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Case study

Traffic management project in Phnom Penh

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ABSTRACT

Traffic congestion and accidents are major issues in Phnom Penh, the capital city of the Kingdom of Cambodia. An inefficient signal system and lack of traffic discipline contributed to the unfavorable traffic conditions. A comprehensive traffic management project was recently implemented. An area traffic control system that controls traffic signals in the city based on the traffic conditions was introduced, and other traffic management improvement works such as pavement markings, traffic signs, and median dividers were installed. The project is making a positive impact on road users. Efficient operation and maintenance are key factors for the project to sustain its benefits.

1. Introduction

1.1. Project background

The Project for Development of Traffic Management System in Phnom Penh is a grant aid project by the Japanese government to Phnom Penh Capital City. It is a comprehensive traffic management project for Phnom Penh Capital City consisting of an area traffic control system and other traffic management works. The project covers the installation of advanced traffic signals at 109 intersections, 196 units of video vehicle detectors and 26 units of traffic surveillance video cameras in Phnom Penh. They are connected with the control center established in the city hall building through self-owned communication network using optical fiber cable. The renewal of pavement markings, provision for median dividers, installation of traffic signs, and repair of damaged pavement are also included in the project.

The project was envisaged in 2012 as one of the short-term high-priority plans of the Phnom Penh City Urban Transport Master Plan (PPUTMP) formulated under the Phnom Penh City Comprehensive Urban Transport Planning Project conducted by the Japan International Cooperation Agency (JICA). Recognizing the importance of the project, the Cambodian government requested that the Japanese government implement it as a grant aid project in 2013, and the Japanese government accepted the request [1]. The basic design of the project was completed in 2014, followed by the detailed design in 2015. Then, a contractor for the project was selected at the end of 2015, and the project started in March 2016. As of the end of November 2018, the project is nearly completed. Installation of signal controller, vehicle detector, video camera, and communication cable was completed and all of new signals are operating in on-line mode under the control of traffic control center. Adjustment of signal control parameters and training of counterpart staff who will operate the system are underway. The project is scheduled to complete in December 2018.

This article first briefly describes the traffic and safety issues in Phnom Penh, and presents an outline and features of the traffic management project being implemented. Finally the results of the traffic survey conducted to verify the effectiveness of the new signal are presented.

1.2. Objectives of the project

The Traffic Management Project was implemented with the following objectives:

- To improve the road traffic conditions in Phnom Penh City by introducing an area traffic control system and associated traffic management works such as pavement markings, traffic signs, and median dividers.
- To transfer the technology of traffic engineering and management to local counterparts so that the works completed by the project continue to exhibit benefits.

1.3. Number of registered vehicles

According to the Organization for Economic Co-operation and Development (OECD) road safety annual report for 2017 [2], there were 3.3 million registered vehicles in Cambodia in 2015. The increase in the number of registered vehicles is rapid and the number increased

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14% in 2015 alone. In Phnom Penh, there were 0.44 million automobiles and 1.6 million motorcycles as of 31 December 2016 [3], indicating that 78% of vehicles were motorcycles. The high share of motorcycles is a factor to be considered in the development of traffic management and safety measures. In fact, 73% of all fatalities are motorcyclists.

1.4. Traffic accidents in Cambodia

The same OECD report shows that there were 1852 fatalities in 2016, a 17% decrease when compared to 2015. More than 80% of the fatalities were vulnerable road users (motorcyclists, pedestrians, and cyclists). Although the number of fatalities decreased, the rate was still high. The fatality rate per 100,000 population was 11.9, which is 3.4 times higher than that of Japan (4431 fatalities or 3.50 per 100,000 population). If the difference in the number of registered vehicles between the two countries is considered, the fatality rate of Cambodia is much higher.

Cambodia is a young country. According to population pyramid data [4], 59% of the population was under the age of 30 and 76% was under 40 in 2018. Although there is no data available as to the ages of the fatalities, young people are considered to be a significant percentage. It is a great loss not only for the families of the victims but also for the nation.

1.5. Traffic conditions in Phnom Penh

Road traffic conditions and features in Phnom Penh are described below. Some of them are common to developing countries, while some are unique to Cambodia or Phnom Penh. The Final Report of the Project for Comprehensive Urban Transport Plan in Phnom Penh Capital City [5] also lists up the traffic management issues such as neglect of traffic rules and regulations by drivers, severe shortage of parking spaces, poor pedestrian walking environment, etc.

(1) Mixture of wide varieties of vehicles and high share of motorcycles

Traffic in Phnom Penh is chaotic, with different types of vehicles from luxurious SUVs to motorcycles and motorcycle-drawn tuk-tuks running on the same road. (See Fig. 1) Of these types of vehicles, the motorcycle is the majority and occupies 70–90% of the traffic volume. Different types of vehicles have different performance and maneuverability, resulting in an inefficient flow and unsafe traffic conditions. The tuk-tuk is a unique type of transport. It is a passenger cart driven by a motorcycle, and a maximum of four passengers can ride on the cart. The motorcycle engine is too small and powerless to pull a significant load. Owing to its poor performance, the tuk-tuk disturbs a smooth traffic flow while occupying a much wider space than a motorcycle. Currently, no control is imposed on the tuk-tuks as to the roads on which they can operate except for Norodom.

