



DRIVERLESS SYSTEMS THE CHALLENGE FOR THE OPERATOR AND MAINTAINER

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SUMMARY

The following paper sets out the experiences of SBS Transit Ltd in the operation and maintenance of two driverless guided transport systems in Singapore. This paper is not a detailed description of the technologies employed, but rather looks at the issues arising from the application of these technologies.

The paper commences by discussing the how the Government of Singapore recognises the role of public transport in the development of the nation and how the provision of high quality public transport is used a development tool. It then discusses the operational performance of the system to date, the operator's and maintainer's challenge unique to driverless systems and sets out challenges for the future as seen by the authors.

1. GUIDED PUBLIC TRANSPORT IN SINGAPORE

Singapore is not unique in having goals for public transport market share but it may well be in a class of its own in implementing those goals. Singapore has set policies based on a 1996 White Paper that recognised the following:

- Transport is not an end in itself but supports many aspects of economic and social life,
- The need to provide a wide spectrum of choice.
- That effective integration between modes is essential.
- Public transport includes all intermediate and end point facilities to enable door-to-door service.
- The cost of consumption must cover the cost of supply.

Further to assist in delivery of the public transport vision it has managed private transport as follows:

- A vehicle quota system was introduced in 1990 to limit car ownership.

- Electronic Road Pricing (ERP) was introduced in 1995 to manage road congestion.
- A Certificate of Entitlement (COE) has been used to influence the demand (cost) for new cars.

As a consequence, in 2005 private car ownership is about one car per ten residents and public transport accounts for 55% of daily journeys.

Singapore has spent approximately \$1 billion per annum over the past 20 years on new guided public transport, primarily rail infrastructure. Having built the early parts of the Mass Rapid Transit (MRT) system to provide existing developed areas with a world class MRT system, Singapore has pushed ahead to provide new infrastructure in advance of demand to facilitate and act as a catalyst for development in the less developed corridors of the Island. This is a result of the Government adopting a much longer planning frame than most cities or countries for both transport and land use. There is a 10 to 15 year view on the urban development and roles of all modes of transport in supporting that development. Consequently there is a better chance of an optimum outcome than the usual reactive approach found in most cities.

It was in the context of this development planning that the North East Line (NEL)

Mass Rapid Transit system and the Sengkang / Punggol Light Rapid Transit (SPLRT) system were conceived and built.

The Sengkang and Punggol areas, previously farm lands and unused land, were selected to be developed as model new towns to absorb the expected population growth. The long term urban planning allows for high density housing, community facilities and industrial development. To connect this new development and the older developed areas of Hougang, Serangoon, Potong Pasir and Boon Keng to the inner areas and the Central Business District the NEL was planned and built.

The SPLRT was conceived and built to provide transport within the new towns. The new towns are planned to have commercial and private development closest to the NEL stations hence the majority of the housing developments commence some 400 metres plus from the stations thus the need for inter-town transport. Figure 5 at the end of the paper is a map of the Singapore MRT / LRT network.

2. SINGAPORE'S NORTH EAST LINE AND SENGKANG / PUNGGOL LRT

Both of these systems are fully automated guided systems. NEL is a steel wheel on steel rail system, about 20 route km long with 16 stations fully underground from terminus to terminus. The NEL runs from Punggol new town in the north east corner of Singapore to HarbourFront in the south. At commissioning, NEL was supplied with 25 six carriage electrical multiple unit trains which apart from their fully automatic operation features are fairly conventional modern trains. It has a design capacity of 600,000 riders per day. The system began commercial operation in June 2003 and current ridership is, on average, 200,000 per day.

The SPLRT is a rubber-tyred people mover system running on an elevated concrete guideway to provide local transport within the Sengkang and Punggol new towns and in particular transport feeder services to the Sengkang and Punggol MRT stations. The route km of both LRT systems totals about 20 km. The SPLRT was supplied with 41 single carriage vehicles. In many respects the SPLRT vehicles are a guided electric bus. The Sengkang system has a design capacity of 57,000 trips per day and the

Punggol system a design capacity of 96,000 trips per day. The Sengkang East system commenced commercial operation on 20 Jan 2003. The Sengkang West and Punggol East systems commenced commercial operation on 29 Jan 2005. Current combined ridership averages about 32,000 per day. Unlike NEL, where the stations are designed to be manned the SPLRT stations are designed to be unmanned, making the SPLRT a more automated system than NEL in this respect.

