Single Bore Concept for Transit Tunnels

V. Nasri
AECOM, New York, USA

1. Introduction

The North American transit agencies are familiar with the application of the twin tube tunneling approach, as most of their recent subway extensions used this method of construction. At the same time, large bore tunneling has been used as the preferred method on multiple projects over the last two decades all over the world including Europe, Asia and elsewhere.

The primary feature of the single tube tunnel configuration for a transit line is that station platforms, crossovers and storage tracks are all accommodated within the tunnel cross section. As such, the location of each of these major elements can be adjusted along the entire corridor to maximize design efficiency and minimize construction impacts. Also, another key feature is that station structures would be located on either side of the street. This would allow for such structures, which are constructed using cut-and-cover method, to be built with minimal impact on traffic along the street. This is critical to residents, businesses and the general public.

The new transit lines are introduced as a means of alleviating traffic congestion and the associated noise and air pollution. But the traffic impacts, noise, dust and business disruption that would be generated by cut-and-cover construction along a highly dense corridor may be counterproductive to the objectives of these projects. Part of this disruption would also affect existing public transportation services during several years construction phase of the underground structures.

2. Placing the Stations inside the Running Tunnel

Since the beginning of the 90’s in many parts of the world, the design of new transit lines generally follows a typical configuration: first excavation of cut and cover stations as rectangular boxes using slurry walls as support of excavation, and then connecting these boxes by a single tube TBM tunnel housing two side by side tracks.

The twin tube system which was preferred during the 80’s since it was considered to be easier to build and to generate less settlement, is nowadays abandoned. Aside from major geometrical constraints, the experience shows that the twin tube is clearly more expensive than the single tube. It should be noted that at the present time, a TBM with a diameter large enough to place two side by side subway tracks within it (external diameter of about 9.5 m) can be well controlled. The conventional mining method for subway tunnel construction is now almost abandoned because of the risks involved with construction crew and adjacent structures which is not totally controllable.

After multiple use of large diameter TBM for building double track side by side transit tunnels, the Spanish engineers decided to go farther and put the stations inside the tunnel by slightly increasing the TBM diameter. This revolutionary concept was applied to 28 km tunnel of the Line 9 of Barcelona Metro using a 12 m diameter TBM housing two stacked tracks [1].
The conventional twin tube tunnels with cut and cover stations construction is disruptive to vehicular and pedestrian traffic and requires significant construction costs to provide for temporary decking, special staging and phasing of the project and usually extends the construction duration due to the restrictiveness of worksite below the surface.

For the single tube option, since the platform is integrated within the tunnel, the remaining underground work at the stations is limited to access shafts and short connector tunnels. Station configuration can be developed to satisfy the transit agencies design criteria and requirements for vertical circulation, ventilation and fire/life safety. Each of the underground stations consists of a cut-and-cover entrance structure and ventilation shafts, which also serve as emergency exits. These excavations will be performed in one side of the street with no impact on the traffic and utilities.

The single tube solution will promote operation safety; in fact the internal slab will seal off the two platforms which will be behaving like two separate tubes with the possibility of closely spaced emergency stairs equipped with fireproof doors between the two tracks. Each platform acts as a refuge area for the other, with connection possibility at a much higher frequency than the actual standard safety requirement.

Platform edge doors solution can be adopted similar to other major cities like Paris, Singapore, London, Bangkok, Hong Kong, and Barcelona. The doors are physically separating the tracks from the platform enhancing safety in case of fire and reducing the psychological effect of the incoming train.

The access shafts can be equipped with high capacity elevators and emergency stairs. The elevators may be synchronized with train arrival, to minimize waiting time at the shaft bottom. The number of elevators per each shaft varies in function of the expected number of passengers.

Based on the studies performed by the author on several North American projects, the duration of construction is clearly shorter for the single tube option. The advance rates for both single and twin alternatives are comparable based on reported cases. In the case of single tube alternative, the platform structure can be completed just after the passage of the TBM. These studies also show that the estimated construction cost for the single tube alternative is clearly lower.

Some of the other advantages of the single tube option compared to twin tube include:

- Minimal construction disruptions on the street, as building the stations, entrances and other structures would be done outside the street right-of-way. Especially considering the large construction areas and muck disposal activity that would occur at each station location, associated with the cut-and-cover that would be required for the twin tube.

- Cost of disruption to businesses as a result of construction, including muck disposal, traffic and pedestrian reductions/restrictions. Cost of construction, especially considering the additional costs that would be associated with the hoarding, piling, decking, detouring, dewatering, utilities relocation and others at the stations.

