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Metro Railways – Automation and a summary of differences from typical main line railways

Version 5

(This document is intended for candidates taking Module A of the IRSE Professional Examination. Some content comes from the IRSE Metro Train Control Systems textbook)

Rail based public transport covers a wide spectrum ranging from tramways with little or no signalling to high speed lines with cab signalling and full automatic train protection. Within that range, this comparison seeks to summarise the main differences between a typical metro and a typical main line railway. The main line railway is assumed to be a mixed traffic network of lines (express passenger, suburban or local passenger & freight). The metro is taken to be a "mass transit" railway with high passenger flows and some underground sections such as exist in many large cities globally. It can also be known as the underground, subway, or tube.

The document also outlines the various degrees of automation applied to metros worldwide.

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Summary of differences

Metro railway	Main line railway
Traffic patterns	
High frequency service, particularly in city centres. Frequency of more than 30 trains per hour can be achieved.	Very wide range of frequencies though not as high as the most frequent metros.
High capacity capable of transporting up to 50,000 passengers per hour.	High capacity can be delivered, usually with longer, less frequent trains.
Trains nearly always stop at all stations	Variable stopping patterns to accommodate express and stopping trains. This has an adverse effect on capacity.
Does not share tracks with freight or inter-city type services, but some systems share some sections of route with suburban trains.	The same tracks are used by express passenger, suburban passenger & freight trains.
Station stops are often close together	Station stops can be very widely separated.
Passenger management	
Carry large numbers of people over relatively short distances in city centres and the surrounding areas. Managing passenger flows within stations is an important consideration.	Typically longer journeys with lower passenger densities at stations. Passenger management is only critical in locations with high passenger densities.
Headway & Capacity	
Station dwell times are minimised because at high frequencies on an existing system, this is the most significant limiting factor on capacity. More and wider train doors tend to reduce dwell time.	Station dwell times are less critical on most routes.
When designing a new metro line, higher capacity trains (e.g. more cars, fewer seats) will increase passenger capacity. High acceleration and braking rates are more important ways of increasing capacity than high maximum speeds.	The same principles apply, but are only significant where there are high passenger densities.
Terminal station layouts and procedures are designed to deliver rapid train turnrounds to maximise the train frequency for the number of platforms. The number of platforms can be a major constraint on line capacity.	Relatively long layovers at terminal stations are usual.
Fixed block is widespread, but with short track circuit sections carefully designed to optimise capacity. Moving block is used by modern CBTC systems to increase capacity and shorten signalling headway by reducing the allowed train separation as the following train slows down.	Fixed block is the norm. Moving block is enabled by the highest level of ETCS (not yet widely implemented), but this is less valuable in increasing capacity where different types of train share the same tracks.

Metro railway	Main line railway
Safety	
More frequent service increases collision risk. Collisions in tunnels have the potential for very serious consequences. Automatic Train Protection (ATP) to prevent collisions is considered essential on most lines. ATP is typically integrated within modern systems such as CBTC	Higher speeds increase the potential consequences of a collision or derailment (though there are far fewer tunnels). A wide variety of ATP systems exist and are commonly used. ATP is typically integrated within modern systems such as ETCS.
Fire or smoke are more dangerous in a tunnel, resulting in many metros implementing their own specific approvals regimes to manage the risk posed by equipment deployed in these locations.	The same applies, but there are far fewer tunnels.
High passenger numbers mean that controls need to be applied in the event of service disruption (e.g. by temporary station closure). Platform screen doors are often provided on new metros.	This only applies where there are high passenger densities.
Reliable and audible public address (both on trains and in stations) is vital to maintain passenger safety during emergencies and service disruption. Robust voice communications between the control centre and the train driver (or attendant) is vital too.	Important, but less critical except where there are high passenger densities.
Evacuation of passengers in tunnels is difficult, particularly if there is no side walkway. As a result, many metros include specific evacuation shafts at certain locations. These are typically equipped with systems to support the evacuation of passengers under the supervision of operational staff and the emergency services.	The same applies, but very little of the network is in tunnel.
Control system	
Modern systems use Communication Based Train Control (CBTC). Currently systems from different equipment suppliers are not interoperable. This is not a big compatibility issue because most metro lines are self-contained. Lineside signals are not necessary for normal operations, but are sometimes installed (e.g. backup, running of trains that are not CBTC fitted)	Most modern systems without lineside signalling use the European Train Control System (ETCS) or a near equivalent. There is a common specification such that systems from different equipment suppliers are interoperable (i.e. each train only needs one set of equipment to communicate with any ETCS fitted infrastructure). Positive Train Control (PTC) in North America has similar functions.

