

# General Guidelines for the Design of Light Rail Transit Facilities in Edmonton



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***In memory of my mentors:***

*D.L.Macdonald, L.A.(Llew)Lawrence, R.A.(Herb)Mattews, Dudley B. Menzies, and Gerry Wright who made Edmonton Transit a leader in L.R.T.*

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## 1.0 Introduction

Transportation Planning requires the resolution of a broad spectrum of technical and social questions. Light Rail Transit is one tool that can be used to provide economically affordable and socially acceptable solutions to some of the problems particular to the Edmonton urban region. These guidelines have been developed to assist planners to appreciate the wide variety of choice which exists within the scope of this particular mode for making technical and planning decisions tuned to the needs of the communities concerned.

The information comprised in these guidelines is based upon the experience of similar transportation systems in North America and Europe in finding solutions to the problems of improving transportation within limits imposed by financial and environmental considerations.

As in all matters closely impacting upon communities, the adoption of a plan for L.R.T. extension in any corridor should be preceded by adequate exchange sessions where the general public as well as special interest groups are fully informed of the environmental impacts and encouraged to have input which will be used in arriving at the final designs. The earlier the public is involved the more readily will the plans be accepted, both at the decision-making level and perhaps more importantly by the transit patron.

## 2.0 The Role Of Light Rail Transit In Edmonton's Transportation System

### 2.1 Definition and Description of L.R.T.

Light Rail Transit is a mode of passenger transportation utilizing a fixed guideway system based upon standard railway technology modified as necessary to comply with specific site requirements and generally employing electricity from an external source as a means of propulsion.

One of the chief characteristics of L.R.T. is its versatility which leads to very significant differences in performance and capacity from system to system and even from line to line within a given system. The advantage of this versatility is the ability of L.R.T. to present a viable solution to a very large range of transportation problems, and to provide room for incremental growth in capacity.

Within the spectrum of transit modes, L.R.T. provides a capacity between that of the trolley bus and the metropolitan railway, ie., between 3,000 and 30,000 passengers per direction per hour, with capacities in the lower range being provided by single cars, and higher capacities being achieved by operation in trains. The practical advantage of this large range is to enable L.R.T. to satisfy transit needs over the long term, with opportunities for progressive upgrading of facilities as and when required. A particularly good example of this is to be found in the city of Hanover in Germany, where the street railway system is being progressively upgraded by the provision of

segregated surface rights of way and with tunnels through the central business district enabling train operation as and when the traffic justifies the expenditure.<sup>4</sup>

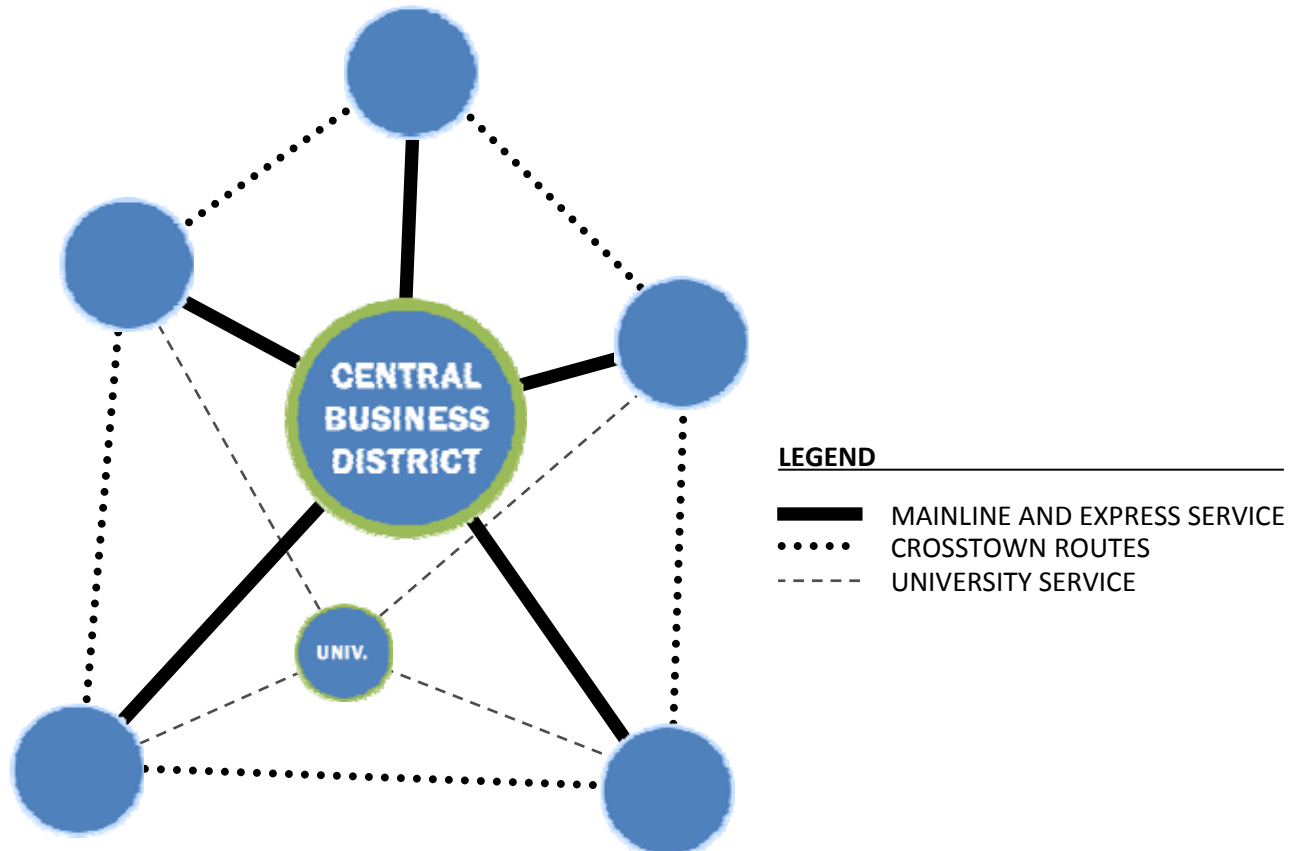
For loadings of more than 3,000 passengers per hour, L.R.T. service can be provided for the same operating cost as diesel buses, although buses on city streets can handle flows of almost 6,000 passengers per hour and even more in particular cases.<sup>2</sup> A city of the size and population density of Edmonton might continue to be served solely by diesel buses, but this would not be a wise use of human, financial and space resources. In introducing L.R.T. to increase capacity, other benefits accrue, benefits which become more obvious as the network expands, and which are the motivation for expansion, rather than the need to provide more passenger places.

Unlike the costs of diesel bus operation, L.R.T. operating costs are not proportional to capacity. Surface train operation on segregated right of way can be many times more economical than buses due to vastly increased manpower productivity but this advantage is quickly lost when expensive capital facilities such as tunnels and elaborate stations are added, resulting in high capital cost and a large staff requirement. In order to obtain the best cost/benefit ratio from the transit system as a whole, traffic volumes must play a major role in corridor selection, and the degree of segregation of L.R.T. right of way must be carefully weighed between what is desirable and what is necessary to provide sufficient capacity in the short to mid-term future.

## 2.2 Integrating L.R.T. into the Transportation System

The basic concept used to guide transit planning in a modern poly-centric conurbation<sup>1</sup> consists of a series of mainline services linking the hub or central business district with major suburban activity centres at which off-street transfer facilities known as Transit Centres are established. From the Transit Centre, local services radiate into surrounding neighborhoods, connecting with mainline services at fixed intervals. This is the geographic basis for the Timed Transfer System. In peak hours buses originating in the neighborhoods continue to downtown as expresses over the mainline or line-haul portion of the route whenever loadings justify this. Other express services may operate from the neighborhoods to particular high demand destinations such as the university campus, and cross-town services link transit centre to transit centre (Figure 2.2.1).

The reason for introducing L.R.T. is to increase productivity both of land and of personnel, and the greatest need for increased productivity is seen in the mainlines. Main lines for the most part have a character of permanence, not tending to change, and therefore both the immediate need and provision for future development is perceived to lie in these corridors. They cater to established travel patterns thus ensuring public acceptance in the planning and construction phases and an easy transition when L.R.T. goes into service. Travel demand will continue to exist in the established mainline corridors and service will have to be provided in them even if L.R.T. should take some other route.



**Figure 2.2.1: All-Bus System** with express bus services from Transit Centres to Central Business District and to University

A less direct but no less important reason is to enhance the magnetism of the city's downtown which is dependent for its viability on easy access not only for employment but for social and cultural purposes.<sup>3</sup>

In extending L.R.T. along a mainline corridor, existing transit centres become principal stations from which the feeder buses continue to fan out into the neighborhoods, but due to the higher average speed of L.R.T., express services to downtown are no longer necessary. This is where a large proportion of the saving in buses takes place. Specialized express bus services to particular high demand destinations also cease to be necessary if those destinations are accessed by mainline L.R.T., since access to the nearest transit centre, already provided by local neighborhood services, is all that is necessary for complete connectivity (Figure 2.2.2).

The light rail system serves, in effect is its own feeder, requiring fewer miles of bus route. This is because of its ability to have branches, to extend for longer distances at low investment, and to have more frequent stations. Therefore the lower service speed achievable by light rail when compared with full metro is more than compensated for by the saving of transfer time and time lost on feeder buses.<sup>10</sup>



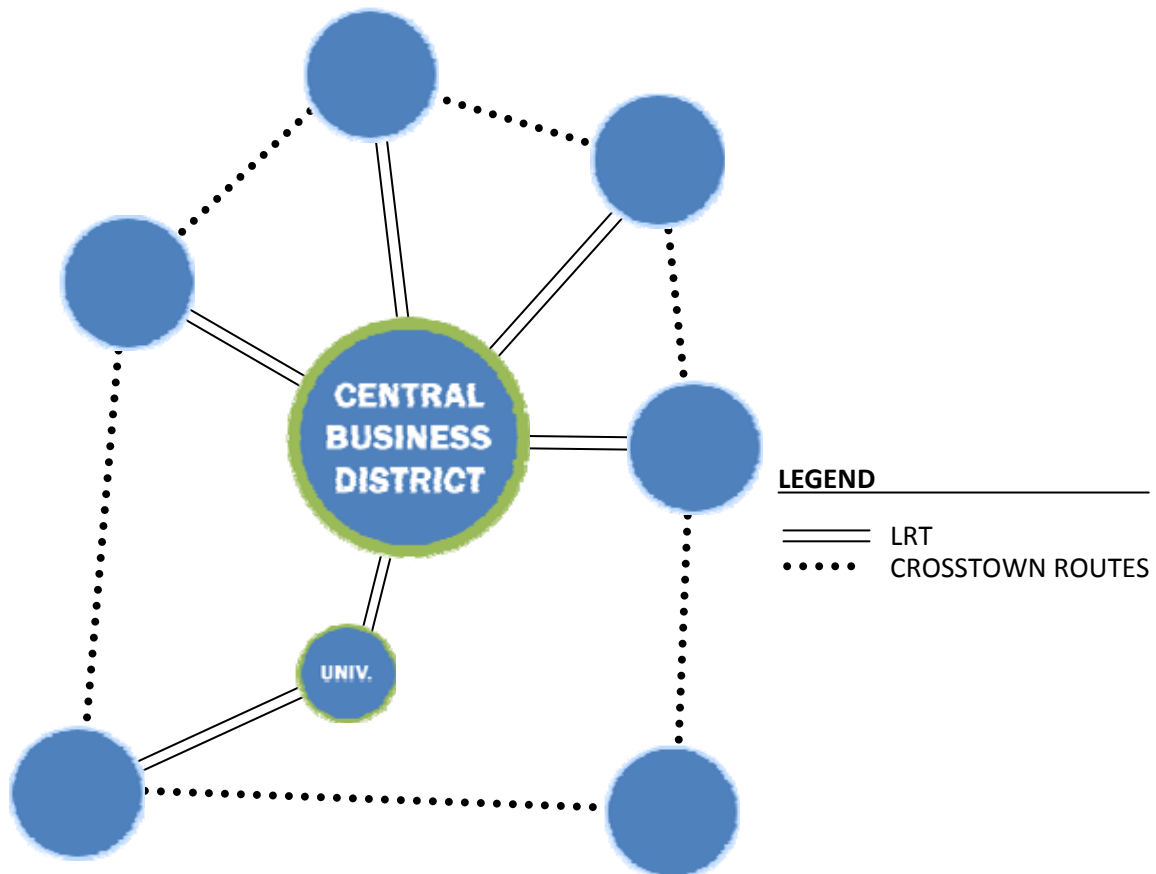


Figure 2.2.2: L.R.T. System with University Station on main line connecting with Central Business District

### 2.3 Segregation of Guideway

L.R.T. can be broken down into categories based upon the degree of guideway segregation. This segregation can be designed for or may arise because of particular site conditions.<sup>2</sup>

- A. Completely segregated, no intersections with other modes, all junctions grade separated.
- B. Segregated except for barrier protected grade crossings and/or level junctions.
- C. Segregated in road right of way except at roadway intersections which are protected by light signals with or without transit priority.
- D. Sharing right of way with pedestrians in transit malls or with other transit modes e.g., buses, and possibly with emergency vehicles and/or taxis.
- E. Sharing right of way with other road traffic.

The Toronto Subway is all category 'A'. Edmonton's northeast line is category 'B'. The majority of light rail lines of recent construction on both sides of the Atlantic are in category 'C'. Calgary's

7th Avenue Transit Mall is in category 'D'. The classic street railway or tramway line is represented by category 'E' and still may be seen extensively in Toronto, Boston, Philadelphia and San Francisco as well as in many European cities.

## 2.4 Intrusion and Accessibility

As a general rule, the more segregated L.R.T. becomes, the more difficult it is to integrate it into the community. The general standard for reasonable accessibility established for bus services is 400 meters to the nearest bus stop.<sup>5</sup> It has been amply demonstrated that a fixed guideway system will attract patrons from a larger radius so that for L.R.T. it is reasonable to postulate a catchment area perhaps half as large again around the stations. Beyond this distance it is necessary to provide feeders of some sort if the mode split potential of the area is to be realized, thus radically increasing the cost of service, and extending travel time.

Factors which militate in favour of the close integration of L.R.T. into a community, whether it be new or established, are its relative unobtrusiveness of scale and its quietness. The guideway or track occupies only the width of one traffic lane per direction no matter how much traffic it has to carry, and the external noise produced by the vehicles is considerably less than that of motor traffic even when no noise suppression measures are taken.

Intermediate stations can be very simple while those occupying nodal points can incorporate or be incorporated into multiple housing developments, local shopping plazas, community service centres, etc.<sup>6</sup>

## 2.5 Segregation from Users (Safety)

With the high level loading platforms which have been adopted in Edmonton, there is always the danger of someone accidentally falling, or being pushed onto the tracks. The relatively low speed at which the trains enter the station area together with the very efficient braking system represented by the magnetic track shoes with which L.R.T. cars are fitted make the likelihood of someone being run over from this cause quite remote. This is a known and accepted hazard common to all high platform transit systems.

Protection of the right of way is another issue. By reason of the fact that L.R.T. is powered from overhead conductors there is no live rail at or near ground level, so that the necessity for man-proof fencing along the line does not arise. By and large delineation is all that is required except in very specific areas where trespass would in fact occur in volume enough to affect operation, or where access to an area of restricted clearance such as a bridge or tunnel would be possible.<sup>7</sup>

Delineation can be carried out in many ways compatible with the surroundings of the line and acceptable to those living in the vicinity, such as trees and shrubs, hedges, ornamental fences, changes in contour etc. In cases where aesthetics are involved, open neighborhood meetings are essential before decisions are taken. Demarking features should take into consideration the action of the wind in depositing blown garbage or snow, as well as their effect on visibility for the motorman and pedestrians and vehicles nearby.

The small disturbance which L.R.T. makes to its surroundings when combined with careful landscaping makes it acceptable in sensitive areas such as packs and ravines, and indeed, the right of way itself can become a linear park. Combined with walkways and bikeways it can become a definite asset to the neighborhood which it serves in contrast to the intrusion of a high capacity roadway.

## 2.6 Change of Mode Split

The influence of transit mode on ridership is known to be significant although it cannot be measured precisely because of other influencing factors. In addition to the higher level of service offered by L.R.T. in comparison with buses, the rails themselves, (and even the overhead wires of trolley buses) give these modes an identification that has a strong psychological effect on potential passengers.<sup>2</sup> Increased ridership brings increased farebox revenues and a reduction in the need to expand the roadway network.

## 2.7 Choice of Corridor

In evaluating priorities for L.R.T. installation, the effect upon the transportation system as a whole should be assessed, taking into account such factors as avoidable roadway construction and the number of line haul buses that would be directly replaced. The ability of the existing L.R.T. network to absorb through, connecting or terminating traffic is of major importance and may, in fact, dictate the order of construction of lines entering the downtown area. A line which is, in effect, a continuation of the existing line on the opposite side of the central area may ease a difficult turn back situation, whereas another line with more traffic potential may add to the problem.

## 2.8 Extent of the Line

One of the main advantages of L.R.T. is its ability to act as its own feeder. Because L.R.T. can operate economically at comparatively low densities, bus replacement need not stop at the erstwhile terminal of mainline service, but can continue on to penetrate neighborhoods beyond in replacement of one or more feeder bus routes. Taking into account the larger catchment area of L.R.T. compared to bus service it is also possible to reduce operating mileage without sacrificing attractiveness to passengers. If the threshold for implementation is taken as 5,000 passengers per peak hour on the existing bus service, this should be applied as an average over the whole line, not over each part, so that the outer suburban portion of the line may, in fact, not reach this figure.

## 2.9 Station Location

The location of stations along the line should take into account existing passenger flow patterns. Transit centres and other transfer points are prime candidate sites. The less change in travel pattern that takes place between bus and L.R.T. the more readily the line will be accepted. It may be advantageous to revise bus routing months or even years in advance of L.R.T. in order to achieve this. Wholesale revision of neighborhood bus routes should never take place coincident with the opening of a rail extension.

### 2.10 Station Spacing

The spacing of stations has an effect on operating speed, and the more segregated the line the greater the effect, as shown in Figure 2.10.1. Arbitrary spacing of stations to achieve a target operating speed is however counter productive since it does not address patron needs. Stations should be located where they will produce most walk-in traffic and with respect to a catchment area of 400-600 metres radius. Typical station spacings for LRT are 500 metres in the downtown area and 800 metres in the suburbs.

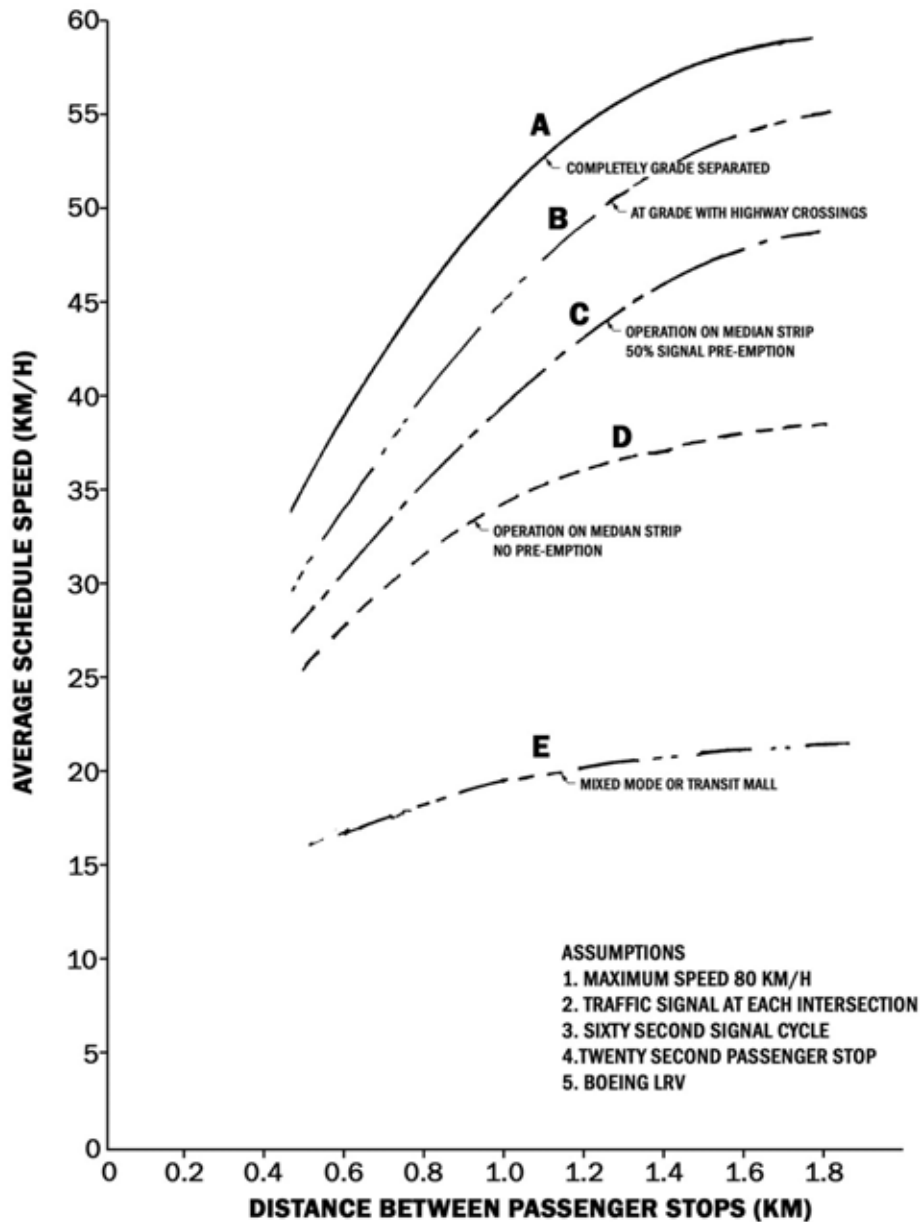


Figure 2.10.1: Relationship between average Schedule Speed and Station Spacing

### 2.11 Incremental Extension

With the basic system operating, it becomes feasible to open new lines in stages. This enables earlier use to be made of capital investment and ensures continuing media interest in the progress of the system and incidentally on the progressiveness of the city. As each station is opened, the local community is involved in a very positive manner and there is a good opportunity offered to encourage walk-in traffic at that point. Except where the line is being opened to a transit centre and bus services can be replaced, the line will not reach its traffic or economic potential, but the interim service will speed the development of that potential.

