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# Holistic framework for optimisation of life-cycle maintenance of the Hong Kong traffic signal system

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A central control traffic signal system covering 1800 signalised junctions is operating round the clock in Hong Kong for proper allocation of the right-of-ways at road junctions and safe movement of vehicles and pedestrians in the built-up area, concentrated in less than 30% of this small city of 1100 km$^2$. The Electrical and Mechanical Services Department (EMSD) of the HKSAR Government is responsible for maintaining this territory-wide traffic signal system, which is centrally controlled by computer systems installed at Area Traffic Control centres, providing optimum traffic signal timings to minimise vehicular stops, journey times and delays of motorists and pedestrians. To optimise life-cycle management of these systems, EMSD implemented a holistic asset management system including compliance with the Publicly Available Specification 55 as well as a geographical information system (GIS) interface with real-time asset condition representations. The GIS is under development as part and parcel of the framework for further enhancement of the life-cycle maintenance and effectiveness of the asset management system.

**Keywords:** traffic signal system; Area Traffic Control; adaptive control; asset management system; PAS 55; geographic information system





## Introduction

A well-developed transport infrastructure is indispensable for every metropolis in the world. A modern traffic signal system serves to cut down travelling time and improve road safety, contributing to a huge economic benefit.

A typical signalised traffic junction consists of a junction controller, lamp poles, visible and audible traffic signals and other associated equipment such as pushbuttons for pedestrians, signal cable and vehicle detector loops (Figure 1).

A visible traffic signal, often called traffic signal lamp, or simply traffic lamp or traffic light, gives out three colours of light (red, amber and green) in sequence to tell drivers and pedestrians when to stop and when they can go. Similarly, audible traffic signals provide an indication to visually impaired persons on the prevailing pedestrian signals' states at road crossings. Q2

The junction controller is the "brain" of a signalised junction. It controls different phases of traffic signals. The signal time depends on traffic plans designed by the traffic engineer. There are often several plans for execution at different times of the day and different days of the week (e.g. plans for peak/off-peak hours and weekdays/weekends). Real-time traffic flow is detected by vehicle detectors embedded underneath road lanes and is used to determine optimum traffic signal timings.

With the advance of intelligent transport system technology, co-ordinated control of traffic lights is now common in major cities around the world. Junction controllers are connected to a central computer, enabling real-time monitoring and control of traffic signals using a pre-defined adaptive control algorithm.

## Traffic signal systems in Hong Kong

Hong Kong is a highly urbanised cosmopolitan city with the populated area concentrated in less than 30% of this small city of 1100 km$^2$. A central control traffic signal system covering over 1800 signalised junctions [1] is operating round the clock for the allocation of the right-of-ways properly at road junctions for safe movement of vehicles and pedestrians.

A stand-alone traffic light was first installed in Hong Kong in the 1960s. The first computerised Area Traffic Control (ATC) system started operation in 1977 when ATC junction controllers were installed as a pilot scheme in Western Kowloon of Hong Kong,[2] enabling

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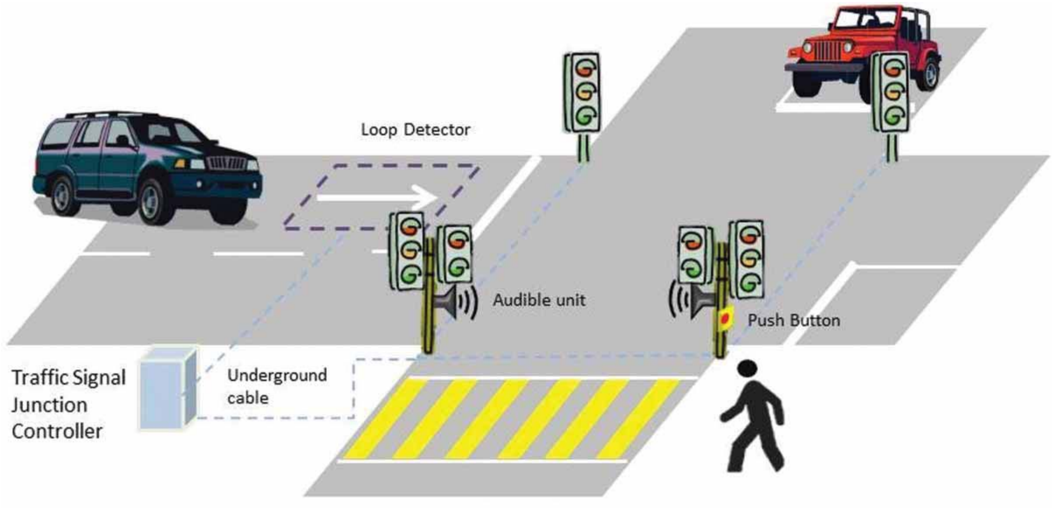


