The Track to Suncheon: Making APMs Intelligent

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ABSTRACT

This paper will discuss the notion that the traditional concept of an APM can be developed from a simple line-haul system into a fully automated transit network (ATN) using smaller vehicles and more sophisticated control technology. Implicate in this ambition is the need to adopt a robust safety regime, which is not excessively complex or expensive to implement. At the present time, it is believed Vectus is the only vendor in the world offering a rail based PRT solution which conforms to internationally accepted mass transit and people mover standards for construction and safety.

These issues will be discussed within the context of the first commercial project being implemented by Vectus, in Suncheon bay South Korea, which will demonstrate the potential of this pioneering technology. Suncheon will showcase Vectus's design-led approach, working with world class partners such as Pininfarina in Italy, and lightweight vehicle engineering using state-of-the-art, carbon fibre composites and a revolutionary new type of space-frame bogie.

INTRODUCTION

Vectus can provide what in PRT speak is commonly termed the ‘last mile’, or perhaps several kilometers of transportation, say from a busy railway station, which might otherwise involve a taxi ride or a bus, directly into a satellite area such as a housing estate or retail centre. Because the vehicles are small-scale and lightweight, they can be carried on a much smaller, (ideally elevated) track infrastructure, requiring minimal ground take and reduced power consumption. In terms of carrying capacity, Vectus is arguably the most cost effective public-transit solution, in comparison with say a monorail or light rail system, for moving up to around ten thousand passengers per hour. Thereafter, one needs to be considering a more traditional, mass-transit mode.

The road, or more correctly the track, to Suncheon began some time ago. As the PRT community is aware, Vectus has operated a test track in Uppsala, Sweden since 2007. It comprises 400 meters of track, three vehicles and one off-line loop with a station. The vehicles are all captive to the track and employ positive mechanical guidance using on-board switches instead of conventional track-switches – which are too slow to be practical for PRT headways. Although the test track was built using in-track linear motors (LIMs), ostensibly to operate in an icy winter climate, the Vectus concept is adaptable to a variety of propulsion solutions including on-board LIMs and much lower cost, conventional rotary motors. It is this latter solution which is being used in Suncheon.

The first trial runs in Uppsala were made to verify the propulsion system and basic controls. Thereafter a rigorous programme of tests and verifications were performed, step by step, with increasingly more complex functionality to cover all aspects envisaged for a full commercial application. Most critically, this included the merging and braking of vehicles running at ever decreasing headways. This eventually led to the creation of a unique safety case and finally the test track being fully approved by the Swedish Rail Agency for PRT operation with passengers.

PERSONAL RAPID TRANSIT VERSUS APM

PRT, or 'personal rapid transit', is a very broad, generic term which Vectus has more inherited rather than inspired. It has very academic roots, and depending upon one's experience and readings of past theories and demonstrations, it can engender very different understandings and pre-dispositions amongst colleagues in the transit industry per se. Indeed there are a lot of myths and prejudices about what PRT is capable of doing and what it might actually cost to realise a fully integrated system; one capable of demonstrating in reality, rather than forever in theory, just what this potentially ground-breaking new technology might really have to offer. The situation is not helped of course by the reluctance of vendors to expose their costing models (for obvious commercial reasons) and the reluctance of risk-averse customers to invest in new solutions, however big the claims, that are as yet unproven in the market place. It is the classic chicken and egg conundrum.

In the Vectus business model, the idea of creating a purely 'personal' transit system is not the main driver. Rather, Vectus are looking for efficiency, flexibility, sustainability, low capital investment and above all, low operating cost. If one can afford passengers the luxury of travelling alone, just with friends or in family groups then this is a bonus - but it is not the absolute goal. In fact, a large proportion of 'PRT' applications being evaluated by Vectus at the moment, seem to point towards a need to be able to offer mix mode running with both small and larger vehicles carrying up to 50 passengers at a time – GRT if you will – to help manage the peak hour loads. In many instances, the Vectus emulations indicate that a GRT vehicle is by far the most cost effective solution to moving large numbers of people between key nodal points in a large network. But then doesn't all this starts to sound a bit like APM territory?

