Emerging Technologies and Urban Rail: Scoping Proposal

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**Title:** Emerging Technologies and Urban Rail: Scoping Proposal

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## Synopsis:

Significant emerging technologies in the areas of signalling and train control, noise management and traction motor technologies have been reviewed. The findings indicate opportunities for adoption by the Australian rail industry. Techniques, particularly simulation techniques, have been surveyed to establish the state of the art in terms of judging the possible impacts of emerging technologies on an urban rail environment. It is proposed that a unified simulation framework combining agent-based and activity-based modelling techniques can be used for better prediction of the overall effects of emerging technologies on urban rail environments.

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Executive Summary

A review of the literature relevant to emerging technologies is reported in 2 sections. The first section focuses on typical technologies that would help to improve the safety, capacity, reliability of the rail network and the liveability of residential area where rail tracks go through. In particular, the automatic train protection technologies (e.g., ETCS, ATMS), rail noise control, and linear motor technologies have been reviewed. These areas can be considered as the ‘hardware’ of the urban rail technologies. The second section of this review focuses on the ‘software’, i.e., emerging modelling techniques applicable to the rail industry. These modelling techniques serve the rail industry in two ways, either as a tool for an effective planning/scheduling process or to study/evaluate the impacts of the implementation of the emerging ‘hardware’ technologies on the rail network, and, more importantly, on the urban environment (e.g., how new technologies change people travelling behaviours, and/or the planning of other transport modes). Various modelling tools and methodologies were reviewed including more recently developed behavioural modelling approaches (e.g., activity-based and agent based modelling). For each of those, the background, characteristics, and examples of application (either research based or industrial based) are discussed.

The review concludes that, even though aspects of the above emerging technologies have been carefully examined and applied to the Australian rail networks, there are still areas that have not been fully explored, particularly with respect to applying emerging modelling techniques to planning and studying socio-economic impacts of changes made to the network. Answering questions related to these social-economic impacts requires a modelling framework that can capture the interactions between major agents in the network (e.g., rail operators, individuals, trains, other public transport), as well as the attributes, behaviours, and goals of each of the agents. We thus propose a unified simulation framework that combines agent-based and activity-based modelling techniques. This framework will not only be capable of capturing the interactions and socio-economic impacts of, for example, new technologies, but also is an effective tool to forecast travel demand and to carry out traditional planning work.
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Introduction

Our urban environments are under increasing stress and there has been a significant increase in demand for urban rail services. Australian cities are forecast to grow significantly as the population increases. Environmental and energy use concerns will dictate more efficient and effective urban development supported by appropriate transport systems.

Decisions taken in the early part of the last century constrain Australia’s capability to provide optimal urban environments and their associated rail systems. These decisions were in turn constrained by knowledge of emerging technologies. For example, the choice of 1500V DC traction systems was based on knowledge of emerging transformer and other technologies. These decisions restrict the possibility of implementing technological improvement. Funding constraints and existing infrastructure constrain urban rail system development. Understanding possibilities within the context of existing Australian rail systems and urban environments allows planning with emerging technology possibilities to be factored in.

Recent forums/workshops, e.g., the ARA Rail Technology Workshop and the NICTA’s Smart Transportation Infrastructure Technology Forum, provide a comprehensive overview of current developments of new technologies that would become key components of a smart infrastructure system. Some of these technologies that would be directly applicable to the rail industry include in-cab signalling, automated control of trains, noise control, distributed networks, alternative energy sources, optimising rail scheduling (i.e., intelligent fleet logistics), and decision support for incident management. The role of these technologies in the development of the Australian urban rail system needs to be understood. This scoping study aims to:

- Review technologies likely to impact on urban rail systems.
- Review feasible approaches to modelling of the relationship between existing and emerging rail technologies and their impact on the possible changes to the urban rail environment.

The literature review in this scoping study will generally comprise two parts. The first part will focus on a cross-section of typical new technologies that may be relevant to the urban rail industry. The focus will be on technologies relevant to train control, noise mitigation and traction motor technology. In the second part, possible modelling techniques will be examined. For example, the agent based modelling (ABM) technique. It should be able to provide a detailed comparison of:

- Advantages/disadvantages of each approach.
- Their applicability and reliability.
- Examples of models developed by each approach (that have been done elsewhere).
1. Overview of Recent Technology Developments in the Rail Industry

Emerging technologies that would help to improve the safety, capacity, reliability of the rail network and the liveability of residential areas are of interest to urban planning. In particular, automatic train protection technologies, research work on rail noise control, and linear motor will be presented. These areas can be considered as the ‘hardware’ of the urban rail technologies.

1.1. Train protection technologies

The latest train protection technology system has been widely considered to be the European Rail Traffic Management System (ERTMS). ERTMS comprises three major components:

- GSM-R, based on the GSN standard but at a frequency reserved for railways, is a radio system used for information exchange between trackside signals and on-board units.
- ETCS (European Train Control System) is a train-based computer system that constantly communicate with trackside electronic units for the authorised speed curve, monitor the train speed, and slow down the train should the actual train speed exceed the maximum speed allowed.
- Rail traffic management.

Most of the developments of ERTMS have been on its signalling part, ETCS. There are three levels of ERTMS/ETCS (Ruesche & Steuer, 2007):

- In Level 1, the most important component is the network of balises placed along the track and connected to the control centre by wired links. When the train passes a balise, the signal is sent back to control centre where brake curve and speed curve are calculated and then sent back to the train via balises or the existing line side electric units.
- Level 2 is based on the same principle of the Level 1, except that communications between trains and control centre are now via wireless signal (using GSM-R). This allows information on train location and speed curve be transmitted in real time. The train does not have to wait until reaching the next balise to get the authority to move to the next blocks.
- Level 3 also uses wireless communications as in Level 2, but route configurations are now calculated by a computer on board. Network equipped with this level of ERTMS/ETCS allows trains operating on the basis of moving blocks rather than fixed blocks as in Level 1 and Level 2.

Page (2001) reported some very good overviews of ERTMS/ETCS especially its benefit in the Australia context, as summarised below.