### 2.12 Downtown Distribution

As L.R.T. expands to serve the city as a whole more than one line crossing the central business district will be required. If connectivity to all parts of downtown is to be achieved, any station should be accessible from any incoming line directly or with one transfer. This might be made possible by the construction of a loop line covering the central business area in a rectangular pattern as dictated by the street grid, around which each train would pass covering at least two sides of the rectangle. The station catchment areas from two opposite sides of the loop should overlap for complete coverage of the area in between, as shown in Figure 2.12.1.

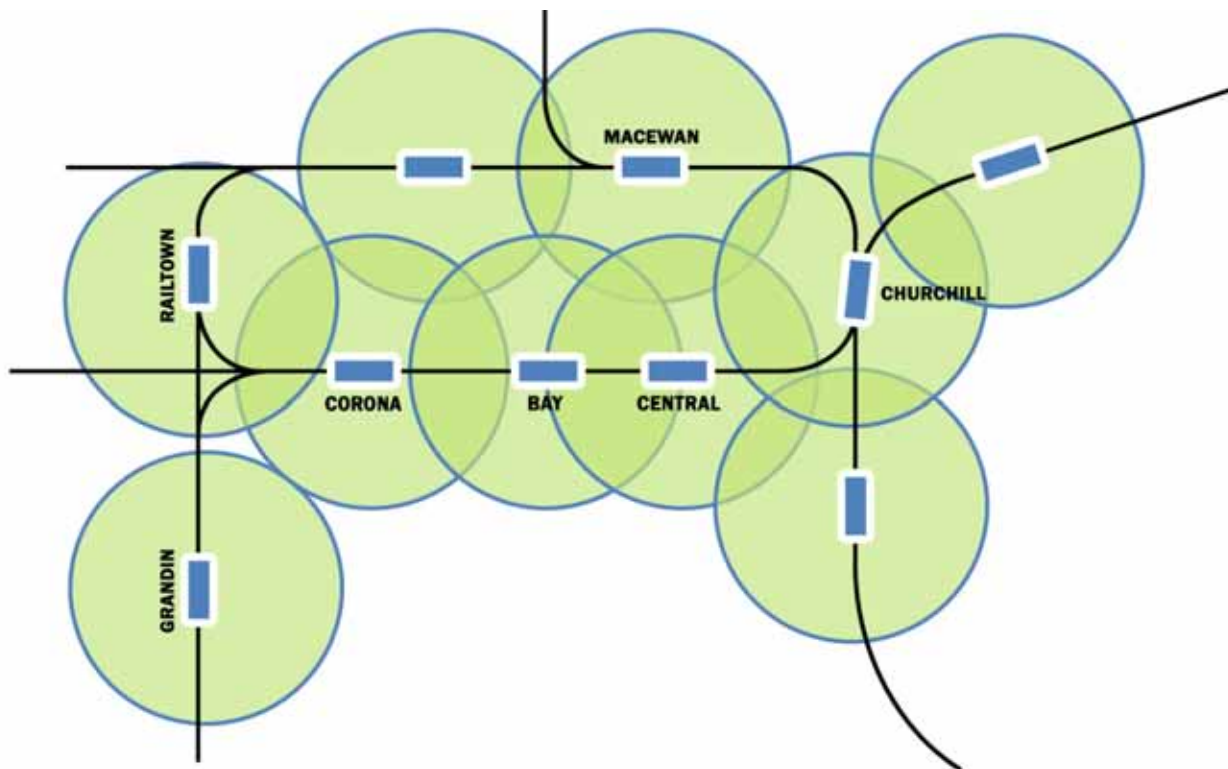


Figure 2.12.1: Complete coverage of the Downtown area is assured by overlapping station catchment areas

### 2.13 Labour Savings

Labour represents some 80 percent of the cost of operating public transit and increasing labour output is the key to reducing this cost. The average output per transit worker in passenger miles per worker per year is influenced by the passenger occupancy of the vehicles, operating speed, volume of service and by the manning of stations and vehicles. A labour requirement model developed to respond to these factors shows that in a typical North American context L.R.T. can attain lower labour costs than urban buses operating at 19 km/h with the same or even less passengers. To attain lower labour costs than express buses operating in the 32-40 km/h range, L.R.T. must carry twice the number of passengers. Fully manned stations can only be provided at about three times the threshold of existing service. Whereas doubling the service on a bus line doubles the labour cost, in the case of L.R.T. the increase is only 0.7<sup>3</sup>.

### 2.14 Energy Savings

On a per passenger basis in gross fuel terms, buses, trolley buses, and L.R.T. are about equal in consuming about one third of the fuel requirements for an automobile in urban use (12 miles per gallon).

### 2.15 Reduction in Pollution

The production of pollutants at the vehicle in the case of L.R.T. is virtually nil compared with a diesel bus, while the emissions attributable to the production of electricity in a fixed generating station can be much more strictly controlled. Much of Edmonton's electricity is produced from natural gas which produces very small amounts of noxious material, while modern coal-fired stations both in use and under development are equipped with efficient electro-static precipitators to prevent solid particles being discharged into the air. The use of electricity for transportation purposes contributes greatly to the liveability of the city, especially in the downtown area.

## 3.0 Transportation System Requirements

In order to determine facility requirements it is necessary to establish a credible estimate of the capacity of L.R.T. under various restraints imposed by design and operating limitations.

### 3.1 The DuWag R.T.E.1 Car

This is the present standard vehicle on the Edmonton system, the fleet consisting of 37 such cars all identical from an operating point of view. These are duplex articulated vehicles, having six axles mounted in three swivel trucks or bogies carrying two body sections joined by an articulating connection allowing full passenger flow between the two sections of the body. (Figure 3.1.1)

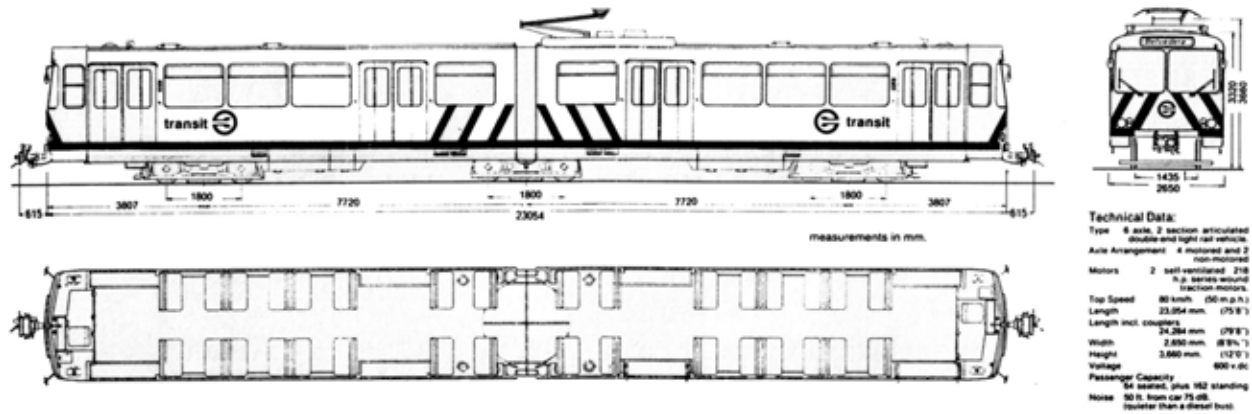


Figure 3.1.1: Edmonton R.T.E.1 type car (DuWag U.2. design)

Seating is provided for 64 passengers with standing capacity for 162 based on eight passengers per square metre, for a total load of 226. While crush loads in the vicinity of 300 have been noted in football take-away situations, this is not a useful measure of capacity except as a vindication of the use of eight passengers per square metre to measure crush loadings. For a figure which could be sustained throughout the period of peak loading and allow for uneven distribution throughout the train due to platform design factors, 75% of total loading can be assumed, that is 170 passengers per car for the existing Edmonton fleet.

Many European L.R.T. systems have adopted triplex articulated vehicles by adding a centre section to their original vehicles making them eight axle, three section vehicles with correspondingly increased capacity. This additional capacity is obtained at lower cost per seat than adding more six axle cars and advantage has been taken of the larger vehicle to operate single cars at periods of reduced demand without sacrificing passenger security. In Edmonton's case the extended cars would raise the design capacity from 170 to 240 that is by 41%. (Figure 3.1.2)

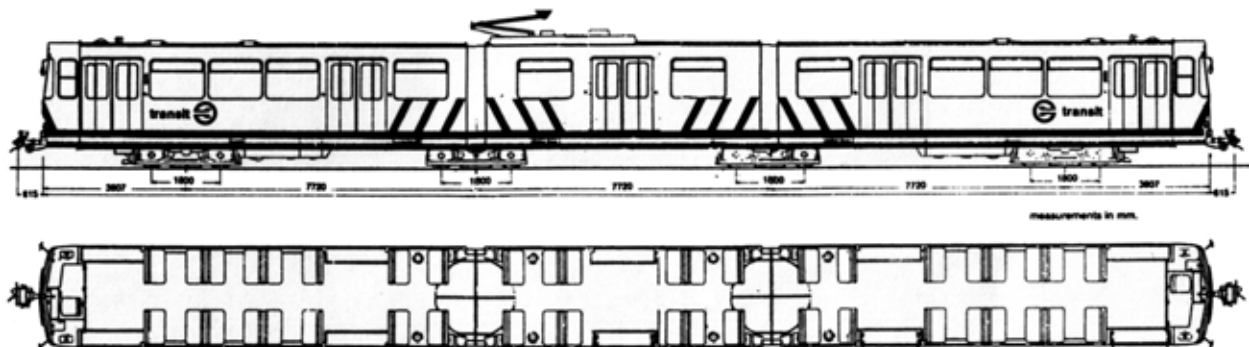


Figure 3.1.2: Modification of U.2. type car with centre section

### 3.2 Line Capacity

Trains are limited in length to five of the present cars, so that the capacity of a train is 850 passengers.

The frequency of trains is limited by the signalling system which imposes a physical (distance) separation between trains, and by the need to avoid or minimize delay to intersecting traffic.

On category 'A' lines, the latter factor does not apply and train intervals are governed by the relationship between operating speed and block length. With tested systems presently available, the practical minimum interval between trains is 90 seconds or 40 trains per hour, giving a potential capacity in Edmonton's case of 34,000 passengers per hour per direction.

Given a real-time computer interface with crossing controls based on schedule times for minimum mutual interference between L.R.T. trains and intersecting traffic, category 'B' lines, such as Edmonton's northeast surface section could be signalled to allow a headway of 150 seconds, giving a capacity of 24 trains per hour or 20,000 passengers per hour per direction.

Rights of way of categories 'C', 'D', and 'E' are not normally signalled by train interval, however they are usually constrained by signals on intersecting roadways with cycle times of up to 150 seconds. Because of the fact that stations, which can handle only one train, are likely to be situated in close proximity to intersections, it is not possible for more than one train to proceed per cycle which in some cases might limit headways to 150 seconds and capacity to 20,000 passengers per hour per direction.

From the above it can be seen that, for all practical purposes the maximum capacity of L.R.T. in Edmonton is in the range of 20,000 passengers per hour per direction.

The population density which exists in Edmonton or could ever be achieved will not demand capacities beyond this range from a single line without requiring extensive bus feeders which defeats the purpose of selecting L.R.T. over alternate modes.

### 3.3 Station Dwell Times

With a crush loaded vehicle, the maximum number of passengers exiting from a single door is 43. On a crowded station platform, boarding passengers tend to distribute themselves evenly and then move to another door if a heavy exit movement tends to delay their boarding. For a complete full load off-full load on cycle, this would give a maximum of about 72 movements per door, at 3 movements per second, this would require 24 seconds plus door cycling time of 6 seconds = 30 seconds. The highly unlikely factor of a smooth on-off movement taking place, for whatever reason, is balanced by the equally unlikely factor of 100 percent on, 100 percent off movement taking place at the same station. For timetable purposes then it is customary to use 15 to 30 seconds dwell time depending on the particular station and time of day. Special allowance has to be made for sporting events because of heavy loadings and patrons unfamiliar with the system preventing doors from closing.



### 3.4 Speed-Time Curve

The speed-time curve considers the operation of trains between stations without constraints other than the performance limitations of the vehicle themselves. It represents a maximum performance which must be modified to take account of operating restraints inherent in system design (gradients, curves, etc.) and restrictions added to enhance safety. Its main purpose is to show where the system is self-limiting and also to avoid over-laying safety controls to the detriment of system operation. (Figure 3.4.1)

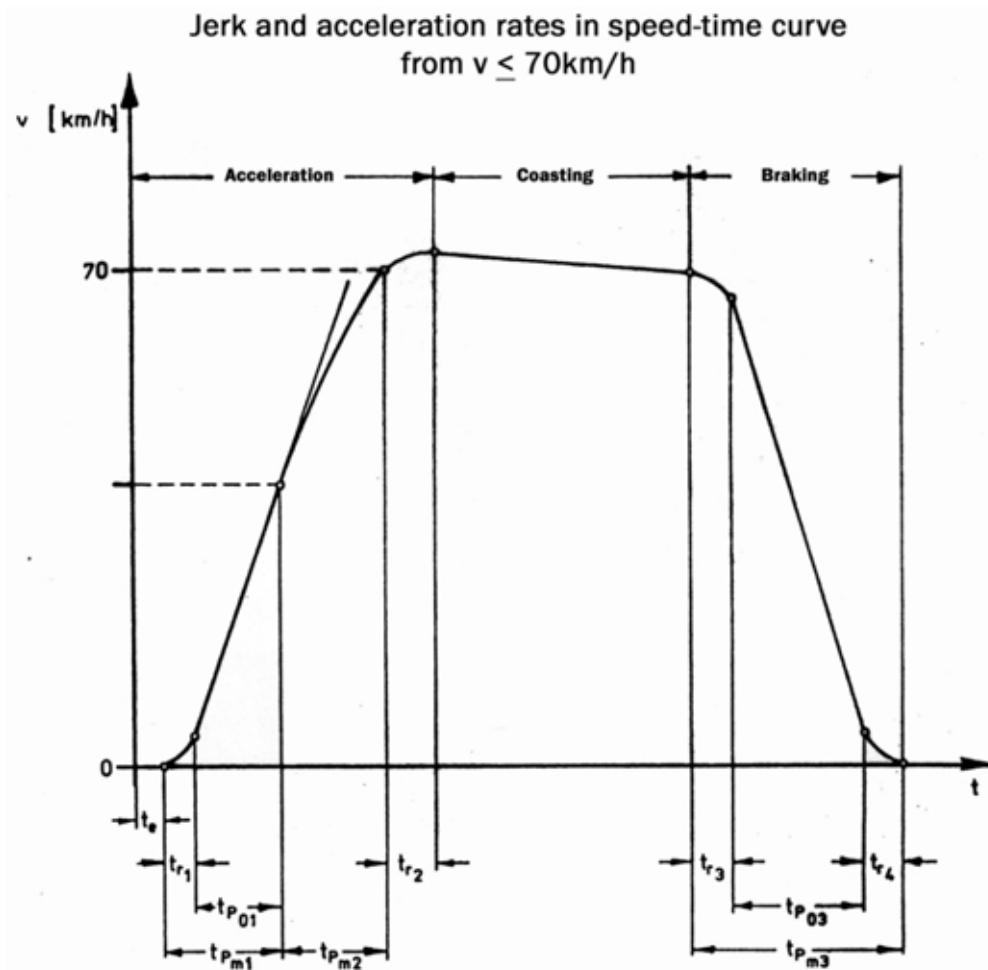


Figure 3.4.1: Typical speed-time curve

The DuWag R.T.E.1 car has an average service acceleration and braking rate of  $1.32 \text{ metres/sec}^2$  and a top speed of 80 km/h. Top speed is reached from a standing start in 18 seconds or 190 metres and service braking is accomplished in the same time/distance. To achieve this performance requires that lineside indicators be erected to indicate braking points. This can be done by use of advance speed limiting signs ahead of the speed enforcement area.

It also requires that trains enter the stations at a speed of about 60 km/h. Observation of Toronto operation indicates that there is no apparent safety hazard in operating at this speed in platform areas and this is further borne out by the practice of PATCO trains operating non-stop through stations at speeds in excess of 100 km/h.

### **3.5 Permitted Speeds vs. Achievable Speeds**

Permissible speeds over any section of the line are calculated on the basis of safety, where restricted stopping distances are involved; protection of equipment through complex track and overhead work; and in the case of curves on the basis of passenger comfort. These calculations are made on a conservative basis, so that the calculated speed is one that is in fact consistently acceptable from a standpoint of safety. If the calculated speed is enforced by means of train stops, it ceases to be achievable because the motorman will not approach at the posted limit in case he receives a penalty stop. Train stops then should be set 5 km above the posted speed in all cases so that the permitted speeds become achievable speeds and the full operating potential of the line is available and achievable.

## **4.0 Transit Operational Requirements**

Operation of a rail transit system differs markedly from bus operation. The most obvious difference lies in the fact that the rail system provides its own guideway and has some control of the design of its facilities, whereas a bus transit system has to fit its service into pre-existing roads whose design parameters are already set. The rail system however does not start with a clean sheet, and if it is to maximize its cost effectiveness it must be designed to optimum operating standards bearing in mind the convenience of the passengers and the limitations imposed by cost and by interface with its surroundings. The engineering factors are therefore much more complex than those involved in freeway design, and require intelligent compromise and adaptation; they must recognize that operating requirements are paramount in the design of a successful rail system.

### **4.1 Peak Hour Capacity**

As discussed in Section 3, the maximum practical capacity of an L.R.T. line is 24 trains per hour. A typical Edmonton mainline in 1983 is served by 40 buses per peak hour and will be carrying 2,500 passengers. Experience with the northeast line has shown that a 50 percent increase in ridership can be expected within months of L.R.T. opening, requiring the operation of two-car trains at 5 minute intervals or three-car trains at 7 1/2 minute intervals. Based on a possible increase to 5-car trains, either alternative provides adequate accommodation for growth; the choice will depend on how traffic is to be handled in the downtown area.

### **4.2 Multi-Line Operation**

As bus traffic converges on the city centre it is funnelled into a few main thoroughfares where peak volumes rise to almost 80 buses per hour, equivalent to 5,000 passengers per hour which would be expected to increase to 7,500 passengers per hour if the buses were replaced by L.R.T. With a 2 1/2 minute service, two-car trains would handle this volume of traffic adequately,

allowing two branches with 5 minute headways, or 3 branches with 7 1/2 minute frequency to be fed into one line through the C.B.D.

If the downtown section were to conform to the requirements for a category 'A' line and was signaled for 90 seconds headway, three branches with 5 minute headways or 5 branches with 7 1/2 minute headways could be accommodated, in theory. However there are practical limitations to handling a station through-put upwards of 30,000 per hour on a consistent basis and again the 2 1/2 minute headway remains the most practical. The purpose of designing the signal system for train intervals of 90 seconds is to allow recovery from unexpected operational problems in the critical downtown area.

### 4.3 Trains Terminating (Reversing) in the C.B.D.

It has been the practice in Edmonton to terminate many bus routes in the downtown area due to imbalance of loading; this is not generally the case with mainline services and should be avoided as far as possible with L.R.T.

With bi-directional operation the reversal process consists of discharging passengers, changing operating ends, loading passengers, and switching to the other track over a crossover. The length of time which is required to do these things, the coordination of action between the operator and central control and the necessity of tying up both directions of line while the crossover movement is being made make it impractical to schedule reverse movements anywhere but at a terminus where in effect the train is protected from opposing movements.

One solution can be found in the provision of a bay platform between the through tracks (Figure 4.3.1) where the train can stand clear of other traffic until it is ready to depart in the reverse direction. A disadvantage of this particular arrangement is that it takes up to twice the length of a normal station. Figure 4.3.2 is another arrangement with two separate platforms one of which serves both the downtown main line and the layover spur, while the other one serves outbound traffic only. One advantage here is that the spur can be made long enough to store more than one train.



Figure 4.3.1: Bay platform for short-turning trains



Figure 4.3.2: Intermediate terminal with split platforms

The more universal solution lies in the creation of a downtown loop whereby all trains become through trains even though they depart by the same line on which they entered the C.B.D. In effect the train is turned around rather than reversed. The idea of a downtown loop as an aid to connectivity is discussed in Section 2.12.

#### 4.4 Special Event Service

Special event services are operated to cater to demands which are outside the normal cyclical fluctuation of demand of a transit system. They may be generated by sports events, concerts and various types of festivals. Some are very predictable and focused, such as football matches at the Stadium, while others are heavily weather-dependent and dispersed in venue, such as Heritage Days and Klondike Days. Due to parking restrictions in the Stadium area, Edmonton Transit has provided a very extensive park and ride operation for football matches. Of recent years the burden of this operation has fallen more and more on the L.R.T. as bus fares have been increased beyond limits acceptable to the public. At the present time L.R.T. is carrying about 25% of the gate at these matches, a figure which is likely to rise considerably as the rail system is extended to the south side. If crowds are to be successfully handled, provision will have to be made for trains to be laid over in the vicinity of the Stadium and called in as necessary to supplement regular service. (Figure 4.4.1)

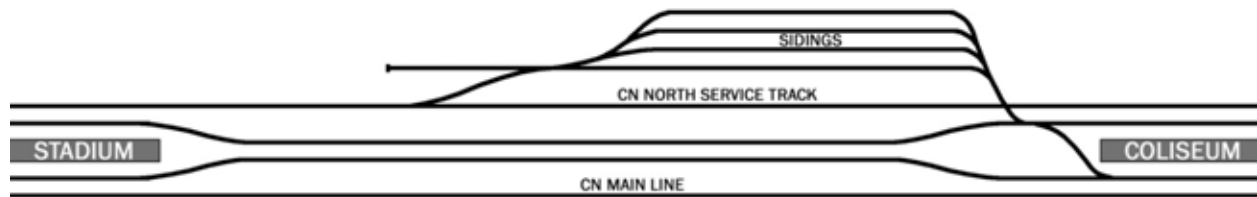


Figure 4.4.1: Sidings for special events trains

The flexibility in train length and the extreme crush load possibilities of L.R.T. make the handling of other types of special event particularly easy and cost-effective when compared to using buses.