The client for both systems on behalf of the Singapore Government was the Land Transport Authority (LTA) of Singapore who also undertook the project management role. In 1999 the LTA awarded the Licence for the operation of the NEL and the SPLRT to SBS Transit after a competitive tender process. In order to ensure competition in the operation of rail transport the incumbent operator Singapore Mass Rapid Transit Ltd was barred from competing for the NEL Licence.

In the case of the NEL the LTA chose to let a number of separate contracts for the main works and systems. In the case of the SPLRT the LTA chose to use a performance specification consisting of the need to move a specific number of people per given hour in a given direction. It was up to the contractor to determine how the LTA's requirements would be met.

The technical details of the major signalling and control systems are to be found in other papers presented at this conference and in other conferences.

3. OPERATIONAL PERFORMANCE

The most common question is, "How well do fully automated systems perform?" The answer in our experience is to paraphrase an old saying, "when it's good it's very good, when it's bad the potential is for it to be very bad".

In fact we would claim NEL is the most reliable metro system in the world with a current average service delivery of 99.9% and a reliability of 99.9%. The trends for service delivery and reliability since start up are shown in the Figure 1 below.

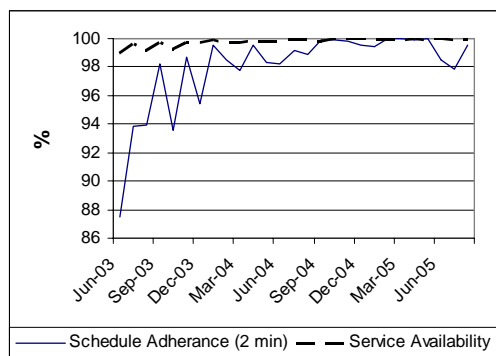


Figure 1

In the case of the SPLRT the critical measure is service delivery. It operates as a carousel service around a loop without a specific time table. Thus the measure is the total number of services delivered in the fixed operating hours compared with the number scheduled. Since start up in Jan 2003 the monthly average for this measure has never fallen below 96.24% and consistently averages over 99.9%. See Figure 2 below.

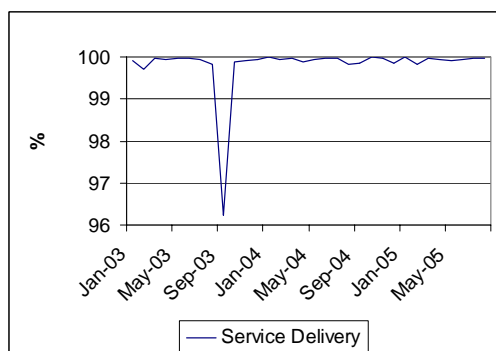


Figure 2

To achieve these figures was not without its challenges. SBS Transit management was well aware of the effect of early performance on the reputation of the system. There was the example of another driverless system in Singapore that for various valid reasons had a very difficult start up and obtained a reputation for unreliability. Today it seems to have put most of its problems behind it, but in the taxis, coffee shops and other places where Singaporeans gather to gossip away from the catchment area, it is still that unreliable system that breaks down all the time. Any incident will still result in adverse publicity out of proportion to the facts.

SBS Transit therefore took two important decisions. One, not to open the systems for public use until a minimum level of reliability had been demonstrated in trial running even if that meant running late

against published deadlines and two, to man all trains for the initial operating periods. On the SPLRT the manning was withdrawn after the first three months or so.

For NEL the manning of most service trains is still standard practice. This seems at odds with the concept of fully automated systems and the engineering purists would argue it is a waste of resources. The Operator's view is different. Their decision is based on what delays can be tolerated within the headway, currently 3.5 minutes during the morning peak. System failures are inevitable. If an unmanned train fails and cannot move in a station, the station staff are trained to undertake basic fault finding and manually operate the train if necessary. Consider a timeline for a typical incident. The train fails and sends alarms to the control centre. The control centre has to acknowledge the alarms and respond, usually first trying to recover the train remotely. There is the first minute or so gone. Then the member of station staff has to be told to attend the train. Another minute or so is lost whilst they become aware of the issue and move to the correct end of the train. Then they have to remove the cover from the driving console and attempt a local reset. By now the following train is probably delayed and the knock-on effects are starting. If the train is halted between stations accessing the train from the nearest station could well take 10 to 15 minutes. In this case the knock-on effects will have spread all along the line.