- Advanced automatic train protection with some features initiated remotely, e.g., temporary speed restrictions, emergency stop commands.
- Reducing headway and thus higher throughput of the whole system; in addition, ERTMS/ETCS Level 3 features moving block signalling, which further improves capacity.
- Eliminating trackside equipments, which reduces maintenance cost, particularly for Level 2 and Level 3.
- Allowing cross border interoperability of incompatible signalling systems.
- Benefits from huge investments already made in the EU, which have resulted in a healthy supply industry, as well as improved knowledge, experience, and skilled resources in the industry.
- Additional features and operating modes can be added to the ERTMS basic features.
- The radio communication system GSM-R is based on the commercial GSM standard, and thus could benefit from that wider market.
- It is possible to migrate/upgrade between ERTMS levels.

Experience from implementing ERTMS/ETCS Level 1 with infill on the Vienna–Budapest line was reported in terms of “high operational benefit” and a “substantial safety increase” at “reasonable implementation and lifecycle cost” (Cerny, 2007). The implementing of ERTMS/ETCS L2 in Europe has also reported the following advantages (De Tiliere, 2007):

- Supporting all type of operations (passengers only, freight only, or mix of both).
o High speed passenger trains (up to 500 km/h on LVG East connecting Paris–Baudrecourt, France).
  o Freight trains (Betuwe route, Netherlands).
  o Mixed (Swiss new lines Mattstetten–Rothrist).
    - Reducing headway to less than 2 minutes on Swiss New Lines, which increases performance by over 20%.
    - Eliminating mismatch between signals and cab display.
    - Much less trackside equipment being necessary, which reduces cost.

Another automatic train protection that is currently ‘under construction’ is the Advanced Train Management System (ATMS) invested by the Australian Rail Track Corporation (ARTC) to improve capacity, safety and efficiency of the interstate rail network. Lockheed Martin is in charge of designing, developing, constructing, integrating and testing 105 km of ATMS equipped interstate track between Crystal Brook and Port Augusta. A fully operational ATMS system will provide (van de Worpe et al., 2009):
  - Increased rail capacity by smaller headways.
  - Improved reliability.
  - Improved efficiency and flexibility of the network.
  - Increased safety via authority and speed limit enforcement.
  - Additional protection for trackside workers.
  - Less consumed fuel, less wear on wheels and brakes, fewer train crew hours.
  - Reduced operation and maintenance cost of trackside equipment.

Besides the benefits, levels of ERTMS have disadvantages. Some of the disadvantages of ERTMS Level 1 include no capacity improvement, high cost (owing to cost for extra equipment, e.g., line side electronic units, infill). For ERTMS Level 2, the shortcomings are from GSM-R, which could be a particular issue for Australia because the European frequency bands are normally not available in Australia. GSM-R is also relatively expensive when applied to geographically dispersed rail network. (Page, 2001)

Ramdas et al. (2010) examined operational issues and risks that implementing ERTMS level 3 may bring to the rail network in the UK. The operational issues include:
  - Combining data entry of train length by the driver and validation by an onboard computer is critical to safety, and particularly where shunting operations are involved.
  - ERTMS Level 3 is associated with the ‘moving block’ signalling concept, which may cause confusion to drivers. At this level, the movement authority of a train is determined by a computer system based on the location of other trains in the network and displayed on the Driver Machine Interface (DMI). The dynamically changing movement authorities (rather than traditional fixed ones on line-side marker boards). In addition, the head-down DMI may require more attention from drivers, which could result in them driving the train more defensively.
  - The concept of ‘virtual block’, in which the movement authorities are issued at fixed points of the infrastructure, was introduced to address the drivability issue of ‘moving block’. The new concept makes the train operations virtually more familiar to drivers and signallers, and yet may cut down some network capacity improvement that the original ERTMS Level 3 brings.
  - Another drivability concern is that drivers may have long used line-side boards as position references and may find it difficult to brake and position the train accurately during station stopping (not supervised by ETCS), as well as when operating in a partial failure mode when ETCS is inactive.

Risks associated with implementing ERTMS Level 3, other than those originated from the operational issues mentioned above, as reported by Ramdas et al. (2010) are:
  - Industrial structural and cultural risks: Change to ERTMS Level 3 may be difficult considering the marginal level of safety enhancements compared to the traditional systems with respect to the cost of upgrading the infrastructure, in addition to changing stakeholder involvements in the railway industry (e.g., passenger and freight operators).
Lost cost train fit: rail operations can only enjoy the full benefit of Level 3 (e.g., capacity enhancement, cost savings by removing line-side equipments) once all rolling stock is fitted with appropriate equipments. Until then, a hybrid system that includes both line-side and cab signalling will be used. This could increase costs and impact both operability and reliability.

Noise mitigation

Anderson et al. (2008) and Talotte et al. (2003) reviewed various methods have been applied to reduce rail noise at sources. For example, in reducing rolling noise, the re-designing of wheels was claimed to reduce noise by 1-5 dB. Optimising the stiffness of rail pad was reported to reduce noise radiation by 4-5 dB. Clamping an additional damped mass-spring system to the rail foot could reduce noise by another 2 dB. In particular, a local shielding method (i.e., bogie-mounted shields and low trackside walls) was claimed to reduce noise by 8-10 dB when tested in the United Kingdom. An example of a bogie-mounted shield and low trackside barrier is in Figure 1.

Most reported techniques to mitigate noise actually did reduce noise to different levels, but no one single technique could substantially resolve the issue. More importantly, they are normally costly, which hinders sustainable and environmentally friendly rail transport. Thus a cost benefit analysis of various noise mitigation techniques is required to ensure that action plans for any noise mitigation project are cost effective.