#### 4.5 Off-Peak Storage of Equipment

The increase of capacity needed to cover peak hour loads can be achieved in one or both of two ways; by increasing the number of trains in service, so as to decrease headways, or by increasing train length. In either case the necessary rolling stock must be held on a siding convenient to where it can enter service and convenient for crewing purposes. If additional cars are to be added to the train there is no necessity for extra crewing, but if trains are entering service it is usually more cost effective to have them start from a point where crew changeover usually takes place. In the normal course of scheduling, full peak service is built up from the outlying end of the line and should come out of service downtown, with the reverse taking place for the evening peak. This would indicate that trains should be laid over close to downtown (see also Section 4.3).

## 4.6 Interference with Other Modes

The use of anything but a completely segregated right of way necessitates some mutual interference with other traffic modes. The severity of this interference can be mitigated by careful consideration of the factors in each case. The use of overhead conductors, which is virtually universal on L.R.T. systems, eliminates the danger from rail-level conductor systems. The possibility of interference with high loads should be addressed by keeping conductor height well above legal limits as well as by providing ample warning signs and tell-tales.

Where trolleybus lines cross, the trolleybus positive and negative wires are carried in gaps in the L.R.T. conductor at a slightly higher elevation so that there is no danger of contact or arcing over from the outer ends of the pantograph shoes in case of wire sag. The pantograph is carried across these gaps, without breaking contact, by means of outrigger bars. If the intersection between the L.R.T. and a crossing trolley route is at right angles, the actual crossing has to be made at an angle of at least 18° to the normal in order to carry the pantograph across the gaps through which the trolley shoes pass. Due to the flexibility of the trolleybus collectors, this can be achieved without significant degradation of performance beyond that normal for a crossing.

Separation of traffic movements can be accomplished by physical barriers such as are used on regular rail crossings or by regular traffic signals. The use of barriers is usually confined to lines in or adjacent to railway rights of way, such as Edmonton's northeast line, due to their complexity, cost of installation and upkeep, and long cycle times. It has also been suggested that public unfamiliarity with this type of crossing is a contributing factor in vehicle-train collisions.

## 4.7 Crew Facilities

Dispatch offices are maintained at the main car storage locations. These facilities include accommodation for the dispatcher together with telephone facilities so that motormen and dispatchers can communicate with each other to ensure that trains are properly manned. Lounge facilities and washrooms are provided to the same standard as for a garage.

Crew washrooms should be provided at each terminal, at all turnback points and at any other station where crews may be changed. In addition to the actual washrooms a lounge area should be provided where crew members can await their departure times and where time boards can be picked up and dropped off. Each crew lounge should have a notice board for operational bulletins and a telephone restricted to local calls only. All these facilities should be secured against access by unauthorized persons and keyed to the common "washroom key" issued to operating staff.

## 4.8 Train Control (Signalling)

The safety, speed, capacity and productivity of transit systems are highly dependent on the vehicle control method. Generally control methods can be grouped into three categories: manual/visual where the driver controls the vehicle without any assistance; manual/signals, where manual control is assisted by automatic signals showing occupancy of the track ahead

(automatic train protection), and automatic train operation in which the driver merely initiates an automatic driving process.<sup>2</sup>

Automatic Train Operation (A.T.O.) is only possible in a fully protected right of way and is therefore not applicable to L.R.T. In fact the primary control mode of an L.R.T. system is manual/visual: the driver must be fully in control of his train at all times and prepared to stop for an obstruction such as, for instance, a vehicle stalled on a grade crossing. This is the reason for the magnetic track brakes which are one of the features distinguishing L.R.T. from heavy rail vehicles. The need for the driver to concentrate upon the track ahead also militates against the use of cab signals on any but category 'A' right of way.

The purpose of signals is to give advance information, as it were extending the driver's perception of approaching conditions, or to relay commands based on an interpretation of conditions in order to increase safety. Signal protection is required in the following areas:

- (a) Against rear-end collisions with stopped or slow-moving trains.
- (b) Against conflicting movements at cross-overs and junctions.
- (c) Against conflicting movements at highway crossings.

Protection against rear-end collision is obtained by dividing the line into "blocks" or sections which can only be occupied by one train at a time. Each block overlaps the next by a distance equal to the braking distance of a train so that adequate protection is afforded to a train coming to rest just past a signal. In order to enforce compliance with a restrictive indication, magnetic train stops are employed to initiate braking and bring the train to a stand within safe limits.

The division of an L.R.T. line into blocks is usually based on station to station distances. Additional blocks may have to be added in order to achieve the necessary headway between trains. Block length should be such that a train travelling at schedule speed can clear it in a time equal to one half to two thirds of the minimum design headway.

The signals protecting against conflicting movements at cross-overs and junctions, known as interlocking signals, may also function as block signals.

The indication given by the two-aspect signal system are red for "stop" and green indicating "line clear". An amber indication is used for some form of restriction or caution.

In the design of any signalling system it is essential to protect the integrity of command. If red means "stop" it must always mean "stop"; it should never be the practice to run at a red signal expecting that it will change. A case in point are signals at barrier-equipped highway crossings which indicate to a train entering the call-on circuit that the gate relay has dropped. The restrictive indication observed must be other than red if the driver is to approach considering that it will change to a less restrictive aspect before he passes it.

"Lunar white" indications are used in combination with other signals to indicate facing switches set for a movement other than the mainline.

Train detection may follow the mainline railway practice of continuous monitoring by means of track circuits. In L.R.T. practice this has the disadvantage that a train may "disappear" due to a build-up of sand on the rail head causing signal malfunction and consequent delay to service. The alternative is to provide overhead contacts which cause the signal relays to drop as a train enters the block and which will only re-energize them when it leaves the block. This system is and has been used on many electric transit systems without problems. Objections to its use are derived from mainline railway conditions which do not apply to L.R.T., for example broken rail detection. The consequences of a broken rail on L.R.T. are minor and do not lead to the serious results which can follow on main line railways with their heavy axle loads.

### 4.9 Speed Control

On the highway, speed restrictions are indicated by signs and enforced by threat of fine. Their purpose is basically to force some uniformity on to a heterogeneous mass of vehicles of vastly different performance capabilities driven by persons of vastly different skills. On an L.R.T. system the vehicles have uniform capabilities and drivers are uniformly trained: speeds are limited by the characteristics of car motors designed for optimum performance at low speeds, and by the comfort of passengers. Given a signalling system enforced by train stops the need for additional speed restriction enforcement is quite minor. The driver's position at the leading extremity of the vehicle well outside of the wheelbase means that he experiences lateral acceleration several times greater than his passengers and it is this fact rather than any speed-limiting legislation which has kept streetcars on their tracks for the past hundred years.

For the most part, speed restriction signs advising the driver of the maximum comfortable speed for his passengers are sufficient except in cases where braking distances are restricted on a signal approach, or where there is a risk of damage to equipment such as a sharp change in elevation of the overhead wire. In these cases it is advisable to use a magnetic train stop activated by a wheel detector or trolley contact or a photo-electric cell in advance, and having a time delay corresponding to the required speed. Where this is used in conjunction with a warning sign, the sign should indicate 2 to 5 km/h less than the speed which will enforce a stop to allow for inaccuracy in car speedometers.

### 4.10 Radio

The first line of contact between Central Control and all persons on the L.R.T. system is by radio. Unlike the bus system where each unit is more or less independent and in the case of trouble can be pulled off to the side, each train on the L.R.T. affects all the others. It is essential that every person on the system is aware of what is happening, so that one channel is used for all operating messages. As the system expands a second operating channel may be required corresponding to a second controller, however the central area must be under the control of one person with all operating messages heard by all trains.

An independent channel is used for maintenance, security and non-operating messages.

Contact is maintained in the tunnel areas by means of a leaky co-axial cable strung throughout, while on the surface relay stations are used.

Radios may be built into the trains, however this requires two radios per vehicle which means that each radio is used 15 to 20 percent of the vehicle operating time. Using portable radios only one radio is required per operator and contact is maintained even when he leaves the vehicle. Each cab must, however, still be provided with a charging receptacle connected to the vehicle antenna and to a hand-held or flex-mount microphone.

#### 4.11 Right of Way Telephones

Before the advent of portable radios it was necessary to mount lineside telephones at interlockings, grade crossings and at intervals along the right of way to facilitate quick communication with Control in an emergent situation. Telephones are enclosed in locked weatherproof boxes and keys are issued to operating staff and maintenance personnel. There is no doubt that they are useful in reducing radio traffic but their overall utility is low compared with the cost of installation. The fact that they are locked to prevent vandalism also precludes their use by the public in an emergency.

#### 4.12 Emergency Telephones

Chiefly to enable patrons to summon help in case of emergencies in unmanned areas, red emergency telephones are provided, prominently signed, in easily-opened enclosures. On picking up the handset the phone automatically rings straight through to Control. The location is known to the controller by an illuminated button on his console.

### 5.0 Alignment Geometry

The parameters for route alignment must take into consideration two opposing needs, the need to provide swift high capacity service and the need to keep costs within reasonable limits. One of the reasons for choosing L.R.T. is that it can perform very well in rights of way which would be marginal for full metro operation. Every square metre of land which is not appropriated for L.R.T. use and every cubic metre of dirt which does not have to be moved contributes to the cost-effectiveness of the system. The design standards recommended therefore are the lowest which are thought to be consistent with safe operation. Any arbitrary increase in these standards must be weighed against the construction cost and the cost or benefit to operations and maintenance in the long term.

#### 5.1 Design Vehicle

Right of way requirements can be based upon the existing system rolling stock or upon some theoretical ideal vehicle which may be purchased at some time in the future. As the system grows the likelihood of such a change becomes less and less, and in fact, there is no record of such a change ever having taken place among existing transit systems. The width of Edmonton's rolling stock is 2.65 m, a dimension which has been widely adopted for heavier L.R.T. systems in Europe; this dimension is the same as L.R.T. and rapid transit systems in Frankfurt, Berlin, Hamburg, New York (I.R.T. and P.A.T.H), and Rotterdam and is wider than heavy rapid transit in



London, Paris, Montreal and Mexico City. The advantage to be gained by a change to (say) Toronto dimensions is small when compared to the cost and disruption which would be involved.

The present DuWag R.T.E. 1 car is therefore used to determine guideway geometry and structure clearances.

## 5.2 Structure Clearances

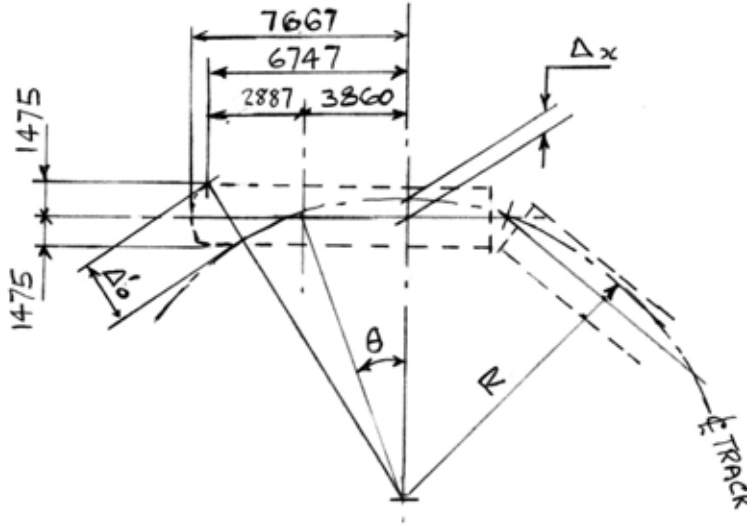
The distance from track centre lines to adjacent structures and to other tracks is determined by establishing the "dynamic profile" of the vehicle. The dynamic profile allows for the maximum possible displacement of the car body due to gravity, loading, wear, lateral shocks and wind pressure. In practical terms there are two critical displacements affecting horizontal clearances, those due to rotation in a vertical plane caused by horizontal and vertical loads and those due to rotation in a horizontal plane caused by the "hunting" motion of the vehicle as it proceeds along the track. These displacements are at their maximum at body eave level at a point ahead of the front truck centre where the end taper begins.

The maximum displacement for the U.2 type of car is given by DuWag as 142 mm for an overloaded car driving into a curve at maximum design speed with a side wind pressure of  $400 \text{ N/m}^2$ <sup>14</sup>. It therefore seems to be prudent to adopt the same standards as the Frankfurt Transit Undertaking i.e., 150 mm plus 75 mm construction tolerance over the total height of the vehicle, as recommended by Siemens<sup>15</sup>.

This gives a tangent track structure clearance of 1550 mm from centre line of track, double track centres of 3100 mm with no structures between and 3500 mm where there are centre poles. The clearance to station platform edges can be reduced because of the reduced speed of trains and is recommended to be 80 mm from car side or 1405 mm from centre line of track with a construction tolerance of  $\pm 20$  mm. Note that track in station areas must be secured against lateral movement towards the platform face. Curved platforms have a minimum radius of 500 m and the clearance is increased to 120 mm i.e., 1445 mm from centre line of track  $\pm 20$  mm. Note that track in platform areas is not superelevated.

Additional clearance must be allowed on curves for the outswing of the car ends, the inswing of the body between the trucks and the increased cant due to superelevation (Figure 5.2.1). In order to fit the best curve into the least space, L.R.T. curves consist mainly of parabolic spirals, rather than being largely constant radius which means that clearances are changing throughout, thus to avoid arbitrary assumption of figures which might lead to over design, clearances should be calculated as part of the design of each curve taking consideration of the maximum speed achievable under operating conditions and the design superelevation as well as the curve radius.

The minimum structure clearances discussed above do not take into consideration personnel access or space for the accommodation of installations such as signs and signals or for cable and utility runs.



$\Delta_x$  = INSWING AT MIDPOINT BETWEEN TRUCKS

$\Delta_0$  = OUTSWING OF END OF VEHICLE

$$\theta = \text{ARC SIN} \left( \frac{3860}{R} \right) \text{ ----- (1)}$$

$$\Delta_x = R (1 - \text{COS } \theta) \text{ ----- (2)}$$

$$\Delta'_0 = \sqrt{[R - \Delta_x + 1475]^2 + (6747)^2} - R \text{ --- (3)}$$

$$\Delta_0 = (\Delta'_0 - 1475) \text{ ----- (4)}$$

CALCULATION OF  $\Delta_0$  &  $\Delta_x$



$$\alpha_{S.E.} = \text{ARC TAN} \left( \frac{\text{S.E.}}{\text{TRACK GAUGE}} \right)$$

S.E. = SUPER ELEVATION

$$W_0 = 1475 (\text{COS } \alpha_{S.E.})$$

$$W_x = (3200 \text{ TAN } \alpha_{S.E.} + 1475) \text{ COS } \alpha_{S.E.}$$

$W_0$  = REDUCED VEHICLE WIDTH DUE TO S.E.

$W_x$  = INCREASED VEHICLE WIDTH DUE TO S.E.

CALCULATION OF  $W_0$  &  $W_x$

Figure 5.2.1: Outswing and inswing of vehicle on curve

The first consideration is for a continuous safety refuge to be provided to the right of the track in the direction of current of traffic of 600 mm minimum width. Note that this space may be occupied intermittently along its length by signal heads or sign boards as long as this does not interfere with its use as a refuge. This refuge should be provided with a reasonably smooth firm footing, such as concrete or steel grating free of tripping hazards and should provide a vertical clearance of 2500 mm. It is preferable for this walk to be at or above rail level, but not high enough to interfere with access to the undercarriage of vehicles.

On the off-side of each track a continuous clear space of 125 mm must be allowed for piping and cable runs. In order to avoid unnecessary crossing over and other types of interference, services should be generously spaced vertically with fire protection pipes at the bottom followed by telephone, signals, lighting, traction power and radio antenna in consistent order.

Vertical structure clearance should be 500 mm above the lowest working elevation of the pantograph, that is 4550 mm. Note that it may be necessary to increase the vertical structural clearance in order to avoid abrupt changes in wire height that may impose operating restraints.

### 5.3 Curve Radii

The trucks and bearing plates for the R.T.E. 1 are common to several other DuWag products and do not limit the turning radius of the vehicle. The limit is determined by the design of the car body parts in the vicinity of the articulation. As the angular displacement of the adjacent body sections increases, they come closer together on the inside of the curve and will eventually foul, causing body damage. On level track this occurs at a radius of slightly less than 25 metres to the centre line of track when the vehicle is unloaded. The minimum recommended curve for use in a yard with no superelevation is 25 metres. With a passenger load and the possibility that the track may be superelevated, the minimum recommended radius on a running line is 35 metres. For mainline track, the desirable minimum radius is 300 metres. Radii less than 300 metres may be used as required and dictated by topography, permanent physical features or other restraints on alignment. In order to keep the platform gap within acceptable limits, tracks through stations may not have a radius of less than 500 metres.

Spiral transition curves are used to connect all circular curves less than 1750 metres radius to the tangent except in yard and shop areas or where operating speeds are restricted.

A minimum tangent length of 15 metres is required between reverse curves in order to allow coupling of cars to take place. This does not apply in yards and in the vicinity of switches and crossings.

### 5.4 Superelevation

Superelevation is achieved by raising the elevation of the outer rail according to the general formula:

$$S = \frac{11.8V^2}{R} - 150 \text{ mm}$$

where  $S$  = superelevation in mm,  $V$  = velocity in km/h and  $R$  = curve radius in metres; to a maximum of 165 mm.

For reasons of passenger comfort and safety from interior accidents, the German regulations for light rail installations specify a maximum lateral acceleration of  $1.0 \text{ m/sec}^2$  which is taken into account in the above formula.

Where circular curves are used in lieu of spiral transition curves, superelevation is run off at a rate of 30 mm per second for the design velocity of the curve. Run-off is located equally on either side of the point of curvature.

## 5.5 Gradients

The maximum recommended gradient for the Edmonton car is 5.5% based on the performance of the disc brakes. The car will start and accelerate on a gradient of 7.5% and can be controlled on that gradient by dynamic and track brakes. It is recommended that the 5.5% maximum not be exceeded for distances of more than 125 metres.

Gradients through stations should be set at 0.3% for drainage purposes and in any case should not exceed 1.0% to avoid affecting architectural features and vehicle performance.

All changes in grade shall be connected by parabolic vertical curves. The length of the vertical curve shall be 60 metres or twenty times the algebraic difference in gradient. The minimum length of constant gradient between vertical curves shall be 15 metres.

## 5.6 Alignment Control

The horizontal control for all alignments shall be based on the Alberta Survey Control grid at sea level, and all intersection points shall be coordinated to the grid.

The reference line shall consist of tangent lines and shall be stationed with an independent chainage system.

Changes in direction of the reference line shall be noted at all points in intersection and shall be indicated by bearings based on the grid system.

All intersection points and intermediate points on the reference line shall be referenced to permanent monuments to be located clear of any proposed construction.

Reference line chainage equations shall be noted at each point in intersection to compensate for reference line curve distances.

Reference line chainage shall be shown to the third place of decimal and angles to the nearest second.

All construction details shall be related to or dimensioned from the reference line.

The vertical control for all alignments shall be based on benchmarks established by the City of Edmonton or the Government of Alberta or Canada. All elevations shall be to Geodetic Datum.

The reference line distance shall be used to develop the profile grade which shall represent the elevation of the top of rail. In the case of superelevated track, the profile grade shall represent the elevation of the top of the lower rail.

### 5.7 Typical Rights-of-Way

The flexibility of L.R.T. makes it possible to utilize a large variety of right of way locations and configurations, below ground, at grade, or elevated. Its ability to traverse sharp curves and steep gradients facilitates the use of existing rights of way paralleling traffic arteries and allows close adherence to established desire patterns.

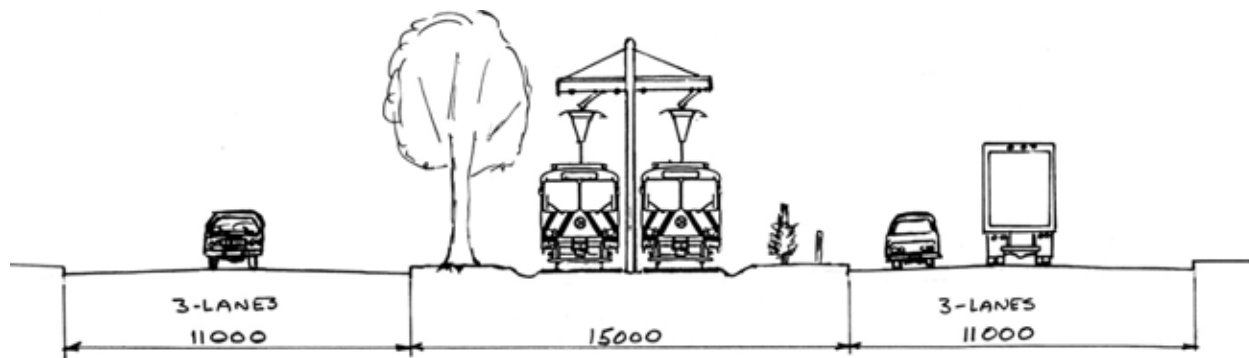


Figure 5.7.1: L.R.T. in arterial median with landscaping buffer

Figure 5.7.1 shows a cross-section of L.R.T. in an arterial median of 15 metres width showing various forms of landscape buffering, trees, shrubs and a low post and chain fence. This width of median allows for station platforms without deviating from a straight alignment for the track.