Metro railway	Main line railway
Automation	
Increasing use of high levels of automation, up to and including driverless and unattended operation. Elimination of lineside signals. Attended operation enables automated driving, but provides an on-board human presence to manage passenger safety and/or manually drive the train in the event of failure. See Automation section below for more details.	Increasing use of automation to support the driver.
Automatic Train Operation (ATO) can improve capacity by consistently driving every train in a way which minimises transit times between stations. This means that recovery margins do not need to allow for the differing driving styles of a large number of drivers.	The same principles apply, but are only significant where there are high passenger densities.
Data communications	
Combination of highly directional aerials and radiating cables (leaky feeders) to communicate between control centre and trains in tunnels. TETRA radio and Wi-Fi with robust coding are the commonly used systems. These systems are sometimes used to provide train fault reporting data (often routed directly to the rolling stock maintenance location) and customer information system updates.	Similar technology used in tunnels. GSM-R is the current standard in Europe for secure communications with trains.

Metro railway	Main line railway
Voice communications	
TETRA radio is the most commonly used system providing voice communication: - Between control centres and trains - For station staff - For maintenance staff - For incident response teams Note that TETRA radio base stations are capable of continuing to provide local service to radio users in the event of disconnection from or failure of the wider network. This resilience is a key feature of their role within operational management of the station (particularly at large underground locations).	GSM-R is the current standard in Europe for secure communications with trains, usually supplemented with track side telephones deployed at appropriate locations. Station radio is often provided by separate local spot systems rather than using the GSM-R network.
Emergency Services radio system coverage is often provided throughout all underground locations (stations, tunnels and evacuation shafts). This is typically achieved by connecting dedicated emergency services radio equipment to the metro's coverage infrastructure.	Emergency Service radio coverage is provided at key locations where a risk assessment has identified it as necessary, for example long tunnel sections. This may be provided on its own dedicated infrastructure or using existing railway coverage infrastructure if appropriate.
Stopping distances	
Relatively slow speeds, high braking performance and uniform rolling stock mean that stopping distances can be quite short. This enables a high frequency of service.	Higher speeds and the variety of train types (including freight) mean that the signalling system needs to allow for long stopping distances on mixed traffic lines.
Signals & Overlaps	
Short stopping distances mean that lineside stop signals do not always have to be preceded by a caution signal providing the sighting distance is sufficient	Lineside stop signals are almost always preceded by at least one caution signal.

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Metro railway	Main line railway
Dependability	
Given the effect on trains and on passenger management of even short duration failures, very high levels of system reliability and availability are required. Robust hardware, equipment redundancy (duplication), remote condition monitoring and fast system recovery can all be used to achieve this. Fallback capabilities to maintain operations also need to be able to be implemented quickly.	These factors are important, but less critical apart from the most densely used sections of the network.
Infrastructure	
Often in tunnels or overhead viaducts, particularly in city centres. Tunnel lengths can be very long.	A very small proportion of route is in tunnels. Most are quite short, except where the routes pass through major mountain ranges or under the sea.
Grade separated junctions (e.g. flyovers) are the norm in the areas of the highest frequency traffic to increase capacity by avoiding conflicting routes.	Similar considerations apply in the areas of highest frequency traffic, but the majority of junctions are "flat" to avoid expensive civil engineering works and greater land take.
Usually completely independent of road or pedestrian traffic. Trains are typically too frequent to allow realistic opportunities for crossing the railway.	Level (grade) crossings for road or pedestrian movements across the railway are common on many lines.
Traction	
Electric for avoidance of air pollution and for high acceleration with high performance motors. Regenerative braking for lower heat gain in tunnels and energy economy.	Mostly electric or diesel. Benefits of regenerative braking are greatest on electrified lines with frequent services so that other trains can use the electricity generated.