(2) Lack of discipline and poor driving behavior

Road users—drivers and pedestrians alike—often do not respect traffic laws and rules. It is not rare to see a vehicle driver or motorcycle rider ignoring a red light when there is no traffic on the crossroad. Sometimes they operate on the wrong side of the road and run in reverse to take a shortcut. The give-way rule is not followed, and yellow boxes drawn at some intersections indicating not to stay within the intersection are not respected. Congestion at an intersection quickly propagates to other locations as drivers proceed. Even the exit of intersection may not be clear, and no one wants to give way to others. The number of motorcycle riders wearing helmets, which is compulsory, is lower than in other Southeast Asian countries such as Malaysia and Viet Nam, where 90% of motorcycle riders wear helmets [6]. The situation is further worsened by the driving behavior of motorcyclists. They are not segregated from four-wheel vehicles and disturb the orderly flow by weaving around vehicles.

One of the reasons for such behaviors is that the driver's license is exempted for motorcycles with an engine displacement below 125 cc [7]. Anyone 16 years old or older can operate this type of motorcycle without a license. Thus, many motorcycle riders do not learn traffic rules or traffic safety. The rule also makes it difficult for traffic police to enforce traffic regulations as engine size is difficult to judge.

(3) Acute shortage of parking spaces and use of sidewalk as parking area

In the central commercial area of the city, there are not enough parking facilities. Most of the buildings are old and lack any parking facilities. Open-air parking is nonexistent in the central business district (CBD). Roadside parking is provided along some roads and is operated by a private company under contract to City Hall. However, the total number of parking facilities is much lower than what the parking demand requires. In fact, indiscriminate roadside parking is common and is a cause of heavy congestion.

Owing to this shortage of parking spaces, sidewalks are often used as reserved parking spaces for shops or customers visiting shops.

Fig. 1. Tuk-tuk running at road center.

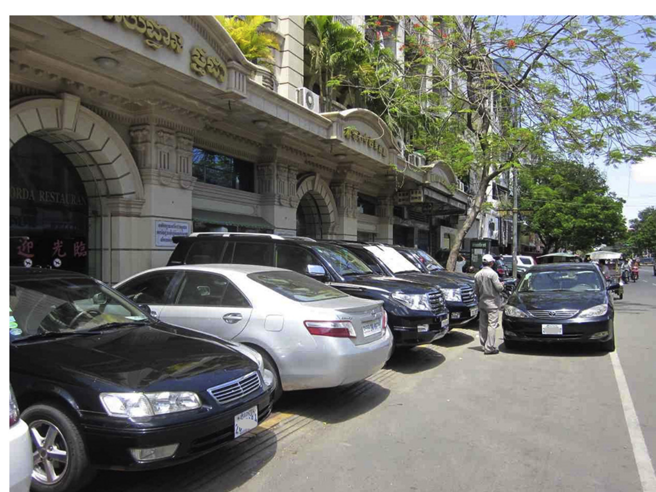

Fig. 2. Sidewalk is occupied by parked vehicles.

(See Fig. 2). This practice is common along many streets, and no space is left for pedestrians. The use of sidewalks as parking areas is encouraged by the slanted curbstone at most of these locations, as it makes access easy. Pedestrians are forced to walk carriageway exposing themselves to traffic stream. The practice is a cause of congestion as it largely reduces effective capacity of the road. Parking management is the one of the serious and urgent traffic management tasks in Phnom Penh.

(4) Sidewalk as shop area

Another lamentable practice detrimental to the pedestrian environment is the use of shop front as store space. Many shops consider the space in front of their shop as their territory and use it for their business leaving no space for pedestrians (See Fig. 3). The practice not only reduces the road capacity but also endangers the pedestrians as they are forced to walk on the carriageway.

2. Traffic management administration

Phnom Penh has been developing rapidly, and traffic conditions have changed drastically in recent years with the increasing number of vehicles. The existing traffic management measures and facilities cannot cope with the changing situation. However, the situation has recently improved through the implementation of the project and technology transfer to local counterpart personnel as part of the project.

2.1. Organizational setup

Phnom Penh Capital City Administration (PPCA) and one of its departments, the Department of Public Works and Transport (DPWT), are in change of traffic management in the city. The Ministry of Public Works and Transport of the central government is also responsible for traffic management on national roads. The Traffic Police of the Ministry of Interior (MOI) is an agency that implements traffic laws and rules. All of these organizations engage in traffic management and implement projects. The delineation of the duties and responsibilities of these organizations is, however, not clearly defined, and sometimes similar projects are conducted by two different agencies. For example, pavement markings were undertaken by both PPCA and DPWT without coordination, and the same road section was covered by two separate projects.

Fig. 3. Motorcycle occupying sidewalk in front of shop.

2.2. Lack of expertise

When the project was formulated, there were already various traffic management facilities such as traffic signals, pavement markings, traffic signs, and median dividers in the project area. These facilities were designed and installed without due consideration to traffic engineering. As there were no established signal design standards or procedures, the traffic signal design was not rational and did not match the traffic demand at intersections, resulting in inefficient signal operation.

Similarly, no design was prepared for pavement markings, and new markings simply followed existing lines. Thus, improper markings were repeated every time new lines were drawn. As a result, no improvements have been made over the years. The existing standards for pavement markings describe only the basics of the design. It lacks instructions on how to apply these standards to existing roads that have many constraints in applying pavement markings. No one in the agency in charge of road traffic administration has knowledge of traffic engineering including pavement marking design.

3. Traffic management facilities before project

(1) Mixture of wide varieties of vehicles and high share of motorcycles

When the introduction of an area traffic control system was planned for Phnom Penh in 2014, there were a total of 69 traffic signals in the city. All of them were isolated, pre-timed time signals made by different manufacturers from seven different countries. Their functions were limited, and the signal timing was not adjusted for a long time. The result was that the signals were useful only in preventing vehicle accidents between conflicting movements at intersections in an inefficient way.