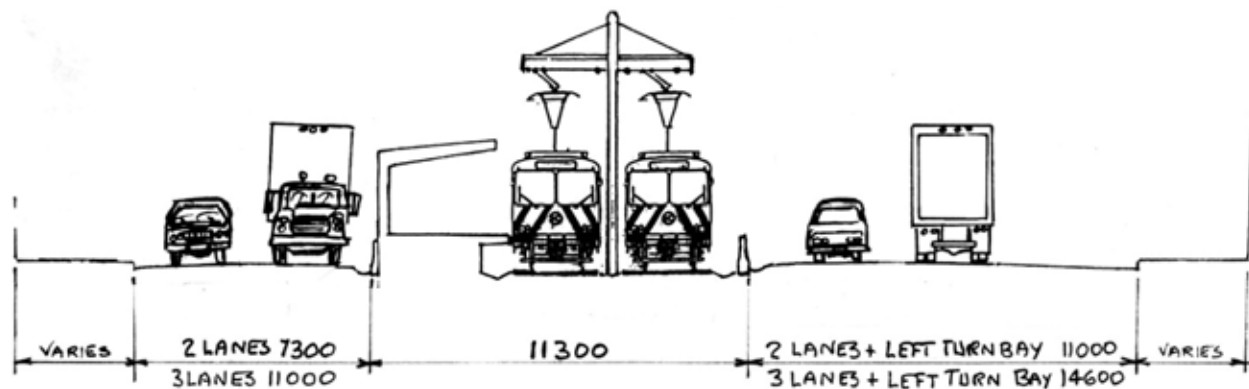


Figure 5.7.2: L.R.T. in arterial median at station far side of intersection with bay for left turn traffic

Figure 5.7.2 shows a far-side station platform and a left turn lane within the original 15 metre right of way. The L.R.T. is protected from side-swipe by traffic in the left lane by a New Jersey barrier.

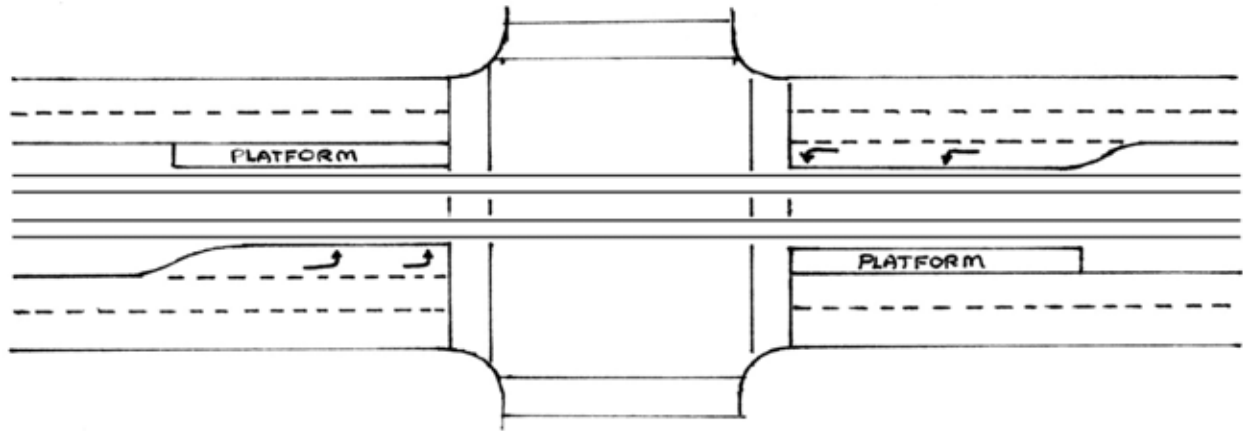


Figure 5.7.3: L.R.T. station in median with far-side platforms

Figure 5.7.3 is a plan view of an intersection with far-side platforms.

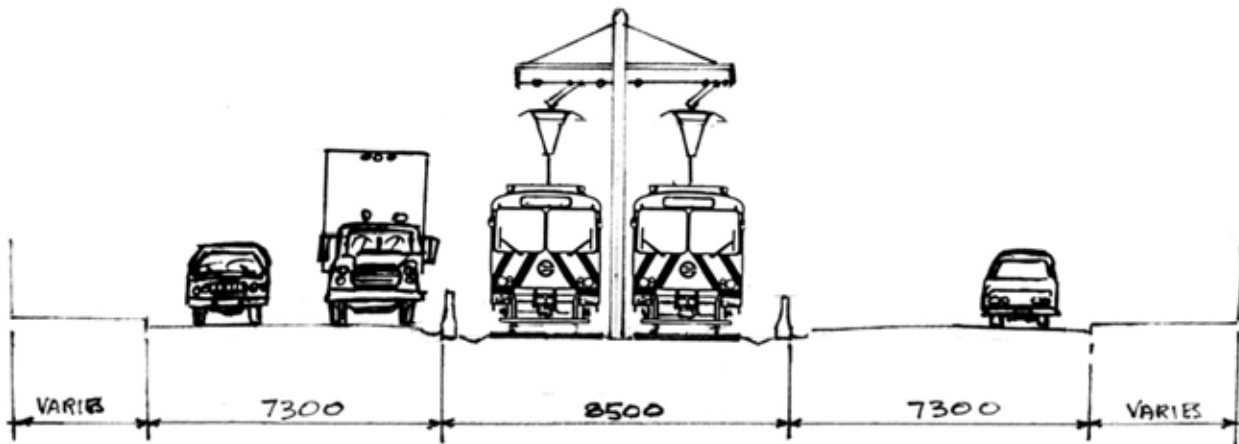


Figure 5.7.4: L.R.T. in restricted median with New Jersey barriers

The track in Figure 5.7.4 is protected both sides by New Jersey barriers on account of its extremely narrow, 8.5 metre width. This would only be possible for short stretches since there is no room for station platforms.

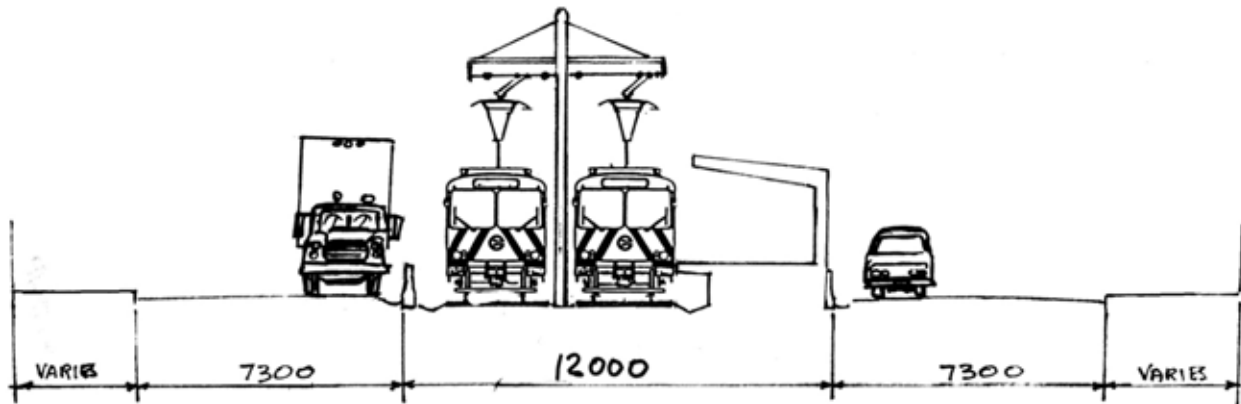


Figure 5.7.5: L.R.T. in median at near side station. Left turns prohibited

Figure 5.7.5 is a section at a near side station in a median 12 metres wide.

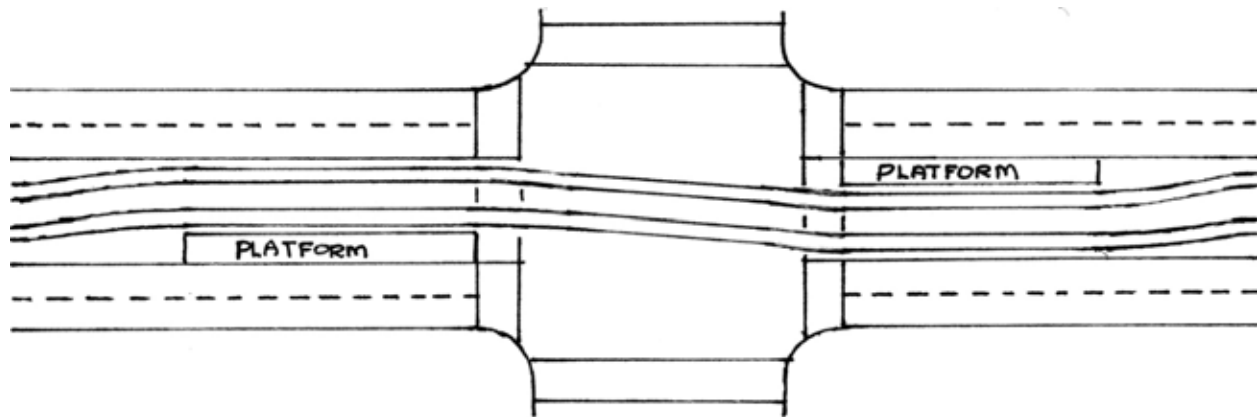


Figure 5.7.6: Track off-set in narrow median to accommodate near-side platforms

Figure 5.7.6 shows the track off-set in a 12 metre median to accommodate near side station platforms. Note that no provisions are made for left turns in this case.

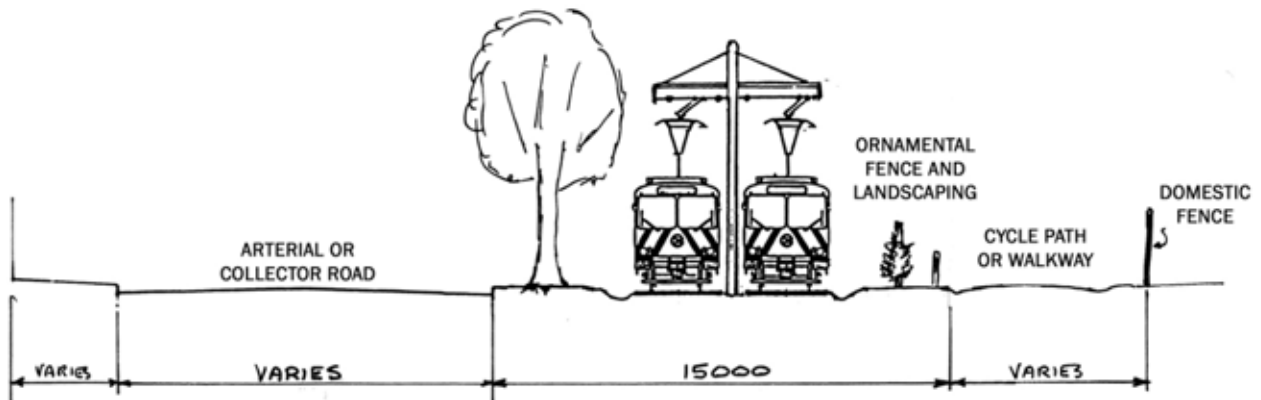


Figure 5.7.7: L.R.T. at side of arterial or collector road. Right of way allows for station platforms accessed from walkway

Figure 5.7.7 shows a side of the road location for a 15 metre L.R.T. right of way which allows for platforms on each side accessed from a walkway. Various types of landscaping are shown.

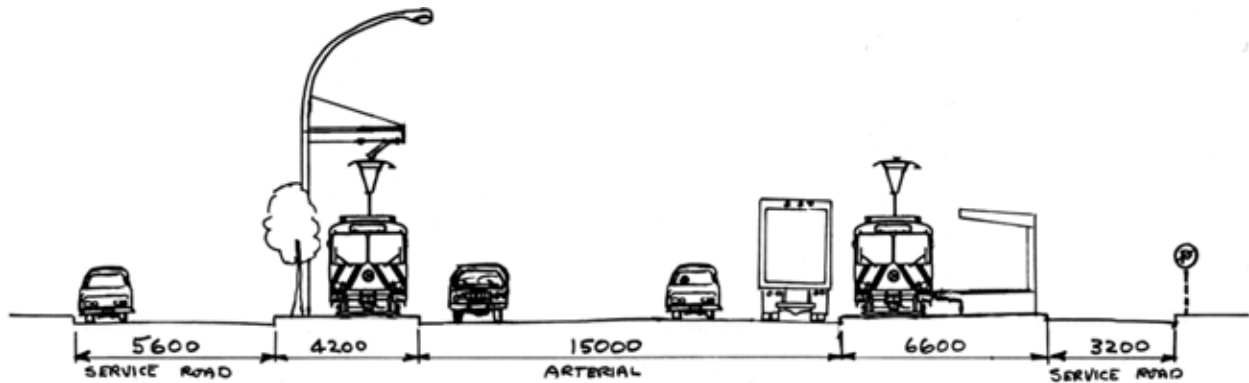


Figure 5.7.8: L.R.T. symmetrically disposed in boulevards of arterial with service roads. Parking is prohibited in area of station platforms

Figure 5.7.8 shows L.R.T. tracks symmetrically disposed on either side of a 15 metre arterial with service roads. Note that station platforms are accommodated by pre-empting the parking on the service road.



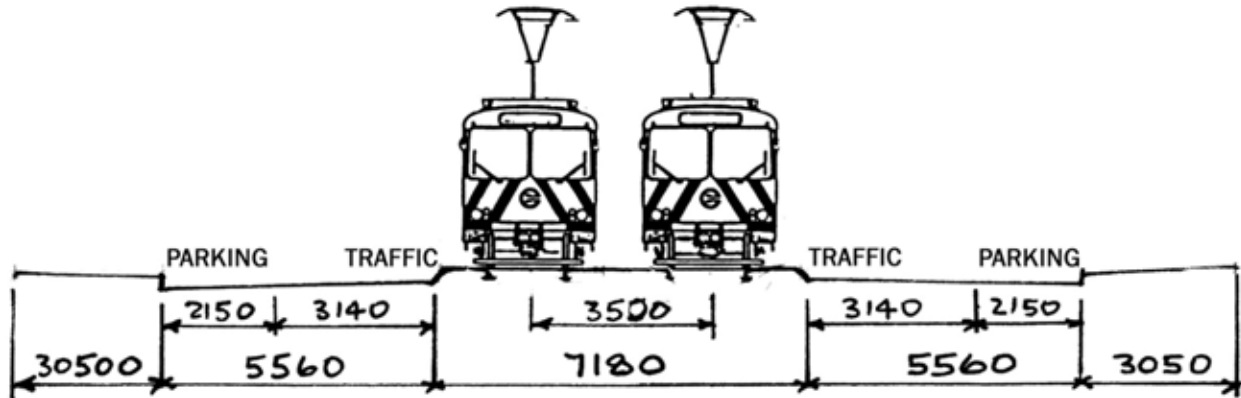


Figure 5.7.9: L.R.T. in paved median with mountable curbs

Figure 5.7.9 shows L.R.T. in a roadway limited to local access traffic. The rails are laid flush with the pavement 210 mm above the regular road surface. Mountable curbs are provided so as not to restrict driveway access and egress.

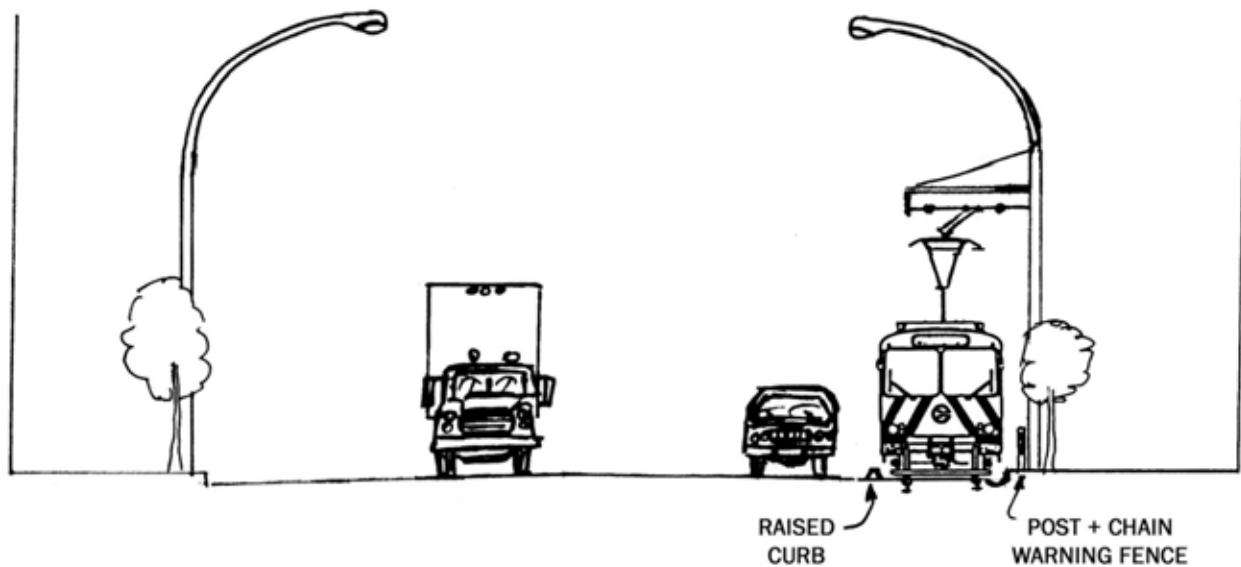
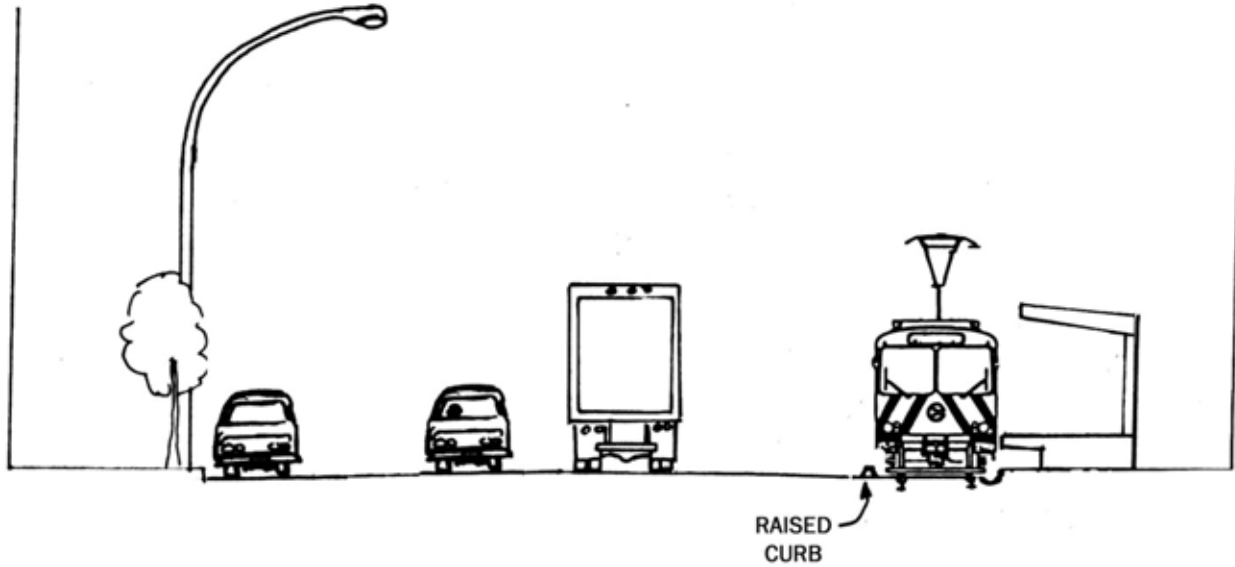


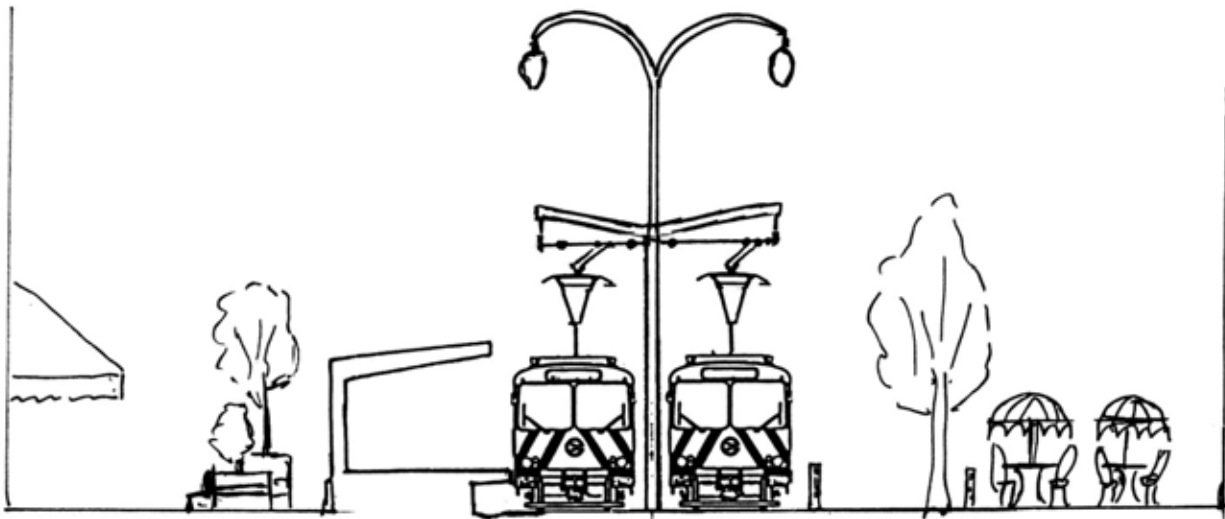
Figure 5.7.10: L.R.T. occupying one lane of city street

Figure 5.7.10 shows L.R.T. occupying a curb-side lane protected by a 150 mm raised curb on the traffic side and a post and chain warning fence on the sidewalk. This type of lane could also be shared by buses if the track is laid with girder rail and the curb is replaced by a rumble strip.