Figure 1. Typical equipment of a signalised junction.

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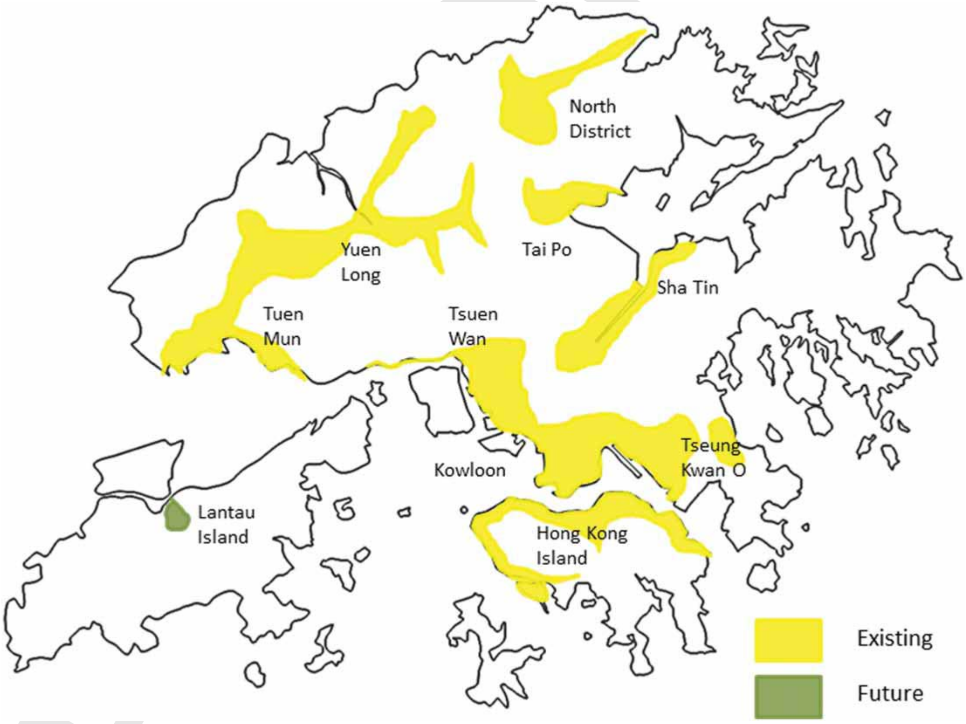


Figure 2. Districts in Hong Kong with ATC.

round-the-clock monitoring and controlling of the states of traffic signals at the junctions. Road efficiency was significantly improved as a result and ATC junction controllers were subsequently widely deployed to other districts of Hong Kong. There are now three ATC centres monitoring 1700 junction controllers and controlling traffic signals throughout Hong Kong in real time according to the prevailing traffic conditions. There are other 100 non-ATC junction controllers scheduled for connection to these three ATC centres in the coming few years (Figure 2).