Oertli and Hubner (2007) reported that such an analysis was carried out as part of the project ‘Strategies and Tools to Assess and Implement Noise Reducing measures for Railway Systems’ (STAIRRS). Acoustically relevant geographic, traffic and track data was collected from over 11,000 km of track crossing seven European countries. Further details of the analysis can be found in papers by Oertli (2006a and 2006b). Figure 2 summarises outcomes of the project STAIRRS. The project concluded that:

- Retrofitting current freight rolling stocks with composite brake blocks has the highest cost effectiveness both on its own and in combination with other measures.
- Noise barriers, particularly high ones, have a low cost effectiveness.
- Combining noise barriers with retrofitting has the highest cost effectiveness.
- The conclusions for Europe also apply to each individual country.
1.3 Linear motor technology

Linear motor technology has been around for a considerable length of time, but has not been implemented in large-scale rail systems. The slow take-up of the technology could stem from the reluctance of railway operators to embrace new technologies, or the cost of the systems. In a 2009 special issue of IEEE, some authors argued that linear motor technology is cost effective when compared to conventional railways. It is obvious that linear motor technology is beneficial for particular operations that require smaller envelopes and high grades, such as in underground subway systems.

In a paper by Hellinger and Mnich (2009), the different type of linear motors available are described. They mention that linear motors are most suited to high speed trains and also high gradient track. Four types are detailed:

- Linear DC machines (not suited to rail applications as brushes are needed between the rail vehicle and guideway).
- Linear synchronous motors (LSM); LSM contains an active guideway and a passive guideway.
- Double-fed linear motor, both vehicle and guideway are actively powered; this allows relative motion between vehicles on the same track.
- Linear induction machines (LIM); the guide way is relatively inexpensive as it consists of solid iron. Efficiency is lower in these types. By way of contrast, Thornton (2009) mentions that LSM can be less expensive than LIM systems.

Linear motors are used in two ways in railway applications. One is where railed vehicles use linear motors as the traction system and braking system, and the other is full maglev systems. The railed vehicle approach may provide a logical approach in upgrading a system from conventional vehicles to linear motor technology as conventional vehicles may be able to run on linear motor tracks.

Maglev systems offer advantages such as high speed and high acceleration, comfortable travel, low maintenance and ability for higher gradient track. Research is being conducted throughout the world on maglev systems. Since there is only a small number rail organisations using maglev and linear motor, more work clearly needs to be done before it has the ability to replace conventional traction devices.

Advantages of linear motors are:
- Lower ride height allows smaller envelope.
- Reduced brake wear.
- High acceleration.
- Reduced wheel wear.
- Reduction in weight.
- Low maintenance.
- Ability to tackle large gradients.
- Ability to deal with tighter curves.
- Low noise.

Disadvantages of linear motors are:
- Higher infrastructure cost (there is some debate about this).
- Lower efficiency owing to the higher air gap required (Hellinger and Mnich, 2009).

The most promising advantages of linear motors are the high acceleration and braking rates. Increases in these have the potential to reduce transit times. Reduction in cost may be achieved by designing guideways based on power requirement, as mentioned by Thornton (2009). The maximum power is required at stations, where trains require the highest acceleration and braking requirements. This has safety ramifications as maximum braking would not be available on all track sections. Additional emergency friction brakes may need to be designed to address this safety concern. Thornton (2009) also argues that maglev systems can be less expensive and more efficient than traditional rail transport. He shows that maglev systems are twice as energy efficient as rail transit systems, but only 20% more efficient than conventional HSR.

Luguang (2009) provides an overview of the linear motor development and use in China’s rail networks. This includes intercity and urban applications. In terms of the amount of linear motor use, China appears to be leading the way.

It is obvious that linear motor technology is a step forward and will provide faster acceleration and deceleration. Efficiency and total cost of linear motors when compared to conventional vehicles is debatable. An in-depth cost comparison could be carried out in this area, but obviously this will change as linear motor technology advances. Change over from conventional vehicles to linear motor technology appears to be a minor issue since space requirements are typically less with linear motors.
2. Computer Simulation and Modelling Techniques

Emerging technologies in the area of planning tools are also of interest. These ‘software’ technologies include developments of new scheduling algorithms, modelling techniques and simulation frameworks. Computer simulations can serve rail industry in several ways, either as a tool for an effective planning/scheduling process, or to study/evaluate the impacts of the implementation of the ‘hard’ ware emerging technologies on the rail network, and more importantly, on the urban environment (e.g., how new technologies change people behaviours and travelling, and/or the planning of other transport modes).

Recent research work on algorithms for real-time train rescheduling will be reviewed. The sections that follow will focus on behavioural modelling approaches, activity-based and agent based modelling (ABM). For each of the modelling methodologies, background, essential characteristics, and potential applications to the rail industry will be presented. The final section of this part reviews rail industry related modelling work that has attempted to combine these two modelling approaches.

2.1 Real-time rescheduling

Trains normally (and naturally should) follow a detailed timetable, which is a result of a series of complicated planning phases, of which the iterative planning process at RailCorp is a good example. Such a timetable is planned with the help of computer software (e.g., RailSys, OpenTrack) to satisfy various criteria, among which are minimising train path conflicts and delays by means of buffer time between train paths. Nevertheless, major deviations from the predefined schedule always occur in actual train operation owing to various sources of disruption, e.g., the volume of passengers at a station and/or their behaviours, in addition to technical problems (signalling system, rolling stock). This poses the need for a robust tool that helps train operators to quickly identify causes of potential conflicts and/or delays and instantly reschedule train paths. Besides, an effective online real-time rescheduling mechanism of train paths not only helps improve safety and reliability but also the capacity of the network, since it would allow less buffer time allocated to each train path during the timetable planning process.

Goverde et al. (2008) developed TNV-Conflict, a Java-based modelling tool, that takes trains and infrastructure elements (e.g., signals, track sections, switches) as objects with an associated updateable set of attributes. The input data of the model consists of:
- Chronological messages of the network, including date/time, code of the infrastructure elements (signals, tracks, switches), binary state transition (occupied/free, stop/go, left/right) and train numbers.
- Infrastructure configurations, e.g. details of signals, number of tracks, switches, speed limits.
- Timetable of all trains on the network, and scheduled events to calculate delays.
- Details of train length, positions (mileage) of signals and switches.

Output from TNV-Conflict provides the following information of the rail network:
- The expected delays with an accuracy of few seconds.
- The expected running and dwell times of all trains with conflict indicators.
- The expected platform track section.
- A ranked linked list of successive delays with major conflicting train paths listed first.
- Blocking time diagrams.