**Figure 5.7.11:** L.R.T. curb-side station. For new developments station could form part of building arcade

Figure 5.7.11 shows a curb side station. Where new developments take place there are broad possibilities for incorporating stations into building arcades.



**Figure 5.7.12:** L.R.T. in transit mall

Figure 5.7.12 shows a transit mall where all traffic except L.R.T. is excluded and the street becomes a people place with landscaping, benches and outdoor eating places. Northern climates limit the possibilities to a certain extent, but since L.R.T. is electrically powered and thus non-polluting, there is the possibility of roofing over the street for one or more blocks.

The aesthetic appeal of an elevated structure is not such as to recommend the use of this form of construction to any great extent, but it may be useful to surmount local intersection problems.

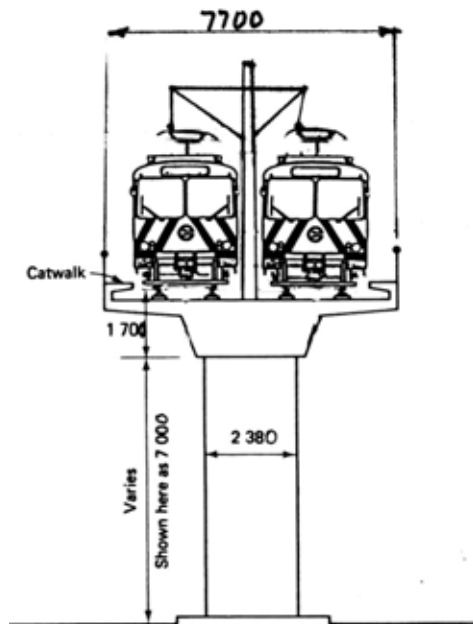


Figure 5.7.13: L.R.T. elevated structure

Figure 5.7.13 shows a typical cross-section of an elevated structure as used in Cologne.

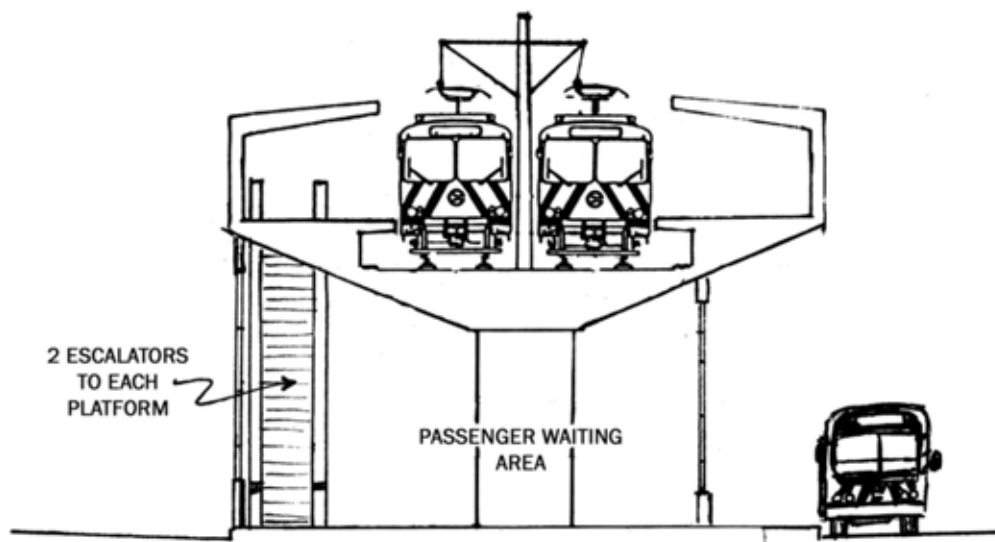
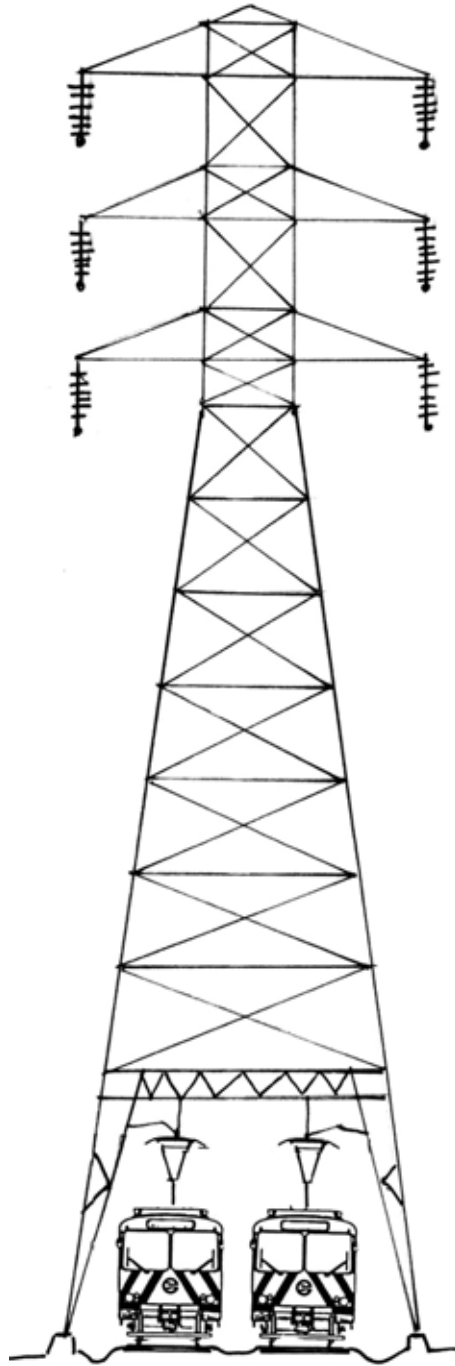


Figure 5.7.14: L.R.T. station on elevated structure with major bus interchange (transit centre) below

Figure 5.7.14 shows an elevated station at a major transfer point with shelters and bus bays at grade level below.

In addition to sharing rights of way with other transportation modes, utility corridors can also be utilized.



**Figure 5.7.15:** L.R.T. station in utility right of way

Figure 5.7.15 illustrates the use of purpose-designed high voltage electricity towers to support L.R.T. overhead.

In areas where it is not possible to accommodate L.R.T. on or above the surface where construction is cheap and it is readily accessible to its customers, underground construction must be resorted to.

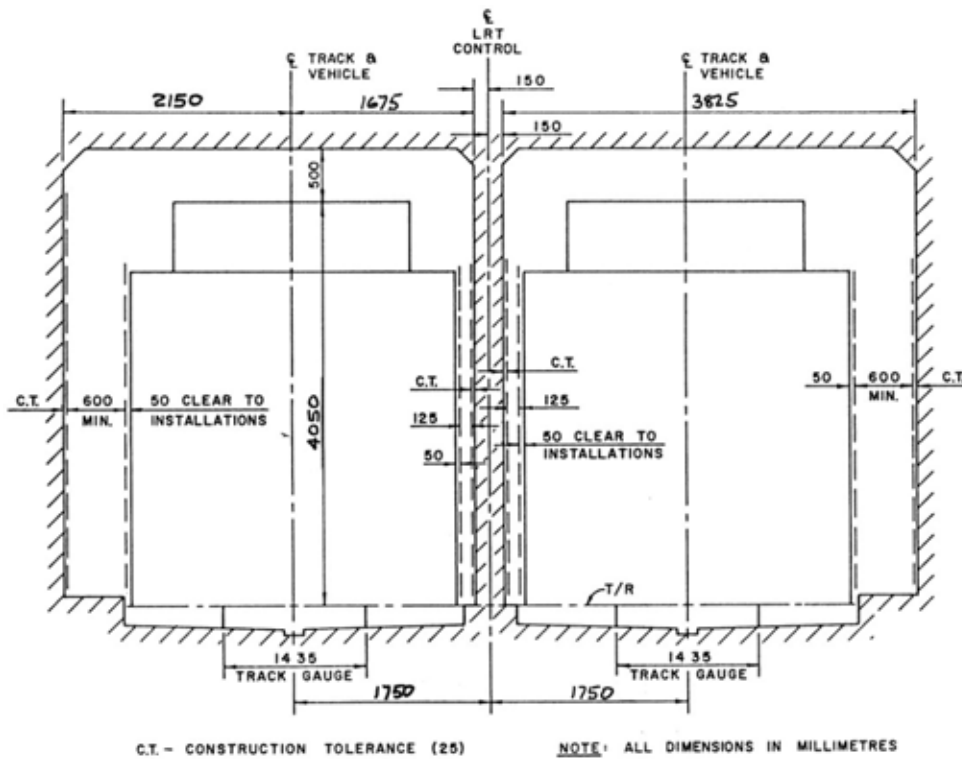


Figure 5.7.16: Clearance diagram. Cut & cover section on tangent

Figure 5.7.16 shows a subway box constructed by the cut and cover method with minimum internal dimensions.

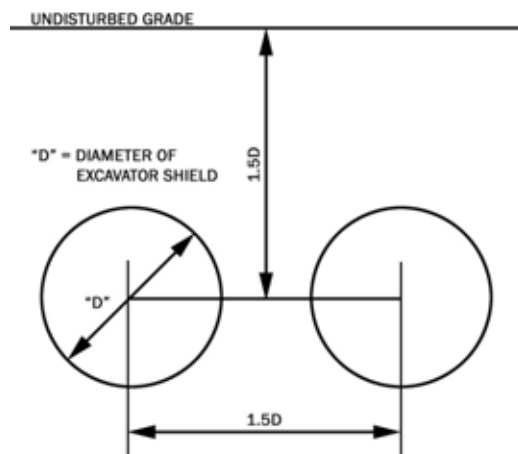


Figure 5.7.17: Minimum spacing and cover dimensions for moled tunnels

Figure 5.7.17 shows twin bores as produced by the Edmonton mole with minimum spacing and cover dimensions.

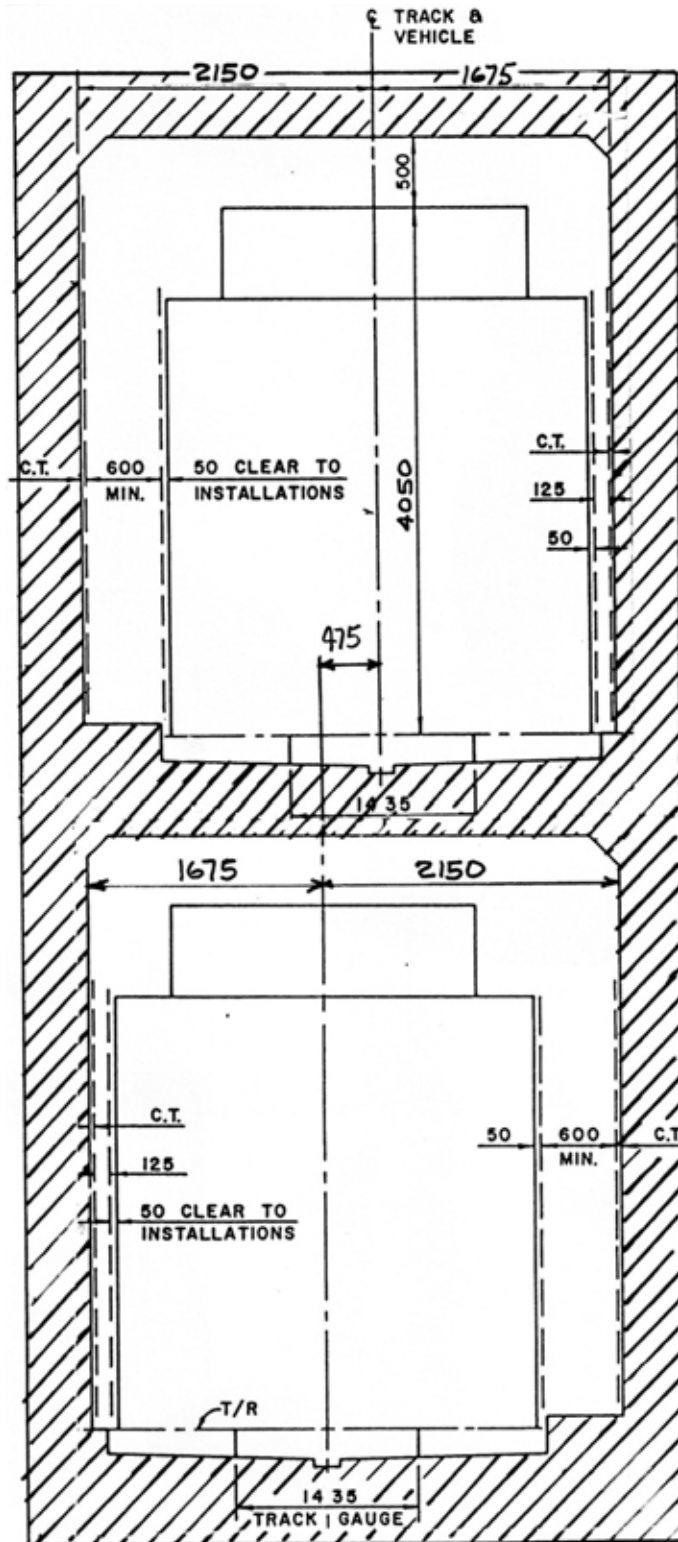


Figure 5.7.16: Clearance diagram. Cut & cover section on tangent

Where space is tight and connections have to be made into the existing system, superimposed or piggyback construction may be resorted to as shown in Figure 5.7.18.

## 6.0 Stations

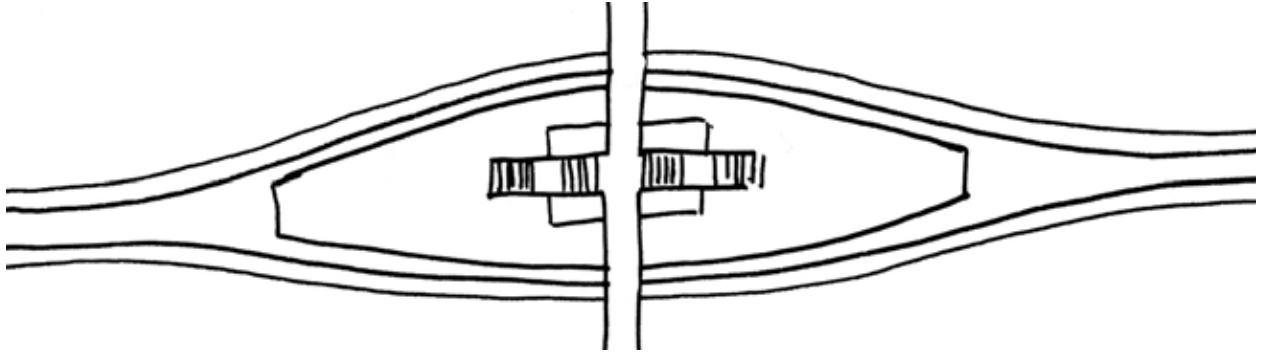
The fact that Edmonton's light rail system opted to use high platform stations on its initial segment together with current concerns for handicapped access indicates a commitment to continue this design throughout the system. San Diego which uses cars of a similar design to Edmonton's have opted to use rail level loading, and San Francisco uses high level platforms in the Market Street Subway and low level platforms elsewhere, their cars having moveable steps to accommodate either. Street level or curb level loading simplifies station location and construction in medians and in transit lanes but leads to problems with access for the handicapped.

When LRT was first opened in Edmonton, Belvedere Station which consisted of an open platform with a ticket booth and three or four bus type shelters was criticized in that it did not provide the same standard of comfort as the underground stations downtown or the stations at Stadium and Coliseum that were designed to handle special events crowds. In fact, Belvedere, at only one tenth of the cost of a larger surface station, was a typical LRT station. The need for shelter at an LRT station should not be greater than the need for shelter at a bus stop since the frequency of service is in the same range. In practice, shelters are placed at bus stops in accordance with criteria which include vehicle headway, and if the headway criteria was applied to LRT it would not score favourably, since train service is much more frequent than most bus routes.

LRT stations should provide some shelter and should be in keeping with their surroundings but the temptation to elaborate should be resisted. Since LRT services run at frequent intervals, shelter accommodation should be provided adjacent to connecting bus services whose headway is usually considerably greater. The cost of a station is not only in design and construction and heating, but also in upkeep. The more complex the station and the more comfort it provides, the higher are the costs of cleaning and repairs necessitated by acts of vandalism. The perceived need for security coverage of transit facilities is in direct proportion to their complexity and the provision of surveillance cameras and security guards is out of all proportion to the costs of transporting the passengers. It is estimated that the cost of maintaining a large underground station may account for as much as 30 cents for every passenger who uses the facility.

### 6.1 Platforms

Station platforms can be located either between or outside the tracks. The centre platform has certain advantages especially in underground sections. Except for immediate downtown stations peak hour loadings are directional and therefore the platform area required for a centre platform can be considerably less than twice the area of a side platform. Savings can also be made in stairways and escalators, while from the passenger's point of view cross-platform transfers avoid the necessity for going up and down stairs. Station design in the use of curved platforms can improve boarding supervision (Figure 6.1.1).



**Figure 6.1.1:** Centre platform with curved faces to improve boarding supervision

The use of side platforms avoids the need to spread the tracks to accommodate the platform and enables the platforms for each direction to be separated. In median applications with grade crossings, side platforms in far side configuration allow for a left turn bay for road traffic, (Figure 5.7.2 and 5.7.3) while in a more constrained configuration tracks can be offset to take up minimum right-of-way width.

## 6.2 Location of Stations Relative to Intersections

In median or side of road operation in a thoroughfare with coordinated signals, but without signal priority, alternate near-side and far-side stops result in the shortest delays to transit vehicles. This principle was developed by Wolfgang von Stein on LRT lines in Dusseldorf in the mid 50's and has given good results. Simply explained; a train can leave a near-side station only during a green phase and will arrive at the next intersection during its green phase, passing through to stop at the platform on the far-side. At the next intersection, which will be near-side, the red phase may be used for passenger exchange, resulting in the shortest overall delay obtainable without signal pre-emption. The presence of near-side platforms may mean that left turns would have to be banned for road traffic at these intersections where the right of way was too narrow for left turn bays.

## 6.3 Design Dimensions for Platforms and Exits

For a side platform, a width of 3650 mm will allow about half a square metre per passenger for maximum assembly crowds. For stations in the central business district and stations serving special event facilities where peak hour traffic is converging, central platforms should be twice this width i.e., 7300 mm. For cases where peak hour traffic is directional, central platforms may be 5500 mm wide. The minimum clear width of passage between the edge of the platform and any obstruction on the platform should be 1500 mm. Platform edges adjacent to the track should be finished in a contrasting non-slip material with a raised warning strip near the edge for the benefit of the visually impaired. Width of warning strip to be about 425 mm. Figures 6.3.1 and 6.3.2 show recommended dimensions for centre and side platforms respectively.



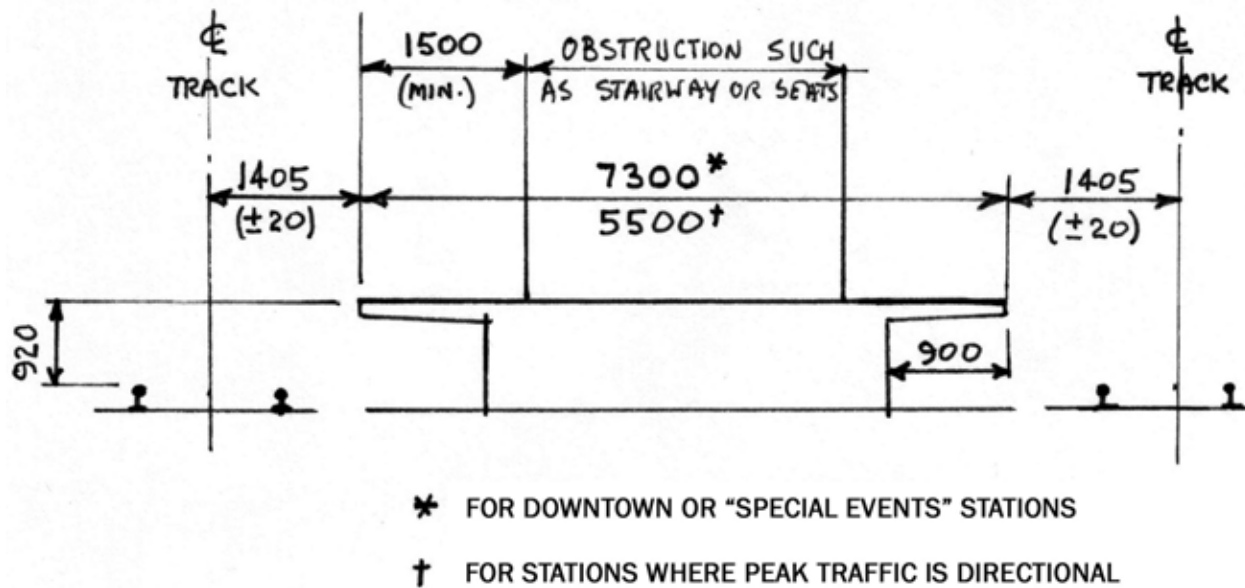


Figure 6.3.1: Recommended dimensions for centre platforms

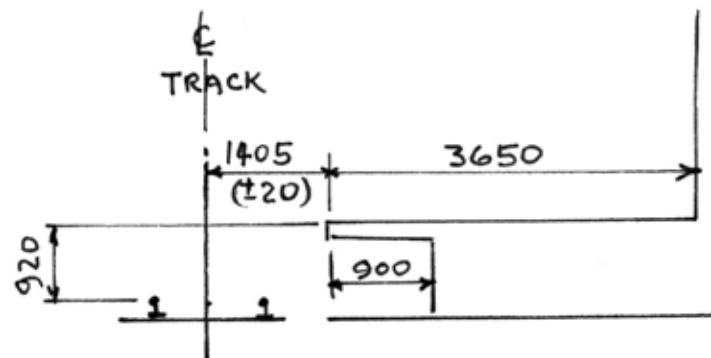


Figure 6.3.2: Recommended dimensions for side platforms

Platform length depends upon the number of cars per train. While Edmonton LRT cars are capable of being coupled in 5 car trains, other constraints keep trains down to 3 cars. It is therefore most economical to construct stations with 80 metre platforms to handle 3 car trains with provision for expansion to handle longer trains as and when the additional capacity becomes necessary. In the case of underground stations where it would be impossible to extend the platforms without drastic interruption to service, these should be constructed to 5 car (123 metre) length.