So where is exactly is the difference? Where is the crossover? When does an APM start to become a GRT, or vice versa; and how big can a PRT vehicle be before it becomes a GRT? And is all this terminology maybe getting a little bit less relevant than before, in the same way that your mobile phone can no longer be described as simply a device for just making phone calls – it can also be your camera, your diary, your GPS and your games console?

By normal understanding, an APM is a line-haul transit, sometimes on rubber-tyres, sometimes with multiple cars, that essentially oscillates between two termini and maybe has one or more intermediate stops along the way. It requires only just enough intelligence to manage ATO (automatic train operation) type functionality without the need for a driver. However, there is usually no requirement to manage any other traffic, or to switch between lines, or to avoid any stations. So sometimes a PRT system, or perhaps a certain section of it, is performing the exact same function as a traditional APM. Under those circumstances, the safety regime for a vehicle performing APM duties is relatively straight forward compared with the complexity of navigating a full-blown network. That said, of course, safety is never to be taken lightly and is always a major cost element in the implementation of any new driverless system - APM or otherwise.

INTELLIGENT CONTROL

Where Vectus starts to add value beyond the notion of simply running point-to-point, is the way that each vehicle controls its speed, position and direction, relative to all other vehicles on the system, as a method of optimising overall system capacity and efficiency. The methodology behind the Vectus control system, which will be deployed at Suncheon, can be divided into four key components: *distributed and scalable control, asynchronous control, dynamic moving block* and *optimal control*.

A distributed system means that the control is carried out locally, in pre-designated zones. If there is a fault, it only effects a small part of the system. The rest of the system will continue to work. With the distributed system there is no increase in the load for each individual control segment when the system is expanded.

With asynchronous control the flow of vehicles is handled as they each travel along their paths to their respective destinations. Merging of vehicles is managed as required on a local basis. Occasionally there may be a need to slow down to facilitate merging in switches; there may even be short queues along the route at times. Travel time may be prolonged by a few seconds, but the overall capacity of the system is maintained, which is essential to the overall ability to transport passengers during periods of high system loads.

A dynamic, moving-block vehicle protection system is superior to any fixed-block system, even if the fixed blocks are very short. It continuously updates each vehicle with information on the position of the one in front of it. With this information, each car can run, by varying its speed relative to the others, with the shortest allowed spacing based on the worst case braking performance. At lower speeds the vehicles run closer to each other; at higher speeds the distance is increased.

Then it is a matter of optimizing the logistics of the vehicles. Vectus has an adaptive-control which learns from travel patterns of traffic from previous days. This can be manually altered in the event of, for example delays in a main line train arriving at one station, or maybe special events where large crowds are generated. Another critical aspect, of course, is to ensure the effective management and distribution of empty vehicles.

These systems, in combination, are the building blocks in providing both safety and capacity within the Vectus system. It is easy to understand then why PRT technology is considered a quantum step beyond anything we currently have in operation in any of our cities around the world today. There are clearly niche applications for PRT, and potential customers are out there – although they may not know it yet - but there is, quite understandably, an air of caution amongst consultants tasked with analysing the opportunities and evaluating the various technologies on offer. One must remember that it is 45 years since the opening of the Victoria Line in London's Underground - which first heralded the concept of automatic train operation – and it is only now that we are finally able to say that driver-less mass transit systems have come of age and are an accepted norm. How long before the same can be said for PRT? We are already 37 years from the opening of Morgantown and so far only three commercial systems are reaching maturity.

It seems logical, therefore, that PRT should be seen as the natural evolution of APM, rather than as something totally distinct, or indeed as a competitor technology. But somewhat disappointingly, to avid third party promoters of PRT anyway, all recent applications, including Suncheon, are not yet able to showcase the true potential of the technology. One might argue that current vendors are really only demonstrating the ability of PRT to perform similar duties to an APM - albeit using a far more sophisticated safety and control regime. However, whilst these systems to date are not seen as being very ambitious (in terms of showcasing the ability of PRT to deliver high capacity, fully automated networks) they are the necessary first step in proving the underlying principles of PRT. They are also a valuable tool in helping to build confidence in the technology from both the operator and customer perspective. It is an incremental process, and what potential buyers of PRT require most of all, is some robust evidence of successful operational experience and longevity. In other words: 'some miles under the belt'.

