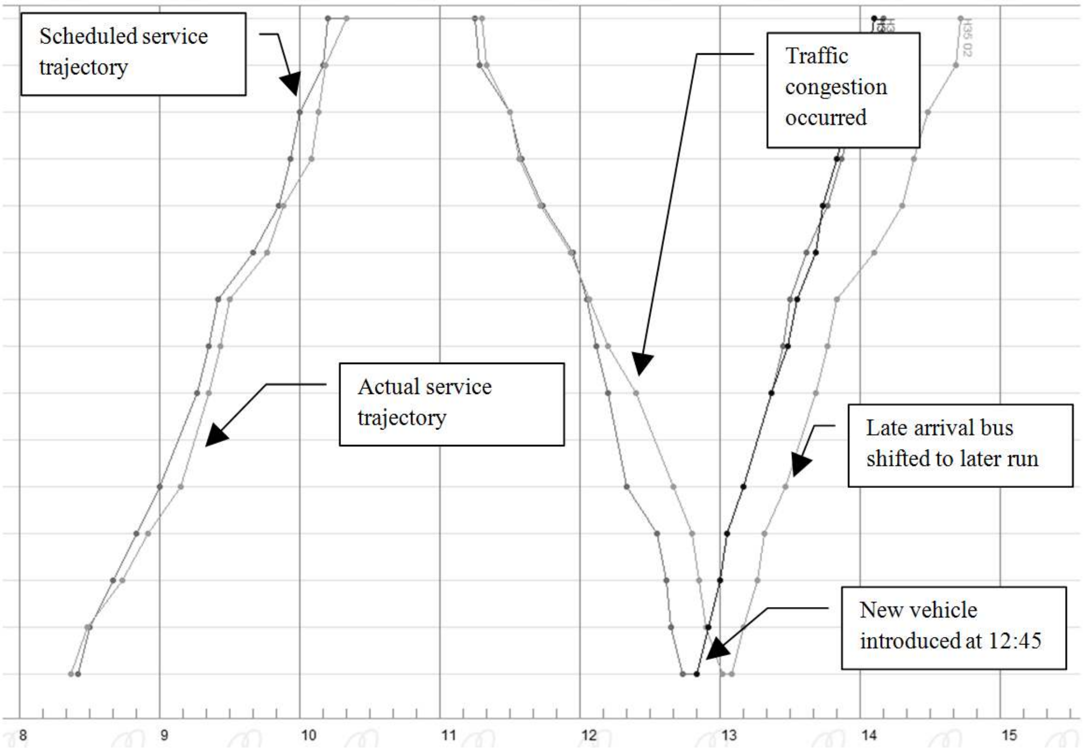


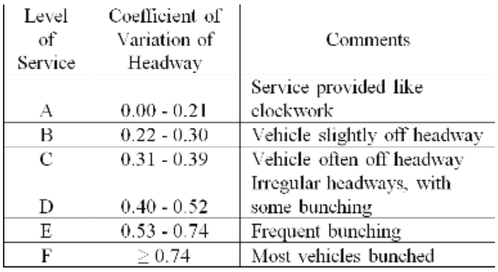
Fig.10: *A case illustration of the action taken by the real-time bus dispatching system.*

service headway from the original plan will cause the increase in waiting time and bus bunching problem during some time periods. The level of service of this bus line at each stop (RFID station) on the service routes (stops A, B, C, , N) is evaluated during a period of one month before and after the implementation of the RFID enabled bus dispatching system. The level of service is evaluated from coefficient of variation of headway (see Table 4) which is the ratio of the standard deviation of the headway ratios at each stop to the average value of the planned headway for that stop. The headway ratio is the ratio of the planned headway between each pair of scheduled service at each stop to the actual headway collected from the RFID data, in which the headway ratio is equal to 1 if there is no deviation from the planned headway.

Fig. 11 exemplifies the comparison of the coefficient of variation of headway at each stop of bus line no 35.

From Fig. 11 in general the coefficients of variation of headway from the operation under the real-time dispatching system are lower than those from the manual operation. This shows that the introduction of the real-time bus dispatching system on this service route can significantly improve the level of service at all stops although the simple bus dispatching adjustment is only considered at the depot (i.e. no consideration of vehicle holding or stop-skipping strategies en-route). Overall, the levels of bus service along this route are between levels B to E under the manual operation. After the implementation of the bus dispatching system, the levels of service of all station are improved at least one level in which the current levels of service are between levels A to D. Note that the quality of service for this bus line degrades with respect to the distance from the starting depot. This is also the case even under the real-time bus dispatching system. This is due to the simplicity of the current operational plan which only adjusts the bus dispatching headway at the starting terminal without considering the deviation of the headway en-route. Noted that, for other bus lines, the same pattern of improvement on the quality of service at different stops (RFID stations) along the service route can be observed.