Platform exits, stairways and passageways should be sized so that the estimated average train load entering the station over the peak 15 minute period can clear the platform within a four minute period. When determining the required width of exits, a crush capacity of 80 passengers per minute per 1000 mm width of passageway, 65 passengers per minute per 1000 mm width of stairways and 100 passengers per minute for each 1200 mm escalator. These capacities are attainable only under unidirectional flow conditions and should be considered as minimum.<sup>11</sup>

Minimum floor to ceiling height should be 2750 mm with 3000 mm preferable to discourage damage by vandals.

Escalators should be provided whenever stair height exceeds 4000 mm in the up direction and 7000 mm in the down direction. They should be provided with stop devices for emergency situations and for manual shutdown to prevent overcrowding of platforms in the case of service delay.

At least two exits should be provided from underground stations, clearly marked and equipped with emergency lighting.

#### **6.4 Passenger Security and Surveillance**

Generally speaking the more isolated the patron feels in a transit facility, the greater is the perceived need for protection. A person standing at a bus stop or waiting in a bus shelter expects neither a security guard or a closed circuit T.V. camera to be provided. Out in the open in familiar surroundings with people and vehicles passing there is little apprehension of danger, but in stations the very structure that provides physical comfort for the waiting passenger isolates him from familiar sights, sounds and movements and he has come to expect protection to be provided. This is especially true of underground stations where there are no reassuring glimpses of the outside world and places of concealment seem to abound.<sup>20</sup>

The industry has come to accept the cost of providing T.V. surveillance and often security patrols as well to counter these fears, whether they be real or imaginary. The aim of the planner and station designer should be to make transit facilities self-policing.

In design, stations should be as open as possible with maximum use of transparent panels. Corners where a person might conceal himself should be eliminated and adequate lighting should be provided in vandal-proof fixtures.

The most successful way to reduce security hazards in major stations is by ensuring that they are busy places, not just with transit patrons, but by providing for multiple use of space. Heavy bus transfer locations might attract news/tobacco/snack bar concessions, while other stations might form part of neighborhood shopping centres or professional buildings. A further benefit of such arrangements would be for rental payments to help keep transit costs down to acceptable levels. Combination with a divisional police station could result in random riding by uniformed officers which would again have a salubrious effect on the patrons' perception of security.

#### **6.5 Handicapped Access**

With an all-bus system it is most practical to provide a parallel door-to-door service for the physically handicapped. This is costly in terms of equipment and manpower and if it is operated as a bus service rather than a taxi service, is costly in terms of the patron's time. Comparison between Calgary and Edmonton shows that, for the same number of total annual rides the taxi-type system in Calgary costs almost exactly twice as much as the bus-type system in Edmonton.

In construction of the north east L.R.T. line, Edmonton City Council directed that the system be equipped to cater to the handicapped with provision of ramps and elevators at each station and wheelchair tie-downs in the cars. The use which has been made of these facilities has not been great because of the inability of disabled persons to get from their homes to the stations, however as the system expands there is potential to reduce handicapped transportation costs by confining the lift-equipped vehicles to specific quadrants of the city and employing them as shuttles to the nearest L.R.T. station for longer trips.

In order to keep this option open it is necessary to continue to equip all stations with the necessary elevators and ramps to standards mandated for other public buildings.

### 6.6 Fare Collection Areas

In order to be able to prevent loitering in the stations, the platform, access stairs and the area surrounding them are designated as "paid areas" inside of which each passenger must carry proof of payment in the form of a pass, transfer or validated ticket. Paid areas must be designated clearly by channelization or other means from areas which are designated as being outside the system. Ticket issuing machines are placed outside of this area where they will not impede the flow of traffic in and out of the paid area or passing through the "free areas"; machines issuing validated tickets or validating tickets or transfers are placed at the actual entrance to the paid area.

## 7.0 Interface of LRT with Other Traffic Modes

Due to the nature of LRT and the need to have it serve the community as it exists, rather than to impose the traumatic changes often necessary to accommodate other transit modes, the possibilities for conflict of movement must receive detailed consideration.

### 7.1 Shared Right of Way With a Railway

The introduction of LRT into an existing active railway corridor brings with it legal obligations due to the jurisdiction of the federal government through the Railways Act. Under normal circumstances the Railways Act does not apply to tramways, street railways and electric suburban railways existing wholly within a province and not built for the general good of Canada.<sup>16</sup> However the presence of LRT within a shared right of way makes it subject to Canadian Transport Commission regulations at all points of interface between it and the railway and at intersections with roadways. Applications have to be made to the Commission for each crossing required and the design and operation of the crossings must comply with C.T.C. requirements. This generally means that standard railway-type barriers with bells and flashing lights must be employed. Accident experience with this type of crossing in urban areas has been confined mainly to damaged gates with a low incidence of vehicle-train impacts in each case due to gross errors on the part of the road vehicle operator. Where such shared rights of way exist they are usually in industrial areas. It is doubtful whether barrier crossings would be acceptable in residential/commercial neighborhoods.

Should the LRT intersect a rail line, the crossing must be protected by interlocking signals to the satisfaction of the railway and the C.T.C. A clearance of 6.86 metres must be maintained for LRT overhead crossing the rail line a factor which may affect structure design for some distance on either side of the actual crossing.<sup>16</sup> A trolley bus line intersecting both railway and LRT will require that the LRT overhead also be raised to enable the requisite clearances to be maintained over the railway.

According to C.T.C. Regulations, railways require to be fenced, a rule more honored in the breach than in the observance. Siting of fences should be given adequate consideration bearing in mind their possible effect on snow build-up and on the safety of patrons who may have to leave a train in an emergent situation, as well as their main purpose to deter trespassers or fare evaders. For legal purposes, notices must be posted regarding trespassing.

## 7.2 Shared Track With a Railway

The operation of main line railway trains on the same tracks as LRT presents additional problems due to the difference in performance characteristics of the two modes. Main line trains are slow in acceleration and braking and are not designed to operate in close proximity to other units. They rely heavily on human judgement and very broad space/time tolerances to maintain safety. Any movement of railway vehicles that may be necessary over LRT tracks during times when passenger service is operating should be restricted to short trains hauled by an electric locomotive constantly in contact with Central Control. Light rail vehicles may share tracks with metropolitan, suburban or interurban electric trains where automatic train protection is in force and where current collection methods and voltages are compatible.

For operation through stations with high platforms, the width of rolling stock must be compatible or a gauntlet track must be provided to enable the wider vehicles to pass freely (Figure 7.2.1).

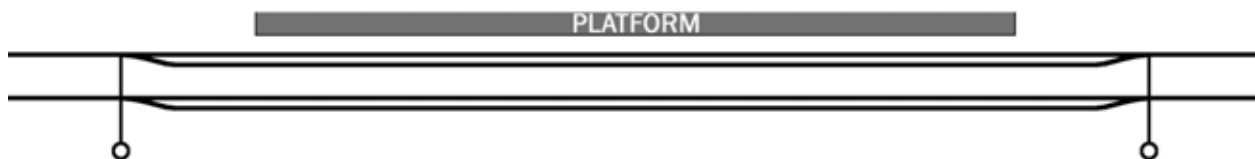


Figure 7.2.1: Gauntlet track to allow wide rolling stock to pass station platform

## 7.3 Shared Right of Way With Buses

Because of common operating characteristics, buses can share rights of way with LRT with fair success when speeds are kept low. It is customary to use grooved girder rail in order to protect the paving next to the flangeway. The close clearances used for rail vehicles are not sufficient to permit safe bus operation unless some form of continuous curb is provided to reduce the possibility of side-swiping contacts. If this curb is not mountable buses should be fitted with coupling sockets so that they can be assisted by a train in case of breakdown. If trolley buses

share the right of way, trolley bus overhead can be mounted beside and slightly above that of the LRT so that it is clear of the pantographs.

When high platforms are used, stopping places cannot be shared and curbing must be provided to prevent bus bodywork contacting the platform edge as shown in Figures 7.3.1 and 7.3.2.

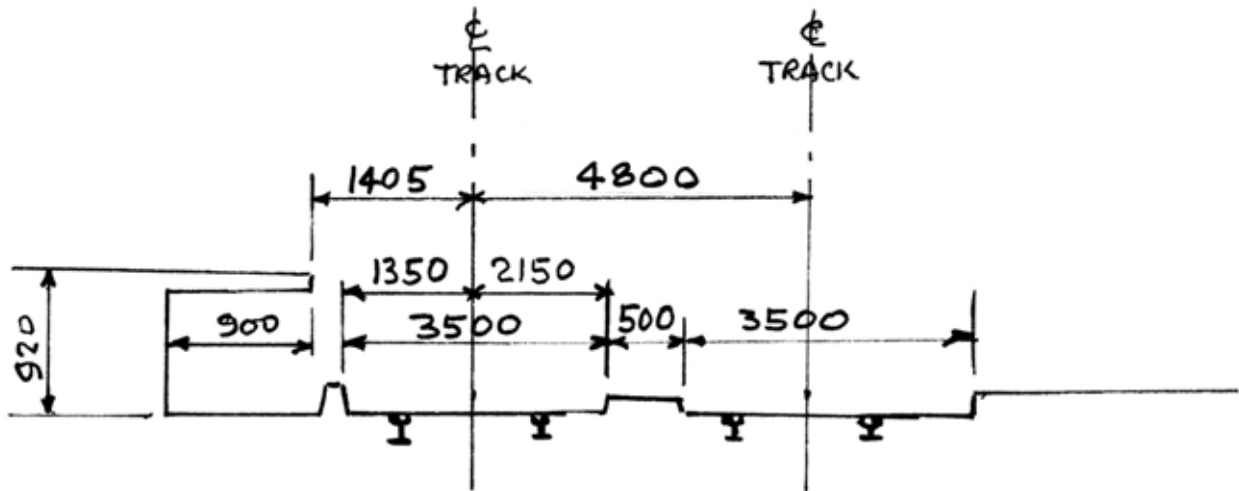


Figure 7.3.1: Cross-section of L.R.T./bus lane at L.R.T. platform

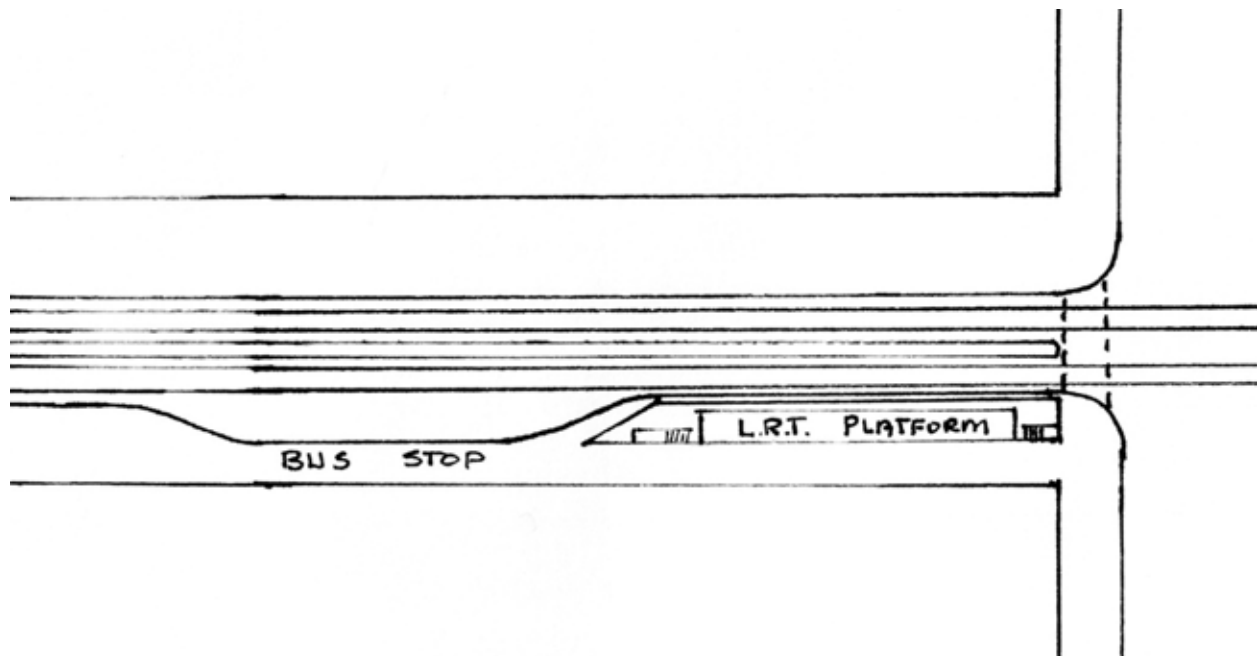


Figure 7.3.2: Separate stopping places for L.R.T. and bus in shared transit mall

## 7.4 Shared Right of Way With Mixed Traffic

Referred to as category 'E' right of way in Section 2.3, mixed mode operation is typical of tramway or streetcar systems in the first half of the 20th century, and was one of the main measures cited for bus substitution. In spite of this, the possibility of mixed mode operation must be kept in mind as yet another asset of L.R.T. and one which extends the possibilities of getting "more for less" in a tightly constrained situation. Most European L.R.T. systems evolved or are evolving from mixed mode operations but even the most advanced retain some street running, if only for a block or so.

Where mixed mode is used grooved girder rail construction is essential to provide a smooth pavement suitable to other traffic. Pavement markings are generally provided indicating vehicle lanes corresponding to the guideway and clearly showing where they converge and diverge: this is most important since there may be a tendency among those unfamiliar with the system to follow the car lines rather than pavement markings. Signage and markings are reinforced by installing coarse block paving or rumble stripping in the "no-man's land" area where the lanes diverge. Such coarse block paving may also be used on exclusive L.R.T. right of way so that it is available for emergency vehicles: this is the case in several European cities making a fast clear path always available for police, fire and ambulance service even in the worst of the rush hour. L.R.T. operators are warned in advance and emergency vehicles can overtake them by moving onto the opposing track between cars.

The risk of accident in a mixed mode situation is greatly increased and if diverging L.R.T. movements were contemplated it would be necessary to install braking and turning signals on the cars. Operation in mixed mode is necessarily slow but may give a satisfactory solution to geometric problems involving occasional movements.

## 7.5 Shared Right of Way With Pedestrians

The concept of a transit mall was illustrated in cross-section in Figure 5.7.11, indicating the track area to be more or less restricted from pedestrian encroachment by low barriers, requiring crossings to be made at certain specific points. There are several instances like the Promenade at Blackpool in England and the Bahnhofstrasse in Zurich where tracks are open to crossing at any point, being analogous to a city street with no jay-walking restrictions. The edges of the right of way are delineated by a low curb or merely by a change of color pattern or texture of the paving blocks. There is a bus transit equivalent in Chestnut Street Mall in Philadelphia. In all these cases it is recognized that the pedestrian has the right of way and operation is restricted to no more than 20 km/hr., nevertheless the arrangement does seem to operate quite satisfactorily and with the hearty endorsement of local Chambers of Commerce.

## 7.6 Grade Separations

Grade separated intersections are certainly the most desirable from an operating point of view but they are the most expensive in capital and in use of space. The relative cost of an overpass compared with an underpass will depend upon the clearances which must be maintained: if the intersecting mode is a railway the required clearance above rail level is 6.86 metres and for a

road 5.33 metres above the pavement. The clearance required above rail level would be 4.55 metres for an overpass of the L.R.T. line.

Other factors are involved including ground water levels and drainage of the surrounding land which can elevate construction costs and incur continued expense in dealing with run-off water, bank erosion etc.

Grade separations are probably most useful in negotiating complex road traffic interchanges where a short stretch of elevated or subway construction may be quite an economical way of quickly by-passing what is a "people-desert" as far as Transit is concerned.

Because of the excellent gradability of L.R.T., separation costs can be sometimes reduced by splitting the grade difference between the intersecting elements which will virtually half the approach length in each case.

Where L.R.T. is being introduced subsequent to the completion of a highway interchange there may be little alteration that can be made to accommodate it, but where an original design is contemplated there may be considerable savings in capital and subsequent operating cost to be made by careful integration in the concept stage.

### 7.7 Barrier Equipped Crossings

As noted in Section 7.1, barrier equipped crossings may be mandatory where lines come under purview of the Railways Act; in these circumstances it is usual for the landlord railway to assume the responsibility for installation and maintenance of gates, bells and lights. L.R.T. trains call down the gates by means of track circuits so situated as to satisfy C.T.C. requirements for approach speed and warning time. Because of the frequency of L.R.T. traffic and the fail-safe nature of barrier installations, defects in the system can have serious consequences to traffic flow. Build-up of road salt in winter can cause false closures as can accidental tripping caused by steel bladed snow clearing equipment. It is often advisable to install a centre median on the crossing approaches to discourage vehicles from by-passing the barriers in the event of a long closure. By-passing is especially dangerous where multiple tracks are present and where sight lines may be restricted by adjacent buildings. A special concern is delay to emergency service vehicles and the calculated risk which may have to be taken in circumventing the barriers.

Barrier crossings seldom occur in heavily built-up areas so that the effect of virtually continuous ringing of bells on those living nearby would have to be taken into consideration if their use was to be extended.

### 7.8 Mid-Block Signal Controlled Crossings

A mid-block crossing is one where an exclusive L.R.T. right of way, or perhaps one shared with buses crosses a public roadway. This can be protected by a simple set of traffic lights activated by the approach of a transit vehicle. Detection can be by overhead detector, wheel detector, track circuit or photo-electric cell and the detector can be so placed as to force the vehicle to stop before entering the crossing or to slow down to whatever extent is considered desirable.

Indication to an approaching transit vehicle can be by regular signal heads masked to show a horizontal bar for "stop" and a vertical bar for "proceed", the reason for not using red and green indications being to preserve the integrity of the block signalling system as mentioned in Section 4.8.

### 7.9 Signal Controlled Crossings at Intersections

Where L.R.T. guideway is disposed in or alongside a road right of way, intersection control can be adapted from regular roadway practice. Phasing must consider the presence of the transit vehicles, which may receive an early "green" or may be protected against conflicting turns by special lane indications.

The inclusion of the affected intersections into an area-wide traffic management system calls for consideration of transit schedules to determine suitable "windows" which would be available for transit priority purposes.

The disposition of stations as discussed in Section 6.2 can reduce the adverse effect of transit priority on intersecting traffic. It should also be borne in mind that the cycle time of traffic lights will limit the capacity of the L.R.T. line since only one train in a given direction can pass per cycle as noted in Section 3.2.

Signal indications displayed to transit vehicles should consist of horizontal or vertical bars (or diagonal for diverging movements) rather than red or green to avoid confusion of other road traffic and, as noted in Section 4.8 to preserve the integrity of the block signalling system. Magnetic train stops can be used to enforce compliance with signal indications.

### 7.10 Uncontrolled Crossings

The incidence of uncontrolled crossings on L.R.T. is generally low and such crossings are usually of a temporary nature. Procedure at such crossings is governed by operating rules which usually stipulate that the train will come to rest before moving on to the crossing at low speed: after the nose of the first vehicle is across the road the train may accelerate up to the allowable speed for the particular stretch of track. Warning signs must be posted on the road in advance of the crossing and stop signs may be placed at the crossing itself if visibility is restricted.

Particular attention should be paid to non-right angle crossings due to the increased difficulty in distance perception which may be present, especially for pedestrians. Disorientation may be anticipated on the part of children and old people and refuge barriers should be provided where the angle of intersection is less than 60°.

### 7.11 Pedestrian Crossings

Pedestrian crossings at controlled intersections are set up in the normal way with "walk" and "wait" phases. Barriers are installed next to the track to keep pedestrians at a safe distance from passing trains and also to make them face the direction from which trains approach before crossing the line (Figure 7.11.1).



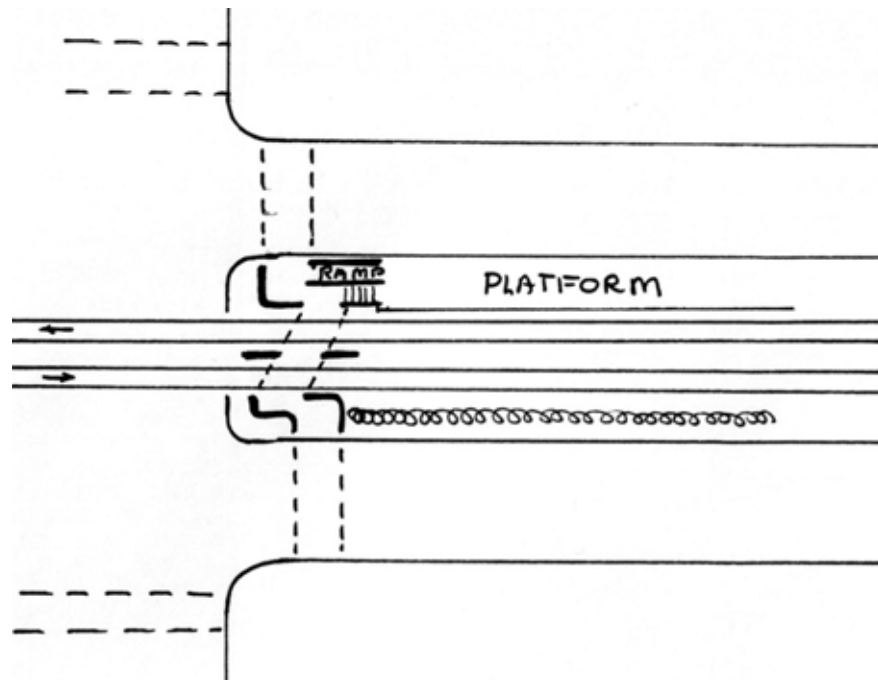


Figure 7.11.1: Pedestrian crossing at controlled intersection

Mid-block crossings are laid out in the same manner and may include pedestrian operated traffic lights for road traffic subject to over-ride in case of an approaching rail vehicle.