STANDARDS AND SAFETY

At present there are no internationally recognised, universal ‘PRT standards’ which can be applied to any system which purports to be PRT; but does there need to be? Certainly, within the US, there are initiatives to develop the ASCE APM standards to be be fully inclusive of PRT. However, in Europe and other parts of the world (which tend to follow the procedures and regulations originated in the EU), this may not prove viable as an umbrella standard. Moreover, one might are argue that the technological and operating differences between rubber-tyred PRT systems such as at Heathrow or in Abu Dhabi and a railway based solution like Vectus are sufficiently un-alike as to warrant a different approach. Therefore, the next few observations are made only in relation to the Vectus system and are not necessarily intended as a pan-industry solution.

It has been suggested that Vectus is really a very sophisticated light railway, much smaller scale and lighter weight, but never-the-less it is still uses solid wheels running on steel track. Certainly the Vectus engineering team been drawn mainly from the railway industry, having designed vehicles and systems and worked on safety cases and operating acceptance procedures for applications as wide ranging as LRT to the London Tube. It will come as no surprise, therefore, that their starting point has been the standards and best practices already adopted and proven for light rail, mass transit and APMs – rather than to write completely new ones.

Whilst it is fair to say that to use railways standards in their entirety would be extreme over-kill, and in many cases not relevant, not to mention expensive, there are precedents within the railway culture for most eventualities that might occur on a PRT network. It is just a case of looking for them. Over the course of the development programme, and in consultation with third party consultants such as Lloyds Register, Vectus has carefully selected those norms - either in totality or with self-nominated exemptions to specific, non-relevant clauses – and included those in their safety-case documentation.

Generally, the safety process follows the EU standard EN 50126/IEC62278 'Railways applications – specification and demonstration of reliability, availability, maintainability and safety (RAMS)'. All suppliers to Vectus must be familiar with the standard and follow the relevant parts of it. This is followed up closely throughout all lifecycle phases, both through specification of detailed requirements, a number of safety studies and risk assessments in all phases, thorough safety documentation of all deliverables, audits (internally and of suppliers) and a traceable system for verifications and validations.

In the test track project in Uppsala, the Swedish Rail Agency (SRA) reviewed all the documentation and held regular meetings with Vectus to make sure that the standard was followed throughout the system development, construction and commissioning introduced. This included using a third party for assessing the safety instrumented element of the system - which is the automated control and safety process.

One specific area, however, where normal railway standards have not being wholly adequate is the control system. Here the safety elements utilise the same principles as any modern CBTC (Communication Based Train Control) system, like ERTMS for example, or a modern subway; however, Vectus employs a much more optimized and ‘correct’ safety approach covering not only the generation of a braking demand, but the whole chain from sensors to activators. The latter also involves a new approach for the integration of safety control aspects into both the track and the vehicles, which creates significant advantages, whilst being compliant with more generic and modern safety standards. So instead of using the traditional (and arguably less modern) railway standards such as EN 50128 (‘Railway *applications. Communications, signaling and processing systems. Software for railway control and protection systems'*) and EN 50129 (*'Railway applications. Communication, signaling and processing systems. Safety related electronic systems for signaling'*) the IEC standard 61508 for *'Functional safety of electrical/electronic/programmable electronic safety-related systems'* is used. This standard is generic for all kinds of SIS (Safety Instrumented Systems).

In the overall approval process for Sweden, acceptance criteria for the Vectus system were established based on the principle that new systems shall be as good as or better than existing systems, against which the risk assessment was measured. The conclusions were that the risk for passengers and personnel was comparable with the best railway levels, and that the risk level for third persons was very low compared to other ‘involuntarily’ risks.

This exact process is now the blue-print for all new Vectus projects, such as Suncheon, going forward. Once this is up and running, carrying passengers on a daily basis, it is the intention to publish a customer oriented guideline to these standards and processes - as Vectus has adopted them.

