Jörn Pachl

Railway Signalling Principles

Edition 2.0

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PREFACE

Railway signalling systems are complex control systems. As a result of the long railway history, there are a lot of specific national solutions based on different technologies. The key to learn how signalling systems work is to understand the fundamental control principles these systems are based on. By definition, the signaling principles are the underlying principles of a signalling-based safeworking system that are based on the national standards but are independent of the requirements of a specific railway operating company and of the technology used.

This E-book explains the fundamental principles all railway signalling systems have in common. It is done in a generic way that does not focus on specific national solutions. The intention is to provide core knowledge of long-term value that will not be outdated just by the next generation of technology. The content of this E-book is based on the long-standing experience of teaching railway operations and signalling at universities and higher vocational training institutions in different parts of the world.

Beside some minor corrections, the 2nd edition provides a revision of the section on the ETCS to keep track with the latest developments.

Jörn Pachl

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1 Basic Elements and Terms

The purpose of signalling systems is to ensure safe movements of trains on a railway infrastructure by locking movable track elements in a proper position, checking the clearance of track sections, locking out conflicting moves, and control train movements in a way to keep them safely apart. This first chapter describes the trackside elements controlled by signalling systems and explains the basic terms used in the operating procedures for the safe control of movements with railway vehicles on a railway infrastructure.

1.1 Controlled Trackside Elements

1.1.1 Movable Track Elements

Turnouts

A turnout is an assembly of rails, movable points, and a frog, which effect the tangential branching of tracks and allows trains or vehicles to run over one track or another (Figure 1.1).

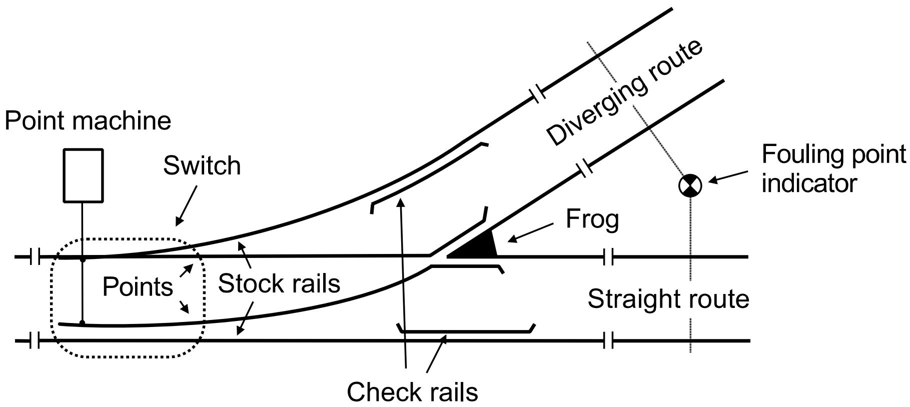

Figure 1.1 Components of a turnout

The movability of the points is provided by using point blades made of flexible steel. In older installations, there are sometimes still turnouts at which the movability of the point blades is effected by bolted joints. The points may be operated manually or by a point machine. Point machines are either electric motor drives or electrically controlled pneumatic cylinder drives. In case of a small angle of divergence, a movable frog (also called ‘swing nose frog’) operated by an additional point machine could be provided. Movements on a turnout where the points face approaching traffic are called ‘facing point movements’ whereas movements in which the frog faces approaching traffic are called ‘trailing point movements’ (Figure 1.2).

The angle of divergence is not stated in degrees but either by its tangent written as a fraction, e.g., 1 : 12, or by the so-called turnout or frog number, which is the reciprocal of that fraction. So, a 1 : 12 angle equals a frog number 12. The limit of occupation of the converging tracks is called ‘the fouling point’. Many railways mark this limit with a trackside fouling point indicator.

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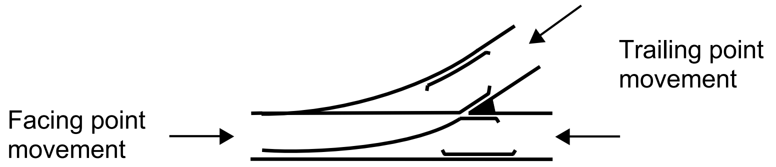

Figure 1.2 Movements on points

Note: The term turnout is mostly used in civil engineering. In railway operation and signalling, a turnout is usually referred to as a pair of points (points in short), although this term in its original meaning only applies to the part of a turnout where the points are located. This part of a turnout is also known as a switch. In North American railway operation and signalling, turnouts are usually referred to as switches (*Armstrong, 2008; Bisset et. al., 2008; White, 2003*). Consequently, the point machine is also called a switch machine.

In British civil engineering terms, points are also often referred to as switches. There, an entire turnout is called a 'switch and crossing', using the term 'crossing' for the frog part of the turnout. This differs from the terms in railway operation and signalling, where the term points is always used instead of switch.

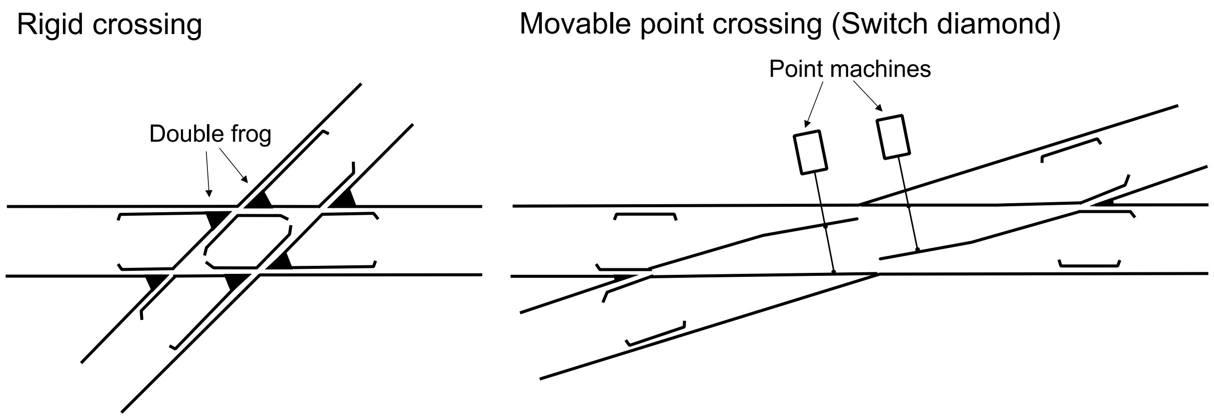

Figure 1.3 Crossings

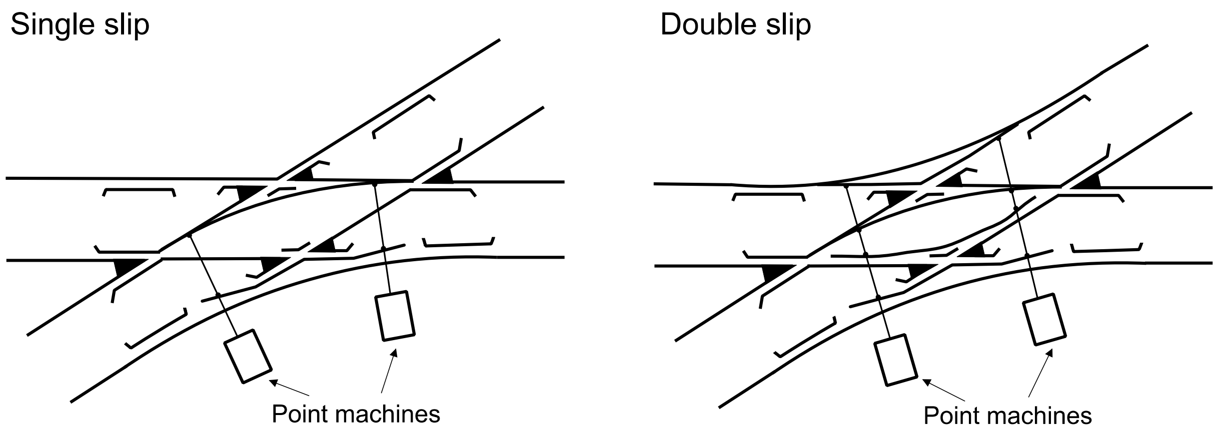

Figure 1.4 Single and double slips

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Crossings

A crossing is an assembly of rails that effects two tracks to cross at grade. Like points, crossings are equipped with fouling point indicators. The inner part of a crossing is called a ‘diamond’. Crossings with a large angle of intersection are designed rigidly. In case of a small angle of intersection (usually less than 1 : 9), fixed diamond frogs are replaced by movable points (‘switch diamond’, Figure 1.3).

Small angle crossings may be equipped with additional points providing a slip connection to permit movements from one track to another. A crossing with a slip connection at one side is called a ‘single slip’, and a crossing with slip connections at both sides is called a ‘double slip’ (Figures 1.4). In the North American terms, crossings with slip connections are called slip switches.

Derailers

Derailers (called derails in the North American terms) are trackside devices that are used to protect train movements against unattended movements of vehicles on converging tracks. An unsafe movement will be derailed before it could join the protected route. In the protecting position, a derailing piece is raised over one rail. Like points, derailers can be hand or power operated. On many railways, derailers must not be installed outside of sidings (see Section 1.2). Instead of derailers, some railways also use trap points, which have quite the same effect.

1.1.2 Lineside Signals

While being gradually replaced by advanced radio-based train control systems, in which trains are guided by cab signal indications, lineside signals are still the most common technology for controlling train movements. On railways where train movements are strongly separated from shunting movements (see Section 1.2), which is the case on most railways outside North America, there are usually also two basic kinds of lineside signals:

Main signals

Main signals authorise a regular train movement to enter a line section. In this tutorial, the term main signal is used in a generic way for all signals controlling regular train movements, no matter, whether or not an individual railway would separate these signals from shunting signals. The movement authority provided by a main signal is limited by the next main signal or a point specified in the operating rules.

Apart from lines with a low speed, a signal that authorises a train movement requires an approach aspect at the braking distance in approach to the signal because the stopping distance is generally greater than the range of vision. The approach aspect is necessary for a safe braking when approaching a stop signal. On lines where the distance between signals does not significantly exceed the braking distance, the approach aspect is usually provided by the signal in rear. On lines with very long distances between main signals, distant signals are placed at the braking distance in approach to a main signal. A distant signal can only provide an approach aspect for the signal ahead but it cannot show a stop aspect. Another common term for a distant signal used in the rulebooks of some railways is warner signal (*Chandra & Agarwal 2008*).

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On North American lines, there is a general lack of distant signals. On signalled tracks, the approach indication is always provided by the block signal in rear, regardless of block length. Distant signals are only used in approach to an interlocking area on a non-signalled track.

Shunting signals

Shunting signals are used to authorise shunting movements and to protect trains against shunting movements. On most railways, the stop aspect of a main signal also applies for shunting movements. On tracks where shunting movements may pass main signals, a shunt aspect is incorporated in the main signal, so that shunting movements may be authorised to pass main signals in stop position. For shunting signals, an approach aspect is not provided because shunting movements run at a very low speed that allows the driver to stop short of any vehicle or obstruction.

On some railways, the stop aspect of shunting signals is absolute, i.e., it indicates stop for all kinds of movements. Such shunting signals must also be cleared for train movements authorised by a main signal. Movements running under authority of a main signal may pass cleared shunting signals at the speed authorised by the main signal or the timetable. Some railways use shunting signals with a shunting stop aspect that does not apply to train movements. This is typical for several East European, Russian, and Chinese railways where a blue light is used for this purpose. On those railways, movements running under authority of a main signal may ignore the stop aspects of shunting signals.

On railways that do not use the distinction between main and shunting signals, there is a signal aspect that authorises a movement to pass a signal cautiously on sight prepared to stop short of any vehicle or obstruction. That aspect is used both for shunting purposes but also to authorise train movements to enter a section that may be occupied.

Concerning the control principle, there is a distinction between controlled and automatic signals. Controlled signals are all signals that protect track sections that contain movable track elements or points where conflicts with movements on conflicting routes may occur. The normal position of controlled signals is stop. To clear a controlled signal, a route is set in the control system that will lock all movable track elements in the proper position and lock out all conflicting moves. The route setting may be initiated by a human operator or an automatic route setting system. If route setting is automated, the signals are still referred to as controlled signals.

Automatic signals work automatically by the passage of the train through track sections. They are forced to stop position by track clear detection devices if the section beyond the signal is occupied. Automatic signals can only be used to protect track sections that do neither contain any movable track elements nor points where conflicts with movements on conflicting routes may occur. Depending on the type of control system, the normal position of automatic signals may be stop or clear.

1.1.3 Track Clear Detection

The purpose of track clear detection devices is to check that all relevant track sections are clear of vehicles before a train may be authorised to pass through a route. There are two types of track clear detection devices: track circuits and axle counters.

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Track circuits

A track circuit is an electrical circuit of which the rails of a section form a part. It usually has a source of current at one end and a detection device at the other. Sections are divided by insulated rail joints (Figure 1.5).

If the section is occupied by a vehicle, the axles produce a short circuit by shunting the two rails. As a result, the detection device does not receive any current and therefore it detects the section as occupied. The detection device is often implemented by a track relay, which is in a picked up position when the section is clear and dropped when the section is occupied. In modern installations, the relay is often replaced by an electronic detector. Since a track circuit is based on the closed circuit principle, any interruption of the current will lead to a safe state by making the section occupied.

The maximum working length of a track circuit is limited by the resistance between the two rails. Track circuit sections cannot be made much longer than about 2 km. Also, non-shunting vehicles and situations in which the safe working is limited by rusty or dirty rails require specific operating procedures.

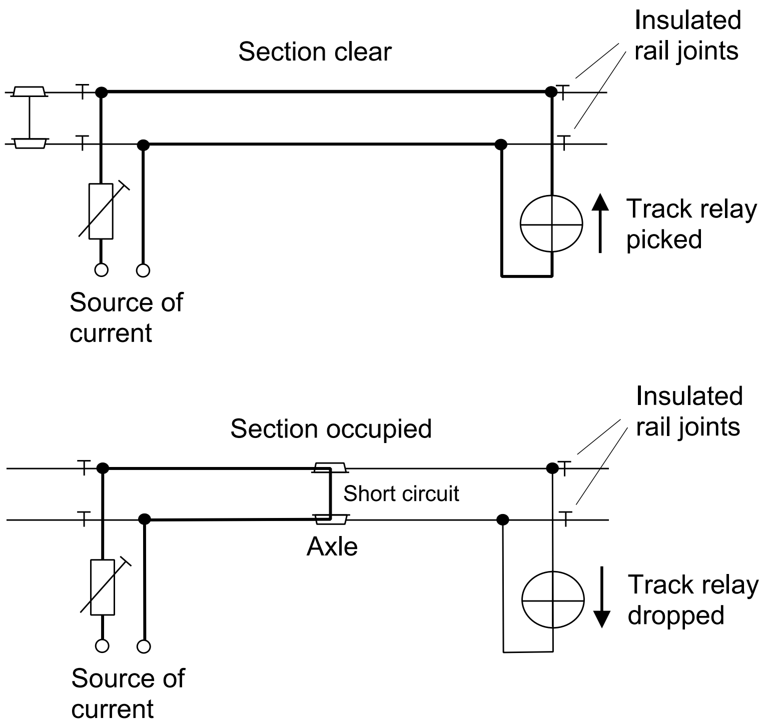

Figure 1.5 Track circuit

Non-shunting vehicles are vehicles that are not safely detected by track circuits, since they do not produce a reliable electrical connection between the rails. A range of maintenance and inspection vehicles fall into this category. Track circuits occupied by non-shunting vehicles must be protected under staff responsibility by securing protective signals in stop position. If the rails of a track circuit section are heavily rusted, even regular vehicles will no longer safely be detected. That is, why most railways established the rule that there must be a minimum number of movements within a specified period of time to keep the track circuits safe. A typical rule is one movement per day. If there was no movement within that period, the next move to enter that section must be made on sight unless the clearance of the section can be checked

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by other means. The rails of a track circuit section must also be kept clean, since heavy dirt may have the same effect as rust.

On electrified lines, the rails are used as a return for the traction current. Therefore, adjacent track circuits must be electrically connected to allow the traction current to pass the insulated rail joints. The simplest solution is providing a common rail by single-rail track circuits. To provide better protection against parasitic currents in case of an accidentally shunted insulated rail joint, joints are often provided in both rails using cross bonds to connect the track circuits (Figure 1.6). This way, the return of the traction current changes to the other rail at insulated rail joints.

On most railways, single-rail track circuits are only used for short track circuits, e.g., within point zones, but not for track clear detection of longer sections. Track circuits for longer stretches of track require a better protection against parasitic currents. For this purpose, double-rail track circuits are used. The electrical connection for the return of the traction current is achieved by so-called impedance bonds (Figure 1.7).

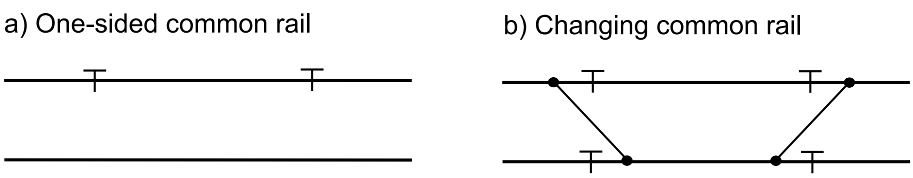

Figure 1.6 Single-rail track circuits

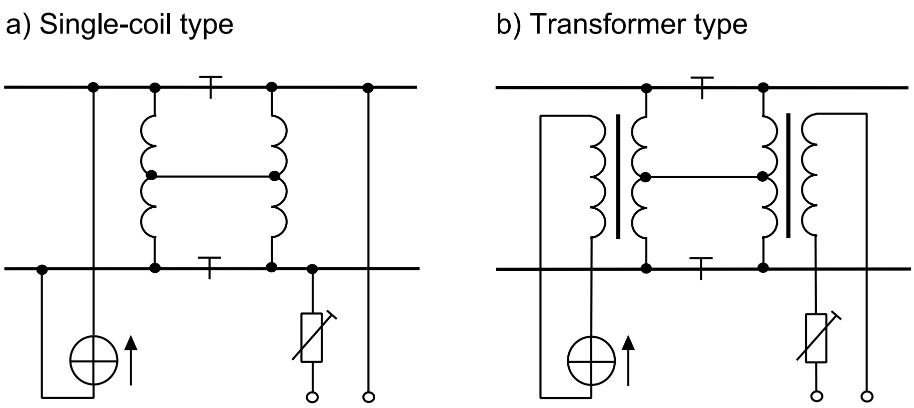

Figure 1.7 Impedance bonds

In its most simple form, at both sides of the insulated rail joints, a coil is placed between the two rails of the track. The coils are connected by a centre connector that divides each coil into two halves. The traction current enters the coil from each rail, and leaves the coil through the centre connection, passing through the opposing coil into the rails of the next section. In this way, two opposing magnetic fields are produced, one in each half of each coil, which are balanced in strength and neutralise each other. By using AC track circuits, the impedance will prevent the coil from shunting the track circuit. In a modified version, transformers are used instead of single coils. Both the source of the traction current and the track relay are no longer

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directly connected to the rails but via these transformers. Since, as explained above, the opposing magnetic fields produced by the traction current in the trackside coils equalise each other, they will not cause inductive currents in the coil connected to the track relay.

Some railways (e.g., in Switzerland) use digitally coded track circuits in which the track relay is replaced by an electronic device. With this technology, single-rail track circuits with joints in only one rail may be used for sections of any length. This eliminates the need for impedance bonds.

There are also jointless track circuits, also known as audio frequency track circuits. These are specific track circuits that work with an audio frequency AC track current. Due to the inductive and capacitive track characteristics, the working length of such a track circuit would limit itself. For a safe continuous track clear detection, the adjacent track circuits must overlap each other. A controlled overlapping of adjacent track circuits can be achieved by S-shaped rail connectors (Figure 1.8). There are also jointless track circuits that provide a controlled overlapping without such connectors but lead to a longer overlapping zone.

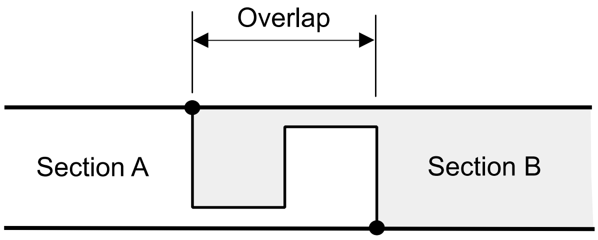

Figure 1.8 S-shaped connector to separate jointless track circuits

Axle counters

An axle counter is a system consisting of counting points at the boundaries of a section and a counter connected to the counting points (Figure 1.9). The occupancy of a section is detected by comparing the number of axles that enter the section with the number of axles that leave the section. To give a clear indication, the parity of numbers is necessary. Counting points are usually made up of double contacts to detect the direction of movement. This is necessary for correct detection whether an axle is entering or leaving the section.

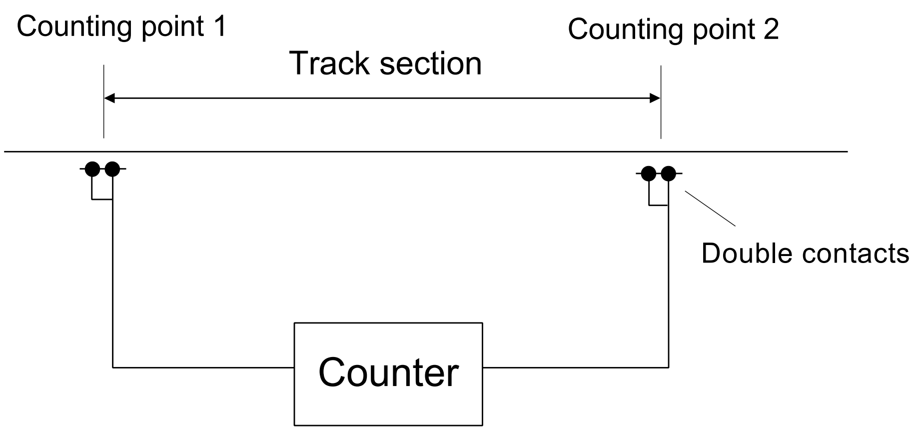

Figure 1.9 Axle counter

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In contrast to track circuits, the maximum working length is not limited. There are also no problems with non-shunting vehicles or rust or dirt on the rails.

1.2 Basic Operating Terms

Classification of Tracks

In railway operations, a track is often also referred to as a line. A route consisting of just one track is called a single line, while a route with double track operation, i.e., two parallel tracks and a specified direction for normal moves on both tracks is called a double line. For operational purposes, tracks are divided into two main classes. While they that are called differently in the rulebooks of individual railways, the basic idea is always the same:

- Tracks that may be used for regular train movements
- Tracks that must only be used for shunting movements

The distinction between train and shunting moves is explained later in this section. The tracks used for regular train movements are called main tracks or running lines. The term main track is mainly used in North America, but was also adopted by some railways outside North America. It is also used in some international textbooks (*Theeg & Vlasenko, 2020*). Many other railways, in particular railways with roots in the British systems, prefer the term running line. The lines between stations and their continuation through stations and interlocking areas belong into this category. It also includes tracks for passing and overtaking trains which are called loops on most railways (Figure 1.10). On signalled lines, tracks used for train movements are equipped with signalling appliances for the safe passage of trains. Along the line a train passes through, points are usually interlocked with signals that provide the movement authority. Sidings are all tracks that must only be used for shunting movements. The points of sidings are often not interlocked.

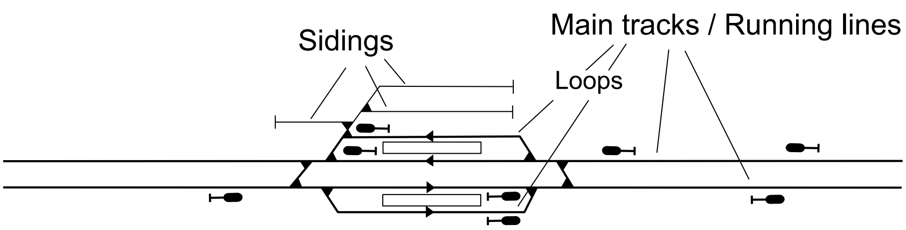

Figure 1.10 Classification of tracks

Note: In the North American terms, a line is a route that may consist of several parallel tracks. Furthermore, loops are called sidings; tracks other than main tracks are called yard, secondary, or industrial tracks. Single-end tracks connected to a main track are called spur tracks.

Block Sections

A line with a fixed block system is divided into block sections for the purpose of safe train separation. A train must generally not enter a block section until it has been cleared by the train ahead. On lines with lineside signals, block sections are limited by signals, which govern train movements. A signal that limits a block section outside a station area is called a block

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signal. While the basic idea of train separation by fixed sections also applies on station tracks, many railways that separate the station areas from the open line (see following paragraph on interlocking areas) use the term block section only outside of station areas.

Interlocking Areas

An interlocking area is a track area, where controlled signals are interlocked with points and other signals in a way that a signal can only be cleared when all points are locked in the proper position and all conflicting moves are locked out. Signals that govern routes in an interlocking area are called interlocking signals. The points and signals are controlled either by a local interlocking station or from a remote control centre. Local interlocking stations are called interlocking towers in North America, and signal boxes or signal cabins on most other railways. A locally staffed interlocking station contains both the interlocking system and the user interface for the operator. Modern interlocking systems are usually remote controlled from a control centre.

There are two basic signal arrangements in interlocking areas (Figure 1.11). First, there are interlocking areas without consecutive interlocking signals. An interlocking signal provides authority to run through the entire interlocking area into the next block section. Second, there are interlocking areas with consecutive interlocking signals.

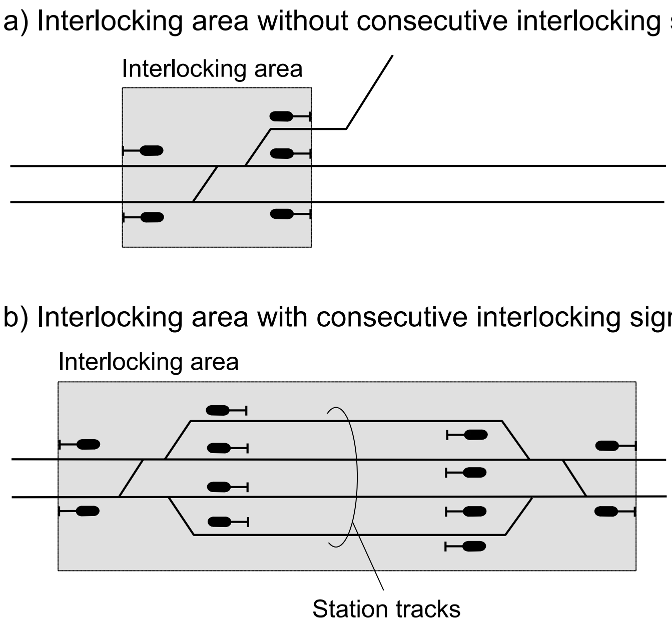

Figure 1.11 Types of interlocking areas

Such an interlocking area may contain tracks protected by controlled signals on which trains may originate, terminate, pass, and turn. In this tutorial, these tracks are called station tracks. Consequently, an arrangement of station tracks is called a station area. Also, in this tutorial, the tracks outside the opposing interlocking signals limiting the station area are called the open line. The terms station area and open line are used here in a generic way not referring to the practice of an individual railway. Due to the big variety of operating principles used worldwide, terms used in the rulebooks of individual railways may differ.

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A station platform for scheduled stops of passenger trains is not necessarily associated with a station track in the sense as defined above, which needs not have a platform. There are also platform stations on the open line, which do not necessarily imply any provision of pointwork or the ability to reverse trains within the signalling system.

On most railways, the interlocking signals protecting a station area from both sides are called home signals. The interlocking signals that govern train movements to leave a station track into a section of the open line are often called station exit signals or just exit signals. These terms are also used in this tutorial. Other commonly used terms for these signals are section signals, starter signals, or leaving signals. Interlocking signals within the station area that are neither home nor exit signals are called intermediate interlocking signals (Figure 1.12). On some railways, they are also called inner home signals (when passed by arriving trains) and inner starter signals (when passed by departing trains).