Crossings should be designed to accommodate wheelchairs and with this in mind the grooved girder rail used in the roadway intersection itself should be extended to include the crossing area.

## 8.0 Ancillary Facilities

In order to conduct the operation of a light rail system in an efficient manner, various types of storage and other facilities are required contiguous to the line. The cost of the basic needs in this context are often very high when the system mileage is small, but as it grows bigger economies of scale are possible. There are precedents for sharing some facilities with mainline railways and also for sharing between nearby light rail systems, as well as using transit facilities to carry out work for other municipal departments.

### 8.1 Main Overhaul Shop

As with any enterprise the decision as to what part of the construction, maintenance, overhaul and repair work will be done in-house and what will be contracted out must be based on a careful cost/benefit analysis. When streetcars were scrapped local maintenance forces were reduced, but new jobs were created in Detroit making spare parts for the buses that replaced them: this situation is now being reversed because the number of manhours which must be performed on the actual vehicle and its major parts is higher for L.R.T compared with the labour content of easily shippable spares for diesel buses.

Edmonton's location rules out the practice of some smaller German systems of shipping their rolling stock back to the factory for major overhauls which represents one end of the scale; nor would the fabrication of complete car bodies be undertaken as it was on occasion in Edmonton's streetcar days and which was common practice in Britain. Nevertheless an undertaking is never too small, as witness the work being done by volunteer labour at Fort Edmonton Park where reconstruction of old Edmonton streetcars is being done from the ground up including fabrication of running gear using locally made castings.

Regardless of where the dividing line is drawn an overhaul shop must be provided where the vehicles can be separated into their component parts. This requires a jacking system suitable to the types of car being operated and cranes of various capacities for handling motors and wheel sets. Wheels require re-profiling to compensate for uneven wear and to remove hard spots caused by skidding: when they are worn out they require to have the tires cut off with a metal saw and new tires mounted in a special hydraulic press. Various jigs and devices can be added to make the work quicker, easier and safer.

Structural damage to light rail vehicles is usually confined to ends and skirting. As these are made of fibreglass a specially ventilated area should be provided where this type of work can be carried on without causing discomfort to the worker and those around him. A paint shop is also essential, capable of housing a complete vehicle with moveable scaffolding and an adequate ventilating and air scrubbing system.

Maintenance of the electronic control system requires test benches as well as portable apparatus for fault diagnosis.

Beyond the provision of basic facilities, the workshop can be expanded to carry out tasks according to the benefits perceived, the principal factor being to maintain steady output from each worker.

## 8.2 Running Depots

Running depots are the equivalent of bus garages and are provided at various points on the system designed to reduce deadhead time.

Essentially they are storage facilities where out of service vehicles can be inspected, cleaned and given light maintenance.

Basic equipment consists of wash racks, vacuum cleaning apparatus, inspection pits, and some diagnostic equipment. Some form of access to pantographs is provided so that shoes can be inspected and changed.

A dispatch office and other crew facilities are also provided at running depots as described in Section 4.7.

### 8.3 Storage Yards

In Edmonton's climate it is not practical to store passenger vehicles in the open on a regular basis except as noted in Section 4.5. However outdoor storage with siding access is necessary for heavy material stocks. Since new car deliveries as well as material come by rail, a connection with a mainline railway must be maintained together with a suitable unloading area. Stock pile sites for track materials, overhead poles, etc. must be provided with suitable all-weather access for trucks, cranes and fork-lift vehicles. Sufficient length of spare track is needed to accommodate auxiliary vehicles used in moving this material to its point of use on the system.

Yard tracks should be level to guard against cars running away and tracks connecting to the mainline should do so on a rising gradient for the same reason. Mainline connections should be trailing and a trailing crossover provided for access to the track in the opposite direction. A tail track should be provided for switching purposes. A typical yard layout is shown in Figure 8.3.1 providing both open and covered storage and a work area for pre-assembly of special trackwork.

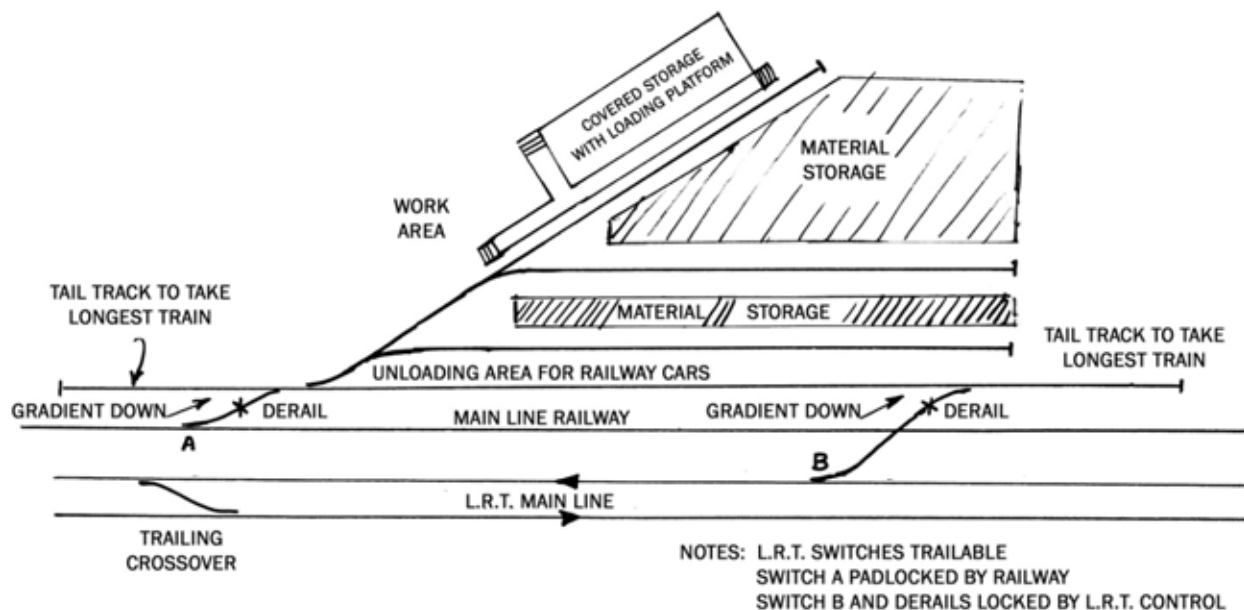


Figure 8.3.1: Typical storage yard for track and overhead material

### 8.4 Substations

The most economic spacing of substations is one in which the interest on the capital investment in equipment is equal to the cost of power losses in transmission. Modern technology applied to current rectification and remote control dictates that small substations should be placed at frequent intervals along the line rather than a large installation serving a wide area. In practical terms provision will be made for a substation at every second or third station depending upon station spacing. About 20 to 25 square metres of floor area is required and access should be

provided in the form of removable wall panels for installation and replacement of the heavier equipment such as transformers. In surface installations substation enclosures should be designed to match the architectural features of the station rather than appearing to be an afterthought. Underground installations can be accessed from street level or from rail level.

### 8.5 Signal Rooms

Relay rooms to house signal equipment are required at intervals along the line where centralized train control is used. They may often be combined in the same structure as the electrical substations. According to the type of equipment used, there may be a requirement for heating or air conditioning.

### 8.6 Mezzanines

The presence of a mezzanine floor in a station may be dictated by platform access or by the need to provide a ticketing area. The typical underground centre platform station is built by excavation from the surface, and except for the landing area for stairs, escalators and elevators and the cross-passages leading to the exit stairs the area for the length and breadth of the station above train clearance level is useless for transit operational purposes. On many older subway systems, the mezzanine area has become a hang-out for the underprivileged and as a result has contributed to loss of patronage, while more recently a solution to the aesthetic part of the problem has been sought in designing the station as a vaulted hall in the grand manner with the mezzanine reduced to a functional bridge or bridges.

Mezzanine space is produced at the cost of removing tonnes of spoil, besides the flooring, finishing lighting and maintenance, a heavy capital outlay and a continuing expense. Prudent economics dictate that it should earn its keep. It can provide opportunities for retail space, access to contiguous buildings and a comfortable pedestrian way in all weather, as well as housing essential transit functions.

One factor militating against the full use of this space is the lack of applicable building codes. This must be remedied: the problems of access and fire protection should be addressed and incorporated into an appropriate City bylaw before design is commenced. This will allow decisions to be made and space to be let from commencement of operation of the station, so that the resulting income can offset part of the high cost of underground operation.

### 8.7 Public Washrooms

Public washrooms should be considered in major stations on an individual basis. The cost of constructing and maintaining public washrooms must be weighed against the consequences of omission. In North American cities washroom accommodation is usually available where there are large stores and eating places. A survey of the area surrounding a station site should be made to assist in coming to a decision. Stations should be planned to reduce the possibility of ad hoc use and where this is not feasible, it should be considered as a factor in favour of provision.

Washrooms should be constructed of vandal-proof materials with securely anchored fittings and should be easily cleaned. In spite of this they should have an appearance of comfort if not luxury.

The comfort factor together with good cleaning and maintenance will help discourage vandalism.

Consideration should be given to washroom cleaning as part of a concession in conjunction with hair dressing salon, manicure, shoe shine or other service outlets, or as a system-wide contract.

Where the station has a continually manned service, whether by Transit or other party, washrooms may be made available on an access by request basis.

### 8.8 Utility Rooms

Space is required in each station to accommodate services and consumable supplies. Generally the larger the station the more utility rooms are required. Size and location should be determined as station plans are developed. It should be considered whether cleaning will be done by individual janitors travelling from station to station by train - in which case each station should have its own cleaning materials and storage space for same, or whether they will be cleaned by a truck-equipped "flying squad" similar to what is done for bus shelters.

Larger stations may require a garbage room, and cash handling may require a vault for the deposit of fare canisters. If garbage and/or cash collection is by train, consideration should be given to uniformity of placement and ease of access to make this process speedy and efficient.

## 9.0 Technical Considerations

The following items are added to the Planning Guidelines to help to describe some of the ways that L.R.T. technology differs from that used by mainline railways and heavy rapid transit operations in North America. When L.R.T. was in its infancy, many railway standards were borrowed because the frequency of street railway traffic compensated for the lighter weight of its rolling stock. In the second half of the twentieth century mainline railways are concerned with freight movement in trains of 100 cars having axle loads of 25 tonnes or more and the transfer of technology is no longer valid. Even in the hey-day of street railway operation on both sides of the Atlantic, much European technology was unavailable in North America due to vested interest resulting in a technological split followed by a cessation of development in North America after World War II. Whereas the Europeans carried on continuous development resulting in light rail transit as we know it today there has been a tendency to discount much of their experience and try to substitute North American mainline railway practice, resulting in inflated costs and inferior operations.

### 9.1 Track Construction

Figure 9.1.1 is a cross-section illustrating typical ballasted track construction. Details are based on Canadian Pacific Railway standards for new branch line construction.

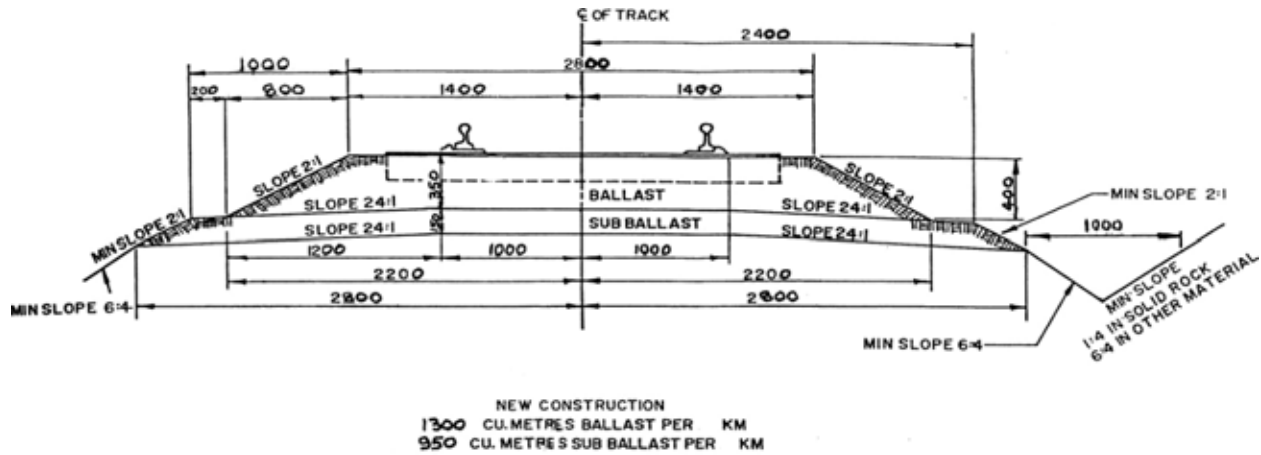


Figure 9.1.1: Cross-section of typical ballasted track

Ballasted track has proven over many years to be a more than adequate concept with regard to riding quality, rail stability, surface and line holding characteristics, noise and vibration, drainage, economics, service life, and flexibility, especially within special trackwork areas. While all of these factors are valid for relatively open at-grade track, their validity is reduced considerably in a typical rapid transit environment. The frequency of train movements coupled with severe restrictions on working room in subways and on elevated structures makes maintenance of tie in ballast system slow, awkward and costly. Ballast in these restricted locations, whether in subway or on an aerial structure, can become fouled with debris and dirt, thereby clogging the best-designed drainage system with the ultimate result being mud rather than clean stone acting as ballast, unless comprehensive maintenance of drains and the ballast is pursued. In addition, the ballast section, which may be 300 mm in depth below the bottom of the ties, requires larger tunnels and heavier elevated structures than would be necessary if a fastening system not requiring ballast were utilized. Stated simply, the use of ballast increases construction costs because of these size and weight considerations.<sup>18</sup>

There are as many types of ballastless track as there are undertakings using them. Basically they fall into three types, those that employ fastenings drilled directly into the concrete invert (Figure 9.1.2), those secured by a second-pour method (Figure 9.1.3), and the mass-spring systems which employ a resiliently-mounted substructure on which the rails are supported (Figure 9.1.4).

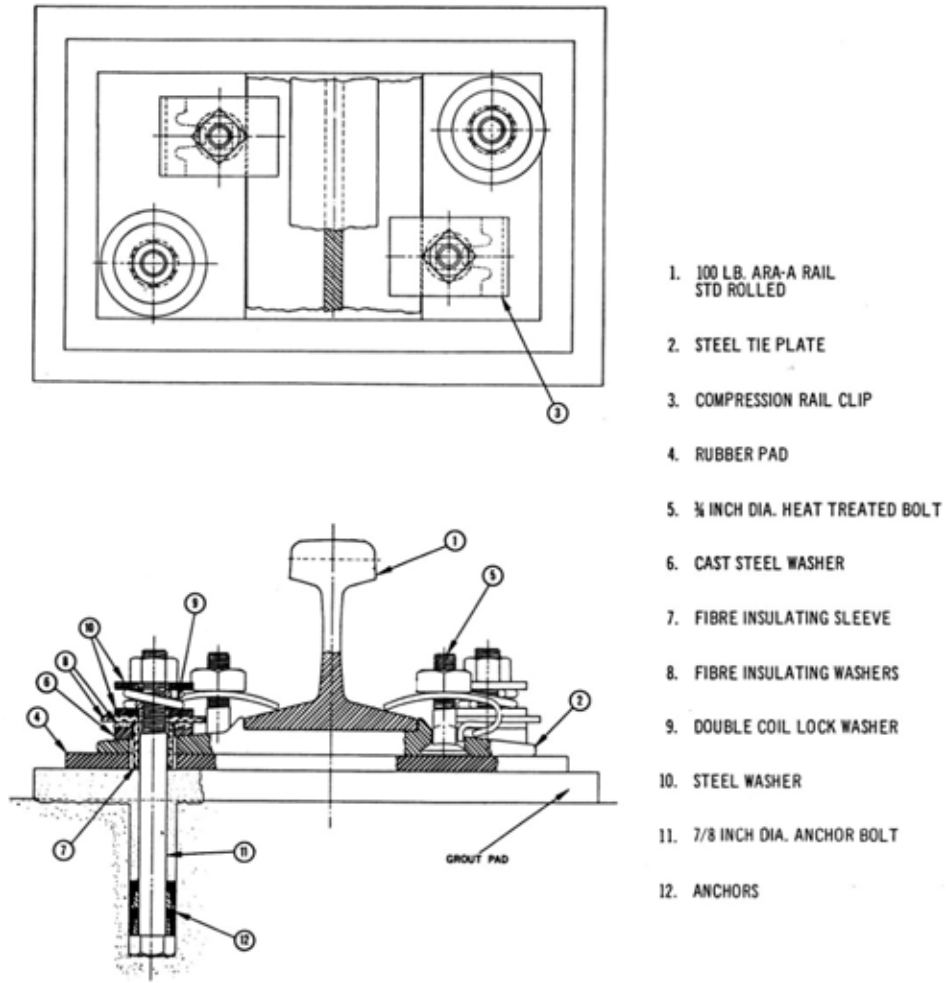


Figure 9.1.2: Direct fixation method of rail securement to concrete invert (TTC)

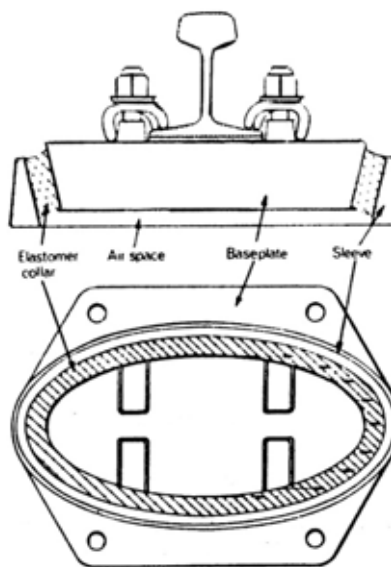


Figure 9.1.3: 'Cologne Egg' rail support used in construction with second-pour method of track laying (KVB)

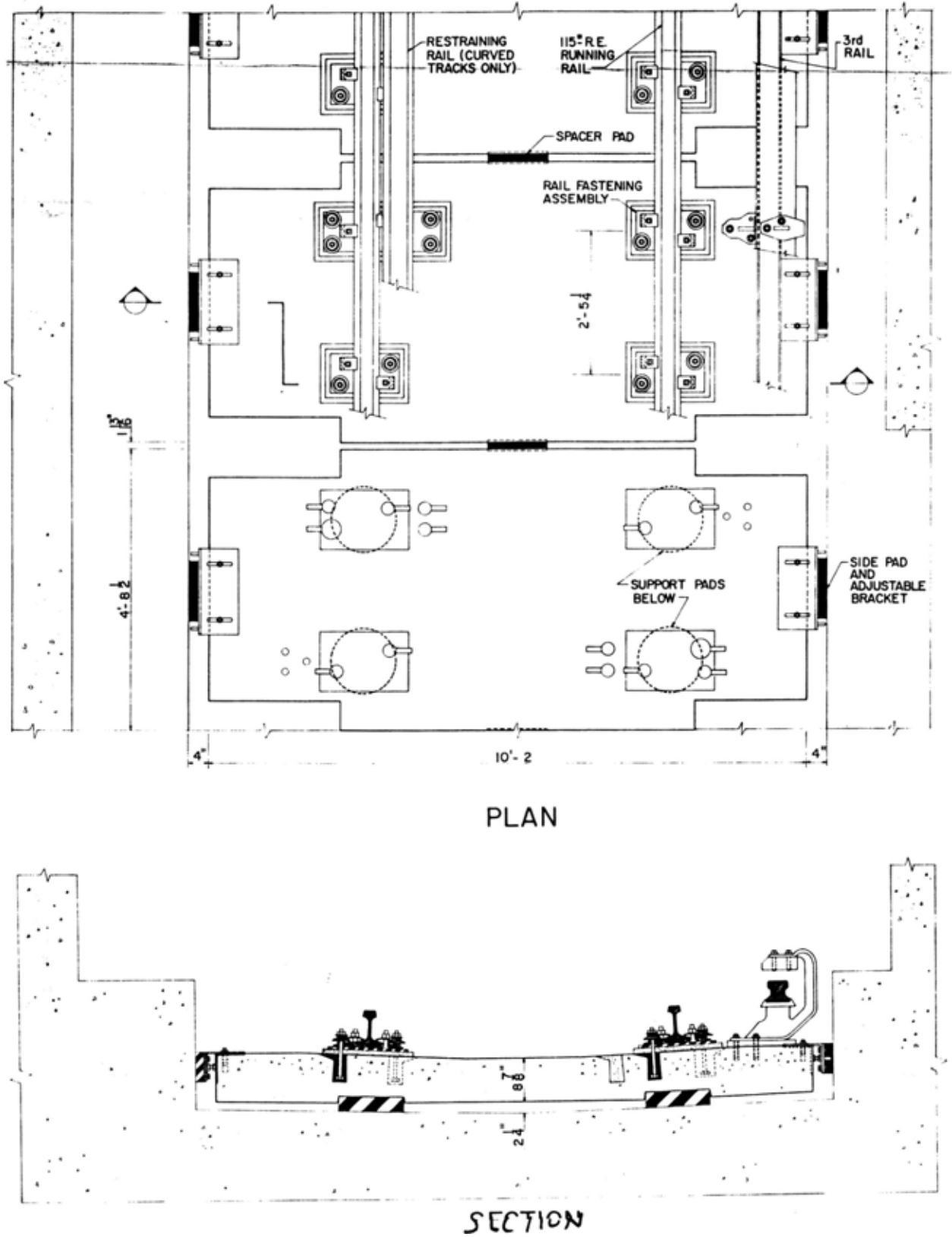


Figure 9.1.4: Mass-spring track system tried out in Toronto



Drilling and grouting installation methods, although cheap to carry out, have proven to be expensive to maintain and have poor noise attenuation.