3. TBM Selection

The worldwide growing need for efficient infrastructure systems encourages tunneling solutions, particularly by mechanized methods. The mechanized tunneling process offers a safe, settlement controlled alternative to other tunnel excavation methods. Innovative solution like the multipurpose use of the tunnel profiles is increasingly demanded. This requires large diameter tunneling technology. Mechanized tunneling with diameters of up to 16 meters is reliably controlled and compared to conventional tunnel construction is substantially faster and its limits are set by logistical issues such as mucking rather than by construction safety or financial concerns [2].

Figure 1 shows the increase in TBM diameter in recent years of one particular machine type (Mixshield) produced by one of the main TBM manufacturers. A dedicated TBM is usually designed for the specific
subsurface materials and conditions expected to be encountered on each project. The alignment is selected to provide at least one tunnel diameter of cover to the extent possible.

The development of underground technology using tunnel boring machines in recent years has reduced the potential differences between the EPB and Slurry TBM systems. A pressurized face machine is often recommended for use on the project. The contractor will have the option to choose either an EPB or a Slurry TBM. Figure 2 shows the change in tracks configuration from side by side at the portal to stacked at the station.

Figure 1. Increase in Mixshield diameter manufactured by Herrenknecht in the past two decades

For transit projects, a large diameter single tube tunnel (12 m to 13 m TBM diameter with about 15 cm annular grouting) can be considered to house both light rail or subway tracks in a stacked configuration. This solution which is similar to the recently completed Barcelona Metro Line 9 integrates station platforms, train storages, crossovers, bypass tracks, and ancillary rooms inside the single tube tunnel (Figure 3). Based on the existing experience, the construction cost and time and environmental impact of this concept is lower than the twin tube option.

Figure 2. Change in track configuration from side by side to stacked
4. Station Configuration

Stations for single tube tunnel consist of 3 separate functional elements:

- Stacked side platforms
- Vertical circulation (entrances and emergency exit buildings)
- Fire ventilation units

The platforms are located within the single tube tunnel itself, one at each level, to one side of the running tunnel. Essentially the station consists of side platforms stacked one atop each other within the tunnel structure to provide consistent access to the vertical circulation elements (Figure 4). As such, a single point of entry/egress to/from both platforms can be located anywhere along the length of the platform(s). In addition, the stacked side platforms can be located to the either side of the running tunnel within the tunnel depending on the preferred location of the main entrance building.

Vertical circulation structures include a main entrance building and at minimum, one emergency exit building, each located at either end of the station. These structures are separate entities connected to the single tube tunnel and platforms via individual pedestrian adits.

The main vertical circulation can include two sets of escalators (one up, one down, 1.6 m each), stairs (2.4 m) and an elevator (2.5 m). Due to the depth of the station platforms, an additional escalator can be included to accommodate faster passenger access between the platforms and the street (Figure 5).

The emergency exit building provides egress from each of the platforms and would include fire doors at each platform level to secure a safe access route to the surface.

Fire ventilation units (FVU's) are required, one at each end of the station beyond the platforms. For the purpose of this study, standard FVU's applied in the transit systems have been used, stacked atop one another beyond either end of the platform. This allows for all vertical circulation and fire ventilation elements to be consolidated into single or adjoining structures reducing the number of footprints required (Figure 6). As such, ventilation shafts can be raised higher, beyond street level to avoid impacts during smoke discharge.

Station design initiatives from other single tube tunnel studies had investigated options for staggering the side platforms within the tunnel, each to opposing sides of the subway or LRT running tunnel. The staggered platform layout was intended to provide direct access from each platform to both sides of the street above. The design investigations can reveal that staggered side platforms within the single tube tunnel would require a complex combination of mezzanines and pedestrian tunnels outside of the main tunnel to connect the platforms with one another and any vertical circulation to the street. This complexity would not only necessitate far more elevators and escalators but also lead to disorientation amongst passengers attempting to connect between the platforms and the street.

The ability to combine FVU's with vertical circulation into a single or adjoining structures reduces the number of structural components required. Albeit larger in size, ideally the station requires only two vertical structures:

- Main entrance building with adjoining FVU
- Emergency exit building with adjoining FVU

These structures exist independently of the single tube tunnel (horizontal structure) and can be located anywhere along the length of the station platform but must always be located on the same side of the tunnel as the platforms. The platforms also exist independent of any site constraints since they are within the single tube tunnel and can be located anywhere along the horizontal alignment limited only by natural topography (slopes) and associated track work. In addition, due to the larger diameter size, the stacked platforms can be located on either side of the single tube tunnel. This versatility in sitting individual elements allows the main entrance building to be located at a preferred location, typically at an
intersection allowing direct connection to surface transit routes. The location of the entrance building will determine the location of the platforms. Opportunities exist for satellite entrances to be located in the immediate vicinity (either side of the street) and connect via pedestrian tunnels to the main vertical circulation building.