The model successfully predicted the route conflicts of two trains running after midnight from Rotterdam to Dordrecht (the Netherlands). The track being investigated was approximately 6 km long with two stations. One of the trains was a regional train that was scheduled to stop at the stations, followed by a nonstop intercity train travelling on the same tracks (Goverde et al., 2008). Such outputs from TNV-Conflict can be used for offline analyses to optimise the timetable, infrastructure and rolling stock usage, as well as serve as an input for an online decision-making system for rescheduling (Hansen, 2010).
Tornquist and Persson (2007) provided a comprehensive review of work done on online re-scheduling railway traffic and proposed a mathematical formulation, called Mixed-Integer Linear Program (MILP), that allows an optimising modelling to re-schedule railway traffic in a large scale, highly interactive, n-tracked network implanted with disturbances. The solution of this formulation was demonstrated by applying it to train traffic in the South Traffic District in Sweden, which comprised 57 double tracked segments, 125 single tracked segments and 169 stations/meeting points. The traffic studied was from the timetable of a normal Friday in 2003 that had 92 freight trains and 466 passenger trains. There were four types of trains with various degrees of priorities: high speed passenger trains, intercity trains, fast freight trains, and slow freight trains. Three time horizons considered were 30, 60 and 90 minutes. Time horizon is period being simulated – the longer this period, the more global optimised results are, but the computational time also increases.

The modelling was formulated in AMPL (an algebraic modelling language for linear and nonlinear optimisation problems, in discrete or continuous variables) and was done on an Intel 2.66 Ghz CPU, 1.5 Gb RAM at 266 MHz. The maximum simulation time was 2.5 hours. The simulation results showed that optimised solutions depended on the optimising strategies (which reflects operational practice, e.g., allowing trains to swap tracks and/or overtake), and objective functions (which reflect the aims of traffic managers/policies and re-scheduling strategies). In addition, the model did not consider various factors, such as train connecting and the effects of switches between tracks.

Later, D’Ariano and associates (D’Ariano & Pranzo, 2009, D’Ariano et al., 2007a, D’Ariano et al., 2007b) proposed a decision-support dispatching system, ROMA (Railway traffic Optimisation by Means of Alternative graphs), which in terms of functionality can be considered a combination of TNV-Conflict and the model of Tornquist and Persson described above. ROMA can automatically re-route the rail traffic to avoid blocked segments and evaluate the effects of re-scheduling options. It takes into account the minimum headway regulations and the corresponding variability of train dynamics (i.e., speed profiles). In order to better forecast and minimise delays, D’Ariano and Pranzo tackled long time horizon of traffic planning (up to several hours) by dividing the long horizon into smaller tractable periods, then used the ROMA system to proactively detect and solve conflicts in each period at a global level.

The architecture of the ROMA system, shown in Figure 3, is comprised of a set of modules. Module ‘Load Information’ periodically loads accurately updated data of the infrastructure status (speed limits, signals, track layout), and the location and current speed of trains. Module ‘Disruption recovery’ checks for unavailable (blocked) segments in the network and assigns each train with the highest priority feasible route available. If no feasible route is found, ROMA requests human interferences. Module ‘real-time optimisation’ calculates train orders and the exact time windows (i.e., arrival and departure time) of each train at stations, as well as other meet points in the network so as to minimise the propagation of delays and deviation from the original timetable.

Two scheduling algorithms were used:
- Branch and Bound (BB): all train reordering options are considered. The solution that minimise the maximum consecutive delays is chosen. A truncated BB algorithm returns a near-optimum solution at a reasonably short calculation time for practical size problems.
First come first serve (FCFS): the train arriving first at the conflicting block section is given high priority to use the block. No dispatching is required for this algorithm because trains cross the meeting point in their actual order, which may not follow the original timetable.

If no optimum (conflict-free) rescheduling solution is found, the dispatcher needs to modify the timetable, e.g., introduce new routes or cancel train service at some stations. The module ‘feasibility check’ makes sure that the train can follow the re-scheduling solution and still complies with traffic regulations (e.g., signalling, speed profiles). Thus the module ‘speed updating’ adjusts the train speed profile if needed. These two modules are iteratively executed until the optimum speed profile is found. If no speed profile is found (i.e., trains cannot comply to the regulation if following the re-scheduling solution), the process goes back to module ‘Disruption recovery’, and so the iteration goes until a conflict-free schedule with acceptable train dynamics is found. While this train path rescheduling model developed by D’Ariano and associates (D’Ariano & Pranzo, 2009, D’Ariano et al., 2007a, D’Ariano et al., 2007b) considers the variability of train dynamics, i.e., the train speed profile. This could also help to avoid exhaustive braking and acceleration, which in turns helps save the fuel and maintenance cost.

In other research related to real-time rescheduling, Albretch (2009) stated that anticipating train driving leads to less fuel consumption and a more comfortable experience for passengers. He also studied real-time rescheduling’s influence on finding the solution for the optimum order of trains that could significantly reduce delays. Luethi et al. (2009), as part of a research program at the Swiss Federal Railway and Swiss Federal Institute of Technology, developed an approach that combined real-time rescheduling algorithms with very accurate train operations (via a driver-machine interface) that could help to significantly reduce the buffer time allocated to train paths, thereby increasing network capacity without compromising network reliability.

2.2 Behavioural Modelling Approaches

These modelling approaches are micro simulations that aim to capture the dynamics of the overall transport picture by simulating the interactions, interdependencies and adaption of elements with their attributes and behaviours in the transport network. Depending on the scale of the specific study, these elements could be individuals, vehicles (which could be trains, cars, vessels), or transport operators, or a combination of all of them. This unique capability could be particularly useful for the rail industry; for instance, in improving the planning process with a better forecasting of traffic demand on rail for both passenger and freight, or studying impacts on customer’s experience of infrastructure upgrades or policy changes. Two major methodologies in this modelling category will be reviewed below, namely activity-based and agent-based modelling, with discussions dealing with their current and potential applications in the rail industry.