Vehicle flow information is collected by the junction controller via detector loops installed beneath vehicle lanes. Vehicles are detected by means of electromagnetic induction. Real-time information such as the number of vehicles travelling through detector loops, time gap between cars and the average moving speed of vehicles can be measured and calculated. Such information is passed to the ATC central server for analysis. Making use of an adaptive control algorithm, the central server would automatically determine the optimised traffic plan over an individual or a group of junctions based on their

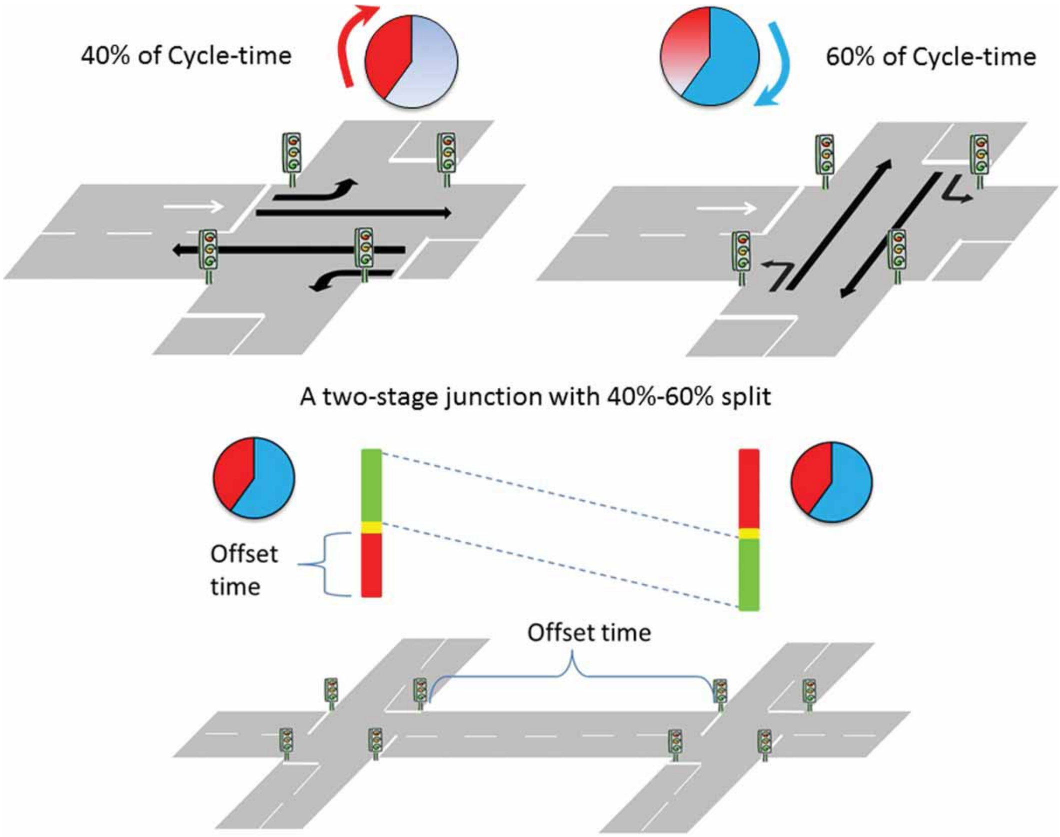


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Figure 3. Split, cycle time and offset time in traffic signal control.



traffic conditions, which can be expressed as a variation of three parameters, namely, "split" – the duration of green light for each approach, "cycle time" – the total time for completing all stages of signals for a junction and "offset time" – the time for a vehicle driving through consecutive junctions, as depicted in Figure 3. The optimised plan would then be sent back to the junction controllers for adjusting the duration of green lights of different directions in order to achieve area traffic optimisation. This real-time optimisation, namely traffic adaptive control, can minimise traffic delay and congestion.

Furthermore, with the help of CCTV cameras installed at major road sections and junctions for traffic monitoring, traffic signal timings can be adjusted quickly for individual junctions or a group of junctions by the operators in the ATC centres to better manage traffic flows and handle ad hoc incidents. Figure 4 shows one of the ATC centres in Hong Kong.

In the case of failure of communication between the ATC centre and the junction controller, the latter can still operate by its own, sending out alternate signal phases according to local traffic plans stored in the junction controller.