![Diagram of single tube tunnel for LRT project](image)

**Figure 3. Example of cross section of the single tube tunnel for a LRT project (lengths shown in mm)**

Construction of the platforms occurs within the tunnel structure which has no impact on adjacent properties or surface activities. In addition, the continuity and independence of the tunnel from the vertical structures allows for increased capacity with ability to lengthen the platforms without additional impacts. As an example, the platforms could be constructed at 64 m lengths for a 2-car train and then in the future extended to 96 m for a 3-car train. Additionally, should demand warrant, these platforms can be extended even further, limited only by the vertical alignment constraints and special track work.

The combined structures of vertical circulation and fire ventilation can be constructed independently from the single tube tunnel. These structures can be constructed prior, during or after tunnel boring operations without impact on street level activities. The impacts will be similar to that of any surface building structure affecting only the immediate sidewalk or curbside lane depending on the size of setback(s). Once both the tunnel and vertical circulation structures have been completed, connections between the two elements can be mined.

In all situations, construction of the entrance and emergency exit buildings along with tunneling operations can occur with no impact on day-to-day surface activities. As such, vehicular and pedestrian traffic can flow unimpeded especially at intersections making it ideal for high density areas.
The vertical circulation structure is based upon local building code standards to determine minimum spatial requirements. The depth of a single tube tunnel and associated platforms may not be conducive for passengers' perception in comfort and safety when implementing engineering minimums. Passenger safety and comfort is directly associated with visibility. Visibility from the entrance building, down the vertical circulation structure and through to the platforms can be highly constrained when using engineering minimums typically applied for shallow or deep stations.

**Figure 4. Single tube station platform**

The design and functional layout of a single tube station are different from the typical centre platform arrangement found at many of the subway stations. The emphasis on connectivity and accessibility in twin tube stations is on horizontality versus verticality in single tube stations. Passenger accessibility for single tube stations should not be perceived as a drastic departure from that for twin tube, since the vertical circulation structure is more similar to that found in buildings especially office towers or shopping centers with multilevel atria.

The perception of depth is a social and psychological factor that is premised upon the volumetric confines within which a person either feels forced or choosing to enter. The ability to see where one is travelling to is an important criterion affecting people's perception of depth and safety. Designing the vertical circulation shaft in a single tunnel station to be spacious and open is equally as important as managing direct and well lit access from individual entrances to a mezzanine or concourse level in twin tube stations.

The introduction of an atrium-type space within the vertical structure would greatly increase visibility between levels and allow passengers to not only see where they are going and want to go but also assists in reducing the perception of depth and distance. Atria have been highly successful in higher
density developments of all types, worldwide. The application of an atrium-type volume would allow the vertical circulation structure to function as the backbone for ancillary underground passages to adjacent properties especially in high density downtown areas.

Figure 5. Single tube station 3D view

Figure 6. Single tube station entrance and FVU configuration
The single tube tunnel concept can be made compliant with all the requirements of the latest version of NFPA 130 and other local codes. Stations will be designed to be evacuated within four minutes with all passengers reaching full safety within six minutes. This is an easily achievable goal given the excellent location potential of fire separations in the structures immediately beside the platforms of the single tube tunnel. It is reasonable to consider the single tube tunnel performs more safe in this regard as fire separations can be placed anywhere along the platforms in the connections to the vertical transportation elements.

5. Conclusion

In this paper, two TBM tunneling methods for transit projects are compared. The alternatives considered in this evaluation are:

- Twin tube alternative – two conventional size TBMs for excavating two running tunnels and cut-and-cover tunneling method for the construction of underground stations and crossovers;
- Single tube alternative – one large diameter TBM for excavating one running tunnel which includes all the stations and crossovers.

These alternative tunneling methods were studied as part of the Environmental Impact Studies for several North American transit projects to determine the most cost-effective method of construction.

Construction staging and maintenance of traffic is determined to be more favorable for the single tube alternative. Major cut-and-cover operations for the twin tube option will result in difficult construction conditions in congested areas along the street. Environmental impact in general is again more favorable towards the single tube alternative.

Over the past twenty years the TBM technology has continued to evolve around the world where TBMs with diameters greater than 12 meters have become common. Conceptually, the primary feature that would make single tube the preferred configuration is that the running tracks, station platforms and ancillary spaces are all contained within a large diameter tunnel. As such, provisions for station entrances, ventilation shafts, etc. can be taken “off alignment” of the tunnels and greatly reduce the need for roadway and intersection disruptions at the surface as would be required with cut and cover construction.

The time savings in construction of the single tube are realized mainly from the construction of the stations. Both the time savings and minimization of roadway right-of-way disruptions, due to cut and cover construction, translate into significant construction cost savings and much more manageable public relations effort.

Given the significant cost savings, overall shorter project construction time, simpler station design and construction with significant less surface disruption and reduced need for complicated cut and cover maintenance and protection of vehicular and pedestrian traffic, the single tube tunnel solution can be considered as a serious alternative in the study of transit projects.

References