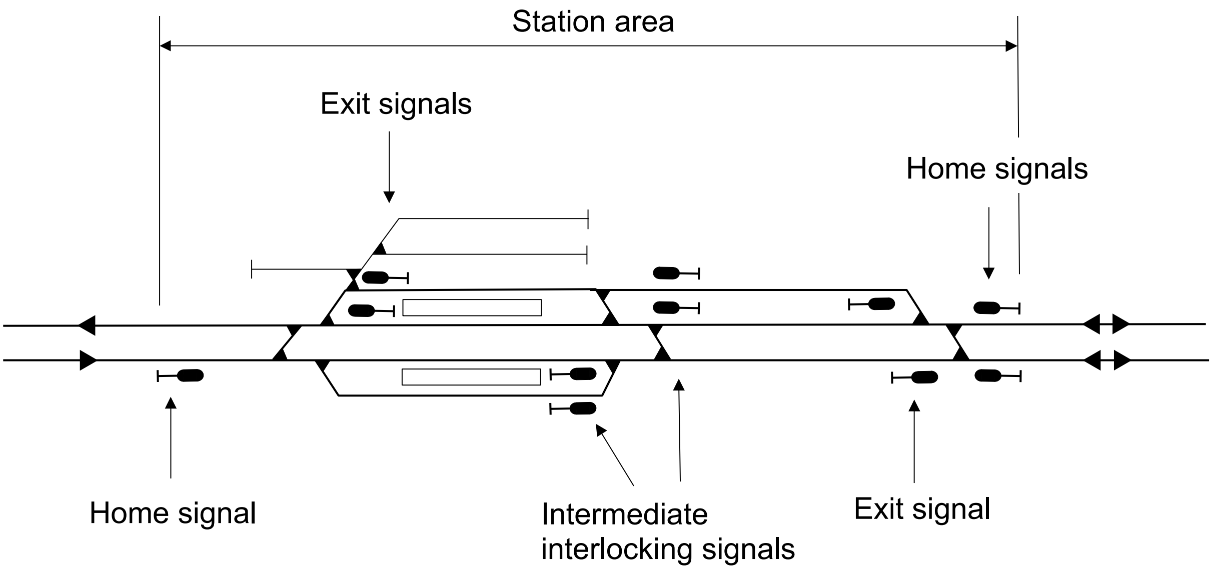

Figure 1.12 Station area with intermediate interlocking signals

In North America, interlocking areas with consecutive interlocking signals within the same interlocking limits are not common. The reason is that the distinction between station tracks and tracks of the open line does not exist in the North American rules (*Bisset et. al., 2008*). In Europe and most other railways outside of North America, station areas with consecutive interlocking signals are very common. In modern British signalling centres, there is also no longer any formal distinction between station tracks and sections of the open line. However, interlocking areas may contain consecutive interlocking signals. So, in a generic way, the terms used here will also fit to the British system.

Movements with Railway Vehicles

On most railways, the normal train movements are separated from the so-called shunting movements. In North America, the rules for both kinds of movements do not differ as significantly as in most other countries. That is the reason why in North American operations, as mentioned above, shunting signals are not used.

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Train movements, also known as 'running movements', are movements of locomotives or self-propelled vehicles, alone or coupled to one or more vehicles, with authority to occupy a section of line under operating conditions specified in the operating rules. Every train displays rear end markers (tail lights or marker boards) to enable the lineside staff to check the train completeness. All regular movements running along the line from station to station are train movements.

The authorisation of a train movement has two elements:

- A valid timetable as the authority to run through the network along a pre-defined route by specified operating conditions (timetable authority)
- A movement authority for every single section of track in the path of the train

The movement authority to enter a section of track is issued by the operator who is in charge of controlling train movements on that section of track. This way, a train is always under external guidance of a train control operator. The authority for train movements is given by:

- A proceed indication of a main signal
- A proceed indication of a cab signal display
- A call-on signal permitting a train to pass a signal displaying a stop aspect under special conditions
- A written or verbal instruction permitting a train to pass a signal displaying a stop aspect under special conditions
- A written or verbal authority on non signal-controlled lines

Shunting movements are movements for making up trains, moving vehicles from one track to another, and similar purposes. Shunting movements are accomplished without a timetable under simplified conditions at a very low speed that allows the driver to stop short of any vehicle or obstruction. On main tracks and on sidings controlled by an interlocking station or control centre, a verbal agreement between the shunting crew and the operator is needed before the operator may authorise the shunting move. That verbal agreement performs a similar function as the timetable authority for train movements. Block rules are not in effect. Shunting units may enter occupied tracks. Movements in industrial sidings are also carried out as shunting movements.

The authority of shunting movements is given by:

- A proceed indication of a shunting signal, which may be combined with a main signal to authorise a shunting move to pass the main signal in stop position
- Verbal permission

In the North American terms, the term shunting is not used. Shunting movements are called ‘switching movements’ or ‘movements of yard engines’.

Concerning shunting movements, the railways designated different limits in accordance with their individual operating practice.

On European railways, apart from modern British rules, shunting units must not enter line sections outside the home signal limits of a station area. The same rule also applies on many railways outside Europe. The area between the home signals that may be used for shunting is usually limited by limit of shunt or shortly LOS boards (Figure 1.13).

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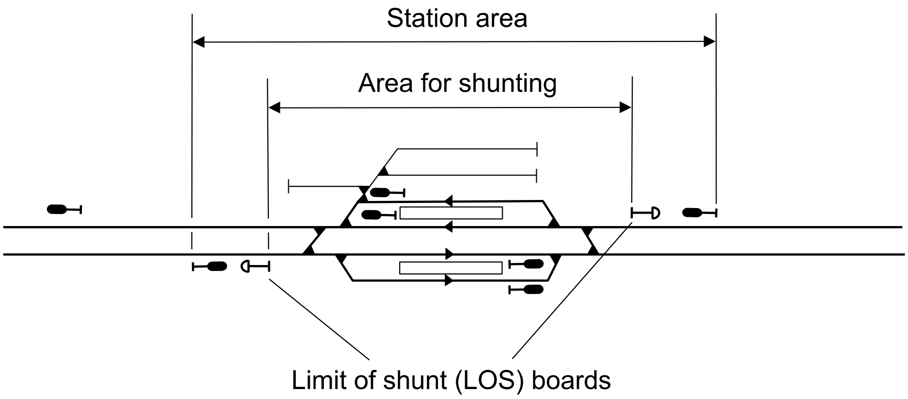

Figure 1.13 Shunting limits of a station area

The distance between the home signal and the LOS board equals the overlap of the home signal. Shunting units may pass the shunting limit boards only with a written permission from the operator. Before issuing authority to a shunting unit to pass the shunting limit board, the operator has to make sure that there is no train approaching the home signal.

While in modern British railway operations, the formal distinction between station areas and the open line doesn't exist, shunting units must be prevented from entering a section on which they are not protected against opposing movements. If no main or shunting signal exists to limit the shunting move, limit of shunt signals are placed at the shunting limit. These LOS signals are inoperative shunting signals permanently displaying a stop aspect.

Double Track Operations

For double track operation, there is usually a specified direction of traffic for each track. While right-track operation dominates slightly worldwide, there is a significant number of countries where left-track operation is the standard form. On lines not equipped with a bidirectional signalling system for two-way working, all regular train movements have to be made with the normal direction of traffic. On such lines, movements against the normal direction (also called 'wrong line moves' or 'reverse movements') have to be authorised by special instructions under staff responsibilty. On lines that are equipped with a signalling system for two-way working, movements against the normal direction can be authorised by clearing a main signal.

Many railways do not install intermediate block signals for reverse movements because on most lines, reverse movements are not carried out frequently. For temporary single track working is case of a track closure, the direction on the remaining track will change after almost every train. So, intermediate block signals would have no effect on capacity. Intermediate block signals for movements against the normal direction do only make sense on sections, where parallel moves on both lines are carried out on a regular basis.

Figure 1.14 shows typical examples of signal arrangements for double track operation. On many railways, a normal direction of traffic is only in effect outside of station areas.

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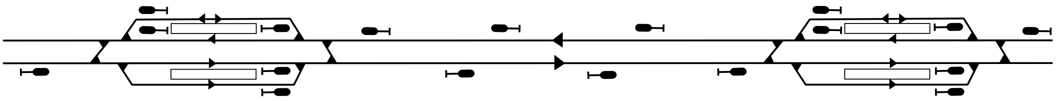
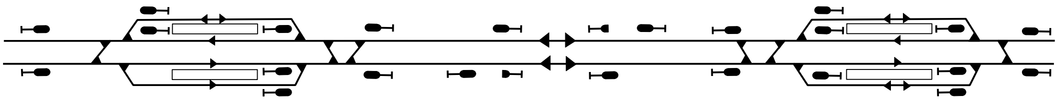
a) Double track operation with one-way working



b) Double track operation with two-way working without intermediate block signals for movements against the normal direction



c) Double track operation with two-way working with intermediate block signals for movements against the normal direction

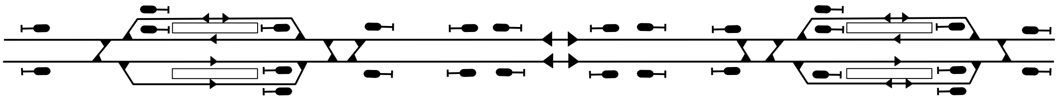


Figure 1.14 Signal arrangements for double track operations

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2 SPACING TRAINS

In a steel wheel on steel rail system, the static friction coefficient is on average eight times less than in road traffic. As a result, the maximum braking force that can be transmitted between wheel and rail for a given weight is also eight times less. That leads to braking distances for railway vehicles that may exceed the viewing range of the driver significantly. Thus, train separation cannot simply be based on the viewing range but has to be controlled by trackside technology.

2.1 Theory of Train Separation

There are three basic theoretical principles of train separation:

- Relative braking distance
- Absolute braking distance
- Fixed block distance

Relative Braking Distance

In relative braking distance mode, the distance between two following trains equals the difference of the braking distances of the trains plus an additional safety margin. For the headway (‘head-to-head’) distance between two trains following each other, the length of the first train has to be added (Figure 2.1 a). The braking distances of both trains have either to be calculated with braking curves based on the same deceleration rate, or by applying the rule that in case of a better braking performance of the second train, a minimum safety margin must always be kept between the two trains.

While relative braking distance leads to a maximum of line capacity, there are two essential problems. When points are to be moved between two trains, the second train cannot follow at relative braking distance but must be kept at full braking distance in approach to the points until the points are safely locked in the new position. As a result, the line capacity is limited by the point zones where successive trains may take different routes. Another problem is that in case of an accident of the first train, the second train has no chance to stop and is going to collide with the first train. For these problems, this principle has not yet applied for train separation but is used by some freight railways for processing the coupling and uncoupling of helper locomotives on the move.

Absolute Braking Distance

Absolute braking distance leads to a distance between two following trains that equals the braking distance of the second train plus an additional safety margin. For the minimum headway, the length of the first train has to be added (Figure 2.1 b).

Train separation by absolute braking distance is often seen as the best suited principle of train separation. The only problem that has so far prevented the introduction of this principle outside of mass transit systems is the lack of a usable technology for on-board checking of train completeness (train integrity) of freight trains, which is needed for safe location of the train’s rear

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end. However, with the further development of radio-based operating technologies, train separation by absolute braking distance may be widely introduced in the near future. The absolute braking distance mode is also generally known as ‘moving block’.

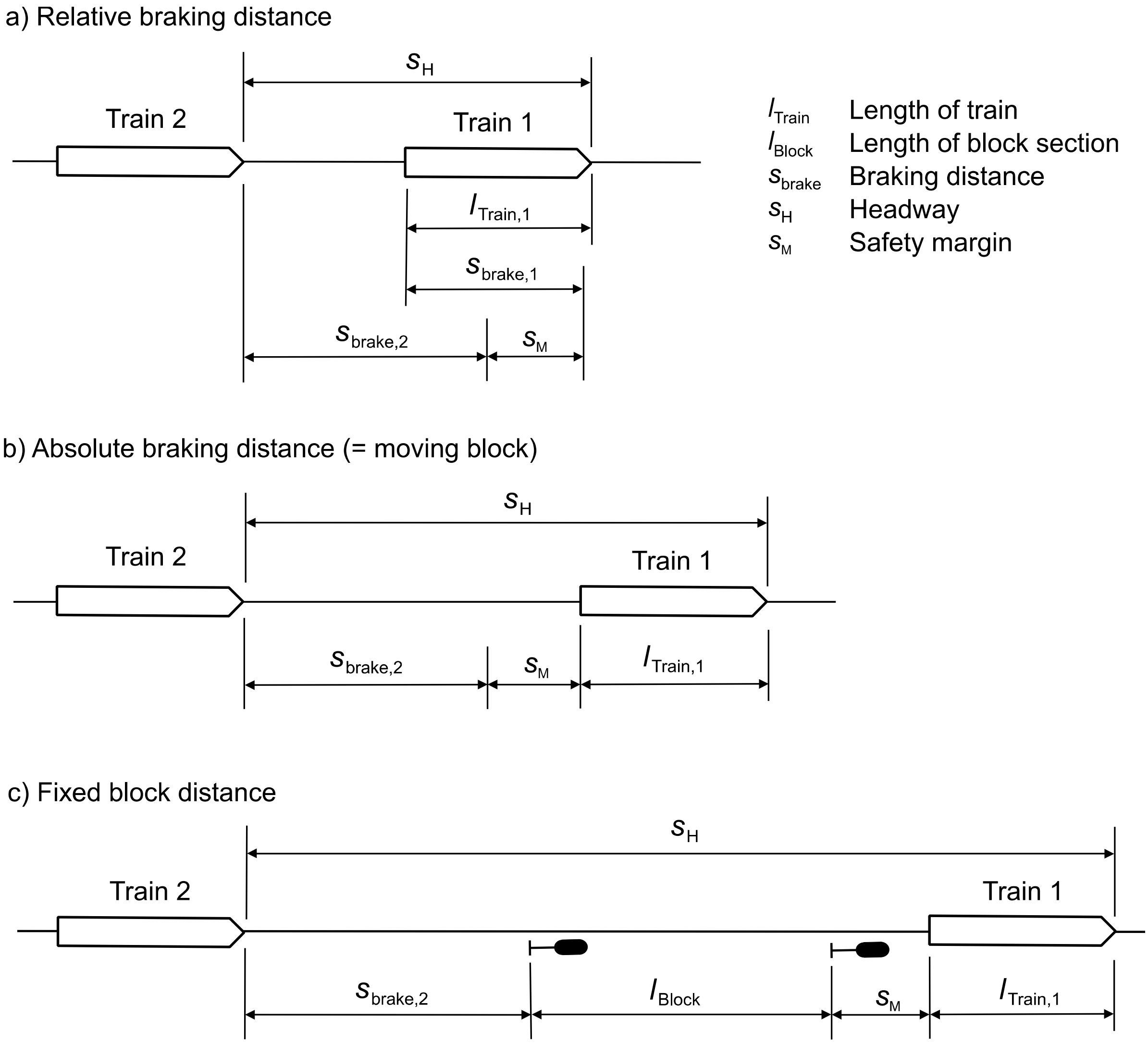

Figure 2.1 Principles of train separation

Fixed Block Distance

In a fixed block system, the line is divided into consecutive block sections. A block section may be exclusively occupied by only one train at a time. The distance between two following trains equals the braking distance of the second train plus the length of the block section plus an additional safety margin. Thus, the headway distance equals the headway of absolute braking distance plus the length of the block section (Figure 2.1 c). While the minimum headway of a fixed block system exceeds the minimum headway of a moving block system, the capacity limiting effect of the block sections is often overrated.

In train control with lineside signals, the block sections are limited by signals. Nowadays, running in fixed block distance is the most common principle of train separation worldwide.

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2.2 Train Control Principles

The principle used for safe train separation depends on the following criteria:

- How movement authority is transmitted from track to train
- How the track is released behind a train

If movement authority is only transmitted at discrete points, e. g. at lineside signals, this will necessarily lead to a fixed block system. Each movement authority has to cover the entire section up to the next point at which further authority may be received. On lines where trains are governed continuously by a cab signal system, this restriction does not exist. However, continuous transmission of movement authority is not yet a sufficient criterion to abolish fixed block sections. In addition, the train has to release the track not in fixed intervals but continuously. This requires a permanent train-borne checking of train completeness. Since for traditional railway systems, a sufficient solution for that problem has not yet been found, train separation at a fixed block distance is still the standard principle for safe train spacing on most railways worldwide.

Before explaining the different principles of train separation, another essential feature has to be mentioned. The braking distance of a train does not mainly depend on the weight of the train but on the percentage of the weight that is used to transmit braking force between wheel and rail. Trains with the same braking ratio have generally the same braking distance. For safe train separation, a train must always have a clear track ahead at least as long as the braking distance. Thus, from the viewpoint of capacity, it makes sense to assemble vehicles into trains. All vehicles that form a train do need just one common braking distance for the entire consist. This will significantly reduce the capacity consumption that is produced by the long braking distances. This is why running whole trains instead of single vehicles is one of the very basic characteristics of a railway system.

2.2.1 Train Control by Lineside Signals

Guiding Trains in Fixed Block Operation

While, with the introduction of radio-based train control system, railways move more and more toward cab signalling, lineside signals are still the dominating from of train control. They are even used in many new installations. Since lineside signals can only transmit movement authorities at fixed intervals, train control by lineside signals always leads to a fixed block operation. For this, the line is divided into block sections limited by signals. To clear a signal for a train that is to enter a block section, the following conditions must have been fulfilled (Figure 2.2):

- The train ahead must have cleared the block section
- The train ahead must have cleared the overlap beyond the next signal (only on lines where block overlaps are used)
- The train ahead must be protected by a stop signal

On lines with bidirectional operation, the train must also be protected against opposing movements.

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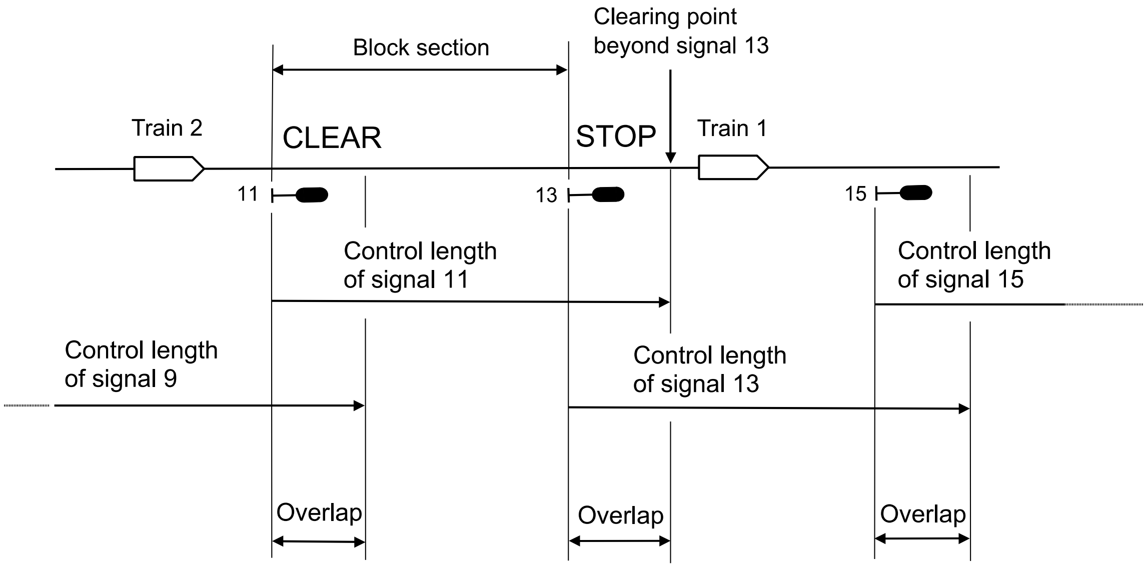

Figure 2.2 Control length of signals on a fixed block line

The control length of a signal is the length of track beyond a signal that must be safe and clear to enable that signal to be cleared. When overlaps are used, the control length exceeds the length of the block section and overlaps with the control length of the next signal. The main purpose of the overlap is to provide additional safety in case a train overruns a stop signal by a short distance due to bad brake handling. A signal must not be cleared until the full control length is clear. Thus, the clearing point beyond a signal equals the end of the control length of the signal in rear. Some railways do not use overlaps. In that case, the control length of a signal equals the block length.

Lineside Signal Indications

Lineside signals provide information both for safe train separation but also for guiding trains through point zones. Concerning the classification of signal aspects, these systems can be divided in two basic principles of signalling:

- Speed signalling
- Route signalling

In a speed signalling system, the signals indicate the speed not to be exceeded by a train. In route signalling, the facing point signals indicate the route over which the train is being sent. In route signalling, the driver must know the speed limit of every route the train may run over. While systems follow the speed signalling principle, route signalling is also still quite common, in particular on railways with roots in the British system.

In some systems, the speed or route information is part of the block signal aspect e.g., by using combinations of different lights. Other systems, in particular modern European installations, use supplementary speed or route indicators. In such systems, the block signal itself gives only information about the occupation of the following block sections. So the block signal aspects can be designed in a very simple form.

For train separation, most railways use three basic indications, usually displayed by a red, yellow, and green aspect. That’s why, such a system is also known as three-aspect signalling.

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Since different names are used for these indications in the rulebooks of individual railways, the generic terms as stated in Table 1 are used here.

Table 1 Basic signal indications

Stop	Train must stop at the signal
Expect stop	Train may proceed with caution prepared to stop at the signal ahead
Clear	Train may proceed

Regarding the principle of providing the approach indication there are two kinds of signalling (Figure 2.3):

- One-block signalling
- Multiple-block signalling

In one-block signalling (Figure 2.3 a), the indication of a main signal depends only on the state of the block section beyond the signal. A main signal cannot provide any approach information for the next signal. So, every main signal must have a distant signal whose only purpose it is to provide the required approach indication. The distant signal is placed at the braking distance in approach to the main signal. On lines with short block sections that do not significantly exceed the braking distance, the distant signal is placed at the main signal in rear. In such systems, the head of a main signal and the head of the distant signal for the next main signal are often mounted one above the other on the same mast.

In multiple-block signalling, the indication of a main signal depends on the state of two or more following block sections. Very common is two-block signalling in which the approach indication is given by the aspect of the rear main signal without need for separate distant signals (Figure 2.3 b). Since two-block signalling uses the same three basic signal aspects as one-block signalling, both principles fall into the category of ‘three-aspect signalling’.

Multiple-block signalling renders a very efficient signalling but requires block sections not much longer than the stopping distance. On lines with very long block sections, multiple-block signalling is not useful because approach indication given too early will reduce the capacity of the line by increasing the the signal headway of following trains. Many modern signal systems may be alternatively used with one-block or multiple-block signalling depending on the actual block length.

Some railways even use three-block signalling in which a main signal provides information on three block sections ahead by using an advance approach indication (Figure 2.3 c). For this, a forth signal aspect is used telling the driver to be prepared to stop at the second signal ahead. That is, why such a system is called four-aspect signalling. By three-block signalling, the braking distance may exceed the block length enabling signals to be placed at shorter intervals to improve capacity. On railways that use speed signalling, the same effect can be achieved by progressive speed signalling (Figure 2.4).

In progressive speed signalling, a train approaching a stop signal is progressively slowed down by speed indications. So, the maximum speed at which the train may pass the last signal in approach to a stop signal will ensure a safe braking within the short block section. Although

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more than three signal aspects are used (mostly four aspects but in some installations even more), it is only a two-block signalling system because an approach information is only given for the signal ahead.

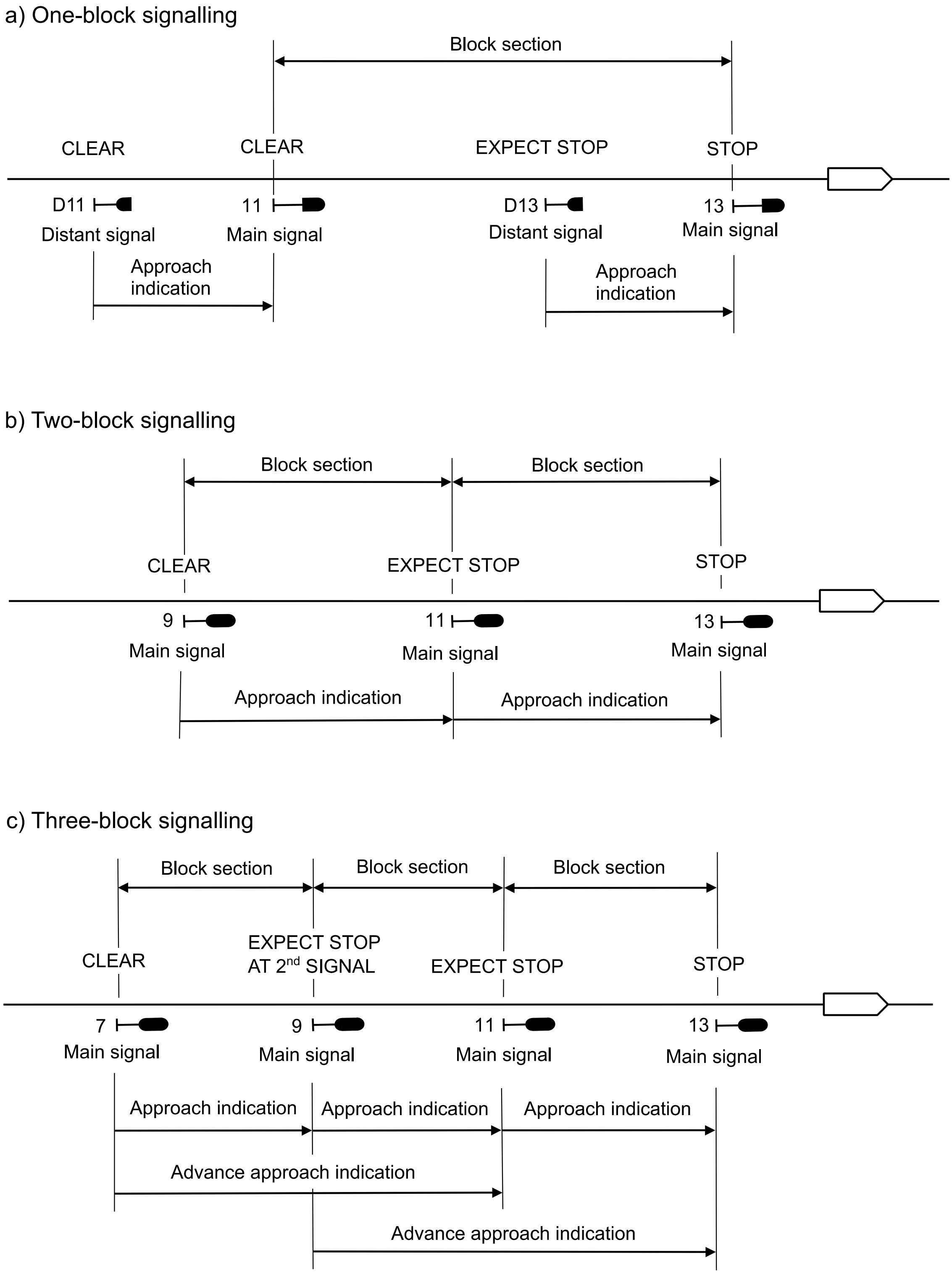

Figure 2.3 Different Principles in the Application of the Approach Indication

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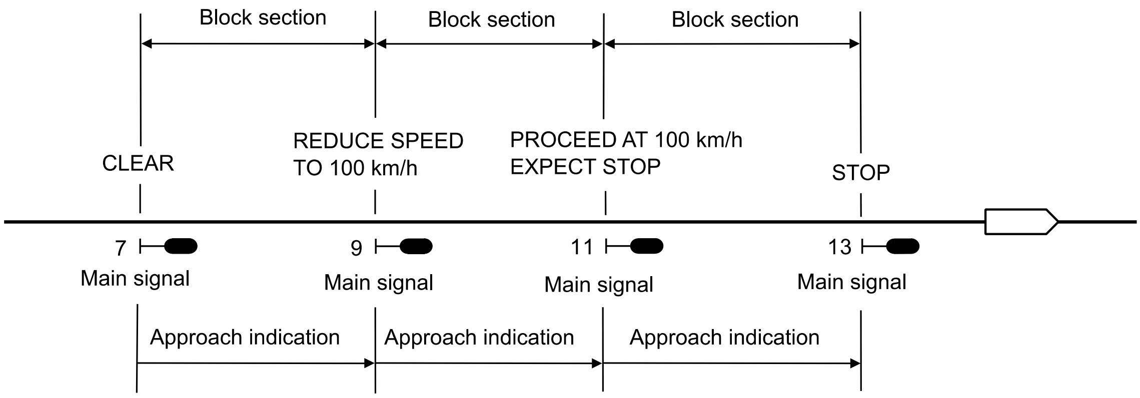

Figure 2.4 Progressive speed signalling

A very common application of short block sections are moving-up signals at platform stations of mass transit railways (also known as staggered or multiple home signals). The purpose of these signals is to save time between the departure of one train and the arrival of the next train at the same platform track. The moving-up signal is placed beyond the station entrance signal directly at the platform. Thus the station entrance signal and the moving-up signal form a very short block section. The control length of the station entrance signal leads up to the clearing point at the end of the overlap of the moving-up signal (Figure 2.5).