It is estimated that the use of the ATC system in Hong Kong has reduced journey time and number of stops by 30%, and stopping time by 50%.[4] Fuel consumption and pollutant emission can also be reduced by 15–18% as a result.[5]

## Maintenance of traffic signal systems

The planning, upgrading and replacement of all traffic signal systems are initiated and undertaken by the Transport Department (TD) of the Hong Kong Special Administrative Region Government, whilst the Electrical and Mechanical Services Department (EMSD) looks after their maintenance. Since its formation as the Electrical and Mechanical Office way back in 1948, EMSD has been providing electrical and mechanical engineering services, including traffic signal systems to government departments (Figure 5).

Today, a team of 60 dedicated professional and technical staff of EMSD and its contractors are responsible for the installation and maintenance of traffic signal systems in Hong Kong.

Maintenance practice of traffic signal systems has evolved with time. To name a few, in the past, substantial manpower was deployed to patrol the streets for spotting traffic signal malfunction. With intelligent networking of traffic signal equipment with the ATC centres, traffic signal faults can now be instantly detected in the central computer. Patrolling nowadays takes on a different

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Figure 4. An ATC Centre in Hong Kong.

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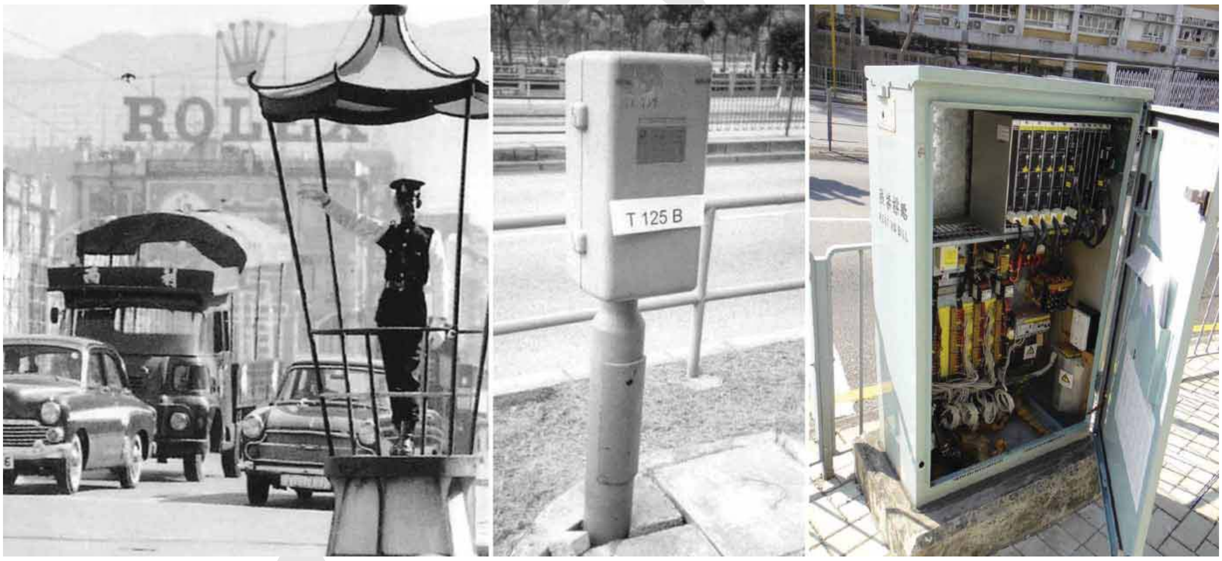


Figure 5. Traffic pagoda (left), early type of traffic signal controller [2] (middle) and latest ATC-connected controller (right) maintained by EMSD.

form – it is performed en route to junctions scheduled for preventive maintenance, and maintenance issues such as tilted signal poles, misaligned lampheads and dirty or rusty equipment are identified, which cannot be detected by the ATC system. In the past, there was troubleshooting of controller faults and maintenance occurred down Q3 to the component level. Nowadays, junction controllers come with self-diagnostic functions that allow easy fault identification, which hugely reduces junction down time.