Automation

Grades of Automation

Metros can be designed to operate under several degrees of automation, ranging from nil (now unusual except for systems operating like tramways) to full automation (with no staff member on the train). These are described by a number of Grades of Automation (GoA).

Grade of Automation	Type of Train Operation	Setting Train in Motion	Stopping Train	Door Closure	Operation in the event of Disruption
GoA0	Train Operator only	Driver	Driver	Driver	Diver
GoA1	ATP with Train Operator	Driver	Driver	Driver	Driver
GoA2	ATP & ATO with Train Operator	Automatic	Automatic	Driver	Driver
GoA3	Driverless Attended	Automatic	Automatic	Train Attendant	Train Attendant
GoA4	Unattended Train Operation	Automatic	Automatic	Automatic	Automatic

The automation functions (ATP, ATO, ATS) are described below.

Automatic Train Protection (ATP)

The ATP sub-system delivers the limit of movement authority to each train. This determines where the train is permitted to travel based on the routes set by the interlocking and the position of other trains. The ATP supervises train movements and ensures that they only occur on authorised routes, in the correct direction and within the limits of the movement authority. The ATP ensures the safety of all train movements, irrespective of whether train control is from the Automatic Train Operation sub-system or the train operator (driver). The primary ATP functions are as follows:

- Trackside ATP equipment, most commonly found in signalling equipment rooms at stations and/or at control centres
    - Train location tracking
    - Movement authority determination to ensure safe train separation
    - Temporary speed restriction application
    - Emergency train evacuation supervision
    - Interlock train movement with platform screen doors, staff protection key switches (work zone protection) and platform emergency stop plungers
- Train borne ATP equipment
    - Determine the position of the train and report to the trackside ATP
    - Determine the status of the ATP sub-system health and which driving modes are available (manual, automatic etc.)
    - Ensure the train does not exceed the movement authority limit
    - Ensure that train does not exceed the permanent or temporary speed restrictions
    - Train direction supervision
    - Correct side door enabling at platforms (door open control protection interlocks)
    - Supervise emergency train evacuation
    - Ensure all doors closed and locked prior to station departure.
- Track-mounted ATP sub-system
    - Equipment mounted on the track (such as beacons/transponders) to provide a positioning reference; also used by the ATO equipment.

Automatic Train Operation (ATO)

This is the sub-system that drives the train between stations within the constraints established by the ATP sub-system. The functionality of the ATO will vary depending upon the grade of automation. For GoA4 metros where no train operator is present, all functions performed by the train operator on a GoA1 metro are performed by the ATO sub-system. The ATO functions include:

- Driving the train from station to station obeying permanent and temporary speed restrictions within the movement authority provided by the ATP
- Train door and platform screen door open and closing
- Platform dwell time management
- Apply applicable energy saving driving strategies
- Jog, realigning an incorrectly stopped train to within the specified ATP door opening tolerance.
- Selecting the appropriate driving profile for the line type, such as surface tunnel, wet etc.
- Applying platform hold, train hold and station skip commands

Signalling and train control facilities in metro depots often are not provided, or they are very simple. However, it is becoming common on modern metro systems (and in particular on driverless/unattended metro systems) to deploy the same signalling solution in depots as on the rest of the line to provide ATP and ATO functions. This could include, for example:

- Automatic routing of trains to and from storage tracks, to permit efficient scheduled and "on-demand" service build ups and reductions
- Automatic close-up of trains on storage tracks
- Automatic coupling and uncoupling of trains
- Automatic cycling of trains through train inspection facilities or exterior car wash facilities.

