3.2 DETERMINANTS OF TRAIN FREQUENCY

Introduction

There are three principle factors which combine to determine the maximum train frequency, or minimum headway, that can be achieved on a rapid transit system. The first factor is the size of the vehicle fleet, or the number of trains, which is available for revenue service. The second factor encompasses a broad range of technical characteristics of the vehicles and of the signalling system. The third and final factor is related to the operating environment. This factor includes the alignment of the transit system (such as the number and spacing of stations, the presence of grades, curves and special trackwork, and the configuration of terminal station facilities), operating rules and procedures, ridership levels, travel patterns and station dwell times. The foregoing factors are described, and their effect on train frequency is explained, in subsequent sections.

Fleet Size

The size of the vehicle fleet available for revenue service can limit the frequency of service that can be provided, independent of the minimum headway that can be achieved. In approximate terms, the number of trains required for service is equal to the time required to travel one complete round trip, divided by the desired operating headway. Clearly, if operating headway is to be reduced, additional trains will be required, unless round trip time can be reduced.

The round trip time is equal to the distance to be travelled, or route length, divided by the average speed attained. Route length is, of course, fixed, but average speed is a function of vehicle acceleration and braking characteristics, maximum speed, station spacing, and station dwell time. Unfortunately, average train speeds tend to decrease during peak periods because of heavier train loads and longer station dwells. Reduced average speeds tend to increase the round trip time, which in turn tends to wider train headways for a given operating fleet.

The length of trains also has an effect on service frequency. An increase in train length would widen the achievable headway, thus reducing the frequency of service which could be achieved. For the purposes of this study, train length has been assumed to be equivalent to six H-type cars, or about 450 feet (except as discussed in Section 3.3 "Vehicle Considerations").

Vehicle and Signalling System Characteristics

There are two performance characteristics of the operating vehicle fleet which directly affect the maximum train frequency that can be achieved. These are the acceleration rate and the braking rate achievable by the vehicles.

Vehicle acceleration rate is an important consideration, because it dictates how quickly a preceding train can clear a station platform and reach operating speed, thus permitting a following train to enter the station. In general, higher acceleration reduces the time to clear out of stations, and hence permits closer headway operation. However, acceleration rates must be consistent with passenger comfort requirements. Vehicles in the H and M series are capable of two distinct rates of acceleration. The standard (or low) rate is equivalent to that of the G-cars, and is used exclusively in the Toronto subway in order to provide consistent train performance. However, the H and M series vehicles are also capable of a "high" rate of acceleration. This high performance capability is unused in current operations, but is safely accommodated by the existing signalling system.

Braking rate capability of trains has two effects on minimum achievable headway. The first concerns the time required for trains to reduce speed and come to a stop in station platforms. Higher braking rates would tend to reduce this time interval; however, braking rates, like acceleration rates, must be consistent with passenger comfort requirements. The second effect of train braking rates is related to the safety of train operation. As explained below, the signalling system ensures that there is always a safe braking distance between consecutive trains in order to prevent collisions. Low braking rates require large braking distance allowances in the signalling system design, and hence greater train separation distances. This in turn results in wider achievable headways. The braking capability of the G-cars is less than that of the H and M cars, and is therefore utilized in the signalling system design in order to ensure safety.

Operation of a mixed fleet of H, M and G cars therefore imposes a two-fold penalty on achievable headway. In order to maintain compatibility with the G-cars, the H and M cars are operated at the standard (low) rate of acceleration. However, the high rate of acceleration of the H and M cars, and the lower braking capabilities of the G-cars must be used in order to produce a composite signal system design which safely accommodates all of the Commission's subway vehicles. As discussed in Section 3.3, the impending retirement of the G-cars presents an opportunity to consider introducing high rate operation. However, the penalty associated with the use of G-car braking characteristics in the design of the signalling system will persist even after the G-cars are retired (unless the signalling system is redesigned or replaced as discussed in Section 3.3).

The primary purposes of the signalling system are:

- to provide the train operator with advance information regarding occupancy of the track ahead thus allowing trains to safely proceed at the desired operating speed;
- to provide a means of ensuring that conflicting moves through crossover areas are prevented;
- and to provide a means of holding trains at terminal stations until the desired departure time, and at other locations where the need arises.

In order to accomplish the foregoing functions, the signalling system must be capable of detecting all trains or the route.