Table 4: *Bus level of service (Pangilinan et al. [10]).*



Level of Service	Coefficient of Variation of Headway	Comments
A	0.00 - 0.21	Service provided like clockwork
B	0.22 - 0.30	Vehicle slightly off headway
C	0.31 - 0.39	Vehicle often off headway
D	0.40 - 0.52	Irregular headways, with some bunching
E	0.53 - 0.74	Frequent bunching
F	≥ 0.74	Most vehicles bunched

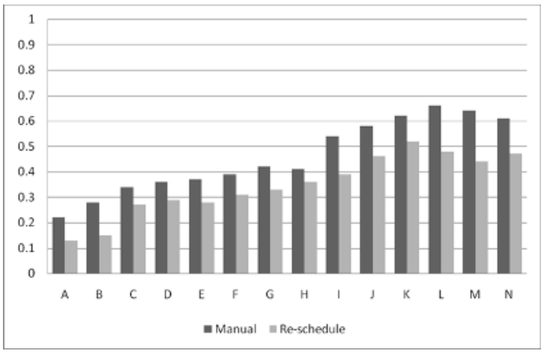


Fig.11: *Coefficient of varaition of headway at each stop along bus no. 35 route.*

The results from test lines clearly demonstrate the benefit of this simple but practical real-time bus dispatching strategy. The analysis and result in this section coincides with the finding reported in Dessouky *et al.* [4] which highlighted the importance of the accuracy of the AVL system in the successful implementation of real-time bus dispatching. The RFID sensor network provides a robust estimation of the space-mean speed of bus between each pair of base stations (RFID readers). The reliable bus journey time information is a key to estimate any possible late arrival or problem with the number of available buses.

5. CONCLUSIONS

This paper presented the implementation of one of the first real-time bus dispatching system in Bangkok which can be considered as a comparable case study for other cities in Asia. The real-time bus dispatching system utilized the real-time vehicle location data obtained from the RFID sensor network. The paper explained the architecture of the RFID sensor network in which RFID readers (or base stations) were installed at various public telephone booths along the bus route and each bus was equipped with an on-board RFID tag. This system design allows the direct application of the data from the sensor network to the bus dispatching system. The proposed system architecture also minimizes the communication cost between the base stations and the central control system. The real-time bus dispatching system then estimates journey time on each route using the real-time bus location data which is then used to estimate arrival time of each bus to the depot. On the basis of the information on current and expected available vehicles/drivers the bus dispatching system then systematically monitor whether the available resources can serve the scheduled bus runs to maintain the planned service headway. The paper explained the simple but effective strategy for adjusting the headway and reassigning the vehicles and drivers. This simple adjustment strategy is implemented in the case study alongside the vehicle and crew scheduling algorithms.

The RFID sensor network and real-time bus dispatching system was then implemented in the case study of a bus network operated by the Premier Metrobus Limited and Premium Management Limited. The paper extracted data sets from bus lines number 35 and 4 of the Premier Metrobus and line number 504, 554, and 558 of the Premium Management to compare the performance of the real-time bus dispatching system against the manual operation. The results showed that with the real-time bus dispatching system the number of additional drivers and vehicles is slightly lower than that required by the manual operation. On the other hand, the increase in service headway and the number of service cancellations were reduced significantly with the real-time bus dispatching system. The paper also compared the performance of the proposed system in terms of the improvement in the bus level of service. The coefficients of variation of the service headway at all stops along both service routes were calculated both before and after the implementation of the real-time bus dispatching system. The result illustrated clearly the significantly improvement of the bus level of services at all stops.

The main purpose of this paper is to illustrate that it is possible to apply the real-time bus dispatching system based on an advanced electronic system (e.g. RFID system) in a typical Asian city like Bangkok. Due to the lack of efficiency in the service and operation of the bus system, several cities in Asia and South East Asia in particular have suffered from the traffic congestion and car dependency issue. The experience and finding presented in this paper should represent a realistic case to follow for the cities in this region and to encourage a more proactive bus management and control strategy. However, it is noteworthy that the result of the current analysis is only based on a one case study of a service line. The system performance may change due to different characteristics of service routes including the scale of journey time variability, passenger demand profile, buffer time introduced in the manual operation, and vehicle types. These issues should be investigated further in future studies. The implementation of the RFID sensor network and the real-time bus dispatching in a large scale platform should also be investigated from case studies in the real world to solicit the finding on this small scale case study. From the customer point of view, a bus arrival time can also be considered as a value added service to the existing RFID sensor network.

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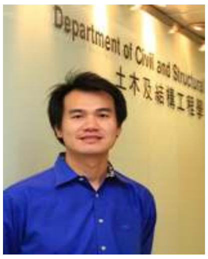
Kriangsak Vanitchakornpong received his Master of Science in Information Technology from Burapha University, Thailand. He is currently a Ph.D. candidate in logistics management at Burapha University. His researches are focused on Non-linear optimization and network optimization.

Nakorn Indra-payoong received a Ph.D. in Computing from University of Leeds. He is currently with Faculty of Logistics, Burapha University, Thailand, where he serves as an associate professor in logistics and supply chain management. His research interests include large-scale network optimization and intelligent transport system (ITS).



Agachai Sumalee received a Ph.D. in Transport Planning from University of Leeds. Dr. Sumalee authored and co-authored more than 50 journal papers and served as Editors and associate editors for many key journals in the field. He is an associate professor, currently at Department of Civil and Structural Engineering, the Hong Kong Polytechnic University. His research interests include network optimization and intelligent transport system (ITS).

Wiroon Sriborrirux received a MSci.Eng in Computer Science and Engineering from Korea University, South Korea. He is currently with the Faculty of Engineering, Burapha University, Thailand, where he serves as a lecturer in Programming, UNIX/Linux, C/C++ for Embedded System, and Data Communication and Networks. His research interests include Embedded System, RF System-on-chip for Wireless Sensor Network, Mobile Adhoc Network Routing Protocols.