2.2.1 Activity-based modelling

Activity-based modelling has been mostly used to forecast and simulate travel demand, which is a result of decisions made by agents (e.g., individuals, train operators) based on their list of activities. The basic units of analysis in activity-based modelling are activities, or more precisely the travelling attributes (modes, time, places) that are being modelled, not the trips. Factors such as social relationships (interpersonal interdependencies) and infrastructure availability (spatial, temporal, transportation interdependencies) both influence these travelling attributes. Thus, activity-based modelling aims at simulating at what time, the objects (e.g., individuals, trains, cars depending on the scope of the study) go where on which route, over which distance, and by which (travel) mode. In other words, objects in the simulation may have the authorities to make route choice or mode choice or both (Zwerts).

The input for activity-based modelling, for example the modes of transport, the time and place of origins and destinations, even people’s behaviours and decision-making, normally comes from surveys. The raw data from these surveys are then processed (synthesised and/or analysed) so they can be fed into the
coding/building of the model, normally in the format of tables and/or statistics. This is also the methodology to process data input to an agent based simulation model, which will be presented in the following section.

Various software packages have been developed for activity-based modelling to serve different initial purposes. A review of some of these modelling packages, e.g., Portland, PCATS, AMOS, TranSims, and Albatross is provided below. (Algers et al., 2001). The Portland modelling package (Bowman & Ben-Akiva, 2000), first developed to model daily activity in Portland (Oregon, US), is very much similar to the conventional trip-based approach in forecasting travel demand. The main thing that makes Portland different is that it treats trips as round-trips (or tour based) rather than individual, completely separated trips in the traditional approach. This means that intermediate activities between the origin and destination of a tour are temporally and spatially coupled. These tours, divided into primary tours and secondary tours, form activity pattern and travel demand of an individual within a day. The Portland modelling package then simulates the choice of destination, mode, and time of daily travel, all based on the random utility maximisation framework. Same approach/modelling framework is used in SIMS (Algers et al., 2005) and PETRA (Fosgerau, 2001).

![Figure 4. An example of daily activity pattern and a generic flowchart in a PCATS model. (Algers et al., 2001)](image)

PCATS (Prism-Constrained Activity-Travel Simulator), developed by Kitamura and Fujii (1998), was also based on the utility maximisation framework. Activities in PCATS could be either fixed (i.e., must happen at a specific location), or can be flexible. The speed of travel, location and time of fixed activities form the backbone of daily activity pattern (the time-space prisms) of an individual. Individuals in the PCATS model choose to carry out their flexible activities (constrained by fixed activities) so that the sum of utilities of activities and the associated trips is maximised. An example of the activity pattern and a generic flow chart is given in Figure 4 above.

AMOS (Activity-Mobility Simulator), also developed by Kitamura and Fujii (1998), aims at capturing the change of behaviours under the effects of, for example, changes of travel management policies. A generic
flowchart of a model in AMOS is given in Figure 5. The model starts with a sample of a base line activity pattern, which is produced in ‘Baseline Activity-Travel Pattern Analyser’ by analysing records of all individuals in the sample. (Algers et al., 2001). AMOS then simulates how individuals would adapt to environment changes (e.g., travel demand management policies - TDM) by first producing a basic response, which could be ‘do nothing’ or switch work-trip mode, or change departure time, in the module ‘TDM Response Option Generator’. This module simulates a neural network that is ‘trained’ by giving a given preference data set. This data set is obtained through actual interviews of people in the study area for their behaviours/reactions over a set of changes in traffic management and/or infrastructure upgrades. The response is then fed to the module ‘Activity-Travel Pattern Modifier’, where the activity pattern is modified if needed, e.g., cancel a few activities in the original pattern and/or change travel mode and/or time. This new activity pattern is then assessed in the ‘Evaluation Module and Acceptance Routines’ according to a set of rules. If the outcome is not ‘good enough’, the ‘TDM Response Option Generator’ will have to generate another response, and so the process goes (Algers et al., 2001).

![Figure 5. A generic flowchart of an AMOS model (Algers et al., 2001)](image)

TranSims was developed at the Los Alamos National Laboratory, and is essentially similar to AMOS, i.e., it focuses on modelling the change of travel behaviours, congestion and pollution as an impact of policy changes, but is equipped with a more advanced micro-simulation methodology with a much stronger emphasis on traffic modelling. The model creates a synthetic population from the provided data set, with activity patterns assigned to each individual in the population. TranSims then undertakes route choice and (travel) mode choice to satisfy combined criteria of cost, travel time, congestion, and safety (Algers et al., 2001).

Albatross was developed by Arentze and Timmermans (2000) at the Eindhoven University of Technology (the Netherlands) for the Dutch Ministry of Transportation and Public Works. The purpose of the software was to provide a better assessment of external spatial and temporal constraints. The set of constraints that has been accounted for in Albatross includes (Zwerts):
- situation constraints (i.e., an object cannot be at two places at the same time).
- institutional constraints (e.g., changes of working hour and/or business hours of shops).
- household constraints (e.g., adults take children to school).
- spatial constraints (e.g., particular activities cannot be carried out at particular places).
- time constraints (e.g., minimum/maximum duration for certain activities).
- spatial-temporal (e.g., an individual cannot be at a particular place at the right time to carry out a particular activity).

A detailed classification of wide range of activities is also accounted for, e.g., fixed activities including work/school, bringing or getting something, medical visits, personal business, sleeping and eating, and flexible activities including daily and non-daily shopping, service-related activities, social activities, leisure activities, home-based activities, etc. Albatross was tested against PCATS and AMOS and was reported to be very competitive with the competing models (Arentze and Timmermans, 2008).

### 2.2.2 Agent based modelling (ABM)

**Overview**

Recent developments in activity-based modelling techniques have approximated it to agent-based modelling. The major difference between the two approaches would be that agent-based focuses on agents, while activities with all their attributes (e.g., travel modes, routes, time) are among other attributes of the agents.