Mass-spring systems on the other hand have excellent noise attenuation and over the short period during which they have been in use, seem to have a better maintenance record, but the cost of construction is about four times that of drilling and grouting.

Systems using a second pour method lie somewhere in between the other two types in cost of installation and in noise attenuation, but their need for attention to rail fastenings after laying is much lower. The second pour method involves the laying of the rails to line and level on temporary supports, mounting the fastening devices on the rails, then forming up and pouring the concrete around them.

The traditional North American method of supporting grooved girder rail for paved tracks by spiking to regular wood ties and embedding the whole structure in concrete proved to be expensive in maintenance not to mention extremely noisy due to its rigidity. Modern construction in pavement calls for a 250 mm concrete track slab, mesh reinforced, on which the rails are held to gauge by tie-bars. The track is then levelled with wedges and grouted with asphalt. Figure 9.1.5 shows the alternate use of pre-cast slabs and asphalt concrete for surfacing materials.

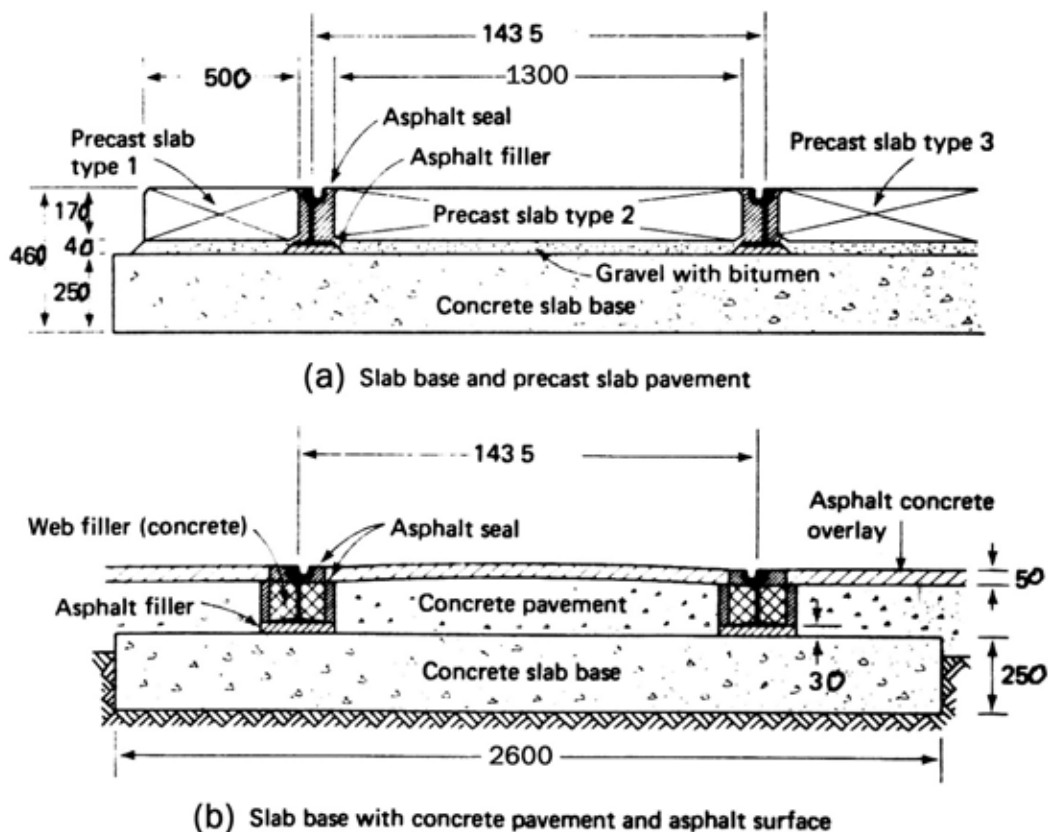


Figure 9.1.5: Flexible track construction in pavement

Where grooved girder track is being laid on the line of existing pavement such as in Figure 5.7.9 or to replace a former busway, it may simply be asphalt-grouted using the existing pavement as a foundation providing the surface is intact and reasonably level. The most important factor in keeping down the cost of maintenance of track in pavement is to allow vertical differential movement between the rail and the paving while at the same time excluding water penetration into the area between the foot of the rail and the foundation. Modern mastic sealants provide excellent performance in this regard and have gone a long way towards making track in pavement maintenance free.

## 9.2 Rail Section

The relatively light loads produced by transit vehicles (10 tons per axle versus 18 tons for main line railways) allow the use of rail of 80 lbs. per yard (40 kgm/m) or over. Many of the established systems use 80, 85 and 100 lb. sections.<sup>11</sup> Since rails are purchased by weight, use of heavier sections can result in a significant difference in cost. A heavier cross-section may be indicated by negative return requirements, but the cost must be weighed against alternate solutions, such as the addition of a negative feeder in the form of a cable or of worn rails laid between the running rails and bonded to them at intervals.

Use of 115 lb. rail rather than 100 lb. results in a cost increase of 15%, and while 100 lb. rails may be becoming obsolete in North American main line railway practice, they are still in demand for export markets. With the cessation of production of 100 lb. rails if such should occur, new 115 lb. rail can be readily joined using compromise splices. Long term availability and compatibility are very minor factors in the selection of rail sections. The reason given for going to the 115 lb. section on the Toronto subway was noise attenuation, a factor which is of little consequence when quiet light rail vehicles are used.<sup>19</sup>

80 or 85 lb. sections are adequate for yard tracks and are readily available in relay quality.

The choice of a rail section for track in pavement, which incorporates a flangeway has a bearing on wheel profile and the choice is generally between U.S. rails produced for use in dock and factories and the standard European sections. Due to the fact that North American rails are designed for heavy duty applications, the European sections, such as the Ri60 section used in Calgary are more economical in cost besides being used for the purpose that they were designed.

Grooved girder rail can be used on tangent track and on curves down to 60 metres radius and as the outer rail on curves having a radius less than 60 metres. A modified girder guard rail is used as the inside rail on curves less than 60 metres.<sup>12</sup>

Where L.R.T. right of way is shared with buses, mixed traffic or pedestrians, grooved girder rail is essential. Consideration should also be given to employing it at intersections and road crossings

since its use enables the entry of water into the roadbed to be prevented, with virtual elimination of the considerable maintenance costs incurred by mud-rail crossings.

### 9.3 Heat Treated Rails

Heat treated rail may be used on main line curves of small radii, and should be especially considered for areas where maintenance is difficult.<sup>2</sup>

### 9.4 Rail Joints

Rails may be joined by mechanical or welded joints. Since the early days of rails, mechanical joints have been a major source of maintenance problems and should be avoided on main tracks. Modern practice dictates the welding of rail into continuous lengths which in turn calls for improved fastenings and better roadbed. Welded joints may be done in the shop to produce strings of rail about 400 metres long, or done in the field by the alumino-thermite process. Shop welding is generally recommended as producing better alignment, however no process is better than the equipment and the operative, and strict attention to quality control is required for either process. All welded joints should be checked for alignment and ultra-sonically tested for internal flaws before they are placed in service.

Welded track requires to be anchored in the vicinity of special work and separated from it by mechanical joints to prevent misalignment of components due to temperature changes.

### 9.5 Rail Fastenings

The use of welded construction demands that rails be held rigidly in alignment to resist the effects of temperature stress. In this context the traditional cut spike even with shouldered tie plates and hardwood ties is only marginally reliable. There are many modern rail fastenings in use across Europe and North America capable of increasing track stability and reducing maintenance costs. Perhaps the best known of these, and the one which has received widest acceptance is the Pandrol fitting, of which Edmonton already has experience. These fittings are supplied with different spring-rates according to the axle weight of the trains. Care must be taken to select the correct fastening otherwise rail rebound will not be absorbed and ties will be lifted leading eventually to "pumping" and undermining of the track bed.

### 9.6 Ties

Ties are either concrete or wood. Concrete ties hold the track more rigidly in place but their heavy weight makes handling during construction more difficult; in service they also tend to pulverize the ballast leading to track drainage problems. Wood ties are relatively light to handle and are resilient, resulting in a quieter ride. Under well drained conditions, the life of a treated hardwood tie is upwards of 40 years. A life of 50 years has been claimed for concrete ties, but there are no records to bear this out, on the contrary wholesale failures such as those which occurred in Chicago in the late 1960's and more recently on Canadian National tend to cast doubt upon the wisdom of departing from the tried and proven wood product.

## 9.7 Track Gauge

Standard gauge is 1435 mm measured 16 mm below rail head. No gauge widening should be allowed on curves. Any curve less than 190 m should have restraining rail with 50 mm flangeway.<sup>13</sup>

## 9.8 Restraining Rails

In a curve the flange of the leading wheel is forced against the outside rail and grinds away the inside of the rail head (side cutting); there is also the tendency for the flange to climb the rail. Both effects are minimized by the restraining (check, guard) rail which is fitted so that it contacts the back of the flange of the inner wheel to relieve the pressure on the outer rail.<sup>14</sup> There is an incidental saving on rolling stock maintenance in reduced flange wear; the restraining rail is usually set slightly higher than the running rail so that a greater area of the back of the flange comes in contact with it with corresponding decrease in the flange thinning rate. Some rapid transit systems use a restraining rail set on its side to allow for simpler adjustment and to be able to compensate for wear.

Restraining rails should be used on all curves of radius 190 metres or less and should be set 10 mm higher than the running rail.

## 9.9 Switches

The track switch is the means of readily diverting vehicles from one guideway to another. The common split switch is the main reason for the fact that conventional railway track principles have remained unchallenged for over 150 years in spite of proposals for monorails and other types of guideway.

Switches may be operated manually from switch stands of various types, by the vehicle in the case of trail-through and spring-return switches, and by various types of point motor. Whatever form of operation is used, there ought to be provision for manual operation in emergent conditions.

From an operating point of view switches are classed as "facing" when an approaching vehicle can take a diverging path, and "trailing" when an approaching vehicle merges with another path (Figure 9.9.1). Generally, facing switches require a point motor for main line applications, except where facing movements are always over the same leg when the installation of spring return mechanism will be more economical in first cost and subsequent maintenance. A trailing switch may be most economically designed using a trail-through switch stand which allows the vehicle to set its own route and yet remains ready to be thrown by hand if an occasional facing movement is required.

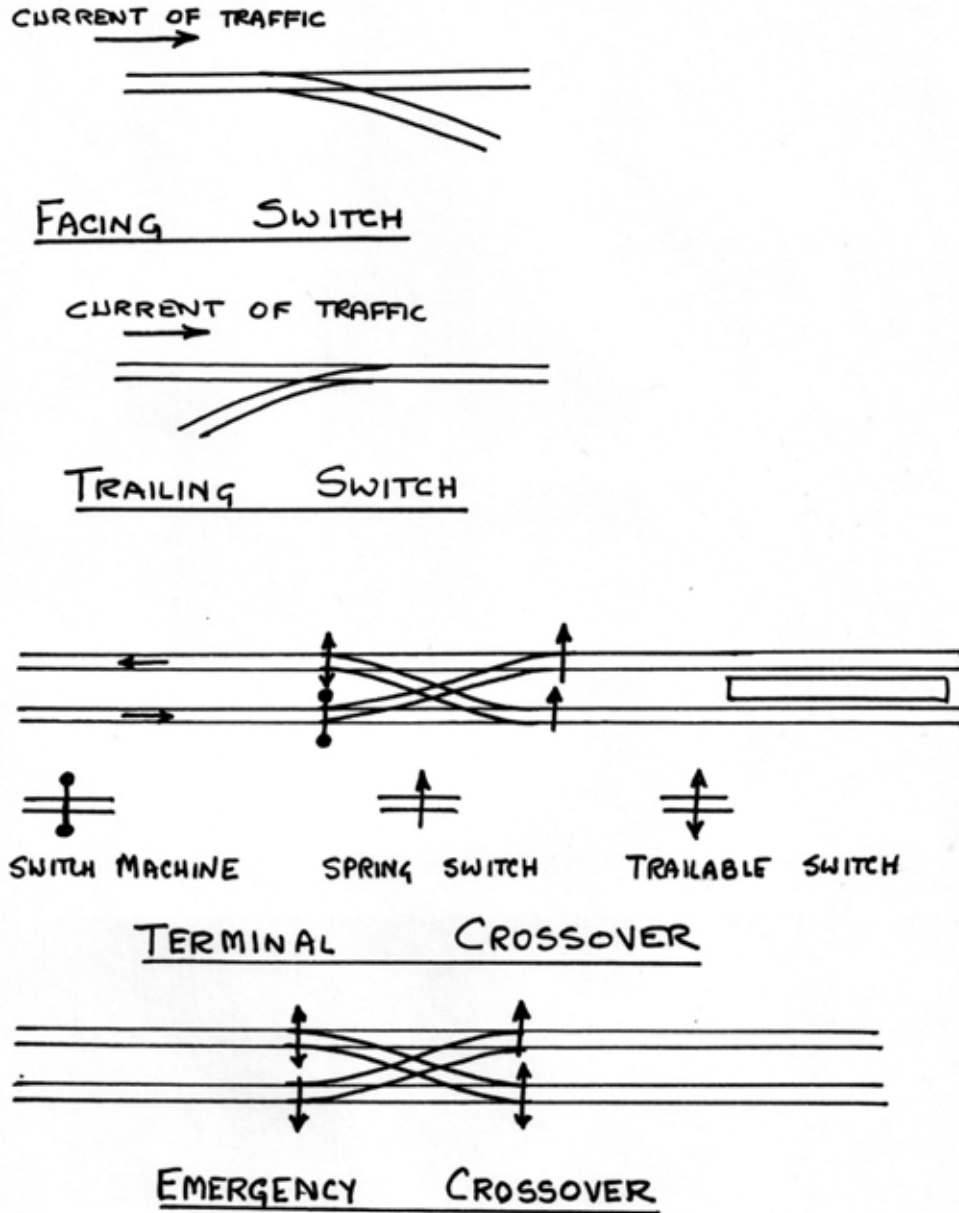


Figure 9.9.1: Switch types and methods of control

### 9.10 Crossovers

In train operation it is usual to provide double crossovers between tracks to allow trains to proceed onto the other track when reversing or to be diverted for single line operation around an obstruction. A double crossover consists of four switches and a diamond. Where this is used at a terminal location, or at a turn-back point, a switch machine is necessary to allow trains to enter either platform; departing movements can be accommodated with spring-return switches set for the right hand track, while the one trailing switch can be of the trail-through type. Intermediate crossovers which are used for emergency purposes only may have any of the four

switches called upon to act as a facing switch, but since they may be used perhaps once or twice a year, the expense of four switch machines which may present maintenance problems due to lack of use and constant bias of traffic in one direction can be avoided by using trail-through switches thrown manually for the duration of the diversion. The two normally facing switches would require to be spring-return switches set for the normal current of traffic.

### 9.11 Ramped Crossings

To avoid wear and noise at crossings and frogs a rising ramp can be added in the flangeway, lifting the wheel tread so that it crosses at normal rail level without dropping into the gap. This is general practice in Germany where light rail wheels are designed with flat flange profiles, but it has been tested successfully on British Railways with regular treads.<sup>17</sup>

### 9.12 Moveable Frogs

An alternate method of reducing wear and noise at switches is to use spring or swing-nose frogs. One of the latter type is shown in Figure 9.12.1. The complexity, cost and poor maintenance record of such installations makes them impractical for L.R.T. applications, although they have been tried on some German systems. The chief disadvantage of moveable frogs is that they cannot be trailed through which has been known to lead to derailment in emergent situations.

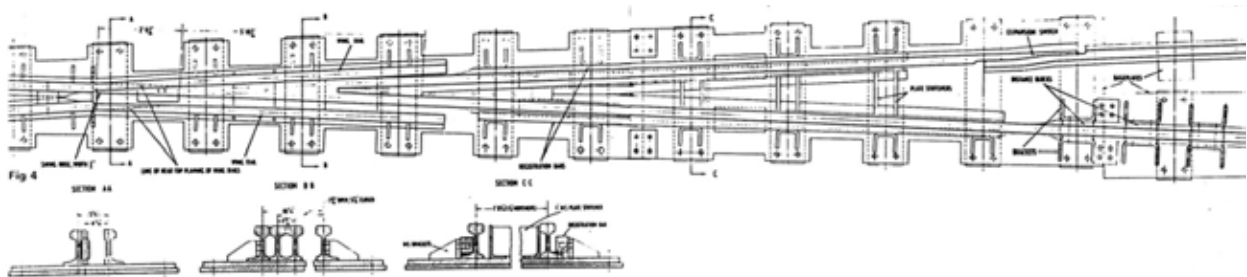


Figure 9.12.1: Swing-nose frog

### 9.13 Switch Locks

The purpose of switch locking is to prevent accidents occurring through a switch being set for the wrong direction either accidentally or deliberately. Where all switches are of the trailable type there is no need to provide this protection for trailing movements as the switch will respond to the vehicle. An unauthorized vehicle movement remains just that and must be dealt with as a signal or rule violation; adding a damaged switch due to its having been locked in position does nothing to enhance system safety.

Switch locking is required for main line facing switches to prevent unauthorized interference on the one hand and accidental operation during a train movement on the other. The former can be accomplished by lock on the manual activating mechanism of the switch which can be released by a key or electrically from central control, the latter case is provided for in conjunction with the signalling system, known as "interlocking".

### 9.14 Power Supply

The tendency of street railway and L.R.T. systems in North America has been to remain with the 550 to 600 D.C. voltage which was adopted when electrification commenced at the turn of the century, while a number of European systems have taken advantage of the better insulating materials now available to push up to 750 or 800 volts which is about the limit without major modification to existing equipment. Such an increase may lead to economies in future installation.

The development of solid state rectifiers have enabled substations to be reduced in size and cost to the extent that the problem inherent with D.C. traction of voltage drop in the conductor has been reduced by spacing substations closer together so that the transmission distance of the rectified D.C. current has been much reduced compared with the more economical transmission of A.C. The spacing of substations is discussed in Section 8.4.

Various overhead support systems are in use according to various maximum speeds, current demand and structural conditions. As with other aspects of L.R.T., tailoring the electrical distribution system to closely follow the actual needs of the system rather than laying down uniform standards can lead to significant economies in capital and maintenance cost as well as reducing visual clutter above the right of way. The design of overhead components, particularly poles and brackets and the placing of screening elements such as trees can do much to enhance the appearance of the track area.<sup>7</sup>

### 9.15 Single Overhead Conductor

The simplest design of overhead conductor has proved sufficient in most cases for speeds up to 50 km/hr. This was designed originally for trolley poles and uses a single conductor with more or less flexible supports at 30 m (100 ft.) intervals; both ends are anchored. Temperature change leads to a change in the sag of the conductor which must be compensated for by vertical travel of the pantograph.

A system which incorporates automatic tensioning guarantees a constant sag and may be used for pantograph operation at speeds of up to 70 km/hr. Earlier installations used a weight and pulley system to achieve this tensioning similar to the catenary system, but modern design achieves constant sag through support of the conductor by angular disposition of drop wires. The overhead is erected in zig-zag fashion between from support to support and expansion due to temperature change is accommodated by change in the angle of the hangers.<sup>8</sup> This is the type of suspension which is currently in use on trolley bus routes in Edmonton (Figure 9.15.1). It is the cheapest to construct and maintain and would be suitable for application to rights-of-way in categories C, D, and E when speeds are not likely to exceed 70 km/hr. because of constraints other than overhead design, and power demand is moderate. For heavy power demand such as might be experienced in the operation of four or five car trains over heavy gradients the simple type of overhead requires additional parallel feeders to augment its capacity; alternately a second conductor can be run parallel to one or both trolley wires.<sup>9</sup>

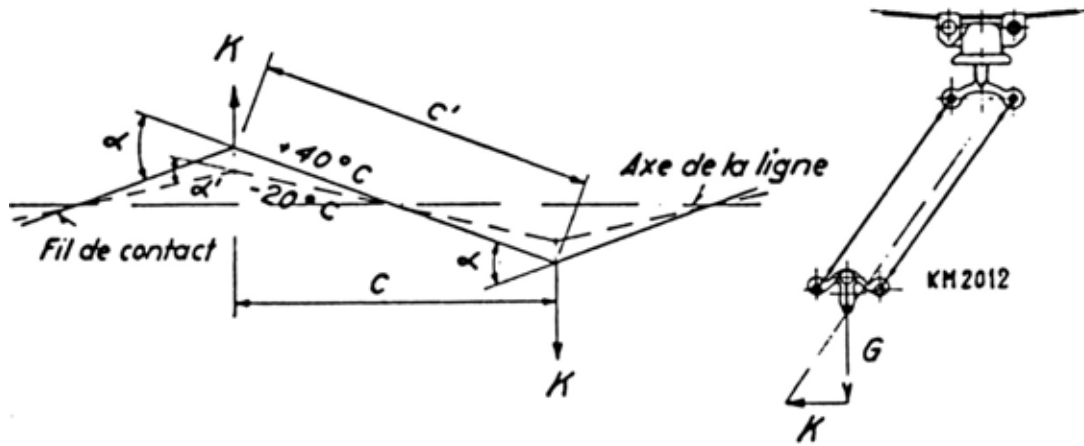


Figure 9.15.1: Single overhead conductor – Pendulum system

### 9.16 Catenary System

For lines that will be consistently operated by heavy trains at speeds of more than 70 km/hr., such as lines of categories A and B, a simple catenary system is specified. The full-length messenger wire serves to support the actual conductor as well as increasing the electrical conductivity by offering a larger cross-sectional area. Vertical drop wires between the messenger and the conductor are placed at relatively short intervals of 10 to 12 m in order to eliminate sag from the conductor and ensure good contact at high speed. The conductor is normally hung in lengths of about 500 m and tensioned by weights, whereas the messenger can be either anchored or automatically tensioned.<sup>9</sup>



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