Automatic Train Supervision (ATS)

The ATS sub-system is responsible for the overall line control function. It is located at the control centre and it presents the state of the railway to the operators. It controls the trains, but the operators can intervene when the service deviates beyond the recovery capability of the ATS sub-system.

The primary functions of the ATS sub-system are as follows:

- Issue commands to the interlocking and other sub-systems to route trains to their destinations.
- Display the state of the railway to the operator, tracking trains and displaying the signalling equipment status.

- Service regulation, adjusting the service to keep to the timetable or to equalise the interval between trains.
- Provide the user interface for operators to adjust the service when needed
- Alarm management
- Provision of service information to customer information systems
- Logging and playback for incident investigation.

Failure of the ATS sub-system should not directly affect the safety of passengers.

Automation benefits

The benefits of the various degrees of automation include the following:

- Automation of the train driving functions can provide for more regular and predictable run times between stations, eliminating the variations inherent with manual driving. This can enable higher line capacity by reducing recovery margins which partly allow for different driving styles.
- Driverless and unattended train operation, with automatic passenger door opening and closing and with automatic train departure from station platforms, can further reduce the variations in line operation.
- Unattended train operation frees the metro operator of the constraints imposed by the need to roster train crews. It also provides the flexibility to operate shorter trains more frequently. This makes it easier to respond to variations in demand throughout the day, while still delivering a frequent service.
- Unattended train operation, when combined with fully automated maintenance yards and stabling tracks, provides the flexibility to respond to unexpected increases in passenger demands by adding additional trains to the service, all without requiring additional train drivers or manual intervention.
- Lower operating costs for driverless trains.
- Automation of turnback at terminal stations can reduce turnover times, reducing the number of train sets needed for operation.
- Automation of train regulation, train dispatching and train routing functions can more effectively regulate the performance of trains in relation to timetable (schedule) and headway adherence. Regulation (e.g. to equalise the time interval between successive trains) can be achieved by automatically adjusting dwell times and/or by automatically controlling run times between stations (e.g., through adjustments to train acceleration and service brake rates, and speeds).
- Automation of train regulation functions can minimise overall system delays by optimising the scheduling of each train.

- The automatic, real-time control and coordination of train acceleration, train coasting, and train braking can also be utilised to implement energy optimisation algorithms, for example though coasting controls or by synchronising the acceleration of one train with the braking of another train to maximise use of brake energy recovery.
- Automated failure detection and response can be more effective in responding to system disturbances and emergencies through the elimination of human error.

There are some drawbacks to set against the benefits above.

- Increased staff costs for any additional passenger service and security personnel
- Additional capital and maintenance costs associated with the automation system itself
- Additional costs arising from contingency arrangements to deal with failures and emergencies on unattended systems.

Control Systems

These range from systems with lineside signals observed by a driver to ones with full automation and no drivers. Three common systems are described below. The more advanced systems will typically be able to deliver higher line capacity (i.e. more trains per hour)

Lineside Signals with fixed block working

The diagram below illustrates the headway that can be achieved with 2 aspect signalling.