In general, the ABM approach captures the behaviours of a complex system from the ground-up by implementing rules, behaviours, knowledge of every single element in the system into the model and executing the interactions of these elements to produce system-level outcomes. The foundation of ABM approach is based on well-established and proven techniques, such as discrete event simulation (an example of this is the activity based approach) and the object-oriented programming. While discrete event simulation provides the framework to coordinate interactions between elements in the system, object-oriented programming allows behaviours and attributes of agents be effectively organised (North & Macal, 2007).

The ABM approach is ideal for applications where there is a natural representation of agents (North & Macal, 2006), i.e.:
- there are decisions and behaviours involved, that can be defined discretely.
- agents adapt and change their behaviours.
- agents learn and engage in dynamic strategic behaviour.
- agents have dynamic relationships with others.
- agents form organisations and their adaptation and learning capabilities are crucial at the organisation level.
- agents have a spatial component to their interactions and behaviours.

The approach is also ideal for applications that have nonlinear relationships between inputs and outputs, i.e., past results/trends cannot be used to predict the future. While agent’s behaviours and attributes are the main inputs to the model, the main model’s outcomes are also an agent’s perspective (North & Macal, 2006). An agent in an agent based model is defined as a discrete object that has its own goals, behaviours, attributes, memory and resources. Agents are autonomous, able to learn and adapt from interactions with other agents in the system. Examples of agents are people, groups, organisations, robots, and insects. (North & Macal, 2006).

**Software and packages**

Computer tools/software that are capable of developing agent-based models range from basic and common tools (e.g., spreadsheet) to those developed specifically for agent-based simulations. Most of these tools are open-source software, i.e., they are freely available for download from the internet, and
have a large user community that functions as a powerful channel of technical support that significantly contributes to the construction of functionalities of the software (North & Macal, 2007).

The most basic and popular tool for agent-based simulation is probably spreadsheets. Any modern spreadsheet program that (i) supports multiple worksheets in a workbook and (ii) provides some forms of a scripting language can be used for ABM purposes; for example, Microsoft Excel. Building agent-based models with spreadsheets is easy to learn by taking advantages of relatively sophisticated built-in functions (to construct agent behaviours) and output tools (e.g., charts and graphs) provided in the program. The drawbacks of agent spreadsheets include limited complexity, size, and diversity of agents (North & Macal, 2007).

An alternative to agent spreadsheets is ABM prototyping environments, the majority of which are available freely online. Examples of these environments are Repast Py, NetLogo and StarLogo. One important common trait of all these environments is they are designed to get first-time ABM developers to start as quickly as possible, with plenty of visual and point-and-click features. The drawback of this seemingly great advantage is limited flexibility of the environment. Another common trait is, of course, the strong support for agent development with tools that help to organise the storage of agent attributes and behaviours and icons for various types of agents. The trade off of this is normally the limited types of agent details that the environments can manage, and thus the diversity of the model. Finally, prototype environments normally do not have sophisticated mathematical functions and fine output facilities. Brief descriptions of certain ABM prototype environments are provided below (North & Macal, 2007).

Repast Py is a member of the Recursive Porous Agent Simulation Toolkit (Repast) family. Repast Py allows users, particularly first-time users, to quickly build small to medium sized agent-based models with graphic user interface and Python scripts (to describe agents behaviours). Repast Py models can be directly exported to other platforms (e.g., Repast J) later for developments to larger scales. This is one of the major advantages of Repast Py, and it compensates for its lack of sophisticated functionalities (North & Macal, 2007).

Both NetLogo and StarLogo are educational ABM simulation environments, and were developed based on a modified version of Logo programming language. They are both easy to learn and use and thus ideal for teaching purposes of ABM, for prototyping basic modelling concepts (in particular well suited for artificial life projects), and for supporting participatory ABM simulation. However, they are limited by the number of agents that can be included in a model and the sophistications of agents’ behaviours, and so are not good choices for large-scale simulations. NetLogo and StarLogo can be freely downloaded at [http://ccl.northwestern.edu](http://ccl.northwestern.edu) and [www.media.mit.edu/starlogo](http://www.media.mit.edu/starlogo), respectively (North & Macal, 2007).

Dedicated computational mathematics softwares (e.g., Matlab and Mathematica) provide a better scalability compared to ABM spreadsheets and prototyping environments. They are also capable of building sophisticated agents behaviours as well as providing high quality outputs thanks to their rich mathematical functions and a wide variety of add-on libraries. The trade-off is that they could be reasonably difficult to learn and apply to building ABM models, particularly if users have no previous experience with the software. Another drawback is that most of this mathematical software are not normally open source codes (North & Macal, 2007).

Above desktop computer tools are suitable for small and not so complex ABM systems. Simulations that require few thousands agents or more with more complicated agent behaviours interactions are considered large scale and require a different level of model development environment. These environments normally must support various features including a time scheduler, communications mechanisms, flexible interaction topologies, a range of architectural choices, facilities to store and display agent states, large-scale software development support (North & Macal, 2007). There main features are as follows:
- A scheduler controls the flow of time in the model, thereby allowing agents to synchronise their activities over time.
- Communication mechanisms, which are basically a message-queuing system, allow the agent send to and receive message and information from others.
- An interaction topology describes how agents can possibly connect with others; various options of topologies must be provided in a large scale ABM toolkit, e.g. ‘soups’, grids, irregular polygons, networks, active environments, and real map (from Geographic Information System (GIS) data).
- An ABM architectural style defines how the three components of an ABM model (user interface, simulation engine, and data storage) interact.
- Displaying agent states is required so that users can observe and modify agents’ attributes. Saving agent states is required so data of agents’ attributes can be examined outside the simulation and for later reuse.
- Large-scale software development supports include object oriented programming support (e.g., Java, C++), a fully integrated debugger (for model verification purposes), refractoring tools, version control support, and literate programming support (for model development purposes).

Various current large scale ABM development toolkits possess all the above features and even more.