The purist may still argue that such incidents happen infrequently, thus it is still a waste of resources. We as the operator have decided to be cautious on this issue. The system was new. The community had an example of a poorly performing automatic system. The public of Singapore are particularly demanding in their expectations of train services and are unforgiving of disturbances. The reputation of the system was considered to be almost priceless. Now some services operate unmanned and no doubt the proportion of unmanned services will increase over time.

The situation of the SPLRT is different. Its stations are not manned or designed to be manned. All staff are roving, attending to passenger requirements, security etc. The circular nature of the system allows passengers to get to their destinations, all be it by a longer route if only one of the

two loops is operational. This is the most common situation. We can usually respond to a stopped vehicle in a station in less than five minutes and a vehicle stopped between stations on the viaduct in 10 to 15 minutes. Given the passenger loadings, number of incidents and the ability to complete the journey by the opposite direction this level of service has been accepted by the passengers.

The operations and maintenance challenge was made both more difficult and easier account the fact that less than 10% of staff had any previous rail experience. The lack of experience meant few preconceived ideas and therefore it was easier to train staff to our requirements. Against this benefit there was no inherited culture of respect for the railway, what it can do, and what must be done to keep it safe and reliable. SBS Transit developed carefully tailored training regimes for all its operations and maintenance staff. As a consequence some of our Rules and Procedures may be considered "over the top" when compared with older railways. We have reached the stage where some of these Rules and Procedures are now being reconsidered. Where the change proposals pass our safety analysis processes some of these rules and procedures are now being relaxed in the light of experience to improve efficiency of operations.

So much for the "very good" and how we achieved it, now for an example of the potential to be "very bad". Just over two years ago for some still unexplained reason the Uninterruptible Power Supply feeding the SPLRT main equipment room dropped its output for a few seconds causing the computers to shut down. Consequently the position of the vehicles in the network was lost to the systems and Controllers. In accordance with design all track circuits were indicated as occupied on restart of the systems. The reasoning for this is, should the system lose its memory of the situation as in the above

case, the indicated location of vehicles cannot be guaranteed. To reinitialise the system, the location of each vehicle must be physically confirmed and checked against their indicated position before restarting the operation. For those vehicles in view of the stations' CCTV it is easily done. For vehicles out of sight of the CCTV, the way to confirm their location is to walk the system. This is not a quick process.

4. FUTURE OPERATIONS AND MAINTENANCE CHALLENGES

The greatest technical challenge is likely to be management of obsolescence at a reasonable cost. Most of the critical operational systems are proprietary and supported by the supplier only. Whilst there may be a contractual obligation to support the systems for a number of years this is not spelled out and costed. The systems are all micro processor based. After only two and a half years of operation we are seeing systems that use commercially available operating systems becoming incompatible with currently available work-station hardware. Challenges of this nature can only grow over time especially if costs are to be contained at a reasonable level.

One people challenge is to keep knowledge up to date especially that pertaining to little used activities. Many of the activities taken for granted on conventional systems are exceptions to a fully automated system. The systems run like clockwork most of the time with minimal intervention. On start up, all the staff are trained for virtually all eventualities with frequent and recent drills and practice runs. To keep the knowledge up to date and usable requires an on-going programme of such drills. The staff must as ready to and competent to handle the challenges of abnormal operations on day 3065 and they were on day 165. This concept is illustrated graphically in the Figure 3 below.

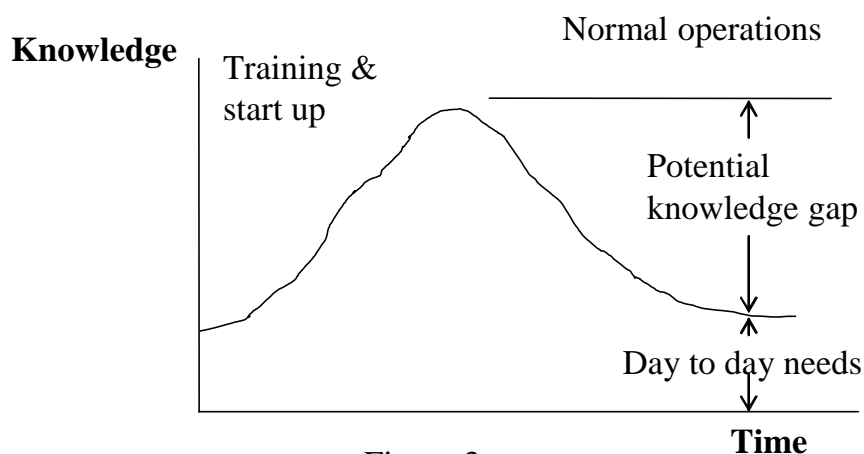


Figure 3

An operational example of this, is the need to ensure that our mobile staff remain competent to driver the vehicles. The last line of defence is a driver, and if all else fails roving staff can board the train, if not already present, and take control. To ensure that they then drive safely, they need to practise this skill on a regular basis, not only to ensure familiarity with the controls but to ensure route knowledge and understanding of operation. The vehicles are designed to be driverless and therefore have no driving cab, the operator taking control at a driving position that is not designed for use over long periods of time. It is also in the passenger area of the train. There is a contradiction in having a driverless system designed for fully automatic operation and the need to regularly practise manual operation in a system that is not designed for manual operation. This means that the complexity of carrying out the practise task increases. Also system performance falls away during these periods of manual operation as the operator cannot drive as smoothly as the computer nor keep time to the same degree.

The other major people challenge is to keep staff interested. With such complex systems the unthinking tendency is to assume that to maintain and operate such systems staff must have very high levels of qualification and knowledge. SBS Transit followed this assumption to a high degree in its original recruitment. In fact experience has shown the greater the degree of automation the lesser the level of skill required to maintain and operate the systems for most of the time.

So for preventive and routine corrective failures with "hard" faults the level of skill

required is not as high as we had thought. However, when things go wrong and transient faults occur or faults that cross the interface of many systems, a much higher level of understanding and capability is required to from our staff to understand what is going wrong and why. Even when this level of ability is available and the root cause of the failure is determined, very often there is nothing that the maintainer can do to rectify the problem as the systems, both hardware and software, are proprietary and we do not have the capability to change any of this, neither would it be cost effective to bring these skills in-house. This leads to further frustration, can lead to motivational problems for staff and potentially provides the operator with unknown ongoing costs for rectifying failures that did not occur during the warranty phase after opening.

This contradiction between day to day needs for routine works and the more complex skills required for cross discipline diagnosis and rectification is something that we have yet to fully resolve and is a major challenge for an operator of systems such as these.

5. DIFFERENCES IN MINDSET REQUIRED IN COMPARISON TO A CONVENTIONAL RAILWAY

One of the advantages of having a relatively inexperienced team, in terms of previous railway experience, is that they came with no preconceived ideas of how it will all work. The added complexity of designing the driver out means that the procedures that need to be developed and implemented are more complex as the traditional last line of defence, the driver, is removed. The simple act of going onto the

track in traffic, which is inevitable from time to time, requires far more control measures to be put in place to ensure that the personnel on the track are safe. A protection measure like the operation of a keyswitch for example, that prevents automatic train movement in a certain area is on the face of it, a straight forward process. However, the interaction between the actual staff going onto the track and the body authorising them onto the track to ensure that this is done in a safe and controlled way makes the procedures more complex with a conventional railway and introduces an increased potential for human error.

Similarly, when preparing operational recovery or fault handling scenarios the procedural complexity involved is high, not only because there is no driver, but also because in the NEL case, a moving block driverless system has been implemented. The system does not react or behave in the same way as a more traditional railway. A whole new language and understanding had to be developed to enable the procedures to be prepared. This is then cascaded into a more onerous training regime and increases difficulty of keeping large numbers of staff conversant with a multitude of complex procedures which, hopefully, are not used all the time.

A simple solution to this would be to manually operate the train in the case of an incident or track access however, this would either mean a slower response time (as the trains are either unmanned or not in manual mode if manned) and hence greater disruption, or operate the trains in manual mode all the time, but that defeats the object of being driverless in the first place.

The "simple" act of replacing the driver by engineering leads to a more complex system. It is not until you decide to remove a driver you discover just how much that one person can do! This adds a complexity that not only makes the systems more unreliable as there is more to go wrong, but also challenges the operator and maintainer to understand what is happening when things don't appear to be operating correctly as the eye witness is no longer present.

From time to time perceived failures of the system actually turn out to be the system operating as designed. However the amount of time needed to determine this may in some circumstances be quite long

as many design documents have to be referenced and a full understanding has to be gathered before a conclusion can be reached. The risk with this situation is that people may assume that something unusual is a quirk of the system and treat it as the norm. Subsequently, this could have serious consequences as the operator does not fully understand how the system they run operates.

The added complexity of the systems and the need to keep the operators in the control centre fully informed as to the state of their unmanned trains requires more information to be presented to them. The number of monitoring points and instability of systems mean that the operators can be overloaded with information and then become tolerant of higher failure rates than would be accepted on a more traditional railway. This in turn presents an increased risk profile for the operator as they get used to this is how the system is, and they could miss more critical alarms that may lead to delays or disruption to service. The flip side is that people overreact to the information that is presented to them and every alarm ends up being treated as mission critical. Education and understanding assist in taking reasonable steps to get the balance right between these two issues and to try to ensure that the correct decision is taken for any given scenario, but ultimately the risk profile for the operator is greater.

Another challenge compared to a more traditional railway, particularly for NEL, is the operation of the control centre itself. The NEL was provided with a fully integrated control system which provides the operator with a single standard interface. This is a clean engineering solution. In principle, this is advantageous as any operator can log on to any work position and carry out their role, radio, public address, telephony, train control, SCADA functions etc. through a single common-user interface. This also presents problems however. The complexity of the interface means that a number of traditionally unrelated functions can become interdependent and one failure can slow down the whole system restricting the operator's flexibility to handle degraded mode situations. This in turn means more procedures are needed to handle multiple failure scenarios at the control centre, particularly when dealing with degraded mode operation and

increases the human error risk to the operator.

Whilst the design is a clean engineering solution, the interfacing between the various systems and their interdependence for feeding a single user interface makes fault finding difficult. Multiple parties can be involved and identifying the origin of the failure. This leads to protracted investigations and longer lead times to resolve issues.

6. CHALLENGES IN THE FACE OF TERRORISM

Terrorism and the threat of terrorist attacks will be a fact of life for public transport operators for the foreseeable future. If trains or vehicles are unmanned extra resources will be required working on the system to check and clear the trains and facilities at regular intervals. It would be difficult to explain if a device was planted on an unmanned system, exploded and on investigation it transpired there was no process in place to regularly check the trains. Thus one answer is to man the trains with personnel who have a customer service, security and train operator role. This is not an engineering driven issue but an issue for the Operator who has

responsibility for such things to make a decision, even though that decision may apparently negate the benefits of the technology supplied.

7. CONCLUSION

The public transport scene in Singapore is far brighter than many countries due to the Government's long term vision and its support of that vision.

From the operational viewpoint driverless systems when they are working well produce unrivalled reliability and service delivery. The operational challenge is to deal effectively with system failures especially in the early stages when fully automatic operation is a novelty to the user.

The maintainers challenge ranges from how to access the asset, a process in our case at least, very different from conventional railways, to understanding the complexity of the systems and dealing with dichotomy created by modern technology whereby many tasks are much simpler than previous generations of technology with occasional very difficult analysis and fault finding due to the interaction of complex systems.

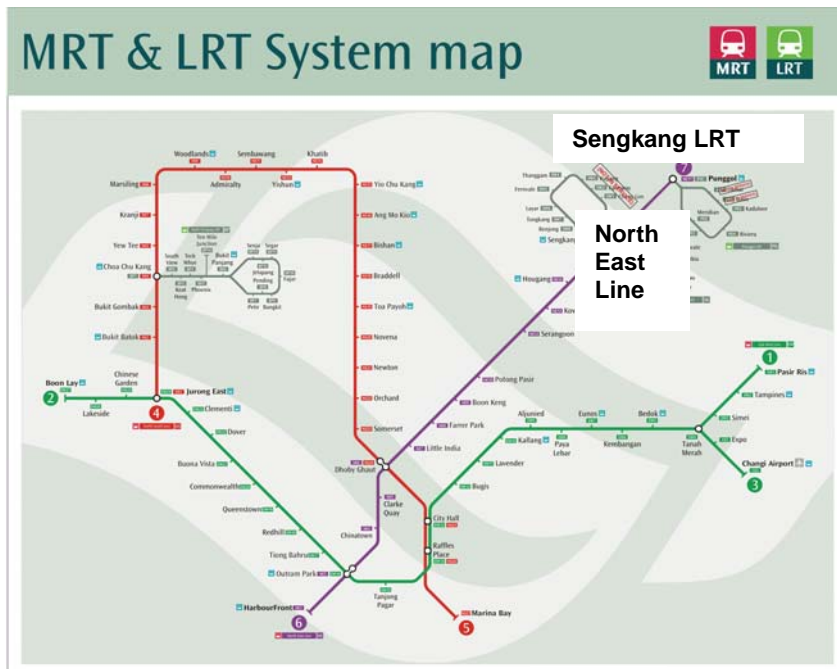


Figure 4

Punggol LRT