Singapore's First Mass Rapid Transit System

The North-South and East-West Lines of the Mass Rapid Transit (MRT) System, with 42 stations and costing S$5 billion, was fully completed in July 1990, within budget and schedule. The engineering work was massive and complex. Over the course of the project, Singapore engineers acquired the necessary skills and knowledge to develop other MRT lines. It was re-known as the world’s first metro system with Platform Screen Doors that save on energy.

Today the MRT system carries about 2 million passengers per day. It serves the densely populated towns and brings the commuters directly into high employment centres and the CBD. It also serves the three regional centres. By providing good accessibility, it supports the economic growth and enhances the social well-being of Singapore residents. It has enabled dense urban development in land-scarce Singapore. The MRT was a major milestone in the transformation of Singapore into a modern metropolis.

Driverless Mass Rapid System (North East Line)

The North East Line (NEL) is the world’s first fully automated underground driverless heavy rail rapid transit line, consisting of 16 stations and stretching 20km from Punggol to HarbourFront. NEL was conceptualised as a fully automated railway with high level of system integration. At that time, new cutting edge technologies for the signalling, communication, rolling stock and integrated supervisory control systems were employed, such as microwave signalling transmission, digital trunk radio, Communication Backbone Network, in-car CCTV monitoring and fully integrated control system. One technology critical in driverless trains is the Automatic Train Operation System, which performs functions previously handled by the train driver. In addition, the Automatic Train Protection System is designed to meet a high level of safety integrity so that there is no compromise in safety.

The main advantage of a driverless MRT system is the flexibility of service deployment. The number of trains in revenue service and their frequency can be adjusted easily to meet fluctuations in travel demands, without demanding more human labour. Driverless trains are also able to follow more closely to the planned schedule compared to human operated ones. Other benefits include the reduced operation costs because less operational staff are needed, and the trains can be run at an optimum speed profile to optimise energy consumption and reduce wear and tear.

Kallang-Paya Lebar Expressway

The 12km long Kallang-Paya Lebar Expressway (KPE) is the largest and most challenging road project in Singapore. It includes 8 interchanges and 6 ventilation buildings, and connects 3 major expressways, i.e. the East Coast Parkway, Pan Island Expressway and Tampines Expressway.

The KPE includes the construction of some 9km of 6-lane underground road tunnel, which is the longest in South East Asia. The tunnels were constructed up to 25m below ground level and were up to 35m wide. The KPE tunnels are equipped with state-of-the-art technology to provide safety, comfort and a pleasant driving experience.

The construction of the KPE was carried out in very challenging ground conditions, with soft clays up to 50m depth, and as close as 3m to existing high-rise buildings. It includes construction under the Geylang River, under 2km of Pelton Canal, under 2 expressways (the ECP and PIE), under the live East-West MRT viaduct, beneath an aircraft taxiway and many major arterial roads. In particular,
Geylang River had to be moved over two stages to permit the construction of the KPE under it. Construction started in 2001 and the KPE was fully opened by the Prime Minister in September 2008.

Marina Coastal Expressway – Singapore’s First Undersea Expressway

The 5km dual five-lane Marina Coastal Expressway (MCE) is the toughest and most massive road project in Singapore. It is Singapore’s first undersea and widest road tunnel, with 3.6km tunnel, 2 facility buildings and involved 13.1ha of land reclamation.

MCE was constructed in land reclaimed from the sea in 1970s and 1980s. Extremely difficult ground conditions with soft marina clay of depth from 25m to 60m with an average depth of 45m, posed a monumental engineering challenge in building MCE.

Extensive ground improvement had to be carried out before excavation. Robust and deep temporary earth retaining walls made up of steel pipe piles, 25m to 60m long, were socketed into firm Old Alluvium. Excavation width was typically 60m, with maximum of 120m which is the widest among all road projects in Singapore to date. Maximum excavation depth was 25m. 420m stretch of MCE was built 14m beneath seabed in close proximity to Marina Barrage, whereby the soft clay extended down to 60m depth. There were interfaces with major infrastructures, like construction below the heavily used ECP and construction of North-South Railway Line Extension tunnels below MCE tunnel. The project also involved 9.1ha reclamation close to Tanjong Pagar terminal from 12 to 15m depth of water before the viaduct and piled road way were built on it.

MCE construction started in 2009. Despite massive engineering challenges, MCE was safely completed on schedule and opened on 29 December 2013.