## Asset management of traffic signal systems

Apart from equipment ageing and system expansion, traffic signal systems and associated equipment distributed throughout the roads of Hong Kong are exposed to all kinds of weather phenomena – from the dry, cool winters to the wet and hot summers, from tropical cyclones to torrential rain and thunderstorms. They are also prone to direct damage by traffic accidents. Underground cables are sometimes damaged by excavation works. With a view to improving the reliability and performance of the equipment, which is of paramount importance in ensuring road safety, EMSD implemented in 2013 an asset management system, which is based on the Publicly Available Specification (PAS) 55, for the maintenance of the traffic signal system in Hong Kong.

The PAS 55 is a specification for the optimised management of physical assets published by the British Standards Institution (BSI). Developed by the Institute of Asset Management in collaboration with the BSI,

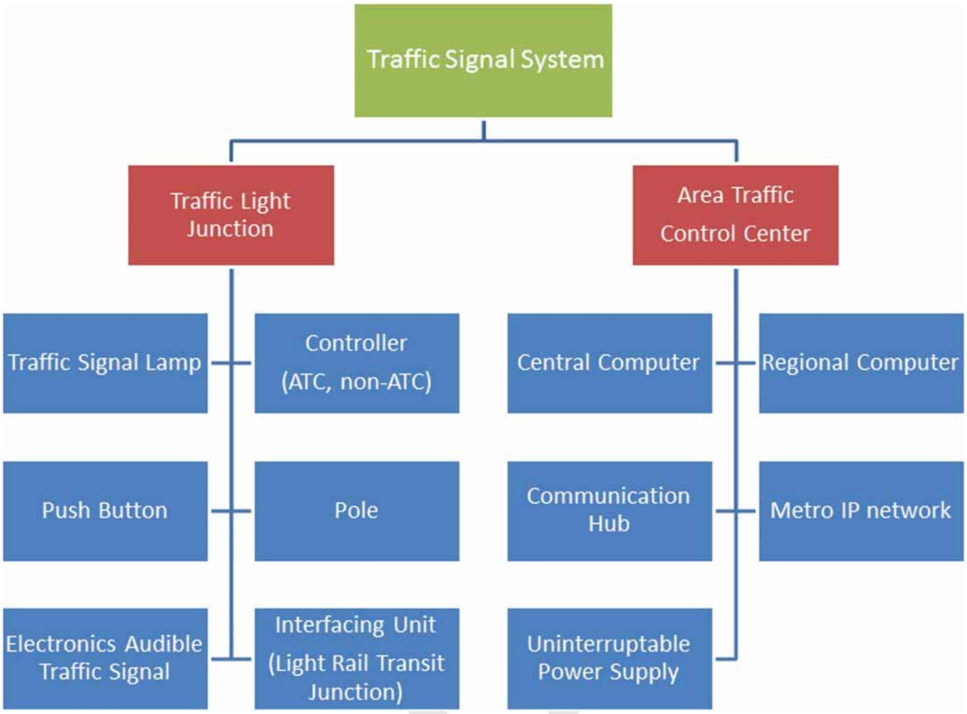


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Figure 6. Asset categorisation of a traffic signal system.



it provides clear definitions for the optimised management of physical assets. The PAS 55 was first published in April 2004. Since then, it has attracted widespread adoption in utilities, transport, mining, process and manufacturing industries around the world, from the oil and gas industry in the North Sea to the public sector in Australia.[6] The International Standards Organisation (ISO) also used PAS 55 as the basis for development of the new ISO 55000 series[1] of international standards on asset management, which were published in January 2014.

The requirements of the PAS 55 follow the familiar plan-do-check-act framework, similar to other management systems such as ISO 9001, ISO 14001 and OHSAS 18001, all of which have already been implemented in EMSD. The establishment of the PAS 55 for traffic signal systems provides a systematic and holistic framework for optimisation of lifecycle management of traffic signal equipment assets. While PAS 55 emphasises on balancing performance, risk and cost, the main objectives in implementing PAS 55 for traffic signal equipment in EMSD are to improve maintenance performance, sustain the reliability and serviceability of traffic signal equipment, and reduce the risk associated with traffic signal failure, which help realise the public value of EMSD's maintenance service.