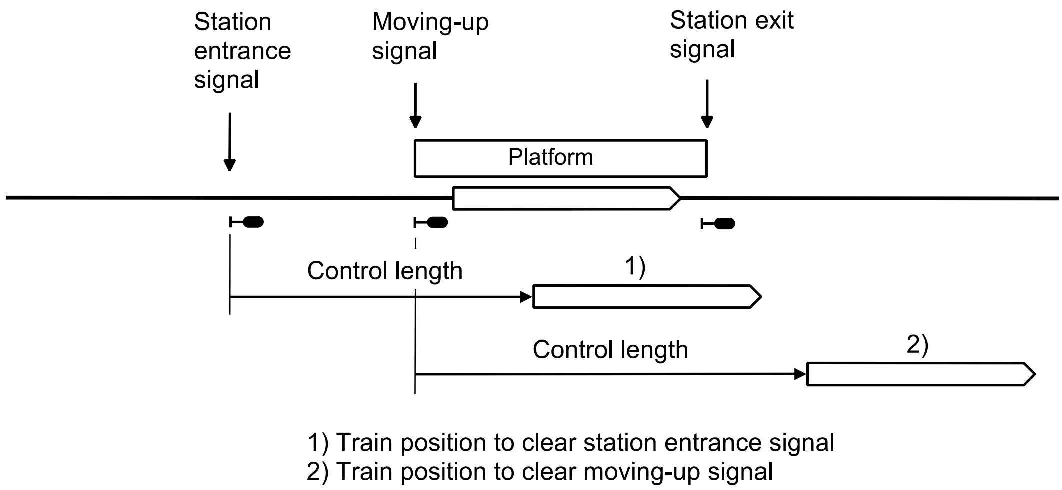

Figure 2.5 Moving-up signal

During a platform stop, a train is protected by two stop signals, since it occupies the control length of both the station entrance signal and of the moving-up signal. When a departing trains has cleared the control length of the station entrance signal (position 1 in Figure 2.5), a following train may already move up toward the platform while the departing train is still protected by the moving-up signal. The moving-up signal clears after the train has completely left the station section (position 2 in Figure 2.5). At stations with a very high density of traffic, multiple moving-up signals may be applied (but hardly more than four). Some railways even place moving-up signals in the middle of the platform.

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The Blocking Time Model

For the non-delayed passage of trains, a signal must be cleared before an approaching train is forced into a brake application by the aspect of the signal in rear. The minimum headway between two following trains depends on the so-called ‘blocking time’ (*Hansen & Pachl 2014, Pachl 2018*).

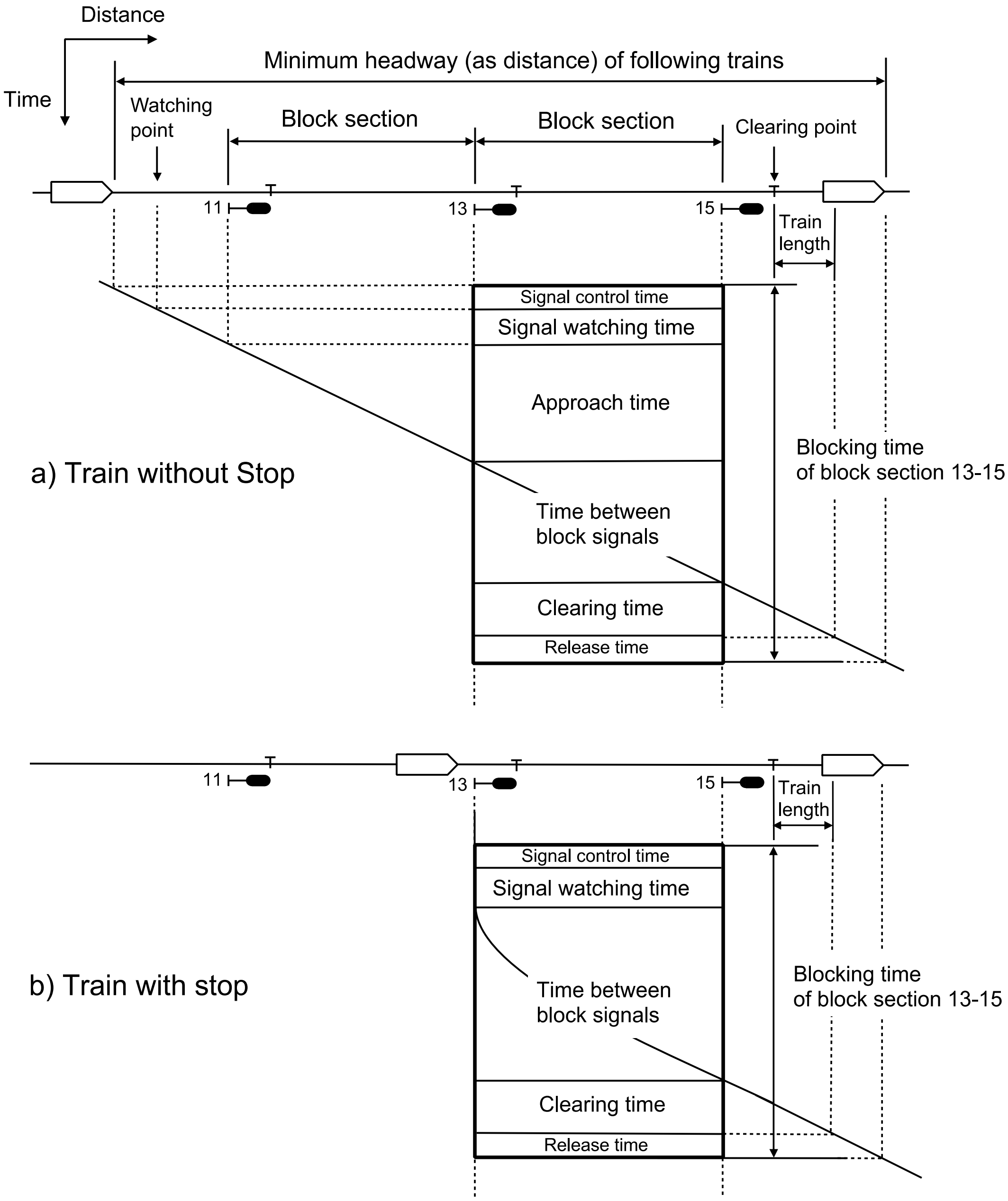

Figure 2.6 Blocking time of a block section

The blocking time (from the German term ‘Sperrzeit’) is the time interval in which a section of track (usually a block section) is allocated exclusively to a train and therefore blocked to other trains. The blocking time lasts from the latest possible time movement authority to enter the section has to be issued by clearing a signal without delaying the train up to the time at which movement authority to another train to enter the same section can be issued. So, the blocking time describes the time window that has to be kept clear for the non-delayed passage of a train

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through a track section. While it is explained here for a lineside signalling system, the idea behind the blocking time model is universal and can also be applied to cab signalling systems and to automatic train operations. As explained in section 2.2.2, it even works for moving block systems.

The blocking time of a track section is usually much longer than the time the train occupies that section. In train control with lineside signals, for a train without a scheduled stop, the blocking time of a block section consists of the following time intervals (Figure 2.6):

- Signal control time, i.e. the control time needed to clear the signal
- The signal watching time, i.e. a certain reaction time by which the signal that provides the approach indication must be cleared ahead of the train to prevent the driver from applying the brakes
- The approach time between the signal that provides the approach indication and the signal at the entrance of the block section
- The time between the block signals
- The clearing time to completely clear the block section and – if required – the overlap
- The release time to ‘unlock’ the block section

The approach time equals the time the signal has to be cleared ahead of a train to prevent this train from passing an aspect at the signal in rear that will force the train into a brake application. It does not apply if the train has a scheduled stop at the signal at the entrance of the block section. In such a case, the signal watching time applies at that signal. There, it is the reaction time of the driver to get the train into motion after the signal has been cleared.

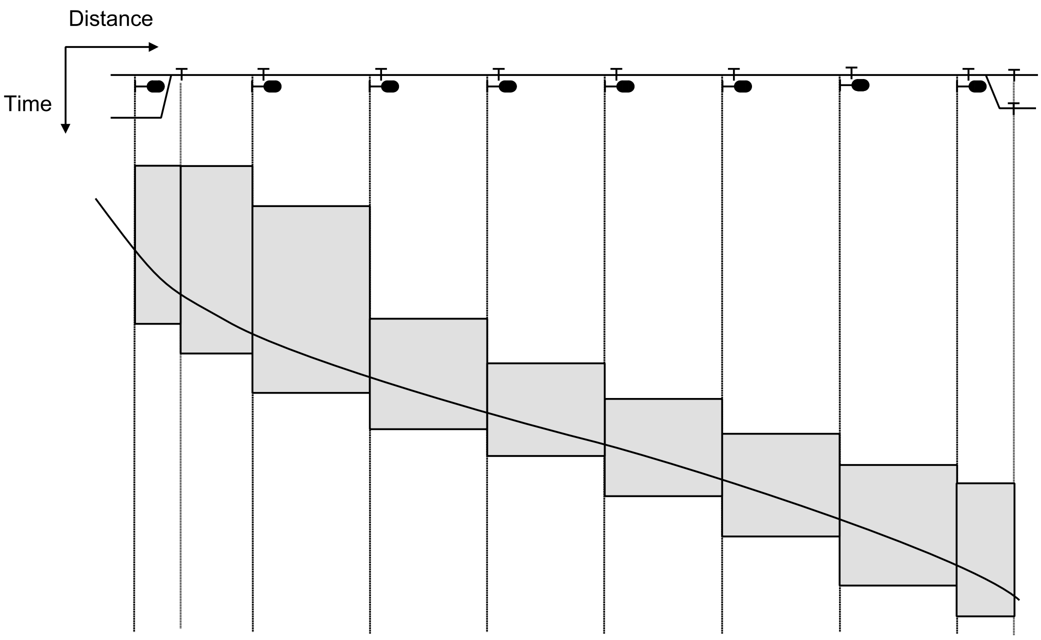

Figure 2.7 Blocking time stairway

Drawing the blocking times of all block sections a train passes into a time-over-distance diagram leads to the so-called ‘blocking time stairway’ (Figure 2.7). The blocking time stairway represents perfectly the operational use of a line by a train. Computer-generated blocking time

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stairways are a typical feature of advanced scheduling systems to establish conflict-free train paths.

By means of the blocking time stairways, it is possible to determine the minimum headway between two trains. The blocking times directly establish the signal headway as the minimum time interval between two following trains in each block section. The line headway is the minimum headway between two trains not only considering one block section but the whole blocking time stairways of the line (Figure 2.8). In this case, the blocking time stairways of two following trains touch each other without any tolerance in at least one block section (the ‘critical block section’).

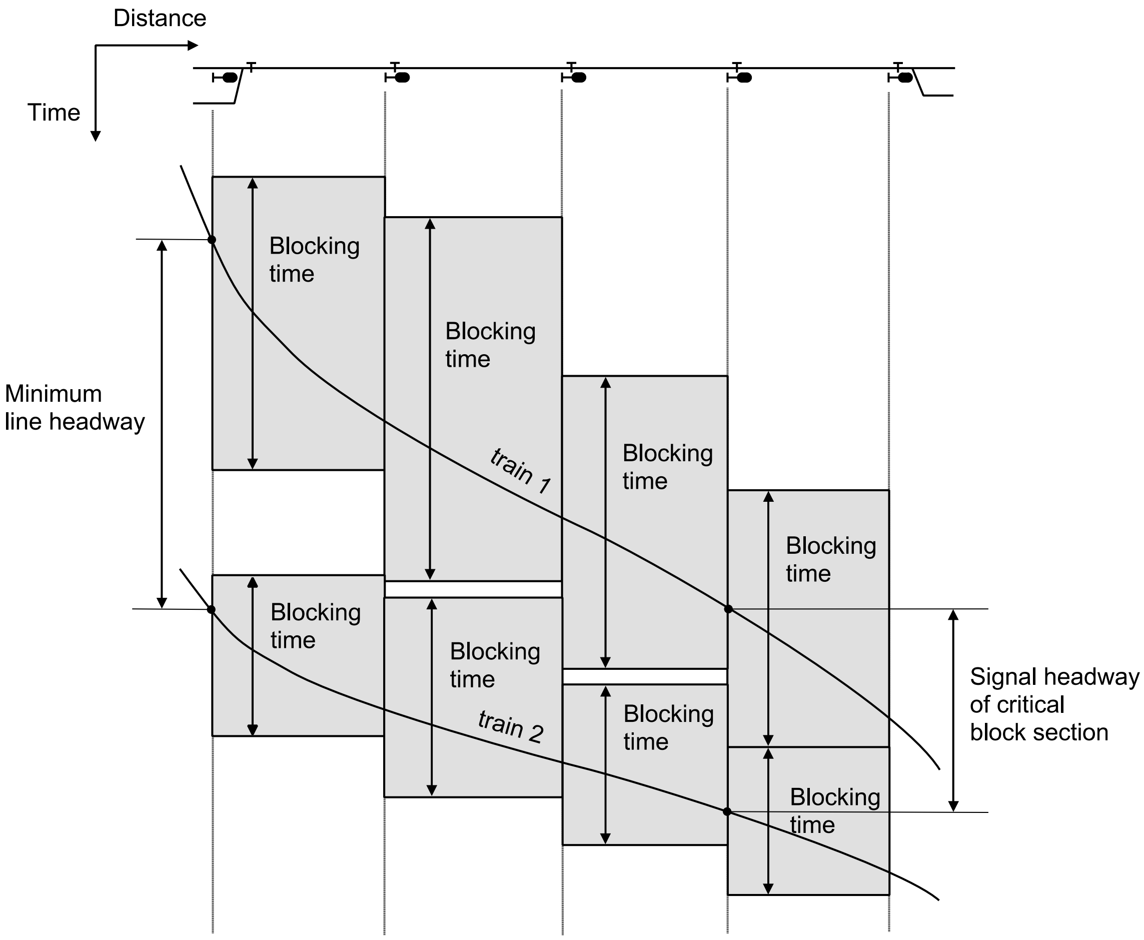

Figure 2.8 Signal headway and line headway

On lines with mixed traffic, the minimum line headway depends significantly on the speed differences between trains. On lines where all trains run at quite the same speed (typical on mass transit railways), the critical block sections are usually the block sections in which the blocking time includes the dwell time of platform stops (station sections, Figure 2.9). On such lines, signals should be placed in a way that keeps the blocking time of the station sections as short as possible.

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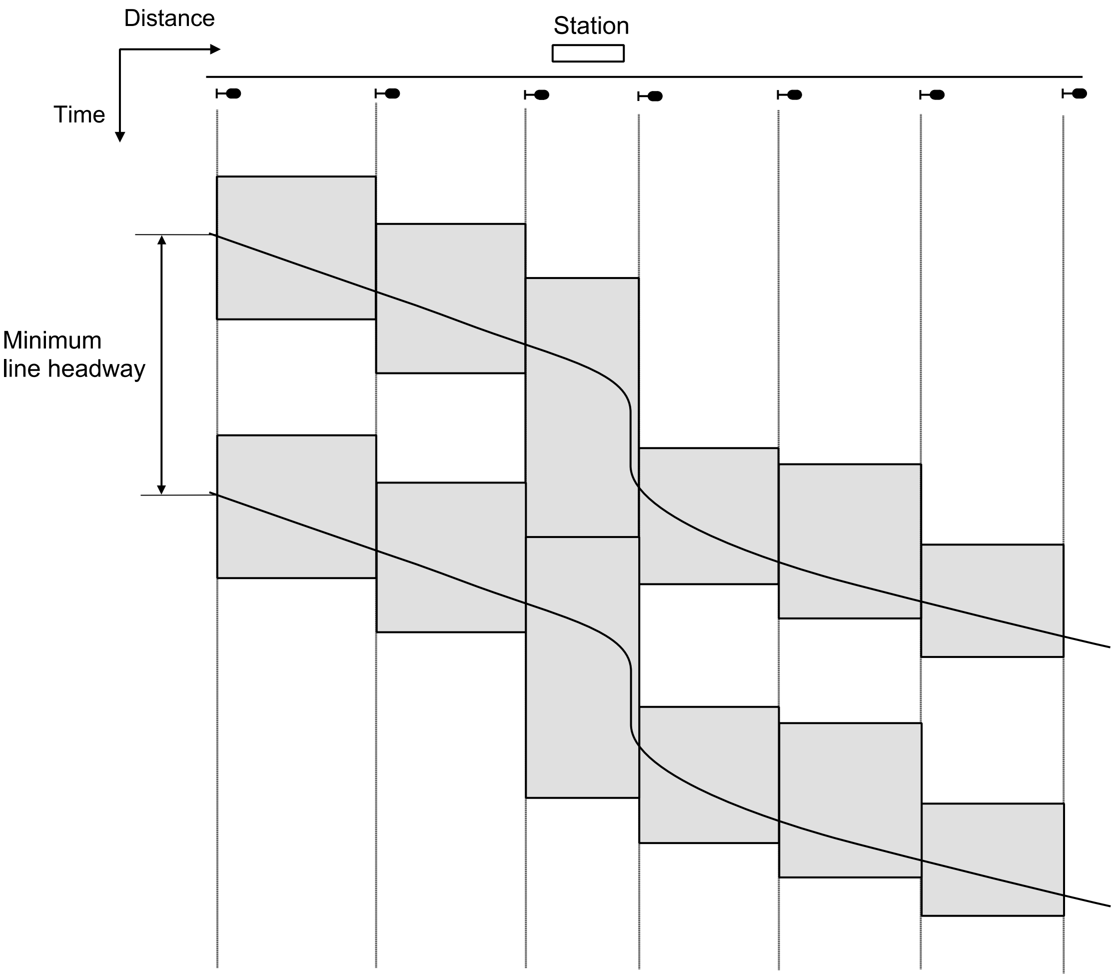

Figure 2.9 Blocking time stairways on a mass transit railway

The Protected Zone Model

The protected zone model is an alternative approach to model the effect, the signalling system has on the spacing of trains. The term ‘protected zone model’ was first used in (*Pachl, 2018*). The basic idea is that behind every train, the signalling system provides a certain zone to protect that train against following trains. The protected zone can be divided into two parts (Figure 2.10 a). First, there is a part of absolute protection, which is marked by red colour. This part consists of all track sections the protected train has exclusive authority to occupy. This is the zone protected by a stop signal. Second, there is a part in which other trains are forced to slow down to prevent them from running into the part of absolute protection. That zone starts at the first restrictive signal encountered by a following train. In the diagram, this part is marked by yellow colour. The protected zone reaches its greatest length when a train is going to clear a block section (Figure 2.10 b). After the train has cleared the block section, the protected zone has its shortest length and starts to grow again (Figure 2.10 c).

The change from the situation of Figure 2.10 b to the situation of Figure 2.10 c represents a single ‘step’ in the blocking time stairway. While diagramming the protected zones with additional times for operating and watching the signals along the path of a train movements would lead to picture similar to a blocking time stairway, there is one essential shortcoming.

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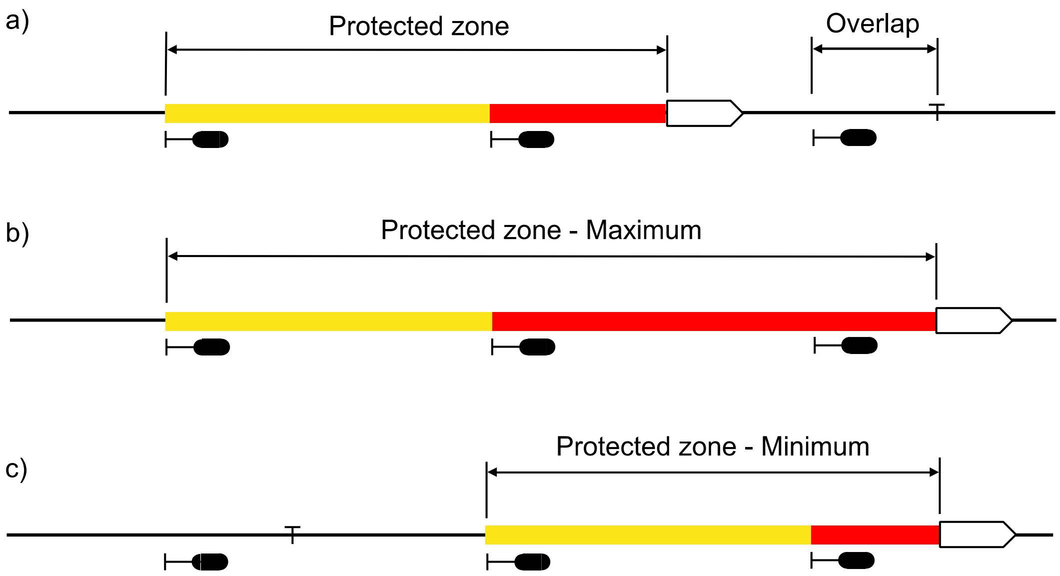

Figure 2.10 The protected zone model

Because the approach time is not added at the beginning but at the end of the occupation of the block section, the protected zone model cannot handle cab signalling systems in which the signalled braking distance depends on the actual speed of a train. In such systems, a train can only calculate its own braking distance but not the braking distance for a following train.

2.2.2 Train Control by Cab Signalling

In cab signalling, the movement authority is directly displayed on the driver's desk. On most railways that use cab signalling, it is combined with a continuous Automatic Train Protection (ATP) system that provides the control data for the cab signals. While cab signalling allows the infrastructure operator to remove lineside signals completely, cab signalling may also be used as an overlay system on lines equipped with lineside signals, so trains may be controlled either by cab signals or lineside signals. To avoid confusion for the driver, most railways established the rule that on such lines, cab signal indications are always superior to lineside signals.

On some railways, there are still older cab signal systems in use that work only as auxiliary systems. On such lines, trains are still governed by lineside signals, but the cab signal indications support the driver in watching the lineside aspects.

Cab signalling with fixed block sections

The main reason for having fixed block sections on lines with cab signalling is the need for checking of train completeness by track clear detection technology. This is the case on all lines with freight traffic, since a sufficient solution for checking train completeness of freight trains does not yet exist. As an approved technology, it is also used on many lines with exclusive passenger operations. On cab signaling lines without lineside signals, most railways use block marker boards to mark the block limits for degraded mode operations.

Sometimes, block sections are also used on cab signal controlled lines with exclusive passenger operations where train completeness is checked on board without track clear detection technology. That principle is called virtual block, because the block sections exist only virtually

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in the control system without any field installations along the line. The reason for having virtual block sections instead of moving block is to reduce the amount of data transmission by radio. In contrast to a moving block system where the continuous upgrade of the movement authority requires data transmission at very short intervals, the movement authority of a virtual block system is only upgraded after the train ahead has cleared a block section. This significantly reduces the data traffic from track to train. If capacity needs to be improved, the block lengths can easily be reduced in the control system without changing anything in the field.

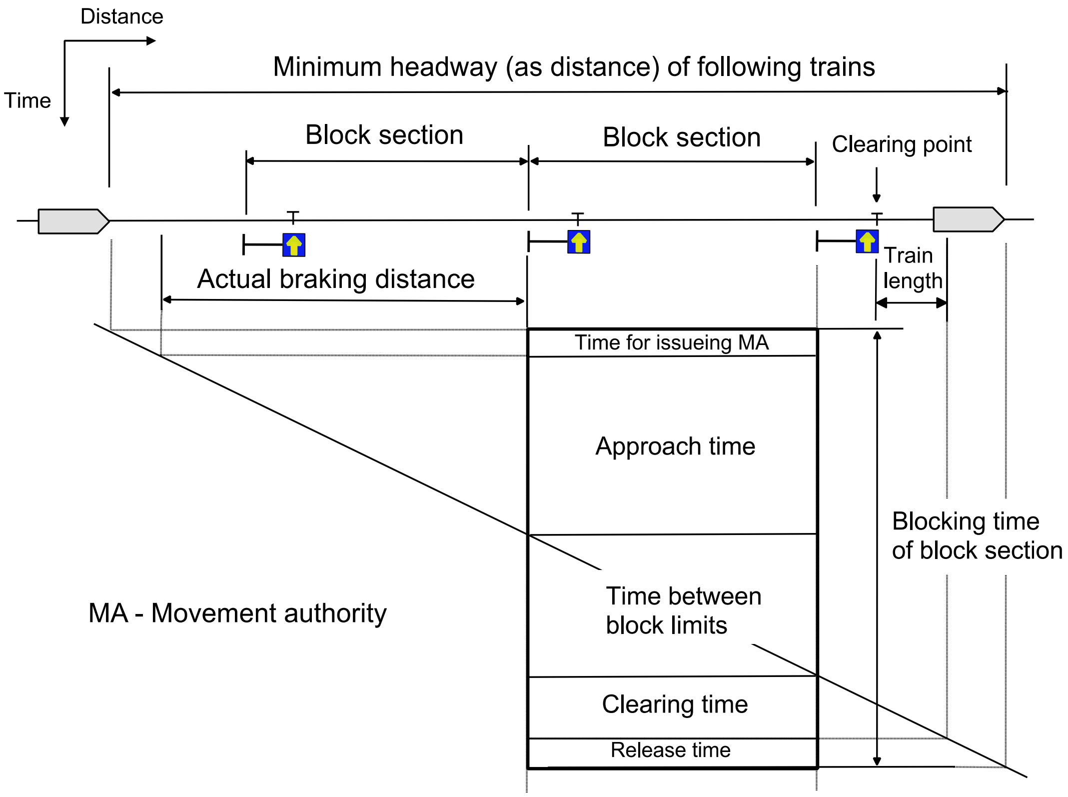

Figure 2.11 Blocking time of a block section on a cab signaling line

The main difference of cab signalling with fixed block sections from a fixed block system with lineside signals is the independence from the approach distance of the lineside signal system, which is the distance between the signal at the entrance of the block section and the signal in rear that provides the approach indication. The approach time is no longer the running time between these two signals but the running time within the real braking distance based on the supervision curves of the cab signal system. Also, due to the absence of lineside signals, a signal watching time to spot a signal aspect at a specific location is no longer needed. The other elements of the blocking time do not differ from a system with lineside signals (Figure 2.11).

Cab Signalling with Moving Block

Moving block is based on absolute braking distance. Since the fixed block sections are eliminated, the line is cleared continuously behind the rear end of a moving train. Beside a contin-

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uous detection of the train location and train completeness, it also requires a continuous upgrade of the movement authority. Figure 2.12 demonstrates the effect on the minimum headway compared with a fixed block cab signaling system.

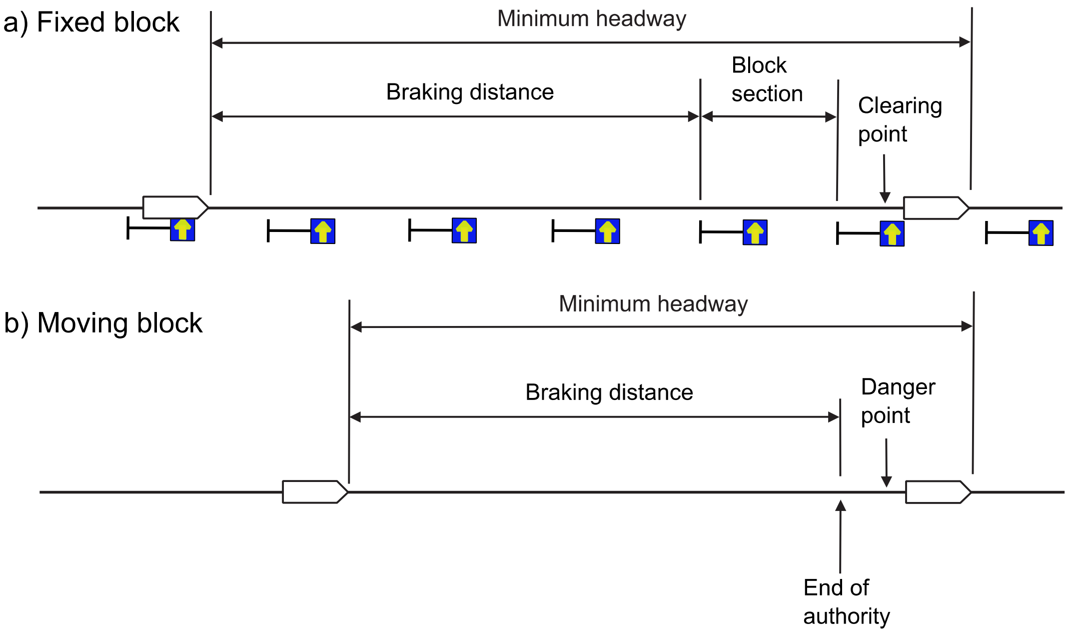

Figure 2.12 Headway in cab signaling with fixed block and moving block

Today, moving block is only used in some transit systems. One reason why the interest of standard railways in moving block is rather limited is that the potential improvement of line capacity by the introduction of moving block is often overrated. On a moving block line, the length of the block sections is reduced to zero. That means that the running time within the block sections will be eliminated in the blocking time diagram. All other components of the blocking time can also be found in moving block. On most lines, the total of these other components is much greater than the part of the blocking time that can be eliminated by moving block. That is why, compared with fixed block operation with short block sections, moving block will just lead to a moderate improvement of capacity. On lines with mixed traffic of trains running at different speeds, the possible improvement is almost negligible compared to a system with short block sections. Same is true for single lines with bidirectional operation. That is, why many railways prefer the principle of virtual block in new developments of radio based cab signalling systems.