Most of the old signals were functioning, but minimal maintenance was conducted by DPWH staff who was not properly trained. The pedestrian lanterns provided to most of the signals were not functioning, as they were disconnected from the controller in all but a few locations. Pedestrians paid no attention to the pedestrian lanterns, and most people did not even know that the lanterns existed. (See Fig. 4).

(2) Pavement markings, traffic signs, and other facilities

Pavement markings, median dividers, traffic signs, and other traffic control devices play an important role in traffic management. They regulate the traffic flow and prevent accidents. Although these devices existed before the project, they were not properly installed based on traffic engineering considerations. Moreover, many of these devices were dilapidated or worn out, and were not performing their functions. (See Fig. 5).

Fig. 4. Old, outdated signal.

Fig. 5. Unruly status of intersection before project.

4. Outline of the project

4.1. Area traffic control system

In an area traffic control (ATC) system, all signals in the area are controlled from a control center based on the traffic conditions gathered by vehicle detectors deployed at various locations in the area covered by the system. Traffic condition at key intersections can be viewed through video wall at the control center. The area traffic control system consists of four basic components:

- Central server system with video wall,
- Equipment at intersection consisting of traffic signals, vehicle detectors, and traffic surveillance video cameras,
- Data communication system using self-owned optical-fiber cable to connect signals, detectors, and CCTV cameras with the traffic control center, and
- Software and database in the central server system that jointly gather and process data and control signals.

The area in Phnom Penh covered by the ATC is shown in Fig. 6, and the system configuration is shown in Fig. 7. The type and quantity of equipment at an intersection are listed in Table 1. Six (6) signals along National Highway No. 1, which was widened and upgraded by another Japanese grant aid project, were added to the project. However, these are separate signals and are not connected to the area traffic control system.

4.2. Signal control mode

The area traffic control system in Phnom Penh is a state-of-the-art system that employs advanced signal control technologies. Since traffic signals control the traffic flow on busy streets, the system must be highly reliable, and under no circumstances should a dangerous situation be created by the system. For this reason, the system is provided with multiple levels of signal control modes as a fail-safe mechanism. (See Fig. 8 and Table 2).

The signal control modes are divided into two levels: central control and local control. Normally, all signals operate under central control. Should the communication link between the control center and a signal at an intersection be interrupted, the signal will operate in local control mode and autonomously control the signal. In addition, a carry-on mode is provided to prevent sudden changes in signal timing parameters at the time of communication interruption. If the communication link is recovered, the signal automatically shifts back to central control.

A brief description of the control modes is provided in the table and figure below.

Table 1
Quantity of Equipment at Intersection

Device	Area	Quantity	Remarks
Traffic signal	Area traffic control (ATC) area	109	64 are replacements, and 45 are new signals
	National Road No. 1	6	One signal is a replacement, and five signals are new
Vehicle detector	ATC area	196	No detector on NR No. 1
Traffic surveillance camera	ATC area	26	No camera on NR No. 1

4.3. Safety considerations in signal design

A traffic signal is a device that efficiently and safely manages vehicle and pedestrian movements. In the design of the signal system, consideration was given to the safety aspects as described below:

(1) Two sets of lanterns for each movement

In the old signal system, only one set of lanterns was placed for each movement, and the lanterns sometimes malfunctioned or were not bright enough. In the new system, two sets of high-brightness lanterns, including arrow lanterns, are used for each movement to make the signal more conspicuous and effective. (See Figs. 9 and 10).

(2) Left-turn phase

Controlling a left turn is a key factor in signal design because the left-turn movement conflicts with the opposing through movement. Three types of phase sequences are possible for a left turn: protected left turn only, permissive left turn only, and a combination of both types [8]. A protected left turn means the left-turn movement does not conflict with other movements, while in a permissive left turn, conflict with opposing through movement occurs, and vehicles are allowed to make left turns only when a gap of the opposing through movement is sufficiently long. A protected left turn is a safe action, while a permissive left turn is more efficient.

In principle, a permissive left turn is applied only to an intersection with a left-turn volume lower than a threshold, and a protected left turn is used only at intersections with higher left-turn volume. No combination of protected and permissive left turns is adopted because the priority rule between through and opposite left-turn movements is not properly observed in Phnom Penh.

A three-aspect arrow lantern was introduced to intersections where the protected left turn is applied in order to control the movements of through and left turns separately.

(3) Additional left turn lane at intersection

At an intersection where the left-turn volume is high and the road width is wide enough, an exclusive left turn lane is provided to intersection approach. This is an additional lane near the intersection that is clearly marked with left-turn arrow symbols on the pavement.

(4) Pedestrian lantern

Pedestrian lanterns (red standing and green walking symbols) are provided at all pedestrian crossings at signalized intersections to guide pedestrians as to when to cross and when to stop and wait at the pedestrian crossing.