Trains are detected by dividing the track into electrically insulated sections known as "blocks". Electrical circuitry known as a "track circuit" is connected to each block. Trains are detected when the wheels and axles short-circuit ("shunt") an electrical voltage which is applied to the running rails. The location of each train is then determined based upon the occupancy status of each block. Entry to each block is controlled by a wayside signal at trackside, based upon the occupancy status of the blocks ahead. The wayside signals display a colour light indication or "aspect" (red, amber, green or certain combinations thereof) to the train operator, thus providing the operator with an indication of the status of the track ahead. The green aspect is the least restrictive, and the red aspect is the most restrictive. Obedience to red, or stop, signal aspects is enforced by an electromechanical device known as a "trainstop" mounted at trackside. Whenever a signal displays a red aspect, the associated trainstop is active, and will engage a lever on any train which passes the red signal, causing that train's brakes to be automatically applied. The aspect sequence, block length, and controlling circuitry are such that if a train, for whatever reason, passes a red signal at the maximum speed possible on that particular segment of track, that train will be automatically brought to a stop prior to the preceding train. In order to ensure safety, the signalling system design is based upon fail-safe principles and incorporates specially designed signalling components., Any failure of any component of that part of the system which provides safety will cause the system to revert to a state that is known to be safe. In addition, suitable safety margins are incorporated where necessary to ensure that safety objectives are met.

The method of signalling presently utilized in the Toronto subway is known as a "three block clearing system", due to the fact that under normal operation, there are at least three unoccupied blocks between consecutive trains with corresponding green, amber and red signal aspects. The minimum headway achievable with this system is therefore dictated by the time for a train to travel three blocks, plus a train length. An allowance, known as "sighting time", is included for signalling equipment operation and operator reaction times (15 seconds in the Toronto subway signalling design). In sections which include stations, additional time for deceleration, station dwell, and acceleration must also be included.

The minimum achievable headway can be calculated individually for each signal on the route. Such an analysis was performed by Transmode over a portion of the southbound Yonge Line which included Bloor Station. The results of the analysis indicate that the minimum achievable headway measured at individual signals is quite variable, largely due to differences in station dwell times. However, the minimum achievable headway over the entire route is determined by the maximum of the individual headway values for all signals.

Operating Environment

The alignment of a rapid transit system has a substantial effect on the minimum headway, or maximum train frequency, that can be achieved. The presence of numerous closely-spaced stations, such as in the downtown sections of the Y/U/S route, has a negative effect on average train speed and thus train frequency. Sharp curves and special trackwork (crossovers) also tend to reduce operating speeds. Steep downgrades lead to increased braking distances and hence longer signal block lengths, resulting in greater train separation distances and wider headways. In addition, the configuration and layout of terminal stations determines the time required to perform the turnaround operation. The minimum achievable headway at the terminal station can limit the achievable headway over the entire route, if the headway achievable at the terminal is greater than the headway achievable at the line stations.

Close headway operation at the terminal stations at Finch and Wilson is more difficult to achieve, compared to line stations, because of the necessity for trains to cross over to the opposite track (either entering or leaving the terminal), and because of the necessity to reverse train travel direction at the terminal station platforms. The minimum headway at the terminals is primarily dependent upon the time required for trains to traverse the crossover switches, which in turn is dependent upon the length and speed limit of the crossover. The length of a crossover is determined by the width of the track centres as well as by the type of crossover used. Wide track centres, necessary for centre platforms at the terminal stations, result in longer crossovers and hence wider achievable headways.

One simple method of avoiding the problems associated with close headway operation at terminal stations is to implement a short turn operation, as is presently done at St. Glair West Station on the Spadina Line. Under this scheme, turnaround operations are performed at both the short turn station, and the terminal station as detailed in Exhibit 3.2.1. The time available for turnaround operations at each location is approximately doubled, compared to single terminal operation. Of course, the level of service beyond the short turn station is halved, and a certain amount of passenger inconvenience is introduced. This type of operation is not desirable on the existing Yonge Line, as the only available short turn location is at Eglinton Station and passenger demand north of Eglinton Station necessitates very close headway operation. However, short turn operation at Finch would be possible if the Yonge Line was extended to a new terminal station.

Other transit systems utilize two further methods of avoiding close headway operation at terminals as shown in Exhibits 3.2.2 and 3.2.3. On some systems, two (or more) branch lines are provided at each end of a main route, with one terminal station at the end of each branch line. The headway on the branch lines would be half of the headway on the main route, if trains are alternately routed to each of the two terminals, and turnaround operations could be easily accomplished. Circular routes are also utilized on some transit systems, wherein turnaround operations are completely eliminated as there are no terminal stations. Both of the foregoing schemes would be feasible for the Y/U/S subway but would require lengthy subway extensions.

Ridership levels and travel patterns also have a significant effect on the maximum achievable train frequency. As previously noted, increased ridership tends to reduce average train speeds because of heavier train loads and extended station dwells. A reduction in average speed results in a reduction in train frequency for a given operating fleet, due to a corresponding increase in round trip time. The presence of a heavily used transfer point at Bloor Station results in excessive station dwell times, as large volumes of passengers leave and board trains, and hence imposes a substantial limitation on train frequency.