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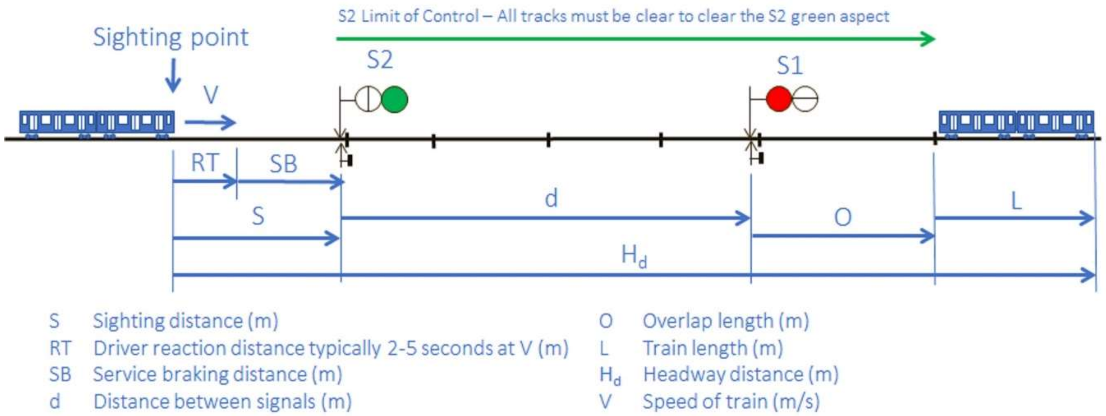


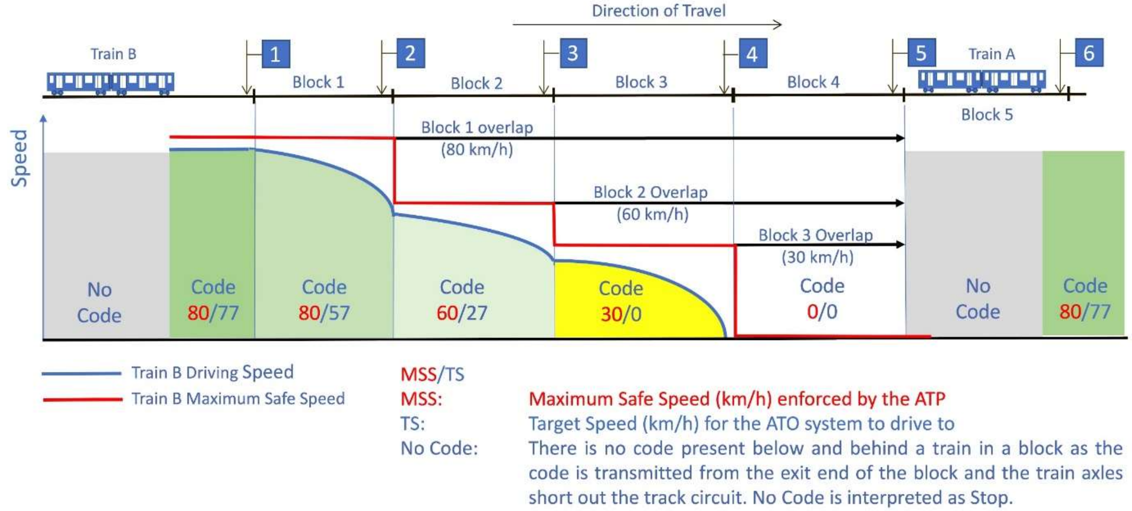
Cab Signalling with Coded Track Circuits

With cab signalling, headway is no longer constrained by the distance between lineside signals. Shorter headways can be achieved by the subdivision of a signal block into shorter sections. Train speed is detected and controlled separately in each of these short sections, thus enabling shorter headways and greater line capacity.

The track is divided into predetermined short track circuit lengths and each track can be fed with any one of a number of codes, each code signifying a maximum safe speed, target speed, or for some metro systems, both the maximum safe speed and target speed.

The appropriate code for each track circuit is determined by the nearby interlocking depending upon the position of track occupancy ahead of any train, or the requirement for junction or other speed restriction. Modern systems typically use audio frequency signals to convey a specific command.

A train traversing a track circuit picks up the coded signal from the transmitter via an antenna. The signal is decoded, and the actual train speed is compared with the decoded track signal to determine if the train is above or below the authorised speed.