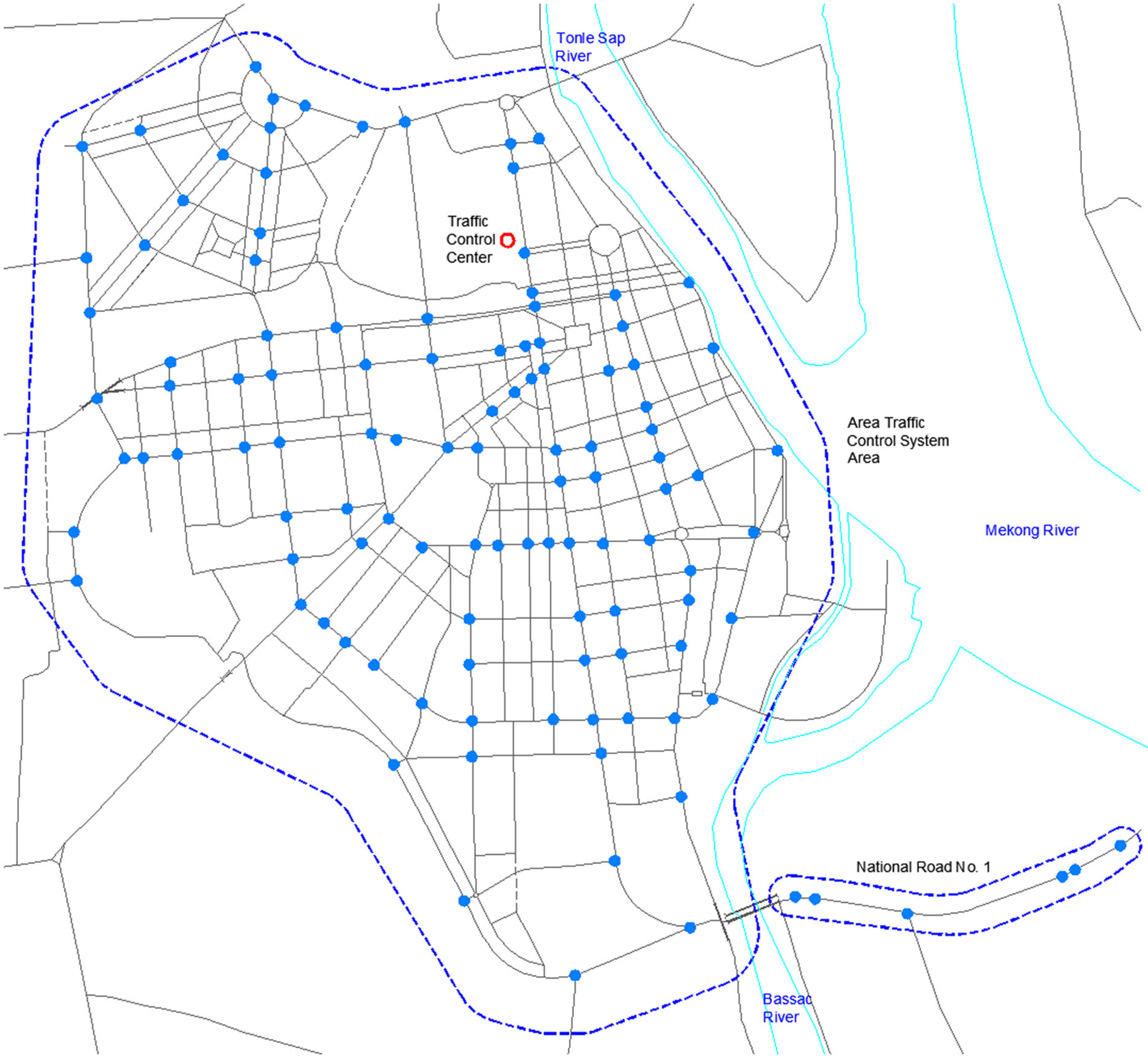

Fig. 6. Project area.

5. Associated traffic engineering works

5.1. Pavement markings

Pavement markings (center lines, lane lines, stop lines, pedestrian crossings, arrow symbols, etc.) are effective tools to guide the traffic flow and enhance safety. Previously there were markings on the road, but they were not renewed periodically. Moreover, the existing pavement markings were drawn without proper traffic engineering considerations. Marking renewal work simply followed the existing markings, and inadequate markings were inherited for many years.

The project included the renewal of pavement markings with new layouts. First, design standards were established such as the lane width, location and size of pedestrian crossing, length of additional left turn lane, and location and type of arrow symbols. (See Fig. 12).

5.2. Traffic signs

Among the variety of traffic signs, only traffic signs related to vehicle movement at an intersection (No Entry, No Right Turn, and No Left Turn) are renewed or newly installed by the project. Some of the traffic signs are mounted on the mast arm of the signal lantern for better recognition.

5.3. Median dividers

A median divider is a physical block that prevents vehicles and pedestrians from crossing. Previously, different types of median dividers (steel fence, low concrete block, and high concrete block) were used without rules. Only high concrete block is used by the project, with some exceptional cases for narrow roads. Sections covered by a divider are extended to an entire section between two signalized intersections in some sections to prevent motorcycles from moving to the wrong side of the road, which was often observed in the past. The layout of the median divider was reviewed and adjusted in conjunction with the pavement marking design. (See Fig. 11).

6. Features of the system

The new signal system completely replaced the existing outdated, pre-timed time signals. Signal controllers, lanterns, and signal poles were all renewed, and a central server system, communication network, vehicle detectors and traffic surveillance video cameras were introduced to establish an area traffic control system. There were no legacy devices or standards to be kept and incorporated into the new system. The signal system took advantage of this design condition and has the following features:

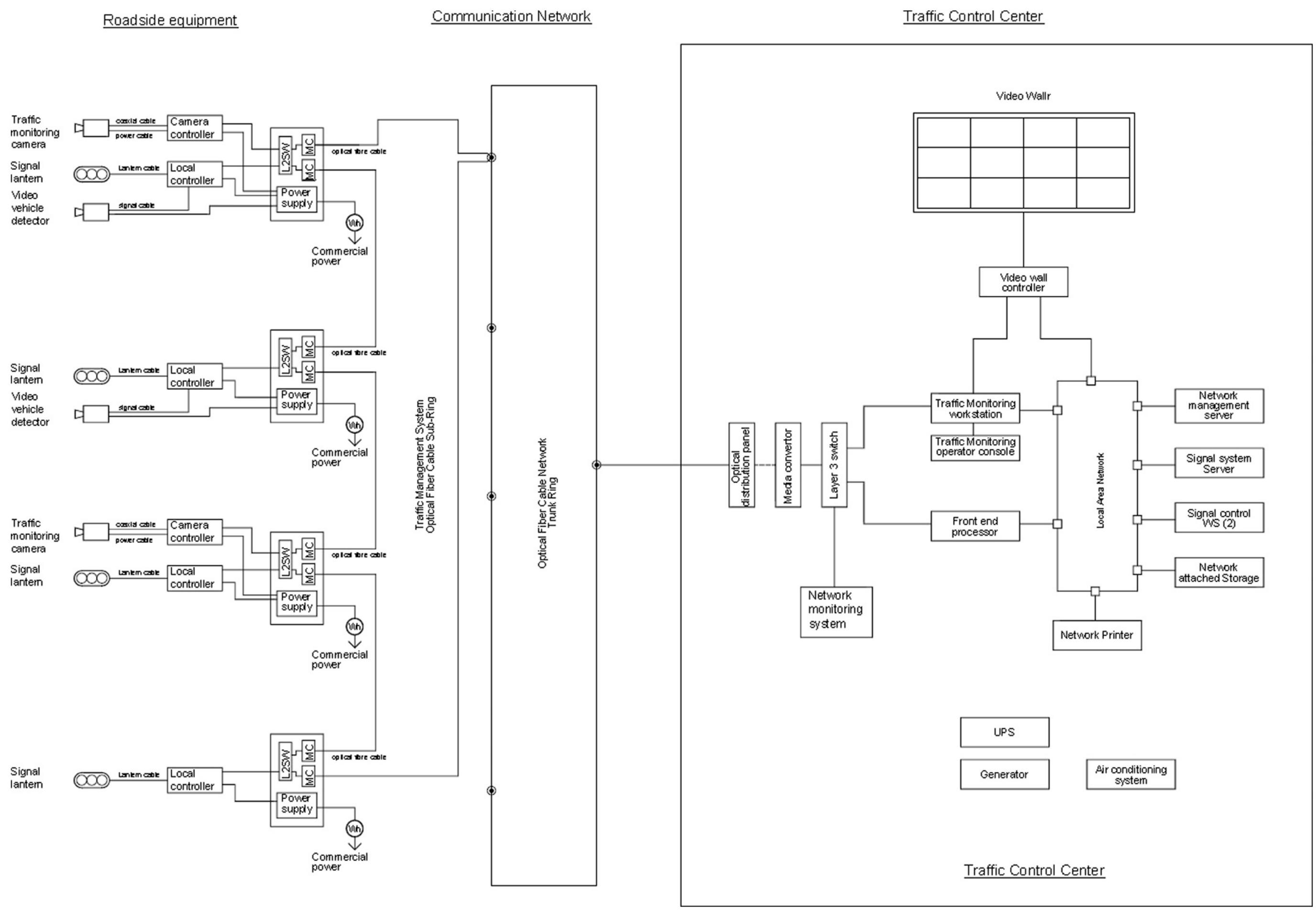

Fig. 7. System configuration.

(1) High-reliability local controller with redundant fail-safe functions

A traffic signal is a device that controls vehicle and pedestrian flow. As such, high reliability is required for a local controller. The system adopts a local controller with a record of high reliability of mean time between failures (MTBF) of more than 300,000 h. In addition, a redundant backup function is provided to the local controller, which keeps operating even if the main processor stops working. In addition, the system has a green conflict monitor that is common to the local controller.

(2) Use of video vehicle detector

Traditionally inductive-loop and ultrasonic vehicle detectors have been used in signal systems. They have advantages and disadvantages.

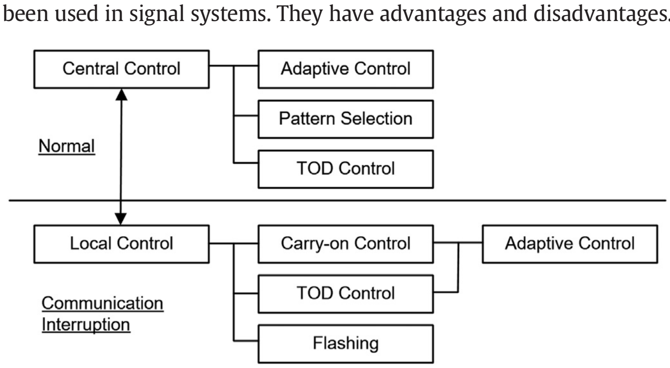

Fig. 8. Signal control mode.

A disadvantage common to both types is that the sensing area is fixed once the detector is installed, and cannot be adjusted.

The traffic flow in Phnom Penh is characterized by mixed traffic of different types of vehicles. Vehicles ignore lane lines and take any position, and motorcycles weave between passenger cars. A vehicle detector with a fixed sensing area does not detect vehicles and count them accurately under such conditions.

On the other hand, a video vehicle detector applies image recognition technology and identifies the vehicles in the coverage area, which

Table 2
Signal control modes.