The assets in the traffic signal systems are categorised in a simple two-level structure, as shown in Figure 6. All the key personnel in the maintenance team were involved in interactive sessions including setting up the asset registry, developing asset management plan, performing risk assessment and root cause analysis, and drawing up risk management and contingency procedure to mitigate the risks of failure of different assets.

A critical self-assessment based on past incidents and media compliant cases was performed, followed by internal and external audits, to ensure the robustness of the PAS 55 system in dealing with maintenance issues encountered during different stages of the equipment life.

The PAS 55 system for traffic signal systems was implemented in August 2013. General improvement in maintenance performance was observed, and the media attention once given to the maintenance of traffic signal systems appears to have subsided since the implementation of this asset management system.

## Benefits in implementing the asset management system

### *Increased staff alertness on traffic signal system failure*

Through the participation of the key members of the traffic signal maintenance team in the development of the PAS 55 system and the brainstorming sessions for asset condition assessment and risk assessment, staff awareness of the risk and consequence, and the alertness of various failures of traffic signal systems were significantly enhanced. All team members were aware of a much wider perspective of the maintenance of the system to prevent traffic signal failure.

### *Better prioritisation for asset replacement*

The comprehensive and regular review of asset condition implemented in the PAS 55 system enabled a more systematic prioritisation of asset replacement, and an early notification to TD, the asset owner, for arranging funding for timely replacement of aged or deteriorating assets.

### *Enhancement in maintenance procedure*

Following detailed risk assessments, new risk mitigation measures, which would help reduce failures, were identified and the associated maintenance procedure was revised and implemented. The initial statistic of fault data collected since August 2013 showed encouraging signs of improvement.

### *Enhancement in monitoring and response to failure*

With the critical analysis of past failures and complaint cases, the maintenance team identified and implemented a number of improvement measures, including the implementation of a two-tier monitoring system to ensure timely feedback of repair status to complainants, enhancement of fault data collection and analysis, taking immediate action to investigate in repeated junction controller failures at the same junctions.

### *Continuous improvement*

An asset management plan has been developed laying down the specific tasks and activities required to optimise performance while balancing the cost and risk. The management cycle of our Asset Management System is illustrated in Figure 7.

The condition of each asset group, associated risk and the failure rate over the past year will be reviewed annually. Specific maintenance activities would be prioritised


Figure 7. A plan-do-check-act framework.

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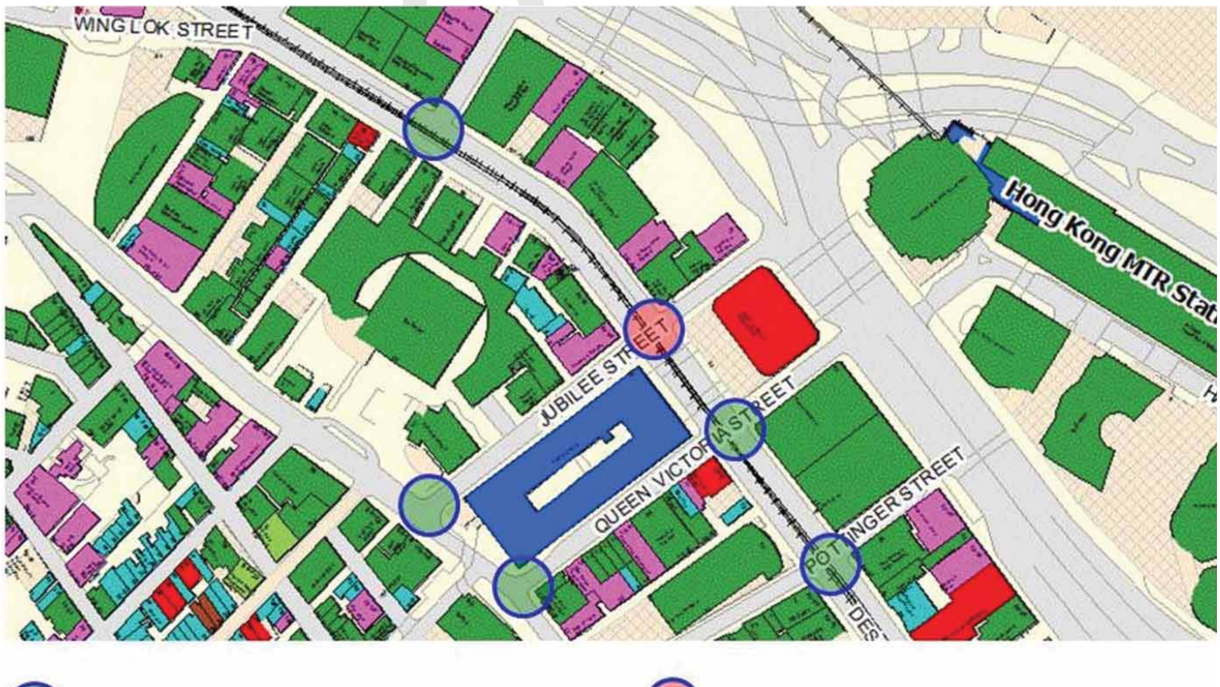