Constructing New MRT Tunnels Crossing Existing Live MRT Lines

As Singapore’s underground space becomes more congested with various competing needs such as underground basements, utilities tunnels and MRT infrastructures, the construction of new underground MRT lines has correspondingly become more challenging, complex and pushing the boundaries of engineering.

To connect the eastern part of Singapore to the city centre, the new Downtown Line stage 3 requires new tunnels to be constructed, diving down at maximum gradient from Fort Canning Station, scrapped above the existing NEL with a 1m gap and continued to dive aggressively to avoid the piles of the National Museum before going deep at 8m below NSL and then deeper at 3m below CCL before docking at Bencoolen Station.

Construction at close proximity to 'live' tunnels, which carry hundreds of thousands of commuters daily, poses high risk to these 'live' tunnels and could results in train service disruption, crippling the public transport system for prolonged periods. To prevent such undesirable consequences from happening and to ensure a successful completion of the project, meticulous planning, design and precise execution of construction works are required. Twice-daily meetings were held to review hundreds of monitoring data, ensuring the good "health" of the live tunnels and optimal TBM operating parameters. Contingency plans were drawn up such that in the event of any undesirable readings, timely intervention could be put in place immediately to halt the condition of the “live” tunnels from deteriorating.
Construction of connecting MRT Tunnels to DTL1 (Chinatown) Undercrossing Singapore River

The construction of Downtown Line Stage 3 brings forth yet another major engineering accomplishment in Singapore. Connecting to Chinatown station, this project involves challenging construction works undercrossing the Singapore River.

It is always a challenging and arduous task to construct deep underground MRT infrastructure in a densely built-up city like Singapore, but this project entails much more, it was to be constructed underneath a water body, in the midst of top tourists spot at Clark Quay. In addition, the construction was to be carried out at just arm’s length beside the underground CTE tunnel, maintaining the waterway for tourism river cruise boats, adequate hydraulic flows to prevent flooding upstream, water to remain clean as it is connected to Marina Reservoir and notwithstanding the complexity and challenges, to complete within aggressive timeline.

Overcoming such engineering challenges requires innovative solutions, detailed planning and iterative brainstorming sessions.

The safety risk of tunnel boring machine stuck underground due to obstructions located under the Singapore River would be an incident too severe for any to bear. The consequential risk is that sinkhole would probably form, resulting in uncontainable river water gushing into the tunnel, flooding the whole MRT network.

A temporary river was first constructed as a bypassed. Debris in the riverbed along the tunnelling alignment are painstakingly removed and replaced with stabilizing material before commencing the bored tunnelling works. The tunnels under the Singapore River have since been successfully completed and the original waterway alignment has also been reinstated.

World's First Electronic Road Pricing (ERP)

Singapore’s ERP System is not only one of the world’s most innovative infrastructure development but also the world’s first integrated pay-as-you-use scheme which maximises the capacity of the road network with variable price levels updated regularly, based on traffic flows. Unlike the road toll plazas in many other countries where motorists queue up to pay the toll charges, this state-of-the-art multi-lane free flow system provides convenience to motorists with seamless payment of ERP charges.

The success of this system is further exemplified by Singapore being labelled as one of the least congested major cities in the world despite the growing urban population and limited land space, according to ‘Infrastructure 100: World Markets Report 2014’ by KPMG. In fact, the average vehicular speed for Singapore city roads is 27km/h as compared to 16km/h in London and 11 km/h in Tokyo.

In addition, the ERP system has also led to the development of Electronic Parking System (EPS) that allows automatic deduction of parking fees based on the same technologies and thus making driving in Singapore a smoother and enjoyable journey experience.

It is also not by coincidence that Singapore has received numerous delegates, from various parts of the world, who would like to learn from our ERP success story.
Symphony for ePayment - CEPAS Card for All (EZ-Link, NETS Flashplay, Concession Card)

CEPAS card provides a superlative level of convenience as it can be used in public transport as well as ERP, Electronic Parking System, taxi and retail. CEPAS card is powered by a sophisticated software engine developed wholly in-house by LTA Engineers.

Development commenced in 2004 with industry players culminating in the publication of CEPAS Standard SS518:2006. A common card platform established with ERP made Singapore the first country in the world to have a common card for both private and public transport. The project was technically challenging as the system needs to ensure high level of integrity to process the data within a short span of time interval as vehicles travel through the gantries.