2.3 Block Control Principles

To ensure safe train separation, the control procedures must ensure that the movement authority to enter a section of line must not be issued unless two basic conditions are in effect:

- The line is clear up to the desired authority limit and the rear end of the last train ahead is safely protected by that limit.
- All opposing moves on the same stretch of line are safely locked out.

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While these basic safety requirements are valid both in fixed block and moving block systems, the solutions to meet these requirements differ.

2.3.1 Block Control by verbal Communication

On branch lines operated at a low speed and a very low traffic density, train movements may be protected just by operating rules under staff responsibility. This is based on verbal communication by radio or telephone. For this, two principles exist:

- Dispatcher-controlled operation
- Train control by local operators

Today, most lines of that kind have some kind of dispatcher control. The dispatcher is an operator responsible for train control on a longer stretch of line. The dispatcher communicates with the train crews by radio. Points are manually operated by the train crews. Train crews report the arrival at stations or specific locations to the dispatcher who keeps track of all movements either by manually recording these messages on a paper train sheet or by entering them into a computer system. Movement authorities issued by the dispatcher are also transmitted verbally by radio and recorded manually. When a computer workstation is used, train locations and movement authorities are visualized on a computer screen. That control system is just an offline system controlled by the data manually entered by the dispatcher, however. On lines with a higher density of traffic, a simplified signalling system may be used as a safety overlay. In such a system, automatic block signals controlled by track circuits would protect occupied sections of line. Since there are no controlled signals, movements authority has still to be issued verbally by the dispatcher. This is frequently used in North America where the traffic density on many lines does not justify the effort to install a remote control system.

While less frequently used today, train control by verbal communication of local operators is still common on some railways. On such lines, all stations that limit a block section must be locally staffed. The local operators communicate by telephone and exchange control messages on trains entering and leaving the block section, and on direction control to protect opposing moves. The exchanged messages and the train movements are manually recorded. Movement authorities are usually issued by lineside signals controlled by the local operators. Under very simplified conditions, station are only equipped with home signals. Then, the authority to leave the station into the next section of line is given verbally, or by a hand or flag signal.

In old British systems, block sections are protected by block instruments in conjunction with bell codes. Local operators offer and accept trains and report trains entering and leaving section by bell codes. This is overlaid by block instruments to indicate the state of the block section. There are coacting instruments at the entrance and the exit of section, which can only be operated from the exit side. These instruments are pure communication devices not interlocked with the signals. So, the basic principle is very similar to a systems based on verbal communication. The telephone communication is just replaced by bell codes and block indications. So, this is not yet a block system with positive locking of signals in the sense of the next paragraph. That kind of block protection is no longer used in new installations.

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2.3.2 Block systems for Fixed Block Operation

In mainline operations, the fixed block criteria are enforced by block systems that provide positive locking of signals in stop position as long it is not safe for a train to enter the block section these signals protect. Since block systems are only used to enforce fixed block operation on line sections between station areas, they are often referred to as line block systems (*UIC, 2012; Theeg & Vlasenko, 2020*). On station tracks between successive interlocking signals, fixed block operation is not enforced by a block system but by the interlocking system when setting routes from signal to signal. This will be explained in Chapter 3. That is, why on many railways, station tracks between successive interlocking signals are not referred to as block sections.

Block Working Principles

To protect a train that has entered a block section against following trains, the signal at the entrance of the section is locked in stop position. The signal can be either a lineside signal or just a section limit (usually marked by block marker board) where a train must not proceed without cab signal indication. If converging lines lead into the same section, the block locking is in effect for all signals leading into that block section. After the train has completely left the block section including the overlap (if overlaps are required) and is protected by a stop signal, the block section is released. Now, a signal at the entrance of the block section can be cleared for a following train (Figure 2.13).

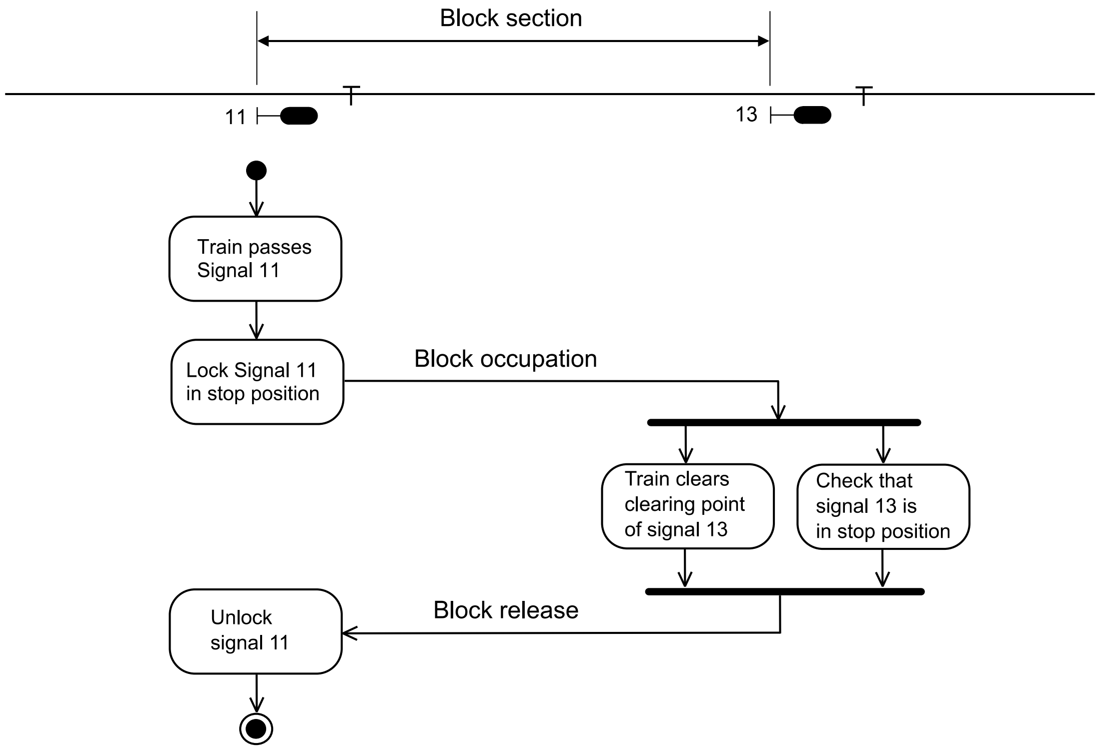

Figure 2.13 Block protection of following movements

If the line just consists of one single block section, opposing moves can be easily locked out by locking all opposing signals in stop position before a signal to enter the section can be cleared. On a longer stretch of line that consists of several block sections, opposing moves

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are locked out by direction locking. A signal to enter such a stretch of line can only be cleared after the entire section has been locked for the desired direction. The direction locking holds all opposing signals in stop position as long there is at least one train on the line.

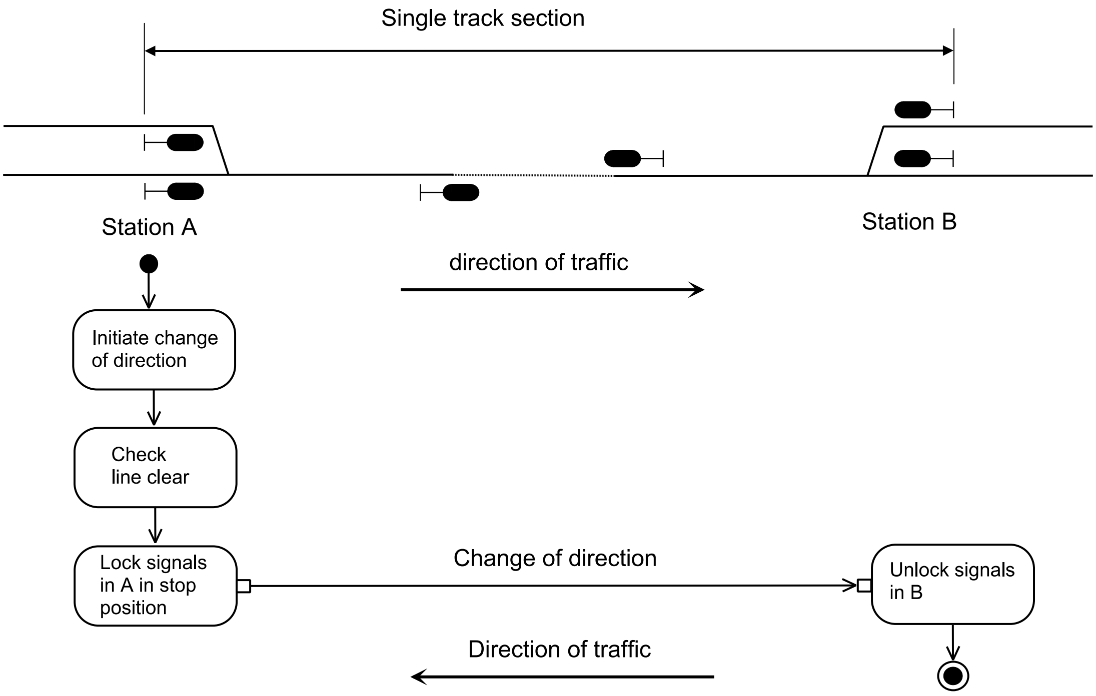

Figure 2.14 Direction locking with non-symmetrical normal position

In some systems, the direction locking releases after the entire section has been completely cleared of trains. In such a system, the direction locking is re-established when the next train of either direction is going to enter the single track section. Thus, no direction is cleared in normal state. This is also known as a block system with symmetrical normal position. In other systems, the direction locking remains in effect even after the last train has left the single track section. Only when a train is going to enter the section from the opposing side, the locking is switched to the other direction. Then, the new direction will be kept locked until another change of direction is required. This is known as a block system with non-symmetrical normal position (Figure 2.14).

If direction locking with non-symmetrical normal position is used on a line section that connects the control areas of different operators, two principles exist for controlling the direction change:

- Direction change is initiated by the station that is currently holding the direction.
- Direction change is initiated by the station that is requesting the direction.

If the direction change is initiated by the station that is currently holding the direction, a procedure for offering and accepting trains must be established between the two operators. Otherwise, the operator receiving the train would not be aware of the necessity to initiate a direction change. If the direction change is initiated by the station that is requesting the direction, the operator that is requesting the direction needs an indication on the control interface that the direction change is currently possible and not blocked by a cleared signal on the opposing station. Otherwise, in case of a failed direction request, the operator wouldn't see the reason. A procedure for offering and accepting trains is not necessarily needed but sometimes used to avoid traffic control conflicts.

An alternative principle for protecting opposing movements is traffic locking, which is the standard solution in North America (*Aubertin, 2018*). There, automatic signals at bidirectional line sections between interlocking areas are cleared in normal state for both directions. When a controlled signal is cleared to leave an interlocking area, all opposing automatic signals up to the next interlocking area are 'tumbled down', i.e., restored to stop. The 'tumble down' procedure is triggered from section to section until the entire direction is blocked. Then, it is also no longer possible to clear an opposing controlled signal at the adjacent interlocking area (Figure 2.15).

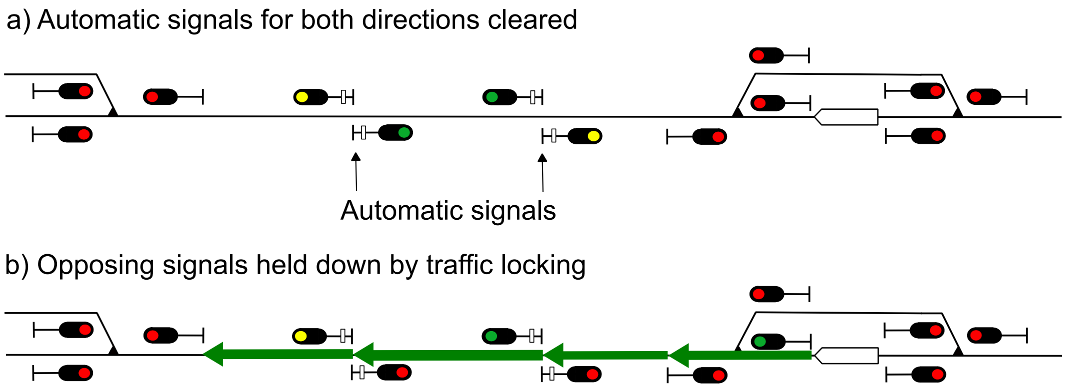

Figure 2.15 Principle of traffic locking

Manual Block Systems

In a manual block system, the block sections are not yet equipped with continuous track clear detection. The signals protecting the block sections are manually controlled by local operators. The stations are equipped with electric block instruments connected by a block line. After a train has entered a block section, the operator at the entrance of the section would restore the signal and operate a block instrument to lock the signal in stop position. A coacting instrument at the exit side of the section informs the next operator on the approaching train. If the operator at the block entrance failed to operate the block instrument, a rotation lock would lock the signal in stop position until it is properly locked by the block instrument. When the train has left the section, the operator at the exit side would check train completeness by watching the rear end marker, restore the signal to stop, and operate the block instrument to release the block section. This will release the block instrument at the entrance of the section, so that the signal at the entrance is no longer locked in stop position. To prevent the operator from accidently releasing a block section when the train has not yet left the section, an electric lock prevents operation of the block instrument at the exit side until the train has passed through a short track circuit beyond the signal. So, these coacting block instruments work exactly in accordance with the block cycle as shown in Figure 2.13.

On lines with bidirectional operation, direction locking can also be effected by coacting block instruments on both sides of the single track section. At the station that is not holding the

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direction, signals pointing against the locked direction are locked in stop position by a block instrument. To change the direction, the operator at the station currently holding the direction would operate a block instrument that will lock the signals in stop position and release the block instrument at the opposing station. The stretch of line between the two stations may contain several block sections. To change the direction, it is checked that all block instruments at intermediate block sections are in the normal position. This meets the principle shown in Figure 2.14.

Today, most manual block systems work as so called semi-automatic block systems, which uses relay circuits instead of block instruments. In a semi-automatic block system, the block locking after a train has entered the block section is effected automatically. However, after the train has left the section, it has to be released manually by an operator. In modern control centres, semi-automatic block systems are often used at the interface to lines still equipped with old technology.

Manual block systems as described above are also known as tokenless block. Another solution to protect single track sections is token block. It's still frequently used on railways with roots in the British system. In its most simple form, every single track section has a physical token (e.g., a staff, key or tablet). Only the operator in possession of the token is allowed to authorise trains to enter the line. To change the permitted direction, the token is handed to the train driver to carry it to the opposing station.

Further development led to electric token block systems. In such systems, corresponding control stations are equipped with token instruments electrically connected to each other. A determined number of tokens is assigned to every track section. Every train has to pick up a token to enter the section. As long as the total number of all tokens kept in the connected instruments equals the determined number of tokens for the section, it is possible to release exactly one token from either one of the two instruments. After having removed a token, all other tokens in both instruments are locked. When the operator at the opposing control station has returned the token into the token instrument there, both instruments are released. After that, another token may be removed to authorise a train to enter the section. Since only one token can be released at a time, intermediate block sections are not possible.

While being old technology, token block controls are also to be found in modern control centres where a token block line connects to the controlled area. Since there is no longer any local staff available, the token instrument is remotely released from the control centre and operated by the train crew. A new development is Digital Token Block (DiBloc). It works like a traditional token block system but with the token instruments no longer connected by an electric block line but by internet or digital radio. This is a very cost-efficient solution for branch lines with low traffic.

Automatic Block Systems

In an automatic block system, block sections are equipped with automatic track clear detection to enable the signals to work automatically. An automatic signal will only clear if the entire control length up to the clearing point beyond the next signal is clear and a train ahead is protected by a stop signal. To release a block section, a train must not only have cleared the section and – if required – the overlap, but must also have restored the next signal. This condition confirms that the train has safely passed the exit side of the block section. So, the safe

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block working does not only depend on the track clear detection but is overlaid by the block cycle of Figure 2.13.

This improves the safety of automatic block systems based on track circuits. If the occupation of the block section disappeared due to a malfunction of the track circuit while the train has not yet left the section (e.g., if some dirt has gotten on the rails), the block section will not release. It will also not release if the train has left the section but failed to restore the signal at the exit side of the section to stop position due to a malfunction of the next track circuit. For automatic block systems working with axle counters, that safety procedure is automatically enforced, since the track occupation could never disappear without having the train passed through the counting point. Passing through the counting point will also safely restore the signal to stop.

Concerning the control principle, automatic block systems can be divided into two classes (Figure 2.16):

- Decentralised automatic block systems
- Centralised automatic block systems

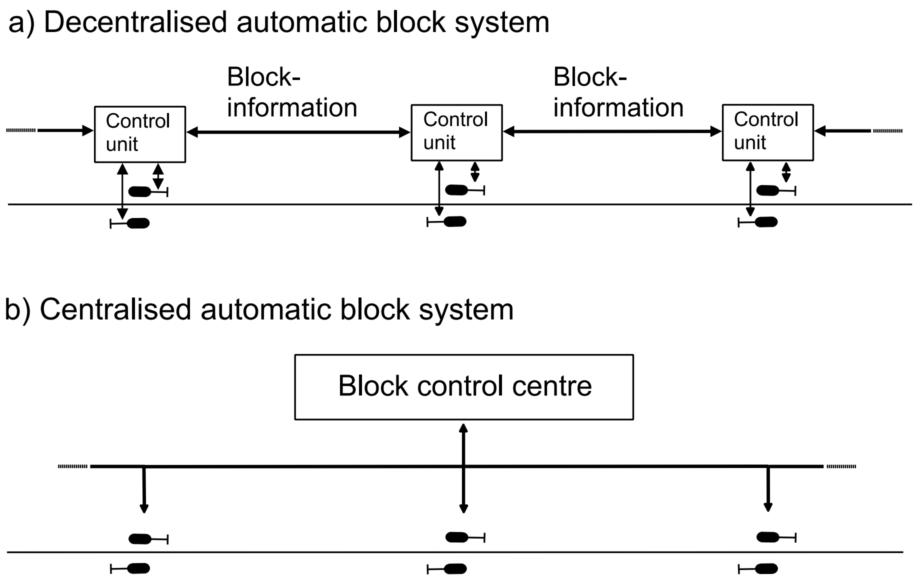

Figure 2.16 Decentralised and centralised automatic block systems

In a decentralised automatic block system, the control devices are located in field cabinets directly at the block signals. These block signal cabinets exchange block control information either by an electric block line or through coded track circuits. After a train has left a block section, the signal at the entrance of that section is immediately cleared. So, in normal state, automatic block signals that are not held down by direction locking are cleared no matter whether a train is approaching or not. On bidirectional lines where opposing moves are protected by direction locking, all signals pointing against the locked direction are locked in stop position. When a direction change is initiated, all signals are restored to stop. After the new direction has been locked, all signal pointing into this direction will clear. On bidirectional lines where opposing moves are protected by traffic locking, automatic signals of both directions are cleared in normal state and only 'tumbled down' to protect an opposing move.

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In a centralised automatic block system, the block control is part of the centralised control system that also controls the interlocking areas. Instead of exchanging block control information, centralised block sections are treated similar like routes in an interlocking system (see Chapter 3). However, these ‘block routes’ do not lock any points or movably parts of the infrastructure. They are just part of the block control logic. Before a signal can be cleared at the entrance of a centralised block section, the block section has to be locked. After the train has passed the signal, it is restored and kept locked in stop position, until the train has released the block section. By locking the block section from the entrance side and releasing it from the exit side, that control logic also meets the principle of the block cycle shown in Figure 2.13.

In normal state, all centralised block sections are released. Consequently, all automatic block signals on a centralised automatic block line are in stop position. By clearing a controlled signal to enter an automatic block line, the first block section will be locked. That block section will trigger the next block section, and so on. So, all automatic block signals will clear ahead of the train. On lines with bidirectional working, opposing moves are protected by direction locking. The direction can only be changed when all intermediate block sections are released.

Depending on the rules of individual railways, block overlaps may be provided at automatic block signals. If block overlaps are used on automatic block lines, there are three different principles to provide overlap protection (Figure 2.17):

- Signals placed at the overlap distance before the track clear detection limits
- Separate track clear detection section for the overlap
- Using the next block section as an overlap

Placing the signals at the overlap distance before the track clear detection limits is the most simple solution. However, in such a system, the overlap beyond a signal is not controlled by that signal but by the signal at the entrance of the block section. If a train has lost vehicles in the overlap, the lost equipment is protected by the signal at the entrance of the block section, while the signal at the exit side may clear not protecting the occupied overlap. This may become a safety problem in degraded mode operations when a train is authorised to pass through a block section cautiously on sight. Then, the driver may encounter a cleared signal in front of the occupied overlap. To safely handle such situations, some railways established the rule that a train with authority to proceed on sight through a block section, has to continue in on sight mode after having passed a cleared signal at the end of the section for a specified distance beyond that signal. This is not necessary if the overlap gets a separate track clear detection section. Then, any occupation of the overlap will always restore the signal to stop. On lines with very short block sections, an entire block section could be used as an overlap. This principle is widely used on mass transit railways.

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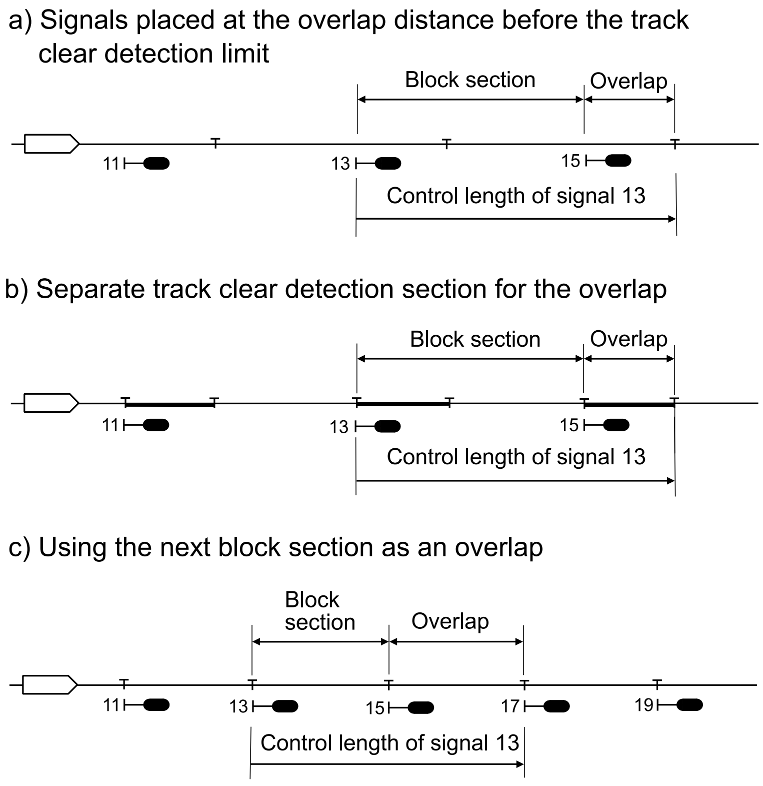

Figure 2.17 Overlap solutions for automatic block lines

Handling Block System Failures

In case of a malfunction of a manual block system, degraded mode operation is based on verbal communication between local operators. When a train has left a block section, the operator at the exit side of the section would report the clearance of the section to the operator at the entrance side. Then, the operator at the block entrance may authorise the next train to pass the signal protecting the block section and report the departure to the operator at the exit side. On lines with bidirectional operation, the operators of the limiting stations would have to offer and accept every single train to protect opposing moves. All these messages are manually recorded. Before a train may be authorised to enter a line with bidirectional operation, the operator has to check in the train record that the last train ahead has the cleared the first block section and no opposing train has been accepted.

On automatic block lines, that procedure is not possible due to the absence of local operators. For degraded mode operations, two different principled are used by individual railways:

- Automatic block lines with absolute block working
- Automatic block lines with permissive working

On automatic block lines with absolute block working, the stop aspect on automatic block signals is absolute, i.e., it does not differ from the stop aspect on controlled signals. A train must not pass any signal in stop position without authority from the operator (absolute stop = ‘stop and stay’). In case of a block system failure, so that the operator has either to execute a resetting command to release the block section or has to authorise the train to pass a signal protecting a block section in stop position, the operator has to perform a clearance check for the relevant block section.

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For that clearance check, the operator has to clearly identify the last train that passed through the relevant block section. For that train, the following criteria have to be confirmed:

- The train has arrived at a station beyond the relevant block section.
- The train must be protected by a stop signal. This includes, if required, the clearance of the overlap beyond that signal.
- The train must be complete. This is to be checked either by local staff or by the train crew.

Before authorising a train to pass a stop signal to enter a block section on a line with birectional operation, the operator has also to confirm that there is no opposing train on the entire section between the limiting controlled signals, and the opposing controlled signals protecting the section are secured in stop position.

If train completeness of the last train ahead cannot be confirmed, the next train has to be authorised to pass through the relevant section on sight. If, in a case in which train completeness cannot be confirmed, the operator is going to reset the axle counter of a block section under staff responsibility, the order to proceed on sight must be issued before the resetting command is executed. If the resetting fails, the operator has to secure the signal protecting the relevant section in stop position. Then, the operator is required to perform clearance checks for all following trains until a signal maintainer has reestablished normal working of the block system.

If the operator cannot clearly identify the last train ahead, a clearance check is not possible. In such a case, the next train has to be authorised to pass through the relevant section on sight, but the operator must not reset the block section. Without having confirmation of the last train ahead, the operator cannot be sure whether a track occupation shown on the user interface is caused by lost equipment obstructing the track, a track clear detection failure, or by a 'forgotten' train that is still occupying the section. In the last case, resetting the block section may lead to a hazard if the forgotten train unexpectedly proceeds. On passenger lines, following trains with the same number of axles are a frequent occurrence. If a second train has occupied the section on sight after the axle counter has been reset, the unexpectedly moving first train may count out the same number of axles the second train has counted in. Thus, the section would clear while still occupied by the second train. For details see (*Theeg & Vlasenko, 2020)*.

The rule to perform a clearance check for each individual train will increase the workload of the operator and significantly decrease the capacity during degraded mode working. That is, why many railways use permissive working on automatic block lines.

On automatic block lines with permissive working, only controlled signals have an absolute stop indication while automatic signals are permissive signals (Figure 2.18). A train may cautiously pass a permissive signal in stop position after the train has stopped in front of the signal and the driver has clearly identified the signal as a permissive signal (permissive stop = ‘stop and proceed’). For that, permissive signals are marked by a special marker plate or by using a special kind of stop aspect. If a train has passed a permissive signal displaying a stop aspect, the train has to pass through the entire block section cautiously on sight.