Figure 8. An illustration of signalised junctions on a GIS interface.

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for the forthcoming year to address the risk identified. The prioritisation would also consider the overall system performance, risk severity and the cost implication.

Following the maintenance plan, specific tasks are arranged. For example, the surge protector would be inspected before the rain season to ensure sufficient protection to the equipment.

At the end of each month, failure data would be consolidated for analysis. Any suspicious fault as well as high repeated failure frequency at the same junction would be further investigated. This could help identify the need for further corrective maintenance.

The overall performance of the AMS would be reviewed for developing the maintenance plan of the next cycle. Such a process helps in the continuous improvement of the traffic signal assets.

### *AMS performance*

Since the implementation of AMS in August 2013, the number of critical faults over the past eight months (i.e. junction black-out) has reduced by 7% as compared to the same period in the previous year. As junction black-out is much more likely to occur during adverse weather, the improvement becomes even more noteworthy as the rainfall during the eight-month period since the implementation of the AMS was 31% higher than the same period in 2012/2013.[7]

## Further development

### *Integration of traffic signal assets with geographic information system*

As there are a huge number of traffic signal assets distributed over the territory of Hong Kong, a part-and-parcel project is under way for the integration of the asset databases with a geographic information system (GIS). The features that will be introduced include representation of asset inventory with real-time equipment condition on a GIS, conditional display of selected junctions based on user-specified criteria and route planning for patrolling of traffic signal systems. The integration of the asset databases with the GIS will greatly improve the user-friendliness and life-cycle maintenance of the AMS, enable faster response to equipment failure, and enhance the effectiveness in maintenance management and replacement planning of these assets. In the long term, the feasibility of integrating other categories of assets, which is under EMSD's maintenance responsibility, with this GIS interface is being explored for better asset management, as shown in Figure 8.

## Conclusion

An area-wide network of traffic signal systems at road junctions of Hong Kong enables safe and efficient movement of vehicles and pedestrians. The implementation of ATC further enables computerised adaptive control of traffic signals, improving traffic flow and reducing congestion.

Proper maintenance of traffic signal systems is of paramount importance to ensure the safety of the public. With the implementation of the PAS 55 AMS to the maintenance of traffic signal systems, major steps were taken to assess and mitigate the risk of various failure scenarios commonly encountered. The critical internal assessment by all EMSD maintenance team members and the external assessment by a third party have proven to be a key success factor to sustain the effectiveness of the holistic framework for the AMS, which help continuously improve the reliability of traffic signal systems, and in turn ensures road safety and reduces traffic delay.

## Acknowledgements

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## Note

1. EMSD is working towards the conversion of the PAS 55 AMS for traffic signal systems to ISO 55001:2014.

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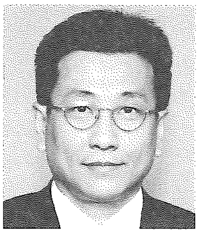

**Ir Chau Fat Chan** is the Chief Engineer of the EMSD, the HKSAR Government responsible for maintenance of transport-related engineering systems of the HKSAR Government.

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