Being an open standard, CEPAS now enables multiple card issuers (EZ-Link, NETS, numerous co-branded cards issued by bank e.g. DBS) to provide for use at transit, as compared to the proprietary transport card used previously. The system is designed to serve the entire population by having more than 30,000 customer touch points and an extensive back-office system that settles up to 30 million transactions daily for all public transport operators and card managers. The system settles transactions with service providers by the next operational day, which assures operators prompt payment while ensuring that transactions made by commuters are processed securely. Such processing standards are comparable to best banking practices.

In July 2010, after only one year of development, Singapore implemented Distance Fares which allow fares for a commuter’s journey across both bus and rail trips to be computed based on distance, providing a more equitable charging mechanism.

The Esplanade Bridge – a memorable, inspirational and iconic bridge across the mouth of Singapore River

The Esplanade Bridge, is a 280m long and 44.4m wide dual carriageway bridge with pedestrian footpath on both sides that spans across the Singapore River at Marina Bay. Completed in 1997, its distinctive design complements the city skyline from the waterfront and other old bridges across Singapore River.

The bridge was designed with three governing criteria. Firstly, it should allow unobstructed view of Supreme Court, City Hall and historical buildings from the sea. Secondly, the bridge must maintain the visual and physical connection between the Esplanade Theatre and Esplanade Park. Thirdly, the bridge soffit clearance must allow light water crafts to pass beneath it.

The bridge was conceptualised with a contemporary design and emphasis on clean lines of a modern engineering structure. To make it aesthetically pleasing, the bridge is divided into seven full arched spans. The bridge is designed as a reinforced concrete structure because of its intricate and complicated shape and for ease of maintenance. Triangular openings were incorporated at the pier decks connections to lighten the visual mass. Specially designed street lanterns with seamless curved pole complement the arch design of the bridge. Below the bridge, the pier features a unique diamond shaped stump with hammerhead arch. The double curvature design with vertical arch and horizontal curve resemble an inverted boat shape seen from beneath.
The Esplanade Bridge is an iconic structure created to define the mouth of Singapore River. Today, it remains an iconic feature of Marina Bay waterfront with the Merlion beaming beside it.

**Downtown Line Bugis Station**

The Downtown Line (DTL) is the longest underground rail project to date and will run through high-traffic and built-up corridors. It will be fully underground and will be built in three stages. Officially opened in December 2013, the first stage is the 4.3km long Downtown Line Stage 1 (DTL1) consisting of six stations.

The most challenging package of DTL1 was Contract 903 (C903). Totalling 600m in length, C903 runs along Rochor Road, through the Bugis Station to Queen Street. The construction and design of the DTL Bugis Station is an extremely complex one as it required a new interchange station to be interfaced with the existing and fully operational East West Line Bugis station.

Arup developed an alternative design that was 20m shallower than the initial base design, resulting in a shorter walking distance between the networks for the commuter and reducing excavation and construction cost for the LTA.

Working within a dense urban area and with limited underground space meant that it was necessary to construct the tunnels using mining techniques. This includes approximately 400 metres of mined and cut and cover tunnels. The mining method was a multi-staged operation in a complicated sequence and included a number of measures to safeguard the structural integrity of the existing Bugis Station, Beach Road and Queen Street Junction. Another construction method that was adopted when excavating very near aged buildings was the adoption of top-down construction method with cross walls to minimise wall deflection and ground settlement.

**LTA contactless smart card reader for MRT stations**

In 1999, LTA launched a tender to design a new interface for the gantries of the MRT stations with the adoption of state of the art contactless smart card readers. The new system needed to be designed to fit four different types of existing stainless steel gates and to coexist with the legacy magnetic strip readers in the initial phase of transition. The installation was inaugurated in 2000 and remained in operation until late 2014.

SMRT needed a cost effective solution that can be retrofitted to the existing gates with minimum modification. The design focused on visual feedback to the end user for the completion of the transaction, the efficiency in the communication between the card and the reader and the strength required to withstand the daily passage of millions of people. The simple streamline shape of the outer shell belies the construction of a complex part where a translucent lens is over-moulded with solid polycarbonate material using a tool with multiple inserts capable of creating the different configurations.

Beside its contribution for a significantly better flow in the train station, the project used very advanced design tools and processes, especially 3D printing, to create fast iteration of prototypes, short development time and saving cost.