Recursive Porous Agent Simulation Toolkit (Repast) is claimed to be the leading open source ABM toolkit. Repast is currently maintained by the Repast Organization for Architecture and Design (ROAD) and is free to download at [http://repast.sourceforge.net](http://repast.sourceforge.net). There are four Repast platforms, which are Repast for Python Scripting (Repast Py), Repast for Java (Repast J), Repast for Microsoft.NET (Repast .NET) and Repast Simphony (Repats S). Repast Py has been briefly described. Repat J is pure Java modelling environment, with features such as a fully concurrent discrete event scheduler, a model visualisation environment integrated with GIS to display agents on real maps, adaptive agent behavioural tools (e.g., genetic algorithms, and neural networks). Repast .NET is a pure C# environment that has all features available in Repast J. Programming languages that are supported by Microsoft .NET framework (e.g. C++, C#, Visual Basic, Managed Lisp and Managed Prolog) can be used to develop Repast .NET models. Repast S extends features of the other two platforms with a point and click graphical user interface for agent behavioural specification and dynamic model self-assembly, as well as advanced agent storage and display (North & Macal, 2007).

Swarm is another free large-scale ABM toolkit, in which users build the model by implementing Swarm library components into their programs. Swarm is currently maintained by the Swarm Development Group, and can be freely downloaded at [www.swarm.org](http://www.swarm.org). Swarm models can be written in programming languages Objective-C and/or Java (North & Macal, 2007).

Figure 6 gives an overview of current computer tools that could be used to develop ABM models in terms of their relative modelling power and model development effort required (North & Macal, 2006).
Research work on applied ABM related to the rail industry

In the context of the rail industry, each element in the urban transport system (e.g., a train, a tram, a bus, a train driver, a passenger) represents an agent in an ABM simulation. The simulation allows agents interact with each other in a predefined context, which could comprise:

- true geographic elements (e.g., rail, roads, stations via GIS data, track-interchanging facility).
- initial behaviours and attributes of agents (e.g., initial timetable of a freight train, authorised course of action of train drivers, general behaviours/habits of groups of passengers).
- rules/regulations governing the transport network (e.g., speed limits, procedures to follow if a loco breakdowns, track work or loco maintenance scheduling, allowable delays).
- incidents (e.g., breakdown of a loco, accident happening to a passenger, change of fuel cost).

The above-mentioned incidents, rules/regulations, behaviours and attributes are governed by the new technologies being considered. The ABM technique then allows the agents to change their behaviours/habits to adapt to various rules/regulations set to the context, and thus would be an effective tool to study the socio-economic impacts of new technologies. Various research works have been carried out in applying ABM technique in the rail industry context, as summarised below.

Tornquist and Davidsson (2002) reported initial developments of an agent based model that aimed to improving the punctuality of the Swedish rail network. The model took into account the rail network configuration, disturbance to the timetable (e.g., delay of a train), and decision-making process of operators to instantly re-route trains, and negotiations between network managers and transport operators. More recently, Zhibin and Chao (2009) also reported a study that demonstrated the potential of using ABM to evaluate the delay propagations on the rail network, taking into account effects of various delay adjustment strategies, which are implemented in the model by an agent.

Abbinck et al. (2009) reported an actor-agent based approach for rescheduling of train drivers owing to disruptions of the rail network, e.g., breakdown of infrastructure and/or rolling stock. The model considered three main agents: dispatchers at strategic/management level, train drivers, and agents that implement the strategic decisions and resolve actual scheduling conflicts. This research work was carried out at D-CIS Lab (the Netherlands) to illustrate the suitability of using ABM techniques for real-life applications.
Gambardella et al. (2002) reported their work on an agent-based model of a complete freight supply chain involving a network of intermodal terminals to examine the impacts of various technologies and management strategies on the terminal performance. The objective was to estimate the effectiveness of intermodal freight transport (i.e., combined rail and road) in comparison with road-only freight transport. The study was set in the context that the European Union was striving to put more long-haul freight on trains. The model comprised two components, an intermodal transport planner and a discrete events simulation system. The intermodal transport planner was an agent-based model that planned the dispatching of intermodal transport units at various stages along the network from origin to destination. The discrete event simulator verified the feasibility of dispatching plans and measured their performances.

Also with reference to intermodal freight transport, Sirikijpanichkul et al. (2007) and van Dam et al. (2007) reported an agent-based model to simulate the decision making process in choosing road-rail intermodal freight hub location. The model included four main groups of agents, namely, hub owners, transport network infrastructure providers, hub users, and communities. Each agent had an objective function. The model simulated the negotiation process of these agents to achieve a global objective. This global objective was designed to make sure that the ABM simulation not only maximises the benefits of hub owners, rail infrastructure providers, and freight operators, but also takes into account the social effects (via agent ‘communities’) of a freight hub location decision.

Li et al. (2010) were also interested in simulating intermodal transport, yet the focus was on urban transit rather than freight transport. They developed an agent-based model of an artificial urban transit system that captured individual’s behaviours in choosing different routes as well as different modes (e.g., cars, buses, trams, trains, or a combination of these). The model could potentially be used to forecast transit flows, set key configurations of urban transport elements (e.g., frequencies and capacities of trains), evaluating various options of train routes and bus routes, and evaluating impacts of disruptions (emergency incidents) on the urban transit network. Jun and Choi (2006) reported similar work, although it was less comprehensive, on modelling the operation of urban rail transit networks, in which they treated each train in the rail network as an agent. The main applications of this work would be limited with respect to evaluating the feasibility of new train plans or new operating policies.

Another major application of ABM technique is crowd simulation. Various work has been undertaken to developed models of pedestrian movements at stations. Rindfuser and Klugl (2007) reported a case study of pedestrian simulation at Bern railway station (Switzerland). The model comprised over 40,000 individuals interacting with each other and the station facilities within the two peak hours of the morning. The agent-based model developed had simple and yet flexible individual path planning with collision avoidance in a continuous space and multi-level layout. The general architecture of behaviour of a simulated pedestrian is shown in Figure 7. Pedestrians were modelled during selecting path to approach the trains, boarding and alighting the trains. The pedestrians on the platforms were allowed to replan their current plan to approach the train doors, based on their perceptions of the surroundings, which included not only the queue in front of the destination spot and distance between the pedestrian and the spot, but also the density around him/her, as well as the queue at the potential spot.
Castle (2006) reported an overview of an underway project developing a prototype agent-based pedestrian movement to evaluate the evacuation of King’s Cross St Pancras underground station. He contended that agent-based is a proper solution because it is capable of representing attributes and behaviours of individual agents that are critical for such a modelling objective, e.g., varying degrees of knowledge of the station layouts (of local residents, tourists, etc.), varying degree of mobility (children, adults, handicapped, etc.). The ABM Repast toolkit was identified as a suitable tool to develop the agent-based evacuation simulation for this project.