Level	Mode	Signal timing parameters
Central control	Adaptive	Created based on data gathered by vehicle detectors dynamically
	Pattern	Selected from predefined sets based on data gathered by vehicle detectors at fixed intervals
	Time-of-day (TOD)	Selected from predefined sets based on current time and day of the week at fixed interval
Local control	Carry-on control	Same timing parameters provided by central control at time of communication interruption are continuously applied to avoid sudden changes
	TOD control	Selected from predefined sets stored in local controller based on current time and day of the week at fixed interval
	Adaptive	Green time adjusted based on vehicle detection data by vehicle detector in real time
	Flashing	Lanterns show flashing red or yellow during night if specified, or when abnormalities are detected in signal operation

Fig. 9. Newly installed signal.

is much wider and longer than the sensing area of a traditional vehicle detector regardless of lateral position.

Another merit of the video vehicle detector is that it can be installed away from the sensing area, and a long feeder cable is not required. In Phnom Penh, the installation of aerial cables along major roads is strictly prohibited, and pavement conditions are not suitable for installing detector feeder lines under the pavement.

(3) Extensive use of adaptive control

In order to make full use of the video vehicle detector, adaptive control, which adjusts the signal timing during every cycle in real time, is introduced to 13 key intersections. This is an effective method to reduce green time wasted and the waiting time of vehicles on a crossroad.

(4) Improved pavement marking

Existing pavement markings were reviewed from the traffic engineering viewpoint, and markings were newly designed for all intersections.

One of the safety improvements achieved by the pavement markings is the provision for left turn lanes. Although left turn lanes existed

Fig. 11. Median divider.

in the old design, they were a continuation of the through lane so that through traffic could proceed.

Left turn lanes separate from the through lanes were provided near intersections by the project. As a result, left-turn traffic can now safely stay in its lane without blocking through traffic until it makes a left turn.

7. Project assessment method

7.1. Benefits of signal control system

The area traffic control system being introduced is expected to produce various benefits. The report issued by the U.S. Department of Transportation [9] lists the following benefits to be brought about by traffic control system:

- Travel time reduction
- Increase in average speed
- Fuel consumption reduction
- Emissions reduction

Fig. 10. Newly installed signal with video vehicle detector above.

Fig. 12. Pavement markings.

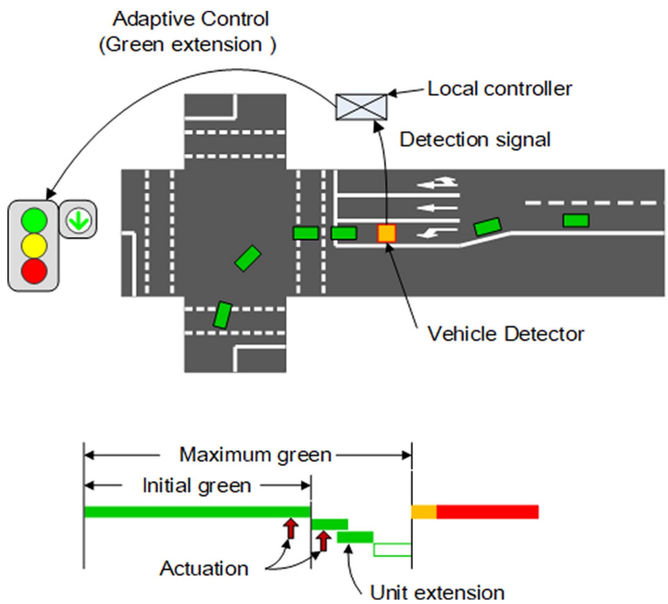

Fig. 13. Adaptive control applied to left turn phase.

- Stop reduction
- Delay reduction
- Crash reduction

The system being introduced to Phnom Penh is expected to produce the same benefits, although their scale may vary. It is noted, however, that in order to examine the benefits listed above, survey must be conducted at a large scale and data must be collected before and after the introduction of the system. Moreover, the survey with and without new feature must be conducted with the same traffic condition. This precondition is not attainable at Phnom Penh where the number of vehicle increases more than 10% annually and traffic condition changes quickly.

Due to the reason above and as the system is still under development when the survey was planned, system-wide survey was not conducted. Instead, survey of the effectiveness of the newly introduced signal control function at selected intersections was conducted.

7.2. Adaptive control

Although the system is still not fully adjusted, all of new signals are operating with advanced functions that the old signals lacked. One of the new features is the adaptive control of signals. Normally, a traffic signal in an area traffic control system operates with a timing parameter set that is updated at fixed intervals (every 5 min, for example). The new signal employs adaptive control and adjusts the timing in real time based on the vehicle detector data. If a vehicle approaching an intersection is detected at the end of a green, the green time is extended to allow the vehicle to pass through the intersection. On the other hand, if no vehicle is detected during the green time, the green is cut short and a green signal is shown to the other approach. Thus, signal operation becomes more efficient, in particular if applied to left turn phase as the number of left turning vehicles normally varies largely every signal cycle. (See Fig. 13).

The function can be applied to one of more approaches at an intersection. If used in an area traffic control system where many signals operate in a network, however, there is a constraint of keeping the cycle time to maintain the coordination with the neighboring signal.

This adaptive control is provided to the 42 approaches of 13 signals located at key intersections in the city.

8. Investigation results

8.1. Outline of survey

In order to confirm the effectiveness of the function, a survey was planned at two intersections: 002 Hotel Sor and 010 Bokor in March 2018. Both intersections are located along Monivong Boulevard, a thoroughfare in the city. At 002, adaptive control was applied to the left turn lane on all four approaches, while at 010 it was applied to the left turn lane on north and south approaches only.

Queue length along the approach was used as an indicator of the signal performance as it represents the delay incurred by vehicles at intersection. The queue length on the approach with adaptive control function is measured under two cases: with and without adaptive control. When adaptive control is disabled, the signal operates with a fixed interval for every signal indication, while the signal duration varies based on the vehicle arrival during adaptive control. Video covering the intersection was also taken during the survey. The directional traffic count was then obtained from the video to verify that the traffic volume is at the same level when different control modes are applied.