SUNCHEON PROJECT

Following a successful four year period of testing and demonstration at the test track, Vectus has now moved forward very rapidly with building its first fully commercial system in South Korea. This is essentially a visitor transit between a park-and-ride location on the outskirts of Suncheon city, in the southern most part of the country, linking to a world famous wetlands and bird reserve in the Suncheon bay estuary. The main station ,'Station One', is located at the entrance to the 2013 International Garden Exposition. From here Vectus will be operating 40 vehicles initially (and one maintenance vehicle) running down to a second station, along five kilometres (end-to-end) of elevated, double track. The track has a full loop at either end with four on-line berths at each.

Adjacent to Station One (the Suncheon City end) is located the Operations and Maintenance building. This houses the control room, vehicle storage (on the lower levels) a five berth daily maintenance area and a five berth, off-line, heavy maintenance facility.

An average of three million visitors per year are expected to visit the Suncheon Wetland Park, once the new system is operational, and daily ridership is forecast at around 5,000 passengers per day.

The guide way itself is predominantly concrete using site-cast columns and pre-fabricated, pre-stressed beams of typically 30 metre spans – although there is also one 50 metre steel box-girder section over a river. Because the entire area is an earthquake zone and is also prone to occasional tornados, the construction has been very carefully engineered, with most of the column piling buried some 30 metres into the marshy terrain. Since, in most cases, the foundations are laid far under the top soil on top of the pilings, this has the effect of placing the bending moment from wind loading deep underground.

The track-work itself is manufactured from rolled steel profiles, mounted along the concrete structure and the entire railway is powered through a 500VDC system of continuous current collection located on both sides of the guide way. For this application, where there is no issue of track adhesion (in comparison with Uppsala, for example, which is prone to very icy winters), there is no necessity for using in-track linear motors at all.

The vehicles are assembled locally in Korea, with specialist components and sub-systems being supplied from the UK, Germany, Sweden and the USA. The first cars are currently in operation around the new test-track facility in Suncheon **-** which is in effect the starting loop around Station One at the city end of the track. Following operational testing, and certification by the approval authorities, the system is now expected commence full public operation in the fall of this year.

DESIGN

It has been important from the outset to envision the Vectus offer as a turnkey transit solution, and not just a collection of vehicles running on a railway track. Vectus believes that the passenger's interaction with the system is from the point where they first arrive at the station to the point where they exit at their destination. It follows therefore that 'design', in all senses of the word, is key to realising a completely seamless and comfortable journey experience.

In 2010, Vectus approached world famous design house 'Pininfarina' – probably best known for its work with Ferrari over the last 50 years or so - to be its design partner for all major components of the Vectus system including the stations, the track profiles and of course the vehicles themselves. With Pininfarina taking responsibility for the emotional and aesthetic elements, the underlying engineering of all the mechanical and electronic systems has been undertaken in-house by Vectus's own development teams based in Uppsala, Gothenburg in Sweden and working with Transport Design International (TDI) in Stratford upon Avon, England.

In concept, the new Vectus vehicle is a modular design, which can be varied to carry anywhere between six and sixty passengers according to project-specific, operational requirements. Similar to a Formula One race car, all the body frames and panels are manufactured in carbon fibre composites. The main driver is achieved a very high strength-to-weight ratio in order to optimise performance and minimise energy consumption. Some of the mouldings are hollow, using the same 'monolithic' composite moulding technology employed in the making of wind turbine blades and bicycles frames, to provide the necessary high degree of structural integrity to meet safety requirements. For example, each entire side frame of the vehicle is designed as a structural 'roll-bar', and being hollow, also serves as concealed ducting for wiring and air-conditioning.

Both the smaller six passenger Suncheon vehicles and the next generation GRT cars, which are now on the drawing board, will draw from a common inventory of parts. So, for example, all line-replaceable units such as windows, doors, seats, lighting, air conditioning, control boxes and other major sub-assemblies will be largely interchangeable across all fleets of vehicles. This has the effect of creating volume, from a manufacturing standpoint, thereby reducing cost and improving reliability, availability and maintainability (RAMs) of equipment within the system generally – with a consequent reduction of risk.

