

Dulles Corridor Metrorail Project

**Review of
Large Bore Tunnel
Engineering and Environmental Studies
from Tysons Tunnel, Inc.
Jan. 22, 2007**

Prepared by Carter & Burgess, Inc.

**In association with
Hatch Mott MacDonald, LLC
Lea+ Elliott, Inc.
Gannett Fleming, Inc.**

02/26/2007

TABLE OF CONTENTS

GLOSSARY OF ACRONYMS

EXECUTIVE SUMMARY	1
1. INTRODUCTION.....	2
2. DOCUMENTS REVIEWED.....	3
3. SUMMARY OF PROPOSED LBT ALTERNATIVE	3
3.1 HISTORICAL PROGRESSION OF TRANSIT DEVELOPMENT AND HOW IT RELATES TO TYSONS CORNER	4
3.2 BENEFITS OF THE LARGE BORE TUNNEL ALTERNATIVE THROUGH TYSONS CORNER	5
4. GEOLOGIC CHARACTERIZATION.....	6
4.1 GENERAL UNDERSTANDING OF GEOLOGY.....	6
4.2 GROUND CONDITIONS NOTED IN THE BORINGS AND PROFILE	6
4.3 PROFILE OF GROUND CONDITIONS ALONG ALIGNMENT	7
4.4 AMOUNT AND DISTRIBUTION OF EXPLORATION	8
4.5 MIXED FACE CONDITIONS	9
4.6 ROCK TYPE, STRENGTH AND STRUCTURE	9
4.7 SOIL MATERIALS	10
5. LARGE BORE TUNNEL.....	10
5.1 THE DEVELOPMENT OF MECHANIZED EXCAVATION.....	10
5.2 TUNNEL DESIGN APPROACH	12
5.3 TBM GROUND BEHAVIOR	12
5.4 POTENTIAL FOR GROUND SETTLEMENT.....	13
5.5 COST CONSIDERATIONS.....	13
5.6 SCHEDULE CONSIDERATIONS.....	14
6. STATIONS	17
6.1 DESIGN APPROACH.....	17
6.2 GROUND BEHAVIOR	17
6.3 BREAKOUTS FROM TUNNEL	18
6.4 NATM TUNNELING	19
6.5 POTENTIAL FOR GROUND SETTLEMENT.....	20
6.6 CASE HISTORIES	20
6.7 COST AND RISK CONSIDERATIONS	20
6.8 SCHEDULE CONSIDERATIONS.....	20
6.9 VENTILATION/MEP	21
6.9.1 Tunnel Ventilation System Sizing.....	21
6.9.2 Ventilation Shaft Sizing	21
6.9.3 Station Platform Space Provision.....	22
6.10 PLATFORM EMERGENCY EGRESS ANALYSIS.....	22
6.10.1 General Findings	23
6.10.2 Maximum Walk Distance “Leaving” the Platform.....	23
6.10.3 Time to Clear Platform.....	23
6.10.4 Time to Reach a Point of Safety	24
7. CONSTRUCTABILITY/STAGING	24
7.1 SEGMENT STORAGE	24
7.2 MUCK/STORAGE REMOVAL.....	25
7.3 TRUCK ACCESS.....	26
8. OVERALL SCHEDULE ISSUES	26

8.1	DESCRIPTION OF LBT SCHEDULE.....	26
8.2	SCHEDULE ANALYSIS.....	27
9.	COST ISSUES	28
9.1	DESCRIPTION OF TUNNEL AT TYSONS, JV ESTIMATE.....	28
9.2	STATED POSSIBLE SAVINGS.....	29
9.3	POTENTIAL ADDITIONAL COSTS	29
10.	OTHER CONSIDERATIONS	30
10.1	OPERATION AND MAINTENANCE COSTS	30
10.2	REDEVELOPING TYSONS AS A PEDESTRIAN-FRIENDLY, TRANSIT-ORIENTED TOWN CENTER	30
10.2.1	Transit-Oriented Town Center	31
10.2.2	Pedestrian-Friendly Town Center.....	33
10.