The survey was conducted for 2 h, during which the signal was set to operate with fixed timing for the first hour, followed by adaptive control during the next hour. During the survey, the queue length from the stop line along the approach was measured every 15 s manually by the survey staff.

8.2. Traffic volume

The directional traffic volume during the survey was counted by playing back the video taken during the survey. At 002 Hotel Sor, the

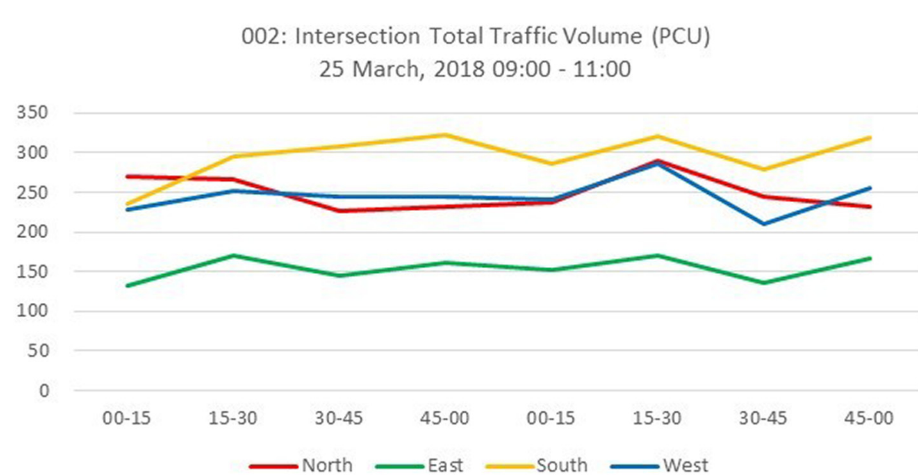

Fig. 14. Traffic volume at 002 Hotel Sor.

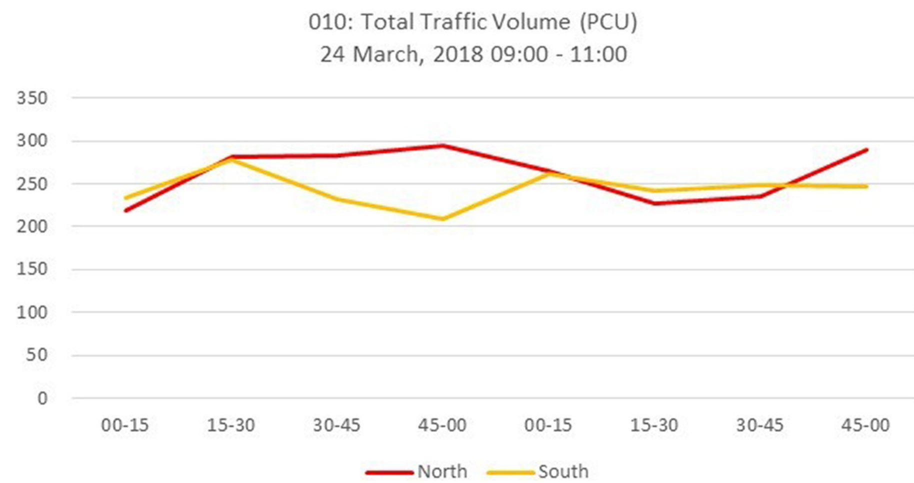

Fig. 15. Traffic volume at 010 Bokor.

traffic volume was counted for all approaches as adaptive control was applied to all of them. On the other hand, only the traffic volume of the north and south approaches was counted at 010 Bokor as adaptive control was applied to these approaches only.

The actual count of various types of vehicles was converted to Passenger Car Units (PCUs) by applying conversion factors used in Phnom Penh. This is necessary because different types of vehicles such as motorcycles and passenger cars have different impacts on signal operation.

The 15-min traffic volume is shown in Figs. 14 and 15. The adaptive control was disabled during the first hour, and it was applied during the second hour. The graphs show that the traffic volume was at the same level, and the difference in 1 h of total traffic volume was 2.3% and 0.7% for 002 and 010 intersections, respectively.

8.3. Survey results

Sum of the queue lengths along the approaches under survey is used as performance indicator. The reason for adopting the total queue length is that the signal operates under the constraint of specified cycle length. When a phase duration is shortened or lengthened, duration of other phases must be adjusted to keep the specified cycle time. It is not possible to attain the optimum signal duration for all phases.

The queue length data, which is the sum of the queue lengths of the approaches under survey, is shown in Figs. 16 and 17. for the two intersections.

The survey results are summarized in Table 3. At 002 Hotel Sor intersection, the hourly traffic volume (the sum of two approaches) increased 2.3% and the total queue length (the sum of two approaches) during adaptive control decreased by 12.3%. On the other hand, total traffic volume (four approaches) decreased by −0.7% and the average queue length decreased by 12.1% at 010. In short, adaptive control did not necessarily reduce the total queue length at the intersection.

The results of the survey are interpreted as follows:

- At 002 Hotel Sor, the queue remains even at the end of the green, indicating that the intersection is fully saturated. The survey data shows that queue seldom disappears during the survey time on all approaches. In other words, total traffic demand at the intersection often exceeds the intersection capacity.
- As a result, the green time was always extended to the maximum resulting in the fix time operation without adaptive control. This situation is called “Max Out” [10]. Further analysis is necessary and signal timing must be reviewed and adjusted, if possible.
- At 010 Bakor, the intersection was not saturated, and adaptive control worked effectively in reducing the total queue length.