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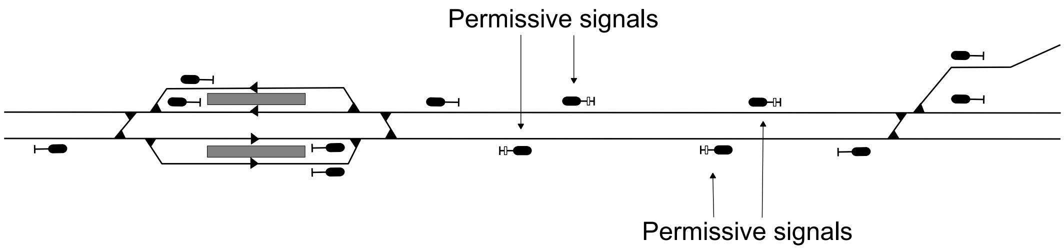

Figure 2.18 Absolute and permissive signals on automatic block lines

On lines with permissive signalling, it is of great importance to restore a signal to stop with a very high reliability. If a signal fails to protect a train that has passed the signal, the signal at the block entrance would remain locked in stop position by the block system. If a following train passed that stop signal in permissive mode, that train would encounter a proceed aspect at the next signal leading into an occupied block section. In block systems where the required high reliability in restoring signals cannot be guaranteed, trains must run under the rule that a train running in permissive mode has to ignore a proceed aspect at the next signal and has to go on running permissive in the following block section. Only when the train has passed a proceed aspect at the second signal, the driver may end the permissive mode and proceed at normal speed.

2.3.3 Block Control in Moving Block Operations

Moving block systems need an accurate on-board train location system that transmits the current location at very short intervals to a radio block centre. With every reported location, the train must also confirm train completeness. By these data, the radio block centre calculates the danger point to protect the rear end of the train.

Between that danger point and the authority limit of a following train, there is a supplementary safety distance that is an equivalent to the block overlap in a traditional fixed block system. It is the minimum safety distance kept between the two trains if the second train stops behind the first train. If points are going to be moved between two trains following each other in moving block, an additional time window for moving the points is needed. That time windows is to be calculated by the radio block centre when upgrading the movement authority for the second train.

The radio block centre will always safely prevent frontal crashes by locking out overlapping opposing movement authorities. On line sections outside of station areas where trains cannot reverse, an additional direction control is needed that works similar as the direction locking in a fixed block system. A train must not enter such section as long any opposing movement is travelling through that section or has authority to enter that section from the next location where the train sequence may be changed.

3 INTERLOCKING PRINCIPLES

When passing through a point zone, beside safe train separation, movable track elements must be locked in the proper position, and the train must be protected against conflicting moves that would interfere with its path. This is effected by interlocking. The term interlocking comes from the fact that the signals governing train moves are interlocked with movable track elements and signals governing conflicting routes.

3.1 Safe Routes through a Point Zone

Interlocking is based on the principle that before a train can be authorised to pass through a point zone by clearing a lineside signal or issuing cab signal authority, a safe route up to the authority limit is established. That route must meet the following conditions:

- All points must be properly set and locked.
- All points must be kept locked as long a train has authority to move on them.
- Conflicting moves must be locked out.
- The route must be protected against inadvertent movements on converging tracks (flank protection).
- All track sections the train has authority to pass through, must be clear.

3.1.1 Route Classes

In modern interlocking systems, locked routes are also provided for shunting movements. That's why, there is a distinction between main routes and shunt routes. Main routes are routes for regular train movement governed by a main signal or cab signal indication. Shunt routes are used for shunting movements authorised by a shunt aspect or verbal authority. Some of the requirements for a main route are not in effect for a shunt route. So, a shunt route may govern a shunting movement into an occupied track. Flank protection for shunt routes is usually either simplified or not required at all.

In North America, where train movements are not as strongly separated from shunting movements, the same routes may be used both for train and shunting movements. This principle is also used on some railways outside North America, e.g., in The Netherlands.

A main route starts always at a controlled signal (the entrance signal of the route). The exit of a route can be:

- The next controlled signal (the exit or destination signal of the route)
- The end of the interlocking area

Routes with an entrance and an exit signal are routes between successive signals within the same interlocking area. On railways where overlaps are required, the points within the overlap beyond the exit signal are interlocked with the entrance signal (Figure 3.1 a). Because the clearance of the section between the entrance and the exit signal is checked by the interlocking system, this kind of a route also directly ensures a safe train separation.

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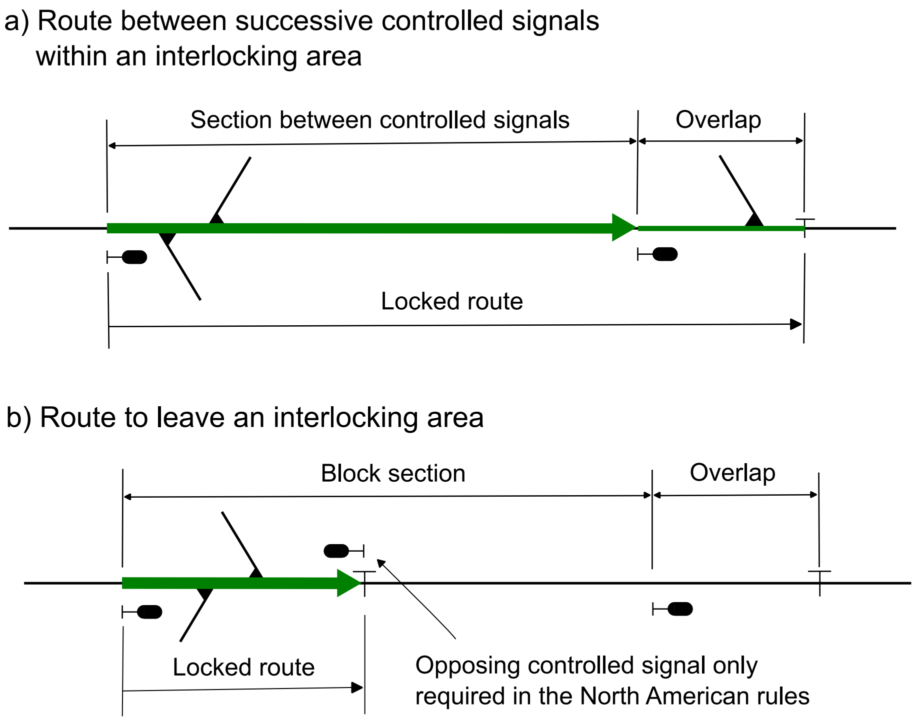

Figure 3.1 Main routes

Routes with the exit at the end of the interlocking area govern train movements to leave that area. Such a route cannot ensure a safe train separation. The route leads into a section of line that is protected by a block system. In North American interlocking systems, the route will always end at a controlled signal facing in the opposing direction that limits the interlocking area (Figure 3.1 b). In the North American terms, this signal is called an ‘exit signal’. That term should not be confused with the use of the term ‘exit signal’ for routes between successive controlled signals of the same direction as explained above. On Continental European railways, the exit of such a route is a track section beyond the last points of the route. In contrast to the North American practice, this route exit is not necessarily associated with an opposing controlled signal. On British railways, the exit of a route is always a signal. There, a route to leave an interlocking area and to enter an automatic block line leads up to the first automatic block signal.

Figure 3.2 shows a more detailed view of the elements of a route between two successive interlocking signals. The details will be explained in the following sections.

3.1.2 Point locking

Before a signal can be cleared, all points and derailers must be locked in the proper position. The locking of points has two aspects:

- To prevent the operation of the points
- To prevent movements of the point blades under a moving train

The first condition is guaranteed by the internal logic of the interlocking system. To meet the second condition, all points are equipped with a point lock apparatus that mechanically locks the point blades in a proper position. Some railways use independent point locks, which are actuated by a separate control device from that which drives the points. More common are dependent point locks that are actuated by the same control device as that which drives the point blades.

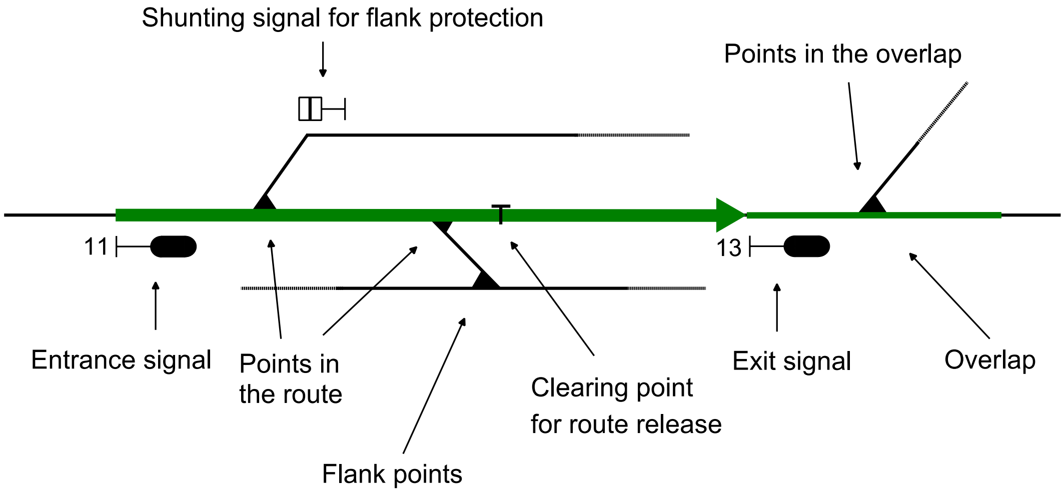

Figure 3.2 Elements of a route

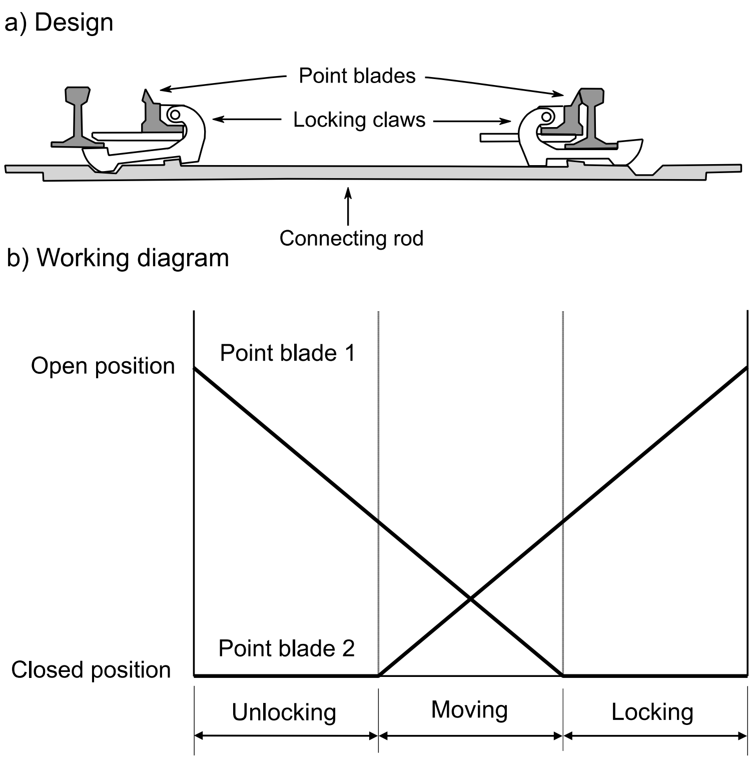

Figure 3.3 Design and working diagram of a claw lock mechanism

A typical example is the claw lock which exists in several variations. Figure 3.3 shows a modern type which is very common in Continental Europe. As typical for all point locks of that kind, the point blades are not permanently connected but can be moved separately. When the points are operated, the open blade moves at first while the closed blade is being unlocked. Then, both blades move simultaneously, until the formerly open blade has reached the closed position. Now, the new open blade on the opposing side will move farther away from the stock rail, until the new closed blade is safely locked.

Large turnouts with long flexible blades may have one or more additional point locks along the blades to hold them safely in place. These intermediate point locks are operated by a back drive that consists of a rodding mechanism driven by the point machine.

Beside the point locking principle described above, some railways use a completely different kind of point locks, which are called internal point locks. By this principle, point locking is not effected directly between point blades and stock rails, but inside the point machine. For this, the point blades are permanently connected, so locking the driving rod in the point machine will hold them in place. To guarantee that the closed blade is firmly pressed against the stock rail, both blades must be kept at a fixed distance, which is enforced by so-called stretcher bars.

3.1.3 Locking and releasing Routes

After the train has passed the signal, all route sections must be kept locked until the train has cleared them or has come to a safe stop.

On many railways, route locking is based on the principle of approach locking. As long no train is approaching, the route is just locked by the cleared signal. When restoring the signal, the route will immediately release. When an approaching train has reached a position at which cancelling the route would change a signal aspect in front of the train, the route will be approach locked. Now, after restoring the signal, approach locking will hold the route locked. After having passed the signal, the normal route locking comes into effect and will maintain all elements locked under the moving train. Some railways, in particular railways that follow German principles, do not use approach locking but establish full route locking immediately when clearing a signal independently from an approaching train. In Figure 3.4, both route locking principles are compared.

The normal release of route locking is usually effected automatically after the train has cleared the points. The automatic route release can be accomplished by complete route release with one single clearing point, or by a sectional route release. For complete route release, the train must have cleared the entire point zone and must have occupied the destination track. Sectional route release requires track elements that may release separately to have separate sections for track clear detection. To prevent separately releasing track sections to be cleared before the train has passed through, they must have a minimum length that exceeds the maximum possible distance between two axles in the train consist. For safety reasons, separately releasing track elements are connected by a so-called sequence locking. This prevents the release of a track element until the previous element has released.

Where overlaps are provided, points within the overlap are equipped with time release. They will release automatically with a defined delay after the train has occupied the last track section on the approach of the route exit signal.

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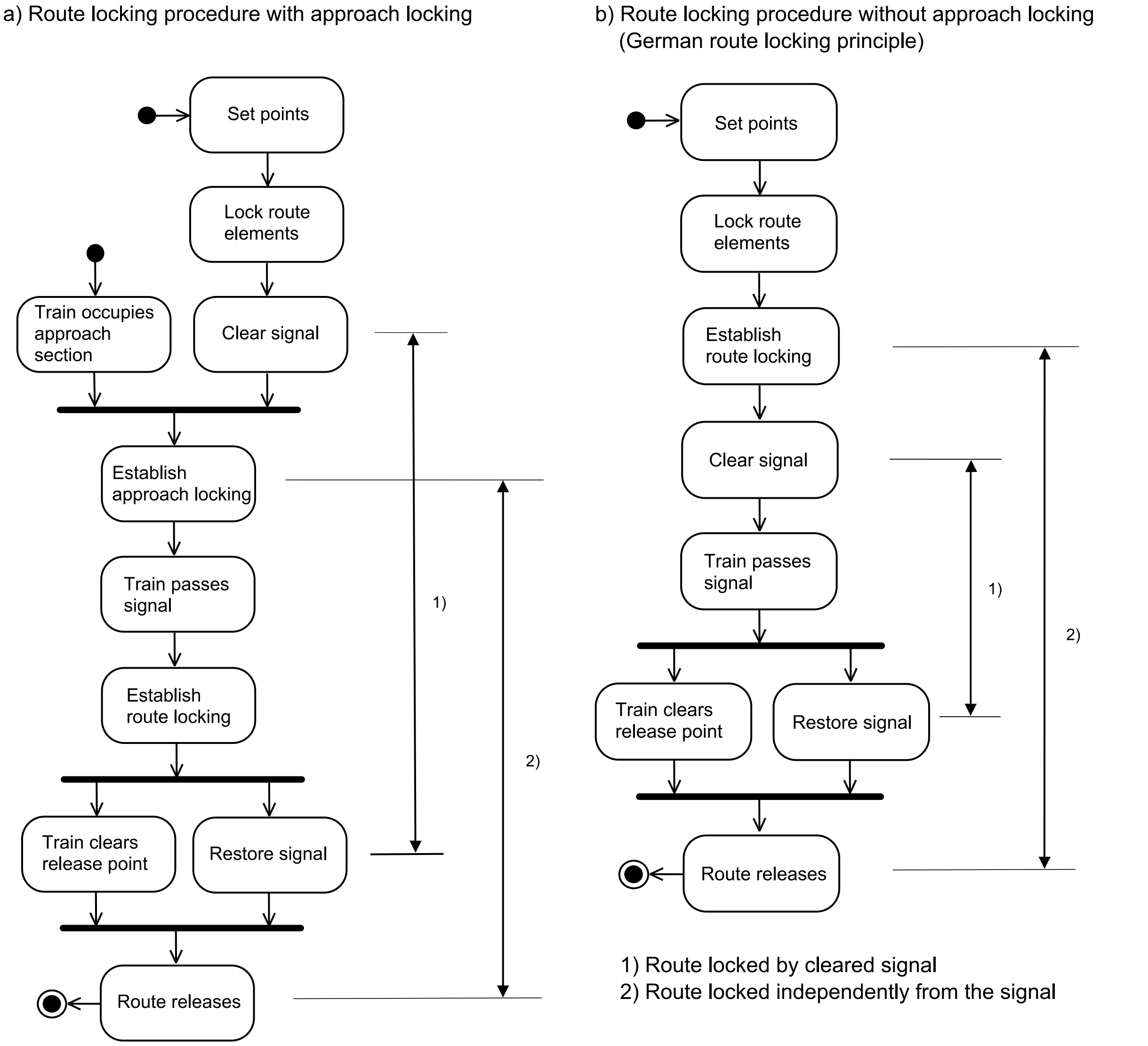

Figure 3.4 Route locking principles

It may happen that a locked route has to be manually released under staff responsibility if the route has either to be cancelled without having a train passed or if the normal route release failed after the passage of the train. For the latter case, most railways provide an emergency route release. Route cancellations and the emergency route releases are protected either by time locking or by a specific command procedure with automatic recording.

3.1.4 Conflicting Routes

Routes that require points to be locked in opposite positions will lock out each other automatically by the locked points. This is known as 'conflicting locking' (Figure 3.5). If there is no difference in the position of the points of two conflicting routes, the interlocking between points and signals will not prevent conflicting movements. In such cases, a special interlocking function must be provided to lock out conflicting routes. Examples are opposing routes leading into the same track (also known as 'opposing locking') and routes with an intersection at a crossing without movable points.

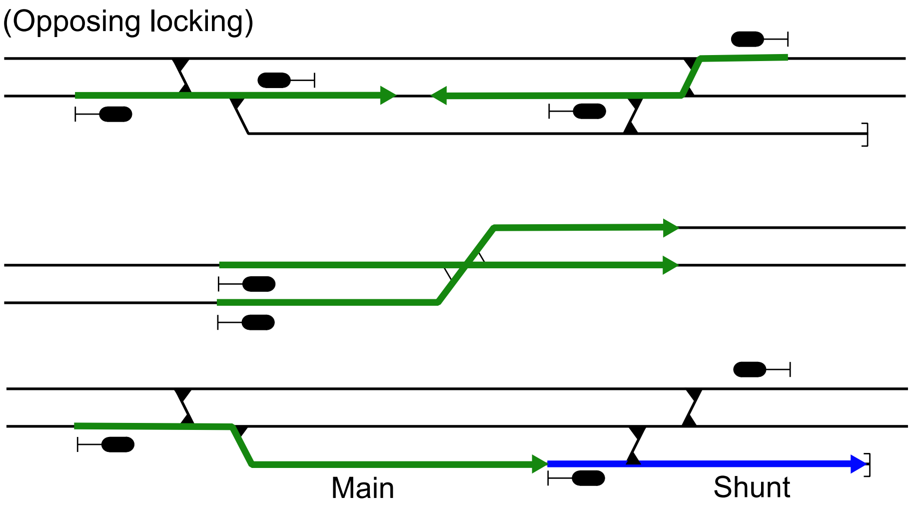

Figure 3.5 Conflicting routes that do not differ in the position of points

When a train has arrived on a station track and is going to proceed in shunting mode, many railways have the rule that the shunting authority must not be issued before the train has come to a stop. For this, a main route leading into a station track and the following shunt route lock out each other.

3.1.5 Flank Protection

Flank protection should prevent vehicles on converging tracks from running into a route that is cleared for a train movement. This could be achieved by:

- Operating rules
- Flank protection devices

Flank protection by operating rules means that to protect a main route against inadvertent movements on tracks joining the path of the train, specific station tracks must not be used for shunting or for storing equipment as long the route is set. Since this form of protection is not very efficient, it should only be used when other forms of flank protection are not available.

Flank protection devices are controlled trackside elements. Flank protection may be provided by flank points, derailers, or stop signals. Stop signals are only sufficient for flank protection against movements controlled by a driver. To protect a train against vehicles that could get into motion unintentionally (e.g., on tracks where equipment is stored), or against the flank hazard from tracks with heavy shunting, flank protection must be effected by flank points or derailers. On many railways, derailers must not be installed outside of sidings. For high speed lines, flank protection against shunting moves and parked equipment is always effected by flank points.

Remote Flank Protection

If possible, flank protection should be provided by elements that are directly adjacent to the route to be protected. If there is no suitable element available, flank protection could be provided by elements that are further away from the point to be protected. This kind of flank protection is called remote flank protection (Figure 3.6).

The points located between the protective elements and the points to be protected are called flank transfer points since they do not protect but transfer the flank protection. At flank transfer points, the protective paths may split, so that one route element is protected by several protective elements.

The flank area, also known as the flank zone (*UIC, 2012*), is the track section between a flank protection device and the fouling point of the route to be protected. When having a turnout in the flank area as shown in the example of Figure 3.6, the flank area splits into several branches so that the fouling point of the route to be protected is protected by several protective elements. While the flank area must be kept clear of vehicles, there may be moves crossing through the flank area without harming the protected route (Figure 3.7).

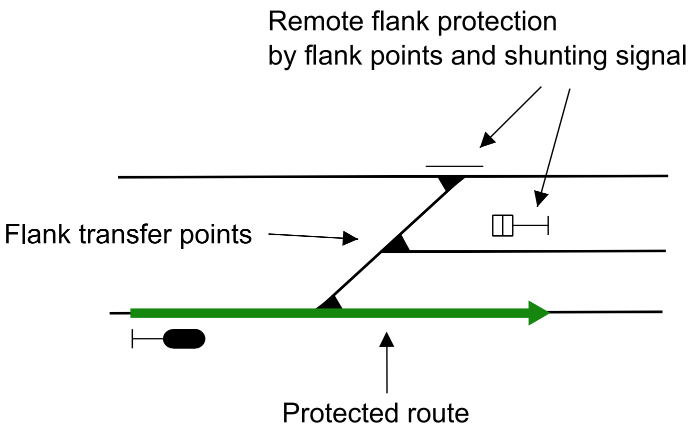

Figure 3.6 Remote Flank protection

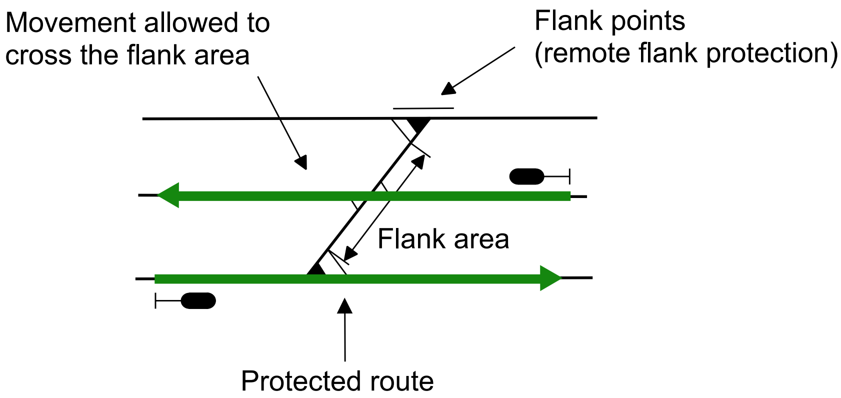

Figure 3.7 Crossing move through flank are

Selective Protective Points

A specific arrangement of flank protection are selective protective points, which are also known as dual-called flank points (Figure 3.8). These are flank points that may receive competing flank calls from the routes of different train moves. To prevent routes from locking out each other by the position of selective protective points, the protective position of these points is usually assigned to one of the two routes. To compensate for the lack of protection for the other route, that route will get remote flank protection. So, for that route, the selective protective points will become flank transfer points.

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There are three different principles to control selective protective points:

- Protective position permanently assigned to one of the two routes
- Protective position flexibly assigned by priority control
- Protective position flexibly assigned by the ‘First In—First Out’ principle

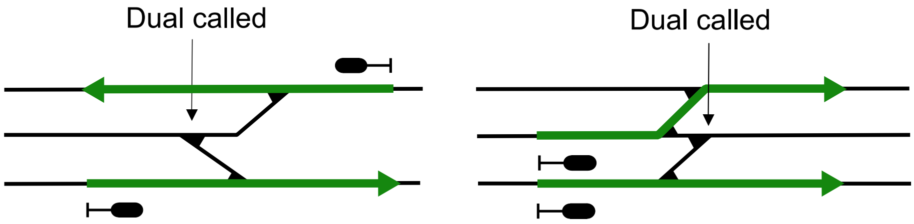

Figure 3.8 Dual called points

When having the protective position permanently assigned to one route, the points will always be locked in the protective position by that route. While this principle is common practice in older interlocking systems, some railways keep using it in modern technology. The protective position of the selective protective points is usually assigned to the route of higher priority. In older interlocking systems controlled by locally staffed interlocking stations, the operator was often required to bring the selective protective points into the protective position also for the inferior route as long that route is set alone. This was not enforced by the interlocking, however.

Priority-controlled flank protection provides more flexibility in assigning flank protection. As long only one of the two routes is set, the selective protective points are moved into the protective position for that route. If the two routes are set at the same time, the selective protective points will move into the protective position for the route of higher priority. The superior route will even take away flank protection from the inferior route. Assigning flank protection by the ‘First In—First Out’ principle is the best solution if the two routes have the same priority. The selective protective points will always move into the protective position for the route that is set first.

On railways that use selective protective points with flexibly assigned flank protection, it's common practice to leave these points unlocked as long they receive competing flank calls. Locked points will even release when called for flank protection by another route. This allows the operator to manually reassign the protective position. This is safe, since in such a case, there is always remote flank protection.

As an additional feature, selective protective points with flexibly assigned flank protection could work in a ‘supplementary’ protective mode. After the route for which flank protection was provided has released, the selective protective points will automatically move to the protective position for the second route.

Points may also get competing flank calls from just one route or from chained routes belonging to the same train movement (Figure 3.9). Dual-called points of that kind are also known as self-selective protective points. In such a case, the protective position is either permanently

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assigned to one of the two points to be protected, or the self-selective protective points remain unlocked. Then, the protection is effected by a common remote flank protection element.

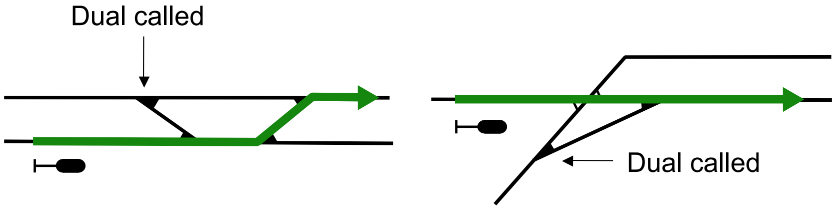

Figure 3.9 Self-selective protective points

3.1.6 Overlaps

If overlaps are applied, the locked route exceeds the authority limit provided by a main signal or by cab signal indication up to a danger point to be protected. Within the overlap, conflicting routes are locked out to prevent a train running into the overlap from crashing into other vehicles. Beyond home signals, the overlap is usually provided by placing the signal at the full overlap distance before the point zone. Then, it's sufficient to check that the overlap is clear before the block section on the approach of the home signal is released.

Inside station areas, there is usually not sufficient space to place exit signals and intermediate interlocking signals at the full overlap distance before the point zone. Then, points within the overlap are locked as part of any route leading to that signal. Also, conflicting moves passing through points or crossings within the overlap must be locked out.

On some railways, home signals may also be placed directly in front of the arrival points with an overlap leading into the point zone. Then, at the braking distance on the approach of that signal, an 'outer home signal' is placed. The section from the outer home signal to the home signal is not part of the block system but controlled by a route of the interlocking system. To clear the outer home signal, a route is set from the outer home to the home signal, which will lock the overlap beyond the home signal (Figure 3.10).

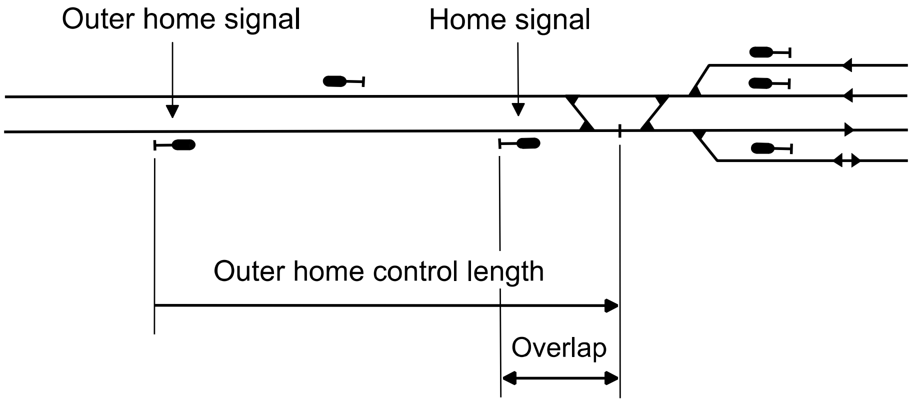

Figure 3.10 Example for the use of an outer home signal

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This is sometimes done to shorten the distance between the home signal and following signals inside the station area for capacity reasons. It's a typical signal arrangement on mass transit railway systems. A typical example is the New York Subway, where the outer home signals are called 'approach signals' (*Dougherty, 2018*). Another reason for outer home signals is to get a level crossing near the station area under protection of a controlled signal. Railways that do not use the term 'outer home signal' would simply call it a home signal and the signal in front of the arrival points an intermediate interlocking signal.

Overlap rules quite differ between railways. Depending on the rules of individual railways, specific points in the overlap may remain unlocked to enable special overlap functionalities. Such special overlap principles are:

- Selective overlaps
- Swinging overlaps
- Shared overlaps

Where selective overlaps are provided, when setting a route, a choice can be made between different available overlaps. The alternative overlaps could be of different length or could lead into different tracks. Once the signal has been cleared, there is no chance to change the overlap without cancelling the route, however. When the selected overlap is shorter than the regular overlap, the train will be slowed down by the signalling system.

Swinging overlaps mean that the overlap can be switched into another track without cancelling the route. As long both overlaps are available, the facing points at the splitting point are unlocked ('able to swing'). Swinging the overlap is no longer possible when the train has overrun the signal. Sometimes, it is already blocked when the arriving train has reached the last track clear detection section on the approach of the signal. This rule is usually applied if there is not a sufficient distance between the signal and the splitting point of the overlaps.

As an alternative solution for selective and swinging overlaps, some railway do not require an overlap if the exit signal of the route is already cleared. When an approaching train should proceed at the exit signal on a route that would be locked out by the overlap beyond that signal, the route at the exit signal is set first. After having cleared the exit signal, the route on the approach of that signal can be set. It's less flexible than selective or swinging overlaps but sufficient in many cases.

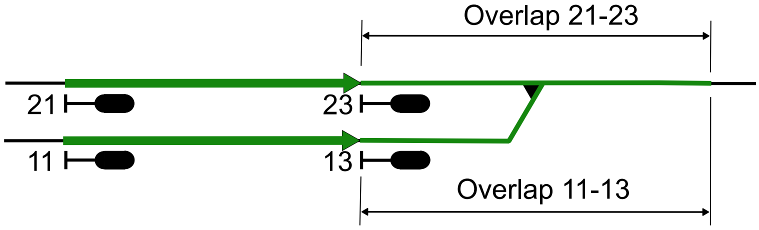

Figure 3.11 Shared overlaps

At shared overlaps, the overlaps of different routes may overlap each other without locking out the relevant routes (Figure 3.11). This is considered to be safe since it is not assumed that two trains would ever run into their overlaps at the same time. To enable shared overlaps, trailing

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points at which one overlap is joined by another overlap remain unlocked. These points must have trailable point locks.

3.1.7 Intermediate Points

Intermediate points are points that are located in a station track in a way that a train that is stopping at its regular stopping position would not clear the points (Figure 3.12). While the signal to leave the station track is located beyond the intermediate points, these points must be locked by a route starting at that signal. So, the route has a section located on the approach of the signal governing the route. When a train has arrived on the station track, intermediate point are either released together with the overlap, or they are kept locked as long they are occupied.

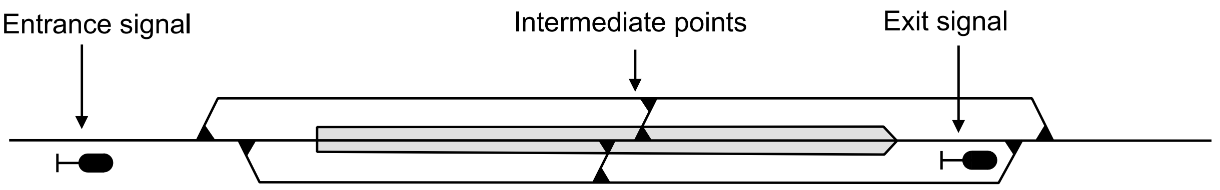

Figure 3.12 Intermediate points

3.1.8 Track Clear detection

For safe track clear detection of a turnout or crossing, the detection limit must exceed the fouling point limit by the maximum possible vehicle overhang ahead of the first axle. For standard gauge railways, the track clear detection limit is planned 6 m beyond the fouling point. If there is not sufficient space between adjacent turnouts or crossings to meet the above condition, points must not be moved as long the adjacent element is occupied.

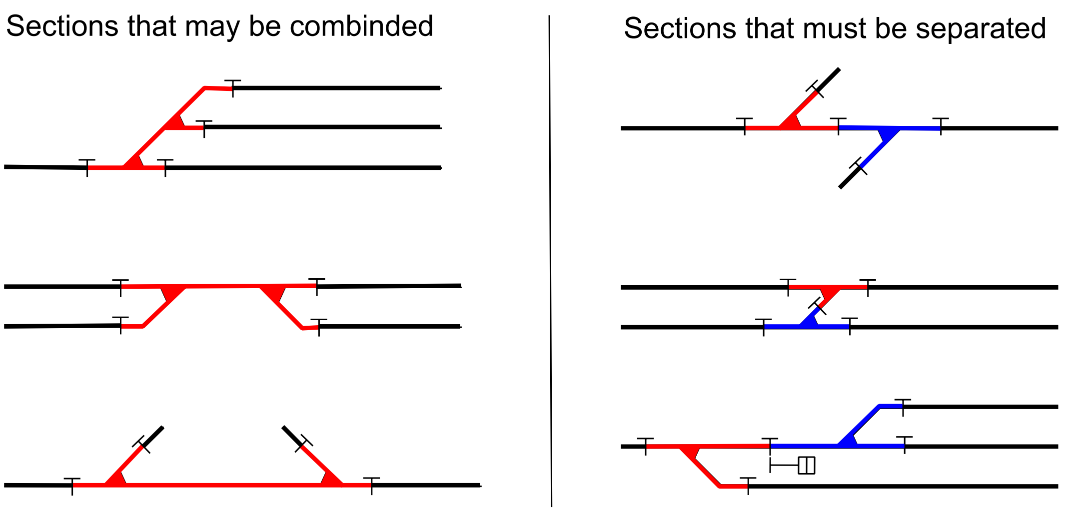

Figure 3.13 Combining and separating track sections of separating points

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If possible, the track sections of adjacent points and crossings may be combined into common track sections to spare track circuits or axle counters. This can only be done if no conflicts between independent routes are generated. Adjacent trackside elements must always be separated in the following cases (Figure 3.13):

- If parallel routes are possible on these elements
- If a signal is placed between these elements

Separate track clear detection of adjacent points is also needed to prevent train moves from being blocked by occupied flank areas or by occupied flank points that cannot be moved to the protective position.

3.2 Internal Logic of Interlocking Systems

For the design of an interlocking installation, all locally relevant interlocking functionalities resulting from the principles described in the previous paragraphs must be put into a logical model. That model is used both as a planning document for the interlocking design for the given layout but also as a control logic for the internal control of the interlocking system for that layout. For that model, two principles exist:

- Tabular interlocking
- Geographical interlocking

3.2.1 Tabular Interlocking

In tabular interlocking, the interlocking conditions are described by a route control table (also known as a locking sheet, locking chart, or interlocking table). In that table, the rows represent the routes and the columns represent the interlocking conditions relevant for these routes. Figure 3.14 and Table 2 demonstrate the principle for a small junction with a single line diverging from a double line.

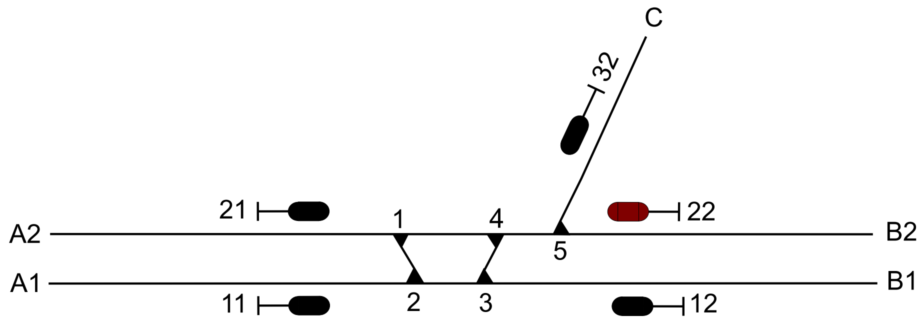

Figure 3.14 Infrastructure example

In this example, Table 2 just contains route conflicts and point positions. A full route control table may have more columns for track clear detection, route locking and release criteria, and signal aspect sequences. Some railways establish separate tables for these issues, however.

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Table 2 Route control table for the layout of Figure 3.14

ROUTE	ROUTES LOCKED OUT	POINTS	
		NORMAL	REVERSE
11-B1	11-B2, 11-C, 21-B1, 12-A1, 12-A2, 22-A1, 32-A1	1, 2, 3, 4	
11-B2	11-B1, 11-C, 21-B1, 21-B2, 21-C, 12-A1, 12-A2, 22-A1, 22-A2, 32-A1, 32-A2	1, 2, 5	3, 4
11-C	11-B1, 11-B2, 21-B1, 21-B2, 21-C, 12-A1, 12-A2, 22-A1, 22-A2, 32-A1, 32-A2	1, 2	3, 4, 5
21-B1	11-B1, 11-B2, 11-C, 21-B2, 21-C, 12-A1, 12-A2, 22-A1, 22-A2, 32-A1, 32-A2	3, 4	1, 2
21-B2	11-B2, 11-C, 21-B1, 21-C, 12-A2, 22-A1, 22-A2, 32-A1, 32-A2	1, 2, 3, 4, 5	
21-C	11-B2, 11-C, 21-B1, 21-B2, 12-A2, 22-A1, 22-A2, 32-A1, 32-A2	1, 2, 3, 4	5
12-A1	11-A1, 11-B2, 11-C, 21-B1, 12-A2, 22-A1, 32-A1	1, 2, 3, 4	
12-A2	11-B1, 11-B2, 11-C, 21-B1, 21-B2, 21-C, 12-A1, 22-A1, 22-A2, 32-A1, 32-A2	3, 4	1, 2
22-A1	11-B1, 11-B2, 11-C, 21-B1, 21-B2, 21-C, 12-A1, 12-A2, 22-A2, 32-A1, 32-A2	1, 2, 5	3, 4
22-A2	11-B2, 11-C, 21-B1, 21-B2, 21-C, 12-A2, 22-A1, 32-A1, 32-A2	1, 2, 3, 4, 5	
32-A1	11-B1, 11-B2, 11-C, 21-B1, 21-B2, 21-C, 12-A1, 12-A2, 22-A1, 22-A2, 32-A2	1, 2	3, 4, 5
32-A2	11-B2, 11-C, 21-B1, 21-B2, 21-C, 12-A2, 22-A1, 22-A2, 32-A1	1, 2, 3, 4	5

In mechanical locking frames based on the traditional British system, a different principle is used, which is known as cascade locking. In a cascade interlocking system, a route is established by a locking cascade, which is effected by permanent and conditional locking between different points and between points and signals. To set a route, the operator has to follow a predefined ‘lever sequence’ to get the route properly locked. That principle is no longer relevant for modern interlocking systems, however. For the different notation of the locking sheets, see (*Pachl, 2018*).

The contents of the route control table may be directly transformed into the software of a computer-based interlocking or into the wiring diagram of a relay interlocking. The internal logic of relay interlockings following this principle is also called ‘free-wired’ logic because every interlocking has its own specific wiring according to the control table. The shortcoming of tabular locking is that the route control tables may become very complex for larger layouts. In relay interlockings, the manual design of the relay circuitry based on the route control table may also become a very complex task. However, tabular interlocking is still a suitable principle for the design of interlocking systems for layouts of moderate complexity. It is also used in several computer-based interlocking systems.

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3.2.2 Geographical Interlocking

Geographical interlocking was first developed for relay interlocking systems to reduce the effort for designing complex interlocking layouts in free-wired logic. In geographical relay interlockings, the track elements are represented by pre-fabricated relay groups, i.e., boxes containing all relays needed to control a particular element including the wiring. The relay groups have sockets by which they can be connected by multi-wire cables in accordance with the track layout. By connecting the relay groups, the correct circuitry for a given layout will automatically appear. For specific functionalities, special plugs could be attached to the relay groups to modify the internal wiring. That simplified the design of complex relay interlockings significantly. The signal planners were no longer required to manually design the electric circuitry. Instead, they established a diagram, in which the relay groups are represented by boxes that are connected by lines representing the multi-wire cables. For the special plugs to be attached to specific relay groups, the relevant plug IDs are entered into the boxes.

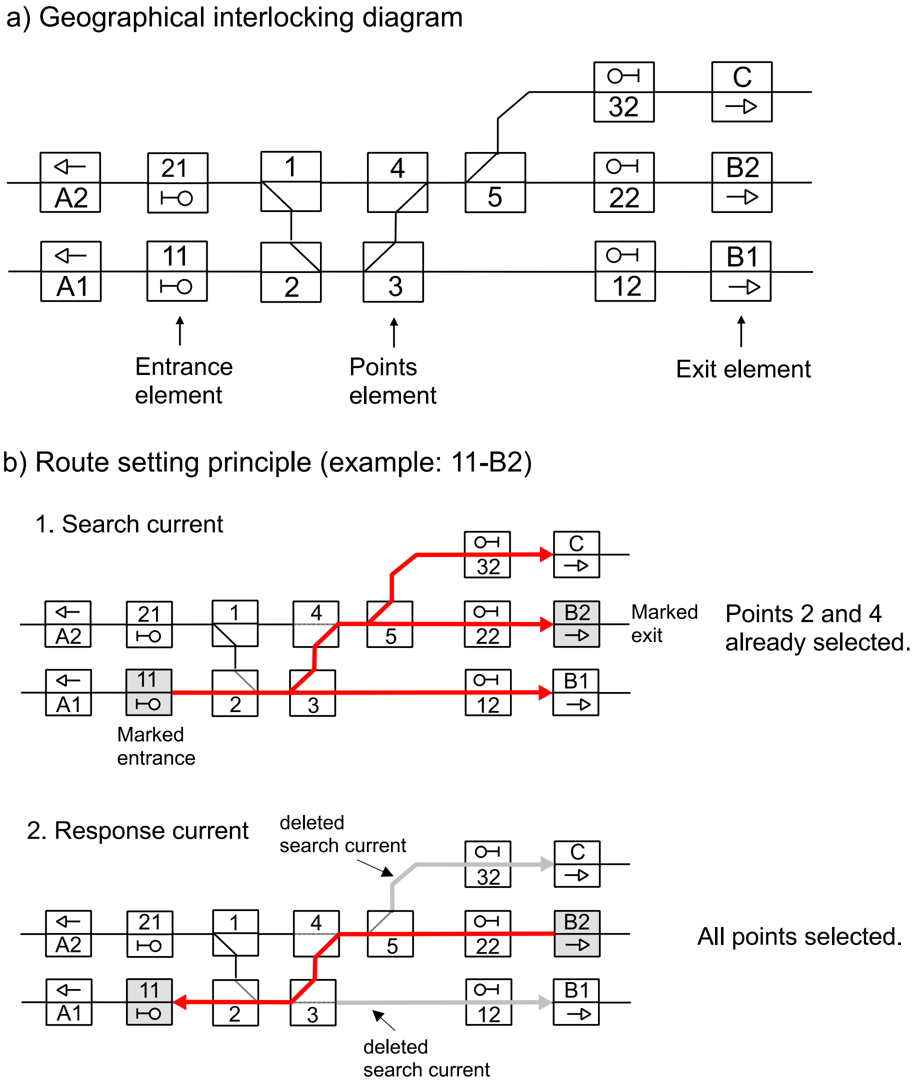

Figure 3.15 Geographical interlocking

The same principle was later adopted for computer-based interlocking systems using a similar kind of diagrams. There, the boxes are longer relay groups but logical elements representing

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the track elements. Instead of plug IDs, numbers representing specific use cases are entered into the boxes.

When a route is set in a geographical interlocking system, the entrance and exit elements are marked and a search current is started from the entrance element of the route. At facing points, the search current splits into two branches (Figure 3.15). The term ‘search current’ still comes from relay interlocking but is also used figuratively in computer-based interlockings. The result is a tree structure of search currents. When one branch of the search current has found the exit element of the route, a response current is sent back to the entrance element. At facing points, the other branches of the search current are deleted.

After this process, a path has been found from the entrance to the exit. Conflicting routes are avoided automatically by the overlapping search currents. When different routes exist from an entrance element to an exit element, additional rules are used which route to select.

All points in the route also send a search current for the flank call into the diverging track. Route setting can only be completed if the flank call gets a positive response from a protective element. On tracks where a protective elements does not exist, the search current must be reversed by a special (virtual) flank protection reverse element to generate a positive response (Figure 3.16). In some interlocking systems, the elements of the points can be programmed not to start a flank call, so that flank protection reverse elements are not needed.

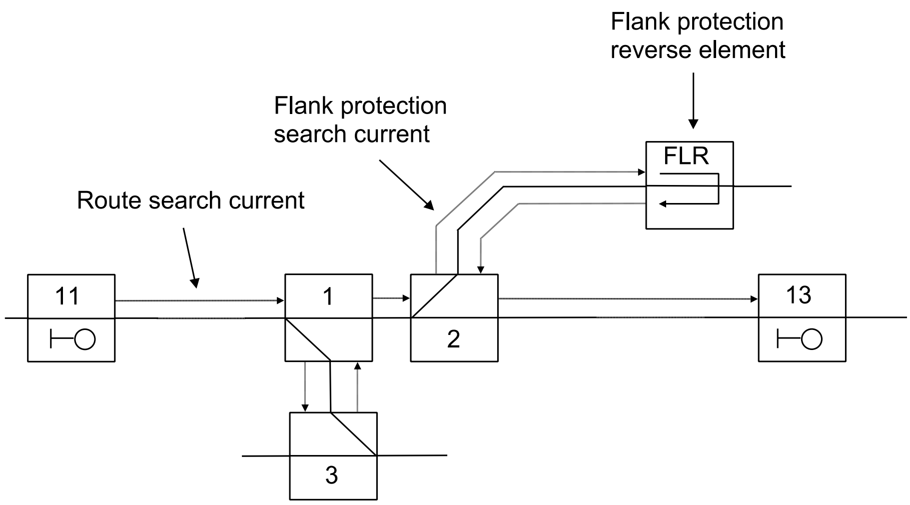

Figure 3.16 Flank protection reverse element

The problem of selective protective points is solved by predefined rules, which determine how points shall react when dual-called for flank protection. The flank points will go into the protective position for the superior route while the flank call of the inferior route is forwarded to search for remote flank protection. In the example of Figure 3.17, point 1 is dual called for flank protection by points 2 and 3. Since the call from point 2 is superior, the inferior call from point 3 is forwarded. The flank search finally finds shunting signal 21X that will provide remote flank protection.

In geographical interlockings, conflicting routes that do not differ in the position of points will automatically lock out each other if the exit elements overlap. Some railways allow opposing

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shunt routes leading simultaneously into the same track. Whether this is allowed or not usually depends on the length of the track. To enable such routes, the exit elements must be arranged in a way so they do not overlap (Figure 3.18). If, on shorter tracks, opposing shunt routes must be locked out, the exit elements must be arranged overlapping each other.

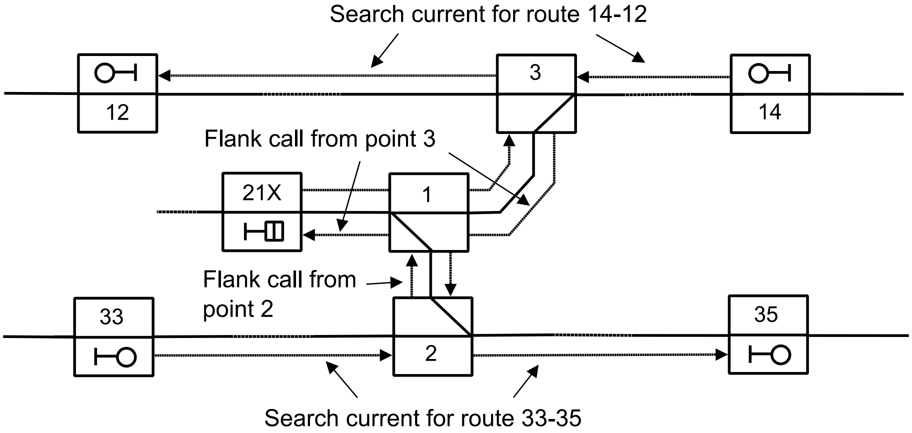

Figure 3.17 Selective protective points in geographical interlocking

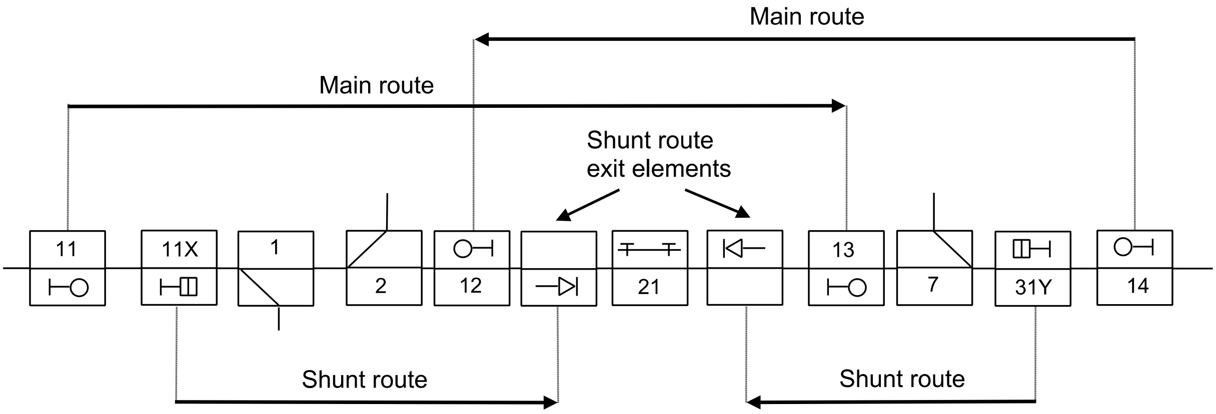

Figure 3.18 Locking out opposing routes by overlapping exit elements

3.3 Generations of Interlocking Systems

While computer-based interlocking is the dominating interlocking technology today and almost exclusively used in all new installations, older generations of interlocking systems are still in use. In some countries, they have still a significant share.

Mechanical and Electro-mechanical Interlocking Systems

Mechanical and electro-mechanical interlocking systems are controlled by leverframe machines, in which the levers of points and signals are mechanically interlocked. The development of mechanical interlocking systems dates back to the late 19th century. In mechanical interlocking, points and signals are operated by the muscle-power of the local operator. The levers are connected to the controlled track elements by mechanical wire or rod transmission. To compensate for the lack of an electrical monitoring of the point positions, facing points are

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often equipped with an independent point lock, which is operated by a separate lever. Since the maximum control distance of points is limited to about 400 m (for signals about 1200 m), large track layouts are often divided into different locally staffed interlocking stations. The first electromechanical interlocking systems were developed at the beginning of the 20th century. In electromechanical interlocking, points and signals are controlled either by electric motor drives or electro-pneumatic drives. The leverframe consists of miniature levers that are actually electrical switches but also still mechanically interlocked. Point positions are electrically monitored.

While developed more than 100 years ago, there are still interlocking systems of that generation in use, outside the core network even in some developed countries. They are expected to disappear within the next decade, however.

Relay Interlocking Systems

In relay interlocking systems, the control logic is realised by relay circuitry without any mechanical elements. The circuitry may be based either on tabular interlocking with a free-wired logic, or on geographical interlocking. Points and signals are no longer operated by levers but by simple push buttons usually located in an illuminated geographical track diagram. The development of relay interlocking systems already started in the 1920s. They were the dominating interlocking technology in the 2nd half of the 20th century. In many countries, they are still used in big numbers. In some countries, they are even still the dominating interlocking technology.

Computer-based Interlocking Systems

In a computer-based interlocking system, the control logic is represented by software. The first computer-based interlocking systems were developed in the 1980s. In the 1990s, for new installations, more and more railways switched from relay interlocking to computer-based interlocking. On many railways, the track elements controlled by computer-based interlockings have already outnumbered the elements controlled by older interlocking generations.

Key Interlocking of Hand-throw Points

Key interlocking is used to interlock hand-throw points at which a siding is connected to a main track. It is a feature to be found in all generations of interlocking systems. For key interlocking, hand-throw points are equipped with a key point lock for each position the points can be locked in. The key locks are designed in a way that the key can only be removed from the lock when the points are properly locked in the position that corresponds to that key. Some points may be equipped with double key locks designed in a way that by unlocking the points another key will be released to unlock other points.

Normally, the key is held in an electric key device controlled by the interlocking system. When a route is set through the points, the key is electrically locked in that device. The electric key device is controlled by the interlocking system like a trackside element. The proper position of the points is checked by the presence of the corresponding key in the device. The locking is effected by locking the key in the device preventing it from being removed to unlock the points.

To enable a shunting move to go into the siding, the electric key instrument is released by the control centre (Figure 3.19 a). When having removed the key, a member of the shunting crew would open the lock to move the points of the main track turnout. This lock is often designed as a double key lock releasing another key to open a flank point or a derailer protecting the

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main track. After having cleared the main track, a member of the shunting crew would move the points to normal position, lock everything, and return the final key into the electric key device (Figure 3.19 b). Now, the control centre could set routes for trains passing on the main track.

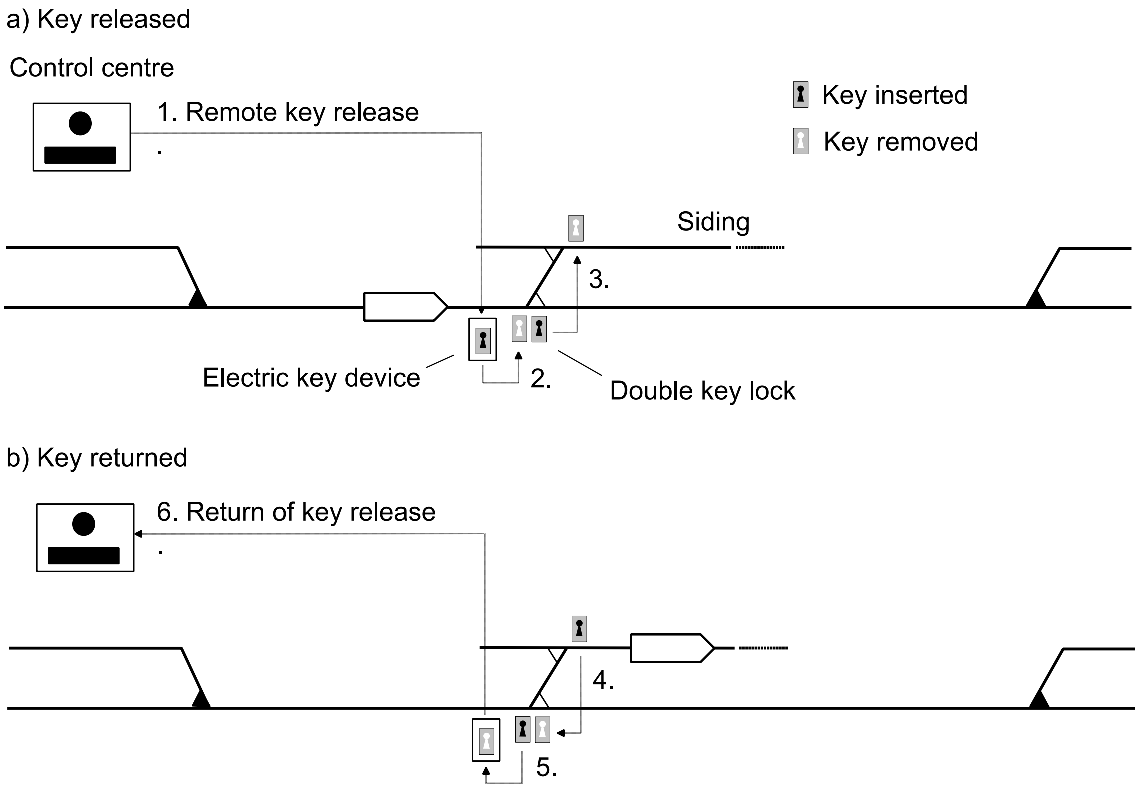

Figure 3.19 Example for key interlocking

3.4 Handling Interlocking Failures

If an interlocking signal doesn't clear as expected, there are three possible causes:

- The route is rejected by the interlocking system.
- The route is not rejected by the interlocking, but route setting has not been completed correctly.
- For interlocking signals leading into a block section: The route is not rejected but the interlocking signal is locked by the block system.

Before taking any action to bypass safety functions under staff responsibility, the operator has to clearly identify, which of the three situations is relevant. If the route is rejected by the interlocking system, the operator has at first to check whether the route is still blocked by conflicting moves, by trackside elements manually locked on the user interface, or by locked trackside elements that have not correctly released after a train or shunting move has passed. If the route is still blocked by a conflicting move, the operator has to wait until that move has cleared the relevant track elements. If the route is blocked by trackside elements manually locked on the user interface, the operator has to check whether it's safe to remove the lockings or to wait until it will be safe to do so. If trackside elements have not correctly released after the last

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move, the operator has to check that the last move has safely cleared the relevant elements. Then it is safe to execute an emergency route release. The safety procedure to perform an emergency route release very depends on the operating rules and interlocking principles of individual railways. While some railways enforce emergency route release just by automatic recording, most railways delay the execution of the release command by time locking.

If route setting has not completed correctly, the operator has to identify the track elements that prevent the signal from being cleared. Then, a safe route has to be established under staff responsibility. For this, there are three different cases:

- Route locking is in effect and displayed on the user interface.
- Route locking is not in effect but the position of all movable track elements is correctly indicated on the user interface.
- Route locking is not in effect and the position of movable track elements cannot be checked on the user interface.

If route locking is in effect and correctly displayed on the user interface, the operator may trust that all movable track elements are locked in the proper position. There is no need to apply manual lockings for trackside elements on the user interface. Before authorising the train to pass the interlocking signal in stop position, the operator just has to check that the track is clear or, if not possible, order the train to proceed through the route on sight. If route locking is not in effect, the operator has to bring all movable track elements manually into the proper position and secure them by applying manual lockings on the user interface. If route locking is not in effect and the position of movable track elements cannot be checked on the user interface, the relevant elements must be secured on site by applying mechanical key locks. In centralised operations, this is usually done by a maintainer who has to confirm that the elements have been secured in the proper position. The need for applying the lockings on site may lead to severe delays. In all cases in which route locking is not in effect, automatic point setting must be switched off before authorising the train to pass the interlocking signal in stop position to prevent any points in the route to be moved unintentionally.

In all cases in which a train is authorised to pass an interlocking signal leading into a block section in stop position, beside the procedures described here, the operator has also to apply the degraded mode procedures for the block system as described in the paragraph on block system failures.

Sometimes, a need may arise to cancel a locked route without having a train passed. An example is a situation in which a signal has been cleared for a train to depart from a platform track but the train cannot depart due to an engine problem. In such a case, the operator has to restore the signal and to cancel the route. Another situation is a wrongly selected route. This may occur by mistake of the operator or by a malfunction of the automatic route setting system. It is always safe to cancel a route as long no train is approaching the signal that governs the route. With a train approaching, before releasing the route under staff responsibility, the operator has at first to reset the signal to stop. On railways where route cancellation of a route with a train approaching is not protected by time locking, the operator has to make sure that the train has safely come to a stop before releasing the route.

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4 AUTOMATIC TRAIN PROTECTION

Automatic Train Protection (ATP) systems transmit information on movement authorities and speed limits from the line to the train to initiate an automatic brake application if the train violates the valid limits. In train control with lineside signals, an ATP system works in addition to the lineside signals and with the main purpose of preventing trains from violating stop signals. On cab signalling lines, the ATP system provides the guiding information for the cab signal indication.

4.1 Classification of ATP Systems

Concerning the form of data transmission between track and train, there is a general distinction between intermittent and continuous ATP systems. In an intermittent ATP system, the data is transmitted to the train at discrete points along the track. Data transmission points are provided at signals and sometimes at selected intermediate locations between signals. While different solutions can be found in existing systems, the most commonly used solution is to use inductive transponders for data transmission. Intermittent ATP systems are mainly an add-on to lineside signals with the main purpose to prevent trains from overrunning stop signals. When approaching a stop signal, the train will get a first data transmission at the beginning of the braking distance. That data transmission initiates a braking curve supervision forcing the train to slow down to a speed at which the train can be brought to a stop within the overlap distance. When violating the stop signal at that speed, the train will come to a stop before the danger point. When passing the signal after it has been cleared, the data point at the signal will upgrade the supervised speed in the on-board unit. To avoid a negative impact on capacity by forcing trains to approach a cleared signal at a slow speed until the speed limit will be upgraded by the data point at the signal, additional data points may be provided on the approach of the signal. When passing such an infill data point after the signal has been cleared, the speed limit will be upgraded immediately.

Continuous ATP systems transmit control data continuously from track to train. This enables the ATP system not only to protect but also to guide the train. The control data transmitted to the train is used for the cab signal indication. Lineside signals are no longer needed but may be provided for degraded mode operations. For data transmission, the following principles are used:

- Data transmission by coded track circuits (pulse or frequency code)
- Data transmission using a cable loop track antenna
- Radio-based data transmission in combination with transponders for the purpose of train location.

Note: In the public transport domain, train control based on a continuous ATP system with two-way data transmission between track and train and a continuous train detection eliminating the need for track clear detection technology is known as Communication-Based Train Control (CBTC). Since this term is not used outside the public transport domain, it is also not used here. Different from the ATP systems used on standard railways, CBTC systems are usually

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closer integrated with the interlocking system to form a common control system for a public transport line or network.

Today, a big number of different national ATP systems exists. Also, there are still railways that do either not yet have any ATP systems or just very simple ones. Today, there are three big international ATP project to replace older systems for better interoperability and to be used in all new installation:

- The European Train Control System (ETCS)
- The Chinese Train Control System (CTCS)
- The North American Positive Train Control System (PTC)

Existing installations of older ATP systems are gradually replaced by systems covered by these projects. That is, why the following paragraphs concentrate on the principles behind these three system families. For a description of principles used in older ATP systems, see (*Theeg & Vlasenko, 202*0).

4.2 European Train Control System (ETCS)

For the European railway system, one of the big challenges is to improve interoperability. One of the key points to be solved in cross-border operation is the interoperability of ATP systems. While on European mainlines, ATP is a standard feature, the variety of existing ATP systems is enormous (*Bailey, 1995*). With a very few exceptions, ATP systems change at any national border. Today, the only solution for cross-border operation is either to change locomotives at national borders or to use expensive multi-equipped locomotives. To overcome this situation, the ETCS project was launched.

4.2.1 ETCS and ERTMS

ETCS stands for European Train Control System and is a layer (i.e., a sub-project) of the European Rail Traffic Management System (ERTMS). Today, the ERTMS just consists of the ETCS and the digital radio system GSM-R. While ETCS represents the train control part of ERTMS, the GSM-R provides the wireless communication system needed for the higher ETCS levels. GSM-R is not only needed for the ETCS but has also replaced the older radio systems for general voice and data communication in railway operations. It is based on the public GSM standard but provides some specific features needed in train control. Since GSM is already an outdated mobile communication standard, it will be replaced in the next years by the FRMCS (Future Rail Mobile Communication System), which is based on 5G radio technology.

Originally, the ERTMS also contained a traffic management layer consisting of a train information system (TIS) for tracking trains in international freight corridors and a project to harmonise interlocking principles (*Winter, 2009*). Later, the traffic management layer was removed from the ERTMS and transformed into separate projects. While the TIS is already successfully applied on international freight corridors across Europe, the harmonisation of interlocking principles is still at an early stage.

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The idea of ETCS is to gradually replace the existing ATP systems by an advanced train control system. In that system, train control information can be transmitted by transponders (so-called Eurobalises), short loop antennas (so-called Euroloops), or by digital radio.

4.2.2 ETCS Levels

Based on the different communication technologies, several levels have been specified for the trackside equipment (*Stanley, 2011*). By these levels, the ETCS can be adapted to different operating needs. In all these levels, the same on-board equipment is used.

ETCS Level 1

In Level 1, ETCS works as an advanced intermittent ATP system. Train control information is transmitted by controlled transponders, which get their information from the traditional signalling system via a lineside electronic unit (Figure 4.1).

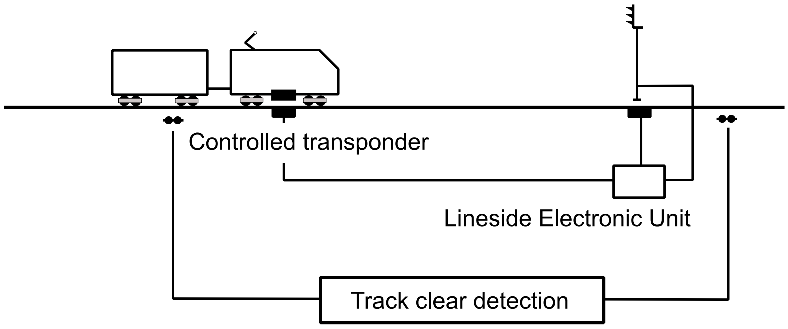

Figure 4.1 ETCS level 1

When approaching a stop signal, a transponder at the beginning of the braking distance will transmit data to calculate the brake supervision curve in the on-board unit. The train will have to follow this curve until having reached a so-called release speed. At this speed, the signal can be passed. If the driver passes a stop signal at release speed, the train will get an emergency brake intervention and brought to a safe stop within the overlap. The system guaranties that the train will never violate the danger point at the end of the overlap (the so-called supervised location). If the signal has been cleared in the meantime, the transponder at the signal will upgrade the on-board unit to the speed permitted in the section beyond the signal.

To improve capacity, a train approaching a stop signal may be released from the braking curve supervision after the signal has been cleared by transmitting infill information. As shown in Figure 4.2, infill information may be provided by additional transponders (spot infill), a loop antenna (loop infill), or by digital radio (radio infill).

ETCS level 1 can be operated either in full supervision or in limited supervision mode. In full supervision, the train speed is permanently supervised by the ETCS. If loop or radio infill information is provided at all points that may limit a movement authority, trains can be governed by cab signals without need for lineside signals. Without such infill information, lineside signals of some kind are still needed. After a train has stopped at a signal, the authority to proceed cannot be transmitted by the ETCS. After the signal has cleared, the driver may proceed at release

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speed. When having reached the transponder at the signal, the locomotive device will read the electronic movement authority and upgrade the cab display.

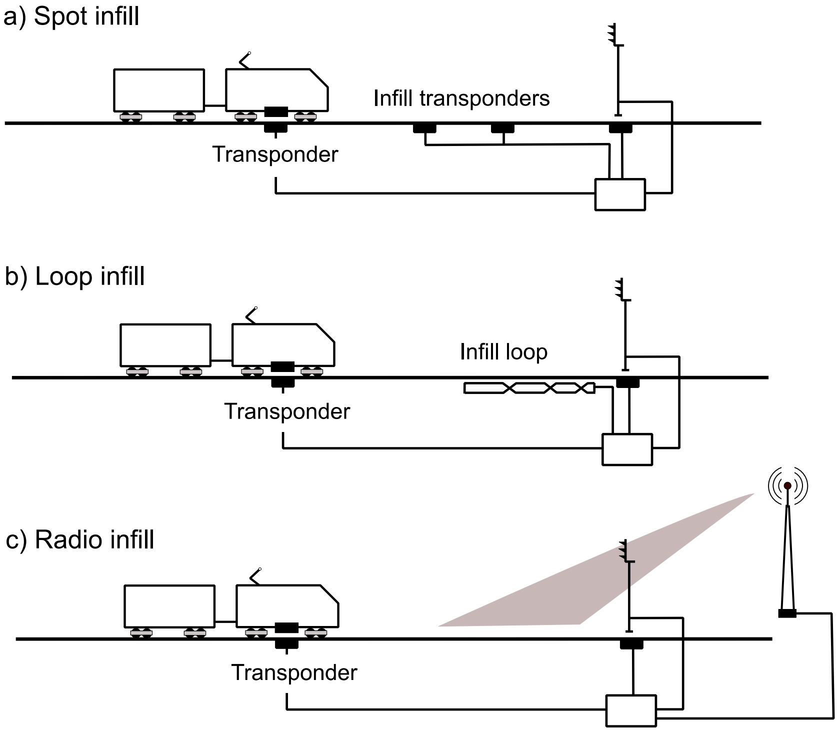

Figure 4.2 Infill solutions for ETCS level 1

This procedure does not require full-equipped interlocking and block signals. Instead, ETCS stop markers with a single signal light indicating that the transponder contains a valid authority are a sufficient solution (Figure 4.3). However, full-equipped signals may be provided for degraded mode operations.

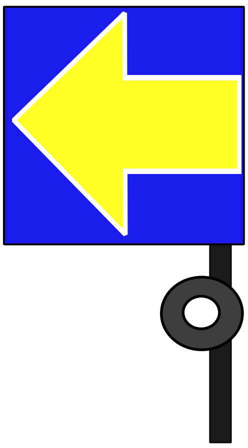

Figure 4.3 ETCS stop marker with authority indicator

In limited supervision, the ETCS emulates the functionality of a traditional intermittent ATP system. In this mode, trains are always governed by lineside signals while the ETCS supervision works in the background.

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ETCS Level 2

In Level 2, ETCS works as a continuous ATP system in which the train control data is transmitted by digital radio (Figure 4.4). Non-controlled transponders are used as reference points ('electronic mileposts') for the on-board train location system.

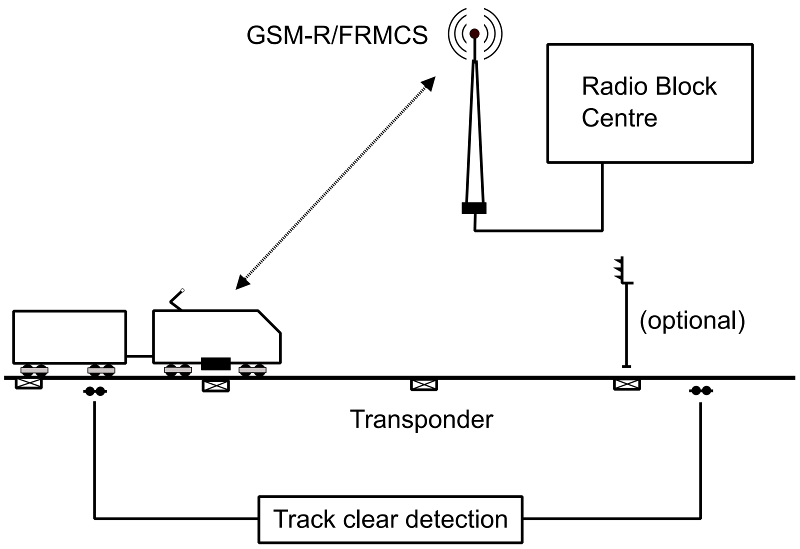

Figure 4.4 ETCS level 2

In specified intervals, trains automatically transmit their location data to a Radio Block Centre (RBC) that issues the movement authorities to the trains. However, positive train separation is still effected by fixed block sections equipped with traditional track clear detection technology (track circuits or axle counters). Lineside signals are not needed but may be provided for degraded mode operations. Most railways prefer to replace controlled signals by ETCS stop markers that must not be passed without valid authority. Depending on the operating rules of individual railways, intermediate block sections may be limited by ETCS location markers. Since these ETCS location markers do not provide an absolute stop indication, the design differs from the ETCS stop markers (Figure 4.5).

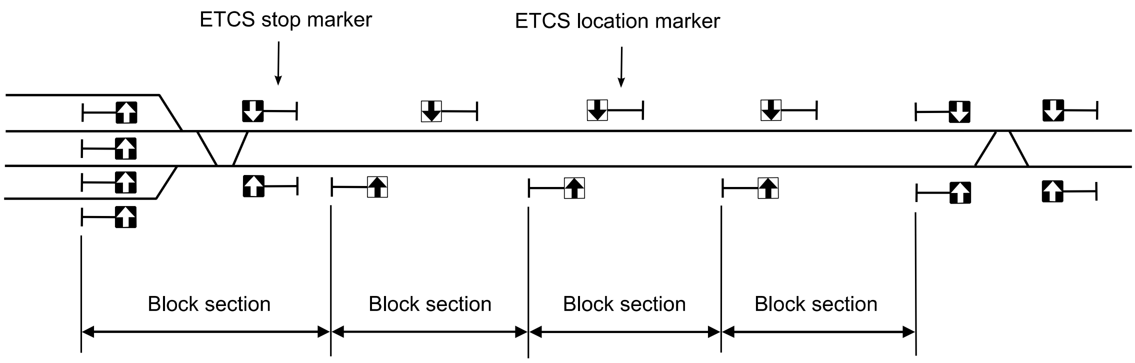

Figure 4.5 ETCS markers on a Level 2 line without lineside signals

Today, the rules concerning the application of the ETCS stop and location markers are not yet completely harmonised between individual railways. Due to different rules for shunting movements, some railways use specific ETCS boards for vehicles running in ETCS shunting mode, while other railways don’t.

ETCS Level 3

ETCS Level 3 finally adds train-borne checking of train integrity (i.e., train completeness) to the system. This eliminates the need for fixed block sections for track clear detection (Figure 4.6). In contrast to Levels 1 and 2, ETCS Level 3 is not only an ATP and cab signal system but provides also a radio-based train separation replacing the traditional block system. Depending on the operational needs, train separation can be effected by virtual or moving block. Due to the absence of traditional track clear detection technology, lineside signals for degraded mode operations cannot be used.

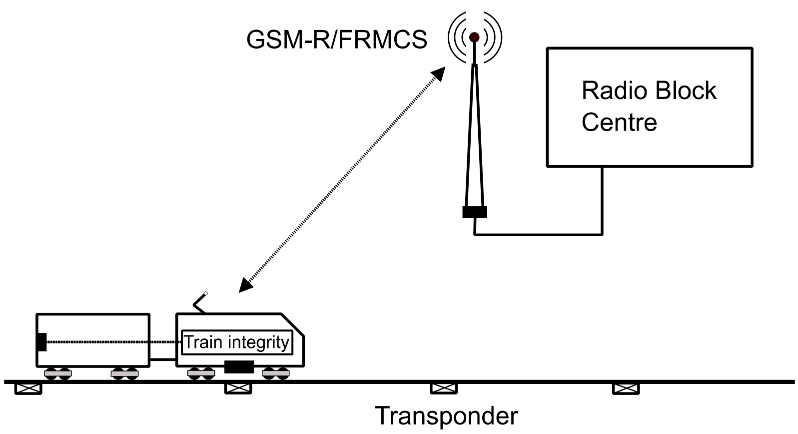

Figure 4.6 ETCS level 3

With virtual block, virtual block sections are established in the control computer without having real physical block sections on the line. While these virtual block sections are not equipped with trackside track clear detection technology, the block limits may be marked by ETCS location markers for degraded mode operations. The location information received from the trains by radio is transformed into information showing occupied and clear virtual block sections. Movement authority is provided by allocating a number of block sections to a train. The end of movement authority is in any case the limit of a virtual block section (Figure 4.7 a). Different from moving block, the movement authority is not to be upgraded continuously with movement of the rear end of the train ahead but in accordance with the release of the virtual block sections. This will significantly reduce the radio traffic for the transmission of guiding data from the RBC to the train. Depending on traffic demands, the operational performance may be flexibly changed by reconfiguring the virtual blocks in the control computer.

In a radio-based moving block system, a train clears the track behind its rear end in accordance with the tracking intervals of train location (Figure 4.7 b). Moving block makes only sense on lines with a very high density of one-directional traffic with harmonized speed profiles. The typical moving block application is a mass transit railway. On standard railways, in most cases, virtual block will be a more efficient solution. That is why most railways are today rather interested in virtual block than in moving block.

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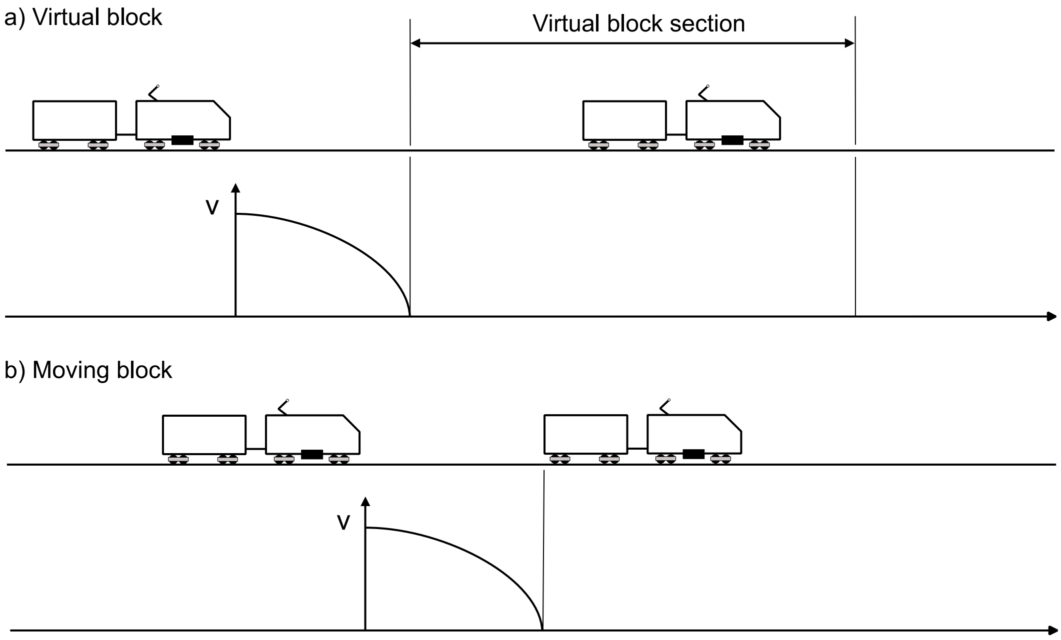

Figure 4.7 Virtual block and moving block

ETCS Hybrid Level 3

ETCS Level 3 requires all trains to be equipped with on-board monitoring of train integrity. For passenger trains, this can be achieved by using existing electric lines through the train consist. In conventional freight operations, such an electric communications line through the train consist does not yet exist. Several European railway are currently working on the development of a so-called digital automatic coupler. That new coupler requires the freight wagons to be equipped with an electric data line that is connected when vehicles are coupled.

With that development, we will see the first freight trains with on-board checking of train integrity in the near future. A complete migration of the new couplers will take decades, however. Thus, for a rather long period of time, we will see mixed traffic of trains with and without on-board monitoring of train integrity. To enable an application of ETCS Level 3 under that condition, a hybrid solution combining the principles of level 2 and level 3 is preferred by several railways. That hybrid solution is based on ETCS Level 3 with virtual block sections that are overlaid by longer block sections controlled by trackside track clear detection technology. Trains with on-board monitoring of train integrity would occupy and release the line according with the virtual block sections. Non-equipped trains may occupy the line according with the virtual block sections but can only release the line according with the longer block sections controlled by track clear detection technology. On some railways, the Hybrid Level 3 is called Level 2 HD (for ‘high density’).

Figure 4.8 demonstrates that principle by a blocking time diagram. For the minimum line headway between two trains, it is always relevant whether or not the first train is equipped with train integrity monitoring. With an increasing share of trains equipped with train integrity monitoring, the capacity will be improving without changing anything on the infrastructure.

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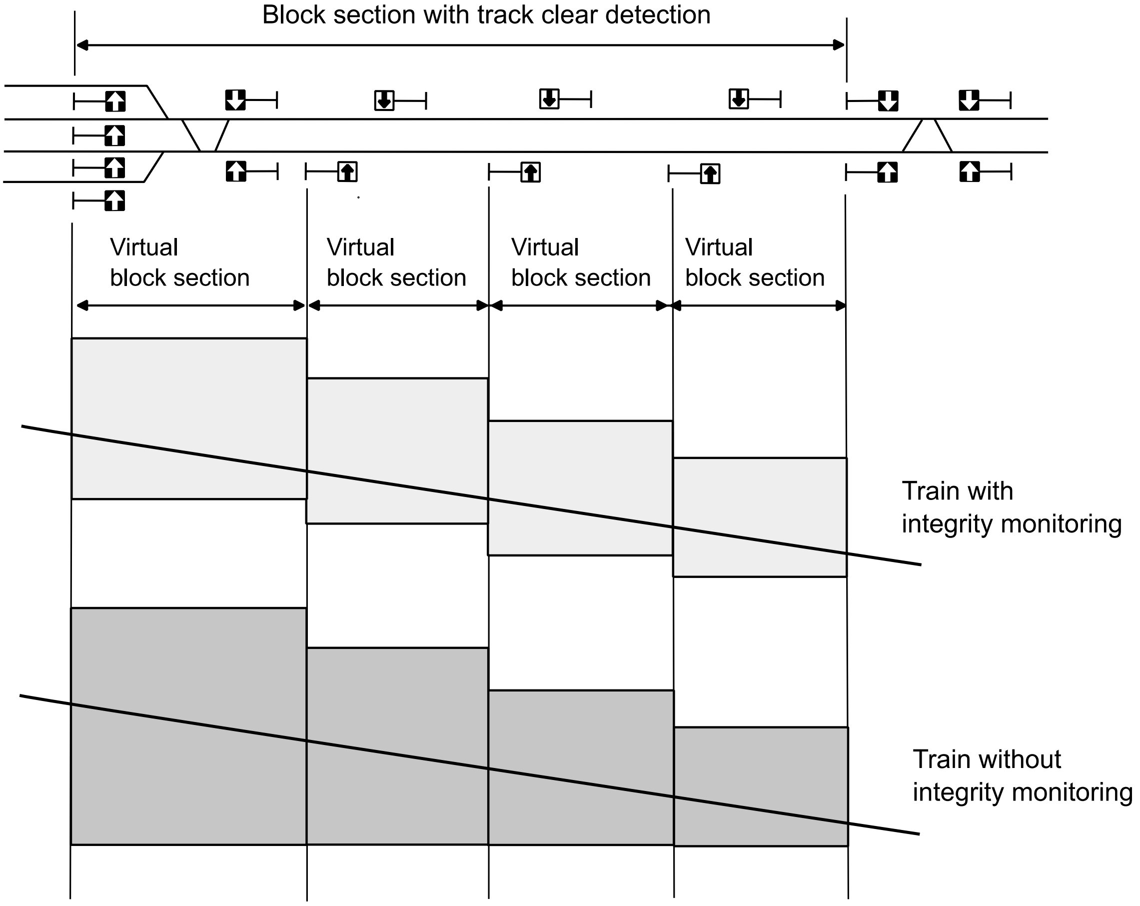

Figure 4.8 Blocking time stairways in ETCS Hybrid Level 3

ETCS Level STM/NTC

The ETCS Level STM/NTC, was originally not a part of the ETCS specification but was added later. STM stands for Specific Transmission Module. It is a specific on-board device that enables an ETCS controlled vehicle to run on lines not yet equipped with ETCS but with an older ATP system. For this, the vehicles must be equipped with antennas needed to read information provided by the old system. In the STM, the data received from the old systems is transformed into the ETCS data format so the control information can be displayed to the driver on the ETCS user interface. However, the degree of control and protection very depends on the capabilities of the old system. In new installations, that level is called NTC for National Train Control.

The STM was developed as a temporary solution to support migration from old systems to ETCS. There are contrary arguments on the usefulness of this approach, however. The key objective of ETCS is interoperability without multi-equipped locomotives. The STM approach is still based on locomotives equipped with multiple antenna systems but reduces the need for a fast roll-out of trackside ETCS installations. This might finally not enhance but slow down the ETCS migration process.

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4.3 Chinese Train Control System (CTCS)

For years, the Chinese railway network has been extensively growing. China already has the world's largest high speed rail network. All new and upgraded lines are equipped with the CTCS – the Chinese Train Control System. The CTCS is based on ETCS technology with some modifications to meet the specific operational requirements of Chinese railways. Different from the ETCS approach, there is no separation between the computer-based interlocking system and the Radio Block Centre. Instead, there is one integrated control system for interlocking and train control. For continuous transmission of train control data, either radio transmission by GSM-R or coded track circuits are used. For the use of coded track circuits, a separate level was defined that has no equivalent in the ETCS specification (Table 3).

In this level, jointless frequency-coded track circuits are used. Location reference is provided by additional transponders of the Eurobalise type. The continuous data transmission by the coded track circuits may be supported by intermittent transmission by controlled transponders. Table 3.3 compares the numbering of ETCS and CTCS levels.

Table 3 Comparision of ETCS and CTCS levels

Functionality	**ETCS**	**CTCS**
Intermittent ATP	Level 1	Level 1
Continuous ATP with coded track circuits	-	Level 2
Continuous ATP with data transmission by radio	Level 2	Level 3
Continuous ATP with data transmission by radio and radio-based train separation	Level 3	Level 4

CTCS level 2 may be used up to a speed of 250 km/h. Lines operated at a speed exceeding 250 km/h must be equipped with CTCS level 3. CTCS level 4, which is an equivalent to ETCS level 3, is not yet in operation. However, since Chinese high speed lines are separated from the conventional network, there are some chances to have the first lines equipped with level 4 in the near future.

4.4 Positive Train Control (PTC)

Positive Train Control (PTC) is a concept from North America that is in some aspects similar to the ETCS, while other aspects are quite different. The objective of PTC is not to improve interoperability but to enhance safety. With just a few exceptions, the majority of the North American rail lines are not equipped with ATP. As stated earlier, a significant share of the lines are even 'dark territories', i.e., lines operated under simplified operating procedures without a signal-controlled operation. In 2008, as a consequence of several severe rail accidents, US congress issued the Railroad Safety Improvement Act (often referred to as the 'PTC mandate'), which enforces the introduction of PTC. By the definition of that act, PTC is a safety system that prevents:

- Train-to-train collisions
- Overspeed derailments
- Incursions into established work zone limits
- Train movements through points in the wrong position

Installation of PTC is mandatory on main lines with passenger traffic, on lines with a high traffic density, and on lines with regular transport of hazardous materials.

On signal-controlled lines, trains are provided clear and safe track sections by the signalling system. The only function to be added by PTC is a continuous ATP system for speed control and enforcement of the authority limits. This is very similar to the philosophy of ETCS level 2. However, PTC can also provide an integrated protection of following trains based on the moving block principle. This is quite similar to the approach of ETCS level 3.

A significant difference from ETCS is the protection of hand-throw points on unsignalled lines. For this, point positions are monitored to prevent trains from running through turnouts if the points are not properly set. That function is nonexistent in ETCS, since even the most simplified ETCS applications are always based on interlocked points with centralised control.

Different from ETCS, PTC is not a technical specification but a set of safety functions defined independently from technology. Interoperability is not mandatory. The degree of interoperability will depend on the needs of the railway companies. The four leading Class I railways (Union Pacific, BNSF, CSX, Norfolk Southern) have already agreed on a common standard to ensure an interoperable systems design. The technology will be based on radio based train control similar to ETCS levels 2 and 3. Different from these ETCS levels, PTC can be used either as a system to govern train movements directly, or as an overlay system to existing train control systems. Another difference from ETCS is the use of GPS as the primary train location system.

PTC may be implemented in three different levels:

- Non-vital overlay
- Vital overlay
- Vital stand-alone

When PTC is used as a non-vital overlay, trains are still governed by conventional systems (signal indications or verbal authorities). PTC just acts as a safety overlay in the background. In a vital overlay PTC implementation, trains are governed by PTC while the block and interlocking functions are provided by conventional CTC. As a vital stand-alone system, PTC will replace the conventional CTC systems and integrate all signalling and train control functions into one system. All currently planned PTC project follow either the non-vital or vital overlay approach. Technology for vital stand-alone PTC systems is not yet available.

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5 Level Crossings

At level crossings, rail traffic has absolute priority. While the design differs a little from country to country, a St. Andrew's cross is used everywhere to mark a level crossing for road users. Depending on the traffic density on the road and the characteristics of the railway line, different protection measures are used.

5.1 Level Crossing Protection

Concerning the protection measures, there are three types of level crossings:

- Level crossings without traffic light protection
- Level crossings protected by traffic lights without barriers
- Level crossings protected by traffic lights with barriers

Level crossings without traffic light protection are just marked by a St. Andrew's cross. Road users must have a clear view on the railway line to be able to stop safely when a train is approaching. For this, an approaching train must be clearly visible from a distance at which a road user approaching the level crossing can make a clear decision whether or not it will be safe to pass the level crossing. That distance includes the braking distance and a sufficient reaction time for the decision making of the driver. The distance from the decision point on the road and the needed approach distance on the railway line form a viewing triangle that must be kept clear of any view-blocking items. That triangle is calculated both for a slow and for a fast road user. The two triangles are put one above the other to get the entire area that must be kept clear (Figure 5.1). Additionally, trains approaching the level crossing would warn road users by repeated whistle signals. This very simple form of protection is only acceptable on secondary railway lines with a low speed and density of traffic.

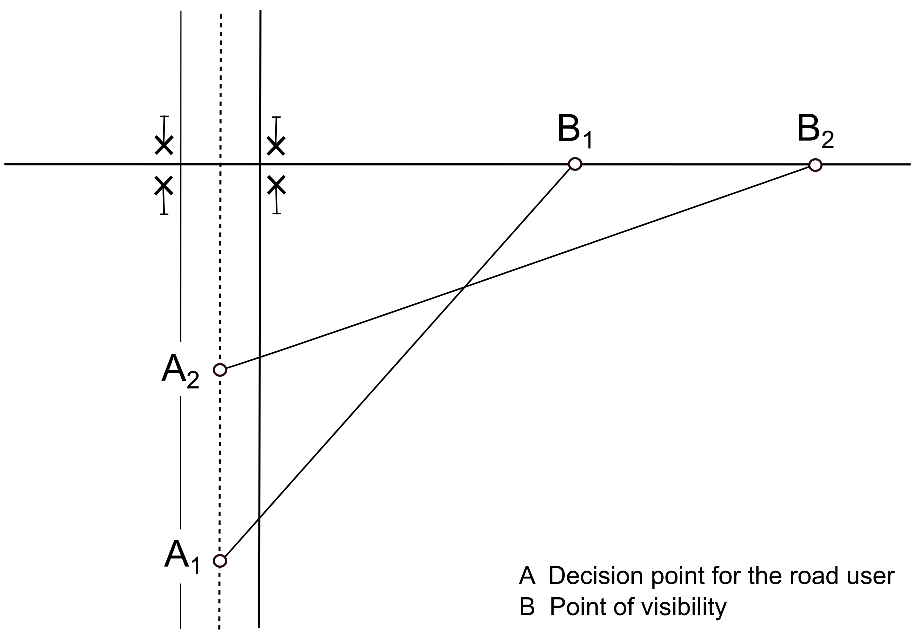

Figure 5.1 Viewing triangles for a fast (1) and a slow (2) road user

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On level crossings protected by traffic lights, stop lights for road users are activated when a train is approaching. Depending on the national road traffic regulations, the stop indication is given either by flashing or steady red lights. In some countries, the traffic light will at first show a yellow light and then switch to red. While in most countries, the traffic lights are just dark as long no train is approaching, in some countries, a clear indication is given (usually a green or white light).

The traffic lights must be activated a sufficient time ahead of an approaching train so that road users that have already passed the beginning of the stopping distance can still safely pass the level crossing. This time is called the level crossing approach time (not to be confused with the approach time in blocking time calculations). The level crossing approach time is calculated from the maximum time a road user needs from the beginning of the stopping distance until having cleared the level crossing by full vehicle length plus a safety margin of a few seconds.

On level crossings protected by traffic lights with barriers, there is another constraint. When the traffic lights are activated, the barriers must not be closed immediately. After the traffic lights are activated, road users that have already passed the beginning of the stopping distance must still be able to pass through the open barriers. The so called pre-signalling time from activating the traffic lights until closing the barriers is calculated from the maximum time a road user needs from the beginning of the stopping distance until having cleared the barriers by full vehicle length. The level crossing approach time is the total of that pre-signalling time, the time for closing the barriers, and a safety margin. On level crossings protected by full barriers, i.e., barriers blocking all lanes of the road, it must be checked that no road user is accidently locked between the barriers. This can be done either by operators checking the clearance of the level crossing visually (either on site of by remote cameras) or automatically by radar scanners. On level crossing protected by half barriers, the clearance of the level crossing is not monitored because the leaving lane is not blocked, so that road users cannot be locked in.

5.2 Control and Monitoring of Level Crossings

A level crossing protected by traffic lights or by traffic lights with barriers can be controlled in three ways:

- manually controlled level crossings
- automatic level crossings
- level crossings controlled by the interlocking system

Pure level crossing operators are almost extinct today. Level crossings controlled by a local operator are still to be found at locally staffed interlocking stations. There, the level crossing is usually interlocked with controlled signals. Level crossings may also be controlled by an operator in a control centre who monitors the level crossing by remote cameras. Sometimes, the level crossing protection is manually activated by the operator but automatically deactivated by trackside devices after the passage of the train.

At automatic level crossings, traffic lights and barriers are activated by trackside devices (rail contacts, track circuits) placed at the required distance on the approach of the level crossing.

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After the passage of a train, trackside devices will also check that the train has cleared the level crossing so that it is safe to automatically open the barriers and switch off the traffic lights.

Automatic level crossings may be monitored by a remote monitoring device, by a driver's crossing indicator, or by a main signal. A remote monitoring device will check the proper working of the level crossing protection for any train passing. Also, the trackside devices for the detection of an approaching train are permanently monitored. If a malfunction is detected, the operator in the control centre will be alerted. Then, all trains must be given an order to pass through that level crossing cautiously until a signal maintainer has restored normal operation.

At level crossing monitored by a driver's crossing indicator, a lineside indicator is placed at the braking distance on the approach of the level crossing. When approaching the level crossing, the train has to check the proper working of the level crossing protection by that indicator. If the traffic lights have been correctly activated by the approaching train, the driver will get an indication that the train may pass the level crossing without restrictions. If the protection was not correctly activated, the driver will get a warning indication to slow down the train and pass the level crossing with caution.

At automatic level crossings monitored by a main signal, a main signal protecting the level crossing will only clear when the level crossing protection has been correctly activated by an approaching train. When, in case of a level crossing malfunction, a train has to be authorised by the operator to pass that main signal in stop position, the driver must be ordered to pass the level crossing protected by that signal with caution. On lines with bidirectional operation, a level crossing may be monitored by a main signal in one direction but by a driver's crossing indicator in the opposing direction.

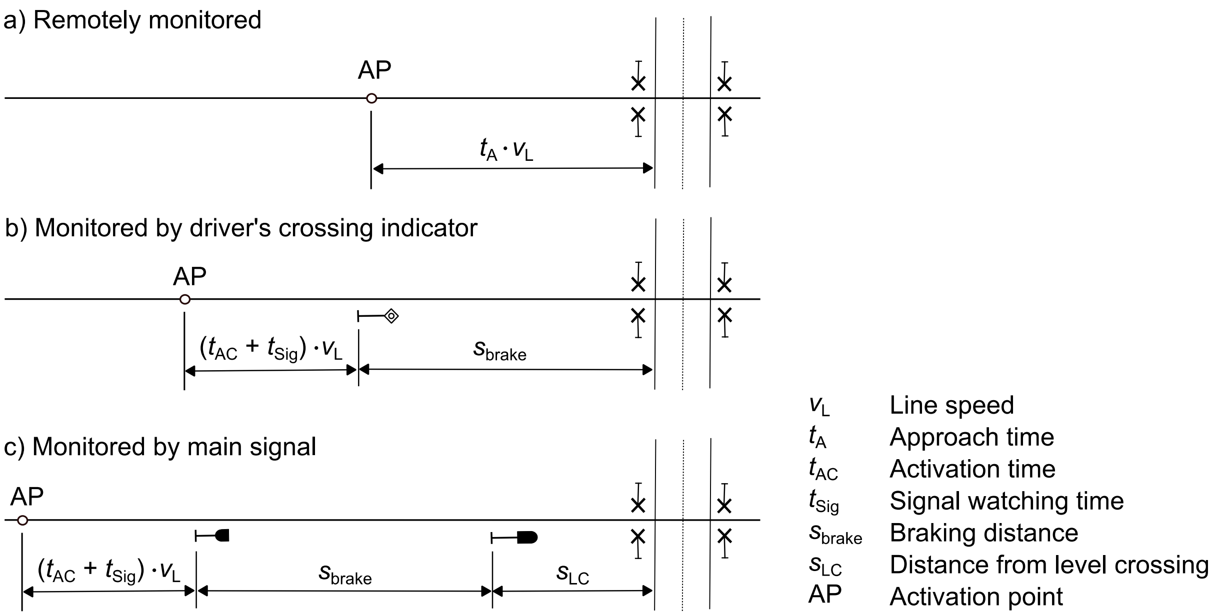

Figure 5.2 Calculation of the initiation section

Level crossings controlled by the interlocking system are part of a locked route and therefore interlocked with the signal governing the route. The level crossing protection is activated by the route setting and deactivated by the passage of the train through the level crossing. In case of malfunction of the level crossing, the signal governing the route will not clear. It shall be

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noted that there may also be automatic level crossings inside of interlocking areas. These level crossings are not part of locked routes but may be monitored by an interlocking signal.

5.3 Calculation of the Initiation Section

The initiation section is the distance at which an approaching train has to activate the level crossing protection. That distance depends on the monitoring principle (Figure 5.2). At remotely monitored level crossings, the length of the initiation section is calculated from the line speed and the necessary approach time. At level crossings monitored by a driver's crossing indicator, the level crossing protection must be activated a sufficient time on the approach of the crossing indicator to enable the driver to watch the clear indication. The signal watching time is the same time as needed at a lineside signal providing an approach indication for the signal ahead as explained in Chapter 2 in the paragraph on the blocking time model. The initiation section is significantly longer than on a remotely monitored level crossing and will extend the time the level crossing is blocked for road users. At level crossings monitored by a main signal, the initiation section is extended by the distance between the main signal and the level crossing. This will also further extend the time the level crossing is blocked for road users.

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REFERENCES

Armstrong, H.: The railroad, what it is, what it does, 5th Edition, Simmons-Boardman Books, Omaha 2008

Aubertin, F. J.: Your Guide to Railway Signals. Simmons-Boardman Books, Inc.. Omaha 2018

Bailey, C. (Editor): European Railway Signalling. Institution of Railway Signal Engineers. A & C Black, London 1995

Bisset, K.; Rowbotham, T.; Thurston, D.; Burkhardt, R.; Power, J.; Hoelscher, J.: Introduction to North American Railway Signaling. Institution of Railway Signal Engineers. Simmons-Boardman Books, Inc.. Omaha 2008

Chandra, S.; Agarwal, M.M.: Railway Engineering. Oxford University Press 2008

Dougherty, P.: Tracks of the New York City Subway. New York City 2018

Hansen, I.; Pachl, J. (editors): Railway Timetabling & Operations – Analysis, Modelling, Optimisation, Simulation, Performance Evaluation. Eurailpress, Hamburg 2014

Pachl, J.: Railway operation and control, 4th Edition, VTD Rail Publishing, Mountlake Terrace 2018

Stanley, P. (editor): ETCS for Engineers. Eurailpress, Hamburg 2011

Theeg, G.; Vlasenko, S. (editors): Railway Signalling and Interlocking – International Compendium. Eurailpress, 3rd Edition, Hamburg 2020

UIC: ERTMS Glossary. English – French – German. International Union of Railways (UIC), 1st Edition, Paris 2012

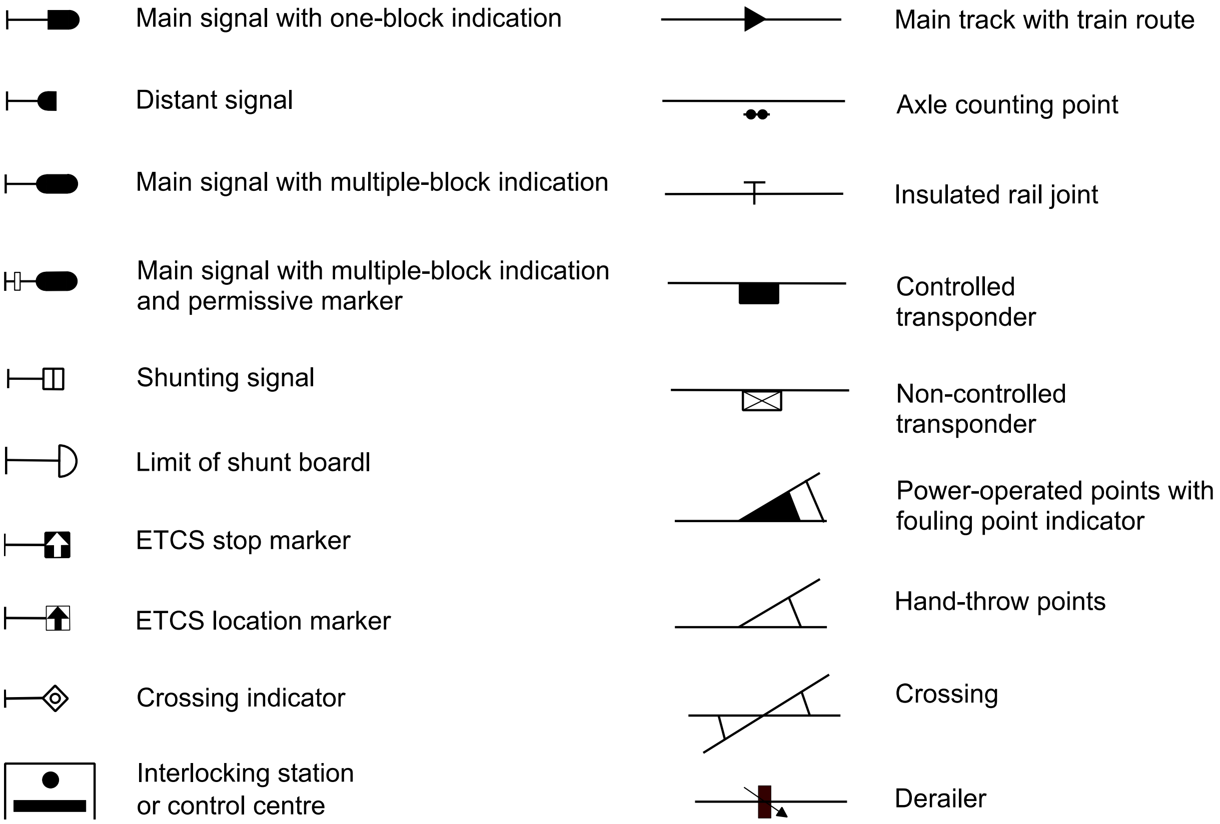
White, T.: Elements of Train Dispatching, Vol. 1. VTD Rail Publishing, Mountlake Terrace 2003

Winter, P. (editor): Compendium on ERTMS – European Rail Traffic Management System. Eurailpress, Hamburg 2009

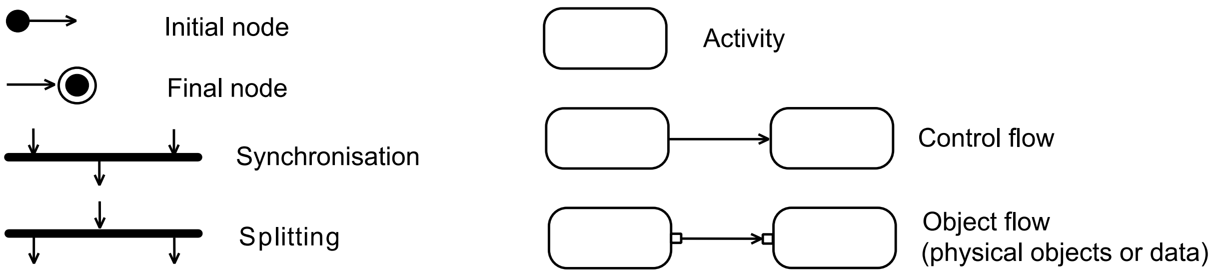
https://doi.org/10.24355/dbbs.084-202110181429-0

SYMBOLS IN DIAGRAMS

The symbols for track and signal diagrams resemble the German standard but are used in a generic way not referring to a particular railway.



The symbols used in activity diagrams are a subset of the SysML/UML notation.



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GLOSSARY

Absolute signal - A signal that must not be passed in stop position without permission from the operator.

Approach locking - Form of route locking that comes into force after the train has occupied the approach section.

Approach time - 1) The running time between a signal that provides an approach indication and the following signal. 2) The time, level crossing protection must be activated ahead of an approaching train.

Automatic block system - A block system in which the signals work automatically. Lines with an automatic block system must be equipped with track clear detection.

Automatic signal - A signal that works automatically by the passage of the train through track sections.

Automatic Train Protection (ATP) - A system that transmits information about movement authorities and speed limits from the line to the train to cause automatic braking if the train ignores the valid limits.

Axle counter - A track clear detection system consisting of counting points at both ends of a section and a counter connected to the counting points. The occupancy of a section is detected by comparing the number of axles that enter the section with the number of axles that leave the section.

Block section - A section of track in a fixed block system, which a train may only enter if the section is not occupied by other vehicles.

Block signal - A main signal that governs train movements into a block section.

Block system - A signalling system that provides a safe spacing of trains. Block systems may be divided into fixed block systems and moving block systems.

Blocking time - The minimum time interval that must be kept clear for the non-delayed passage of a train through a track section.

Cab signaling - A signalling system that displays the movement authorities on the driver's desk.

Clearing point - A point a train must have cleared completely before a signal in rear may be cleared or a locked route may be released.

Controlled signal - A signal that is controlled by an operator.

Control length of a signal - The length of track beyond a signal that must be clear and safe before the signal can be cleared for a train movement.

Crossing - An intersection of two tracks at grade.

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Derailer - A flank protection device that would derail an unsafe movement before it could join the protected route.

Direction locking - A form of opposite locking in which a locked direction is established that holds opposing signals in stop position. Direction locking may be in effect on a block line that consists of several block sections.

Distant signal - A signal that provides an approach indication to a signal but that cannot show a stop aspect. A distant signal does not limit a block section.

Double slip - A crossing combined with four pairs of points to provide slip connections at both sides of the crossing.

Driver's crossing indicator - A lineside indicator placed at the braking distance on the approach of a level crossing, by which the driver can check the proper working of the level crossing protection.

Dual called points - Another term for selective protective points.

Dwarf signal - A ground mounted signal.

Emergengy route release - A manually initiated release of a route or parts of a route if normal route release fails after the passage of a train.

Entrance signal - An interlocking signal at a route entrance.

Exit signal - 1) A controlled signal that governs train movements to leave a station track. It is also called a station exit signal. 2) A controlled signal at a route exit. It is also called a destination signal.

Facing point movement - A movement on a pair of points in which the point blades face approaching traffic.

Fixed block system - A block system in which the track behind a train is sectionally cleared in accordance with fixed block sections.

Flank area - The section of track between a flank protection device and the fouling point of the route to be protected.

Flank points - Points that are locked in a protective position to provide flank protection to a route.

Flank protection - A measure to prevent vehicles from running into a route, which is cleared for a train movement.

Flank protection device - A trackside element that provides flank protection.

Flank transfer points - Points that are located in the flank area between an element that provides remote flank protection and the route to be protected.

Fouling point - The limit of occupation of converging tracks at turnouts and crossings.

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Geographical interlocking - An interlocking system in which the track elements are represented by logical objects connected to each other in form of the track layout.

Headway - The time or distance interval calculated from ‘head to head’ between two successive trains.

Home signal - 1) A signal governing entrance to an interlocking area. 2) A signal governing entrance to a station area.

Initiation section - The distance at which an approaching train has to activate the level crossing protection.

Insulated rail joint - A rail joint that ensures electrical insulation of adjacent rails to limit a track circuit.

Interlocking - An arrangement of points and signals interconnected in a way that each movement follows the other in a proper and safe sequence.

Interlocking signal - A controlled signal that governs a route within an interlocking.

Interlocking station – A locally staffed control room from which an interlocking area is controlled.

Intermediate interlocking signal - An interlocking signal that is neither a home signal nor a signal that governs a route to leave the interlocking area.

Intermediate points - Points that are located in a station track in a way that a train stopping at its regular stopping position would not clear the points.

Intermittend ATP - An ATP system in which the data is transmitted to the train at discrete points along the track.

Jointless track circuit - A track circuit that uses an AC audio frequency current, so that the working length is limited by the capacitive and inductive track characteristics without a need for insulated rail joints.

Key interlocking - A method to achieve interlocking between signals and hand-throw points by mechanical key locks.

Line headway - The headway that results from the blocking time stairways of two successive trains.

Main route - An route governed by a main signal.

Main signal - A signal that governs regular train movements. This term is used by many railways to distinguish these signals from shunting signals.

Main track - A track that may be used for regular train movements.

Manual block system - A block system in which the signals are controlled manually and the clearing of the block sections is checked by local operators watching the rear end markers.

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Moving block system - A block system in which the track behind a train is cleared continuously.

Open line - Main tracks outside of station areas.

Operator - An employee who is in charge to authorise train and shunting movements.

Outer home signal - A controlled signal in approach to a home signal that does not directly protect points but that may be interlocked with points within the overlap beyond the home signal.

Overlap - A certain length of track beyond a signal that must be kept clear as long a train movement is approaching that signal.

Permissive signal - A signal that may be cautiously passed in stop position after the train has stopped at the signal. After having passed a permissive signal in stop position, the movement through the next block section must be made cautiously on sight.

Point lock - A locking device that mechanically locks the points in a proper position to prevent unintended movements of the point blades and movable frogs as long a train is running through the points.

Point machine - A machine that drives points, movable frogs, or derailers.

Points - The movable parts of a turnout that are moved to set different routes.

Rear end marker - A marker at the rear end of a train.

Relay interlocking - An interlocking system in which the interlocking is achieved by relay circuits.

Remote flank protection - Flank protection that is provided by an element that is not directly adjacent to the route to be protected.

Route cancellation - A manually initiated release of a route after having restored the signal.

Route control table - A tabular sheet that contains all interlocking conditions for a given layout.

Route locking - The locking of all points and flank protection devices as long as a route is set.

Route release - The release of locked points after the train has cleared the clearing point of a route.

Running movement - Another term for a train movement.

Selective protective points - Flank points that may receive competing flank calls from different routes.

Self-selective protective points - Protective points that could receive conflicting flank calls from one train movement.

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Semi-automatic block system - A block system in which the block locking after a train has entered the block section is effected automatically, but the section has to be released manually.

Shared overlaps - A form of overlap protection in which two or more overlaps may share a track section without causing a route conflict.

Shunt aspect - A proceed aspect allowing a shunting move to pass a signal.

Shunting - All movements other than train movements.

Shunting signal - A signal that is used to authorise shunting movements.

Shunting limits - An area marked by shunting limit boards or signals, shunting movements must not leave.

Shunt route - A route governed by a shunting signal or the shunt aspect of a main signal.

Siding - A track that may not be used for regular train movements.

Signal aspect - The appearance of a lineside signal, as viewed from the direction of an approaching train, or the appearance of a cab signal.

Signal headway - The headway that results from the blocking times of two successive trains in a single block section

Signal indication - The information that is given by a signal aspect.

Single slip - A crossing combined with two pairs of points to provide a slip connection at one side of the crossing.

Station area - An arrangement of station tracks limited by opposing home signals.

Station exit signal - A controlled signal that governs train movements to leave a station track.

Station track - A main track protected by controlled signals within an interlocking area on which trains may originate, terminate, pass, and turn.

Swinging overlap - A form of overlap protection in which the overlap can be switched into another track without cancelling the route.

Tabular interlocking - An interlocking system in which the locking between signals and points is achieved in form of a route locking table.

Time locking - An application that will hold a route locked for a specified time after the signal has been manually restored.

Token block - A block system for single track operation in which the movement authority depends on the possession of a token which is handed out to the train driver.

Track clear detection - A device that detects the occupation and clearance of a track section.

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Track circuit - A track clear detection device consisting of an electrical circuit of which the rails of a section form a part. The clearance of the section is detected by a detection device at one end of the section which receives a current from a source at the other end of the section.

Traffic locking - A principle of protecting opposing movements on automatic block lines on which automatic signals of both directions are cleared in normal state but automatically restored to stop position (‘tumbled down’) by an opposing move.

Trailing point movement - A movement on a pair of points where the frog faces approaching traffic.

Train movement - A locomotive or self-propelled vehicle, alone or coupled to one or more vehicles, with authority to occupy a main track in accordance to rules specified for train movements.

Turnout - An assembly of rails, movable points and a frog, which effect the tangential branching of tracks and allows trains or vehicles to run over one track or another.

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