Various commercial packages that are designed specifically for agent based modelling of pedestrian movements are available, e.g., MassMotion, Legion. Castle (2007) provided an overview of issues to be considered in the process of choosing which package to be used for crowd evacuation simulations, which are summarised below:

- What is the financial cost of the package? (e.g., cost for annual licences and technical support).
- How is the application available?
- What are the required configurations of computer hardware?
- What is the required operating system?
- Does the package original design suit the purposes of the simulation (e.g., for rail, road, maritime, is it suitable for residential buildings or crowded public places)?
- What is the nature of the application: individual’s movements only, optimisation-movement, movement-behavioural, or partial behavioural?
- At what scale does the package represent the structures to be modelled?
- In which format is data imported to the package to represent network connections (XML, CAD, GIS)?
- At which scale does the package treat occupants, i.e., at global scale (community or group of people), or at individual scale? And at which scale do the occupants perceive the environments?
- How is the pedestrian moving speed specified?
- For walking speed values integrated in the package, what is the origin and validity of this data, and are they suitable for the current research purpose (e.g., evacuation)?
- How is the direction of occupant movement simulated? (e.g., flow/hydraulic equation, cell based, velocity based vector).
- What behavioural approach does the package use? (e.g., none, implicit, rule-based, artificial intelligence).
- What are details/logics/architectures of agent behaviours that the package is using?
- To what extent has the package been validated?
- Is the package maintained? Is it still under development? Is technical support or training available?
Validation of a behavioural simulation model

There is no firm guideline of how a behavioural simulation model can be validated since the developed model is very often not deterministic and has certain random elements. However, certain techniques can be used to gain the credibility of a model (North & Macal, 2007).

Validation can be carried out for several aspects of a model (North & Macal, 2007):

- Requirements validation: validate the questions the model is supposed to answer, whether they are clearly stated and whether they have changed.
- Data validation: is the input data credible?
- Pace validation: do the general assumptions sound reasonable? Do the results look right?
- Process validation: is the internal process of the model (e.g., its flow chart) describing what’s happening in the real world process?
- Output validation: if the real world system is available, how are its outputs compared with those from the model?
- Agent validation: do agent behaviours, attributes, interaction mechanisms reflect the real world counterparts?
- Theory validation: are the theories used in modelling the agents and/processes valid? How correctly these theories have been implemented in the model?

Validation can also be done via (North & Macal, 2007):

- Comparing the model outputs with (limited) various cases in the real world.
- If the real world does not exist, comparing the model outputs with results from other models that simulate the same system. The other models may have different modelling techniques, level of detail included, and/or even different underlying assumptions.
- Comparing the model outputs with expectations from experts working in the areas related to the system/process being simulated.

Use of such approaches to modelling

An example of a combination to capture (i) station based activities (crowd simulation), (ii) network based activities (activity based simulation), (iii) people perceptions on travelling experience, and (iv) interaction between people experience with operators (developers) is provided in the swim lane diagram in Figure 8.
Figure 8. An example of a swim lane diagram demonstrating the proposed unified modelling framework.
3. Conclusions and Proposals for Future Research

The reviews contained herein have summarised current developments of railway technologies, including emerging computational tools that could be beneficial to the urban rail industry. The ‘hardware’ technologies reviewed, i.e., signalling, noise mitigations, and linear motors may improve safety, capacity, reliability and liveability of residential regions around rail track. Some ‘software’ technologies, modelling techniques (i.e., the real time rescheduling technique) reviewed may also create such benefits.

Findings

While parts of the above technologies have been studied for the Australian context (e.g., noise mitigation, ETCS level 1), other areas still have not yet been fully explored and/or applied to the Australian rail, particularly in using emerging modelling and simulation techniques in (i) planning and forecasting travel demands, and (ii) studying the socio-economic impacts of implementing emerging “hardware” technologies or operational initiatives/policies.

Proposals for future research

The activity-based modelling technique reviewed in section 2.2.1 has been considered a good (more accurate) alternative to the traditional 4 step model, which has been used in the planning process by various Australian rail operators, in forecasting transport demands not only for rail, but also for urban transit with a combination of travel modes. The ABM technique is a powerful tool for feasibility study to examine socio-economic impacts of changes made to any element in the rail network. For example:

- A new signalling system or operating strategy is implemented that improves reliability and capacity. How will this affect the way people travel and planning other parts of their lives? (e.g., would they use cars less frequently because there are more frequent trains? Or would they plan to leave home later for work now as a new train timetable has been applied?) And, more importantly, how would these changes in daily activity plans of each individual affect the demand on train usage?
- If actions must be taken to make people flow when boarding and alighting trains at a station more effectively (to reduce dwell times at that station), would they be replanning the platform layout? If so, to what extent should the platform be replanned? Or should trains be rescheduled to stop more or less frequently at previous stations to reduce number of people transiting at this station? Or a combination of both?
- If a noise barrier is to be built in a residential area, how would it benefit people in that area, taking into account the times of day trains running most frequently and times of day when most residents are at home (which is heavily influenced by the demographics of the area)?

Answering these questions requires a holistic modelling framework that comprises the rail network and operation of trains (both freight) on that network, other urban transit modes (buses, cars, trams) with their timetables and associated network, behaviours and backgrounds of individuals in the study area, the rail operators who will make decisions of changes made to the network, etc. We are thus proposing a unified modelling framework that combines activity-based technique and ABM techniques. Besides answering questions related to the socio-economic impacts, the new modelling framework is also a powerful tool in forecasting travelling demand, in addition to other traditional planning activities.
References


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