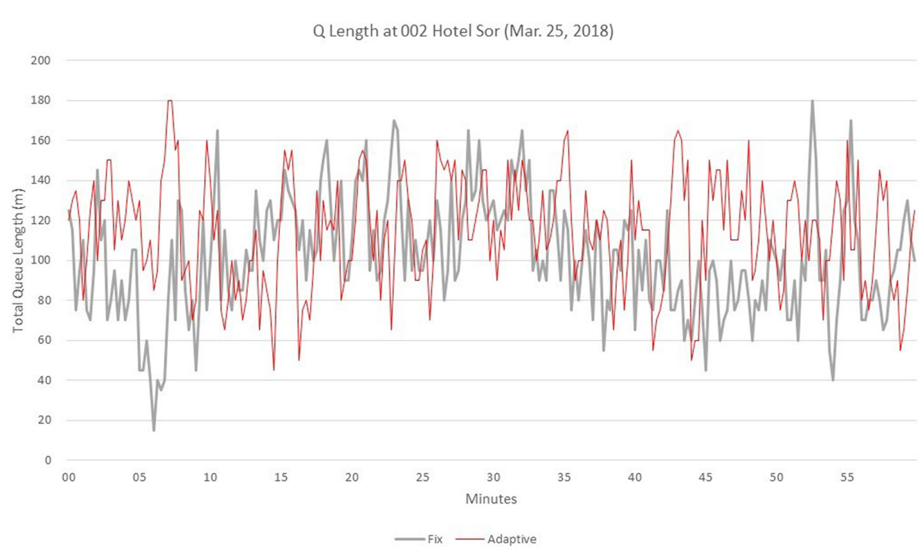

Fig. 16. Total queue length along four approaches at 002 Hotel Sor.

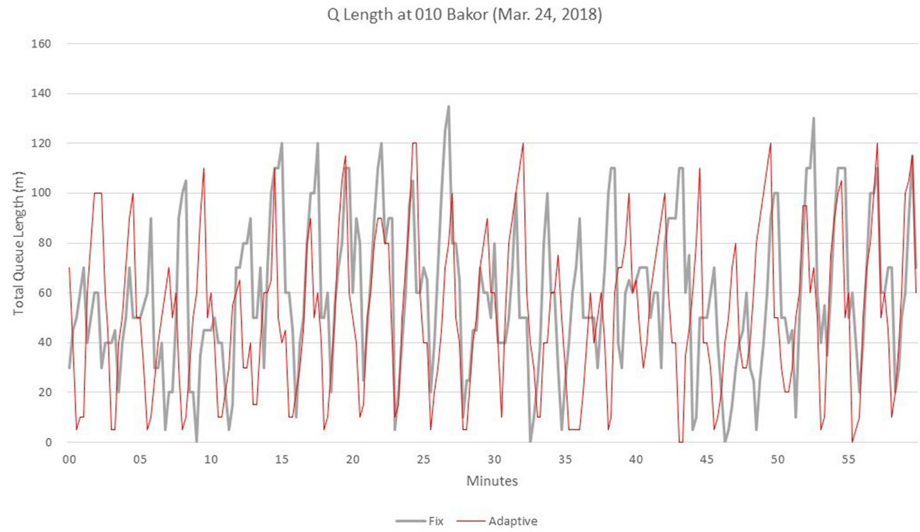

Fig. 17. Total queue length along two approaches at 010 Bokor.

Table 3
Queue Length Survey Results.

	002			010		
	Fixed	Adaptive	Difference	Fixed	Adaptive	Difference
Total traffic volume (PCU)	3736	3826	2.3%	2029	2015	−0.7%
Average queue length (m)	101.6	114.1	12.3%	58.7	51.6	−12.1%

- It is not clear that how the 2.3% increase in traffic volume contributed to the 12.3% increase in the average queue length at 002. Likewise, decrease in traffic volume may have affected the decrease in queue length at 010.

8.4. Future challenges

The project is still underway and is scheduled to be completed in December 2018. Once completed, it is expected to exhibit the benefits of a better and safe traffic environment. In order to maximize and maintain the benefits of the new signal system, continuous efforts are required in the following areas:

- Proper operation and maintenance of the system are essential for the system to keep functioning. As part of the operation, the signal timing parameters must be reviewed and updated periodically to cope with changes in traffic.
- With the increasing number of vehicles, traffic conditions will change, and the requirements for the signal system will also change. Expansion and upgrading of the system in the near future is inevitable.
- For the tasks above, the capacity of the personnel of the organization engaged in the system and traffic management must be developed.
- Road user education and campaigns as to traffic rules and safety are urgent tasks to be carried out. In particular, safety education for the younger generation, who are the majority of motorcycle riders, is an urgent task.

9. Conclusion

A comprehensive traffic management project for an area traffic control system and other traffic management works has been undertaken in Phnom Penh. The area traffic control system introduced is a state-of-the-art signal system. At the same time, the characteristics of road traffic particular to Phnom Penh are also taken into consideration in the design. This signal system, in conjunction with other traffic management improvement works, is expected to make the traffic environment in the city efficient and safer.

Efficient operation and adequate maintenance are crucial for the signal system and other improvement works continue to be effective. Efforts must be continuously exercised as more vehicles are expected and traffic conditions change over time.

Traffic efficiency and safety are not attained by the traffic engineering works only. Education and enforcement are equally important for better and safer traffic. Now that Phnom Penh has the latest traffic engineering facilities, enforcement and education must also be strengthened.

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