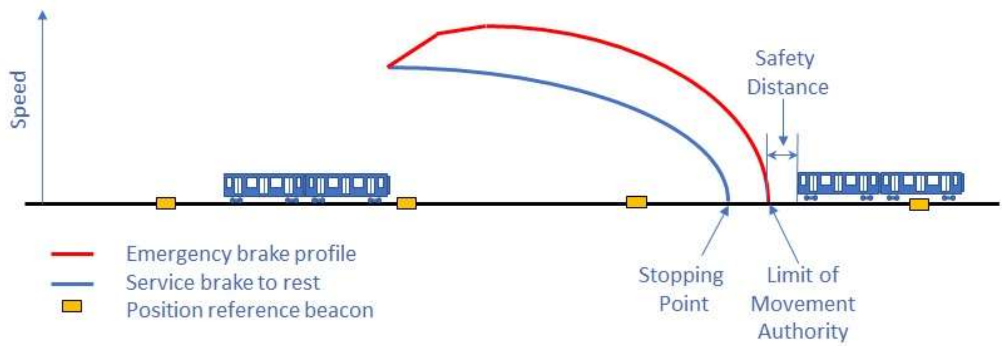


Example of ATP code sequence in a track circuit based speed code system

If the train speed is excessive the driver must reduce the speed to below the authorised speed or be subjected to an emergency brake action, generally to a standstill. A typical arrangement is shown in the diagram above in which it can be seen that if the train is driven in accordance with the Target Speed indications, it will be brought to a stop with one track circuit between it and the preceding train. Should the train fail to operate below the Maximum Safe Speed profile at any time (and no corrective action is taken) the train will be automatically brought to a stop within or before the 0/0 code track circuit. As a train moves from block to block, the codes step up in the blocks behind.

Moving Block Signalling (loop & radio-based systems)

Moving block systems provided by Communication Based Train Control (CBTC) systems are now the preferred metro train control technology. The principle of a moving block system is that each train moves within its own allocated block. A limit of movement authority is issued to the train which defines the point beyond which the train must not go. This is usually the end of the route or the rear of the train ahead, whichever is encountered first. There is a safety margin to account for rollback and errors in train location reporting. As the preceding train moves, so does the block, hence the name. The length of the block depends on the braking distance of the following train, so (unlike a fixed block system with lineside signals) a train can safely come to a stop very close to the rear of a stationary train.



Moving block signalling train separation

Moving block systems do not need traditional train detection sub-systems such as track circuits or axle counters, but some do have them to support mixed-mode operations or to facilitate system recovery following a train location determination failure. Moving block systems require continuous communications between the train and trackside to receive train position reports and provide updated movement authorities. Two solutions are currently in use, inductive loops and radio.

Fully automatic trains

There are no technical reasons why trains cannot be driven fully automatically without the need for any manual intervention on board trains. The economic and operational benefits of fully automatic operation are significant, largely due to the greater degree of flexibility in scheduling trains without the need for arranging for drivers to be present at the correct time and place.

Trains equipped with a continuous form of ATP and ATO are capable of operating safely and efficiently with minimal action by drivers or attendants. Generally the role of the staff is to ensure that alighting passengers are clear of closing doors prior to train departure from stations and/or opening train doors on arrival at stations. Such functions can be automated, provided that equipment is installed to fulfil these roles safely and provide passengers with information which may have been provided had a driver been present. Such equipment may include:

- additional CCTV equipment on station platforms to ensure passenger safety;
- on track obstruction detection equipment in-station areas (infra-red or radar systems);

- platform screen doors;
- bi-directional voice communication between train passengers and control centre;
- additional train systems monitoring and reporting equipment for diagnostic purposes.

However a trained human presence on the train can deal with failures and emergencies (e.g. by manual driving or passenger evacuation) and it is necessary for a fully automated line to have processes for both passengers and trains to deal with these events.

Metros operating fully automatic systems include:

- Vancouver Skytrain
- VAL systems (France and elsewhere);
- Lyon Metro Line D