Another very good example of innovation within the Vectus vehicle is the drive bogie unit. Whereas the test track cars used a more simplistic, twin axle arrangement, the Suncheon vehicle has gone back to more traditional railway principles and reinvented the bogie in super light weight form. Almost unrecognisable for what it is, the miniature Vectus drive bogie is fashioned from a system of CNC-formed, high tensile steel tubular frames. These are soft-mounted together to form part of the primary suspension and then fitted with high-performance, automotive braking units borrowed from the race car industry together with secondary, air-bag suspension. Vehicle dynamics has been optimised using state of the art simulation and calculation tools like *Gensys*, and ride quality improvements are significant.

Each bogie unit carries one permanent magnet 15 kW drive motor supplied by state of the art IGBT VVVF inverters. The motor is coupled to one pair of running wheels via a bi-directional, limited slip differential. There is also a battery powered low speed drive for movement within the workshop (which does not have current collection) as well as the storage facility. The safety brakes operate on the same principle as the test track proven units capable of retardation levels up to 5 m/s2 in any climatic condition.

The door system, typically a problem area in most transit operations, is a totally new design which departs from the previous test track vehicles. The twin, slide-plug door wings (one pair per side) themselves are manufactured in very stiff, lightweight carbon fibre, and are actuated by permanent magnet linear motors in order to reduce the number of serviceable moving parts. These mechanisms have been rigorously life-tested, achieving over 1.5 million cycles with no stopping faults or maintenance required.

Located within the cabin is the vehicle control equipment, which is the heart of the Vectus system. This comprises two identical boxes, of different colour: the ‘vehicle controller’ and ‘safety controller’, each utilising high speed dual-core Power PC processors with cores running in lock-step mode in order to reach the required safety level. The controllers are rugged and run bare-board with real time software (no operating system) at SIL 3. They have been thoroughly tested under laboratory conditions prior to running a pre-series prototype on the track in Sweden. Similar controllers, albeit with different programming, are also used to control each designated track zone throughout the system.

Other aspects of the vehicle design, such as aerodynamics (CFD), structural integrity (FEA), fatigue and crash-worthiness have all been undertaken using standard automotive computer modelling techniques to optimise the design and ensure passenger safety.

In terms of the passenger environment, the vehicles take a further cue from the automotive industry by introducing the options of heated windows all-round (to eliminate fogging); a heated floor and heated seats to warm the interior, along with a powerful HVAC air conditioning system.

CONCLUSIONS

So what conclusions can be drawn from this first commercial installation by Vectus?

Firstly, that Vectus is, in effect, an autonomous, micro light railway or *intelligent people mover*, which aspires to meet, at scale, all the safety and operational standards required of a traditional guided transit system. The major value-added, is that a large number of small vehicles - and potentially a mix of small and larger vehicles in the future ranging from six to sixty passenger capacity - can all operate simultaneously on the same network, on relatively short headways down to three to four seconds. They can go point-to-point (that is they do not need to stop at intermediate stations) and waiting times are reduced to an absolute minimum.

Secondly, as will be demonstrated in Suncheon, Vectus is most definitely one method (the missing link if you like) by which transport planners can finally realise a low cost, fully integrated, multi-modal transport system. It is not intended to be ‘mass-transit’, or compete with long distance public transport services such as commuter rail; rather it is designed to enhance and improve the viability of such networks by providing feeder lines and links into areas where ‘heavy rail’ and metro (in inverted commas) would otherwise be too expensive to install and operate.

Thirdly, that the new Suncheon vehicles are state-of-the-art in people mover technology showcasing innovations in bogie design, lightweight vehicle structures, passenger door actuation, system safety and control and last but not least, advanced, elegant styling. Because they are lightweight and (being rail based) are able to use simple current collection infrastructure, they have by default unlimited range and can accommodate the most powerful HVAC equipment, where required, to operate in extremes of ambient temperature. ‘No batteries required’.

So overall, Vectus suggests (perhaps) that its new technology is really the beginning of a next generation of APMs - with added intelligence - having the ability to navigate a complex network, using different size vehicles, as well as perform more traditional line-haul duties where required.

In other words: an Intelligent People Mover for the twenty-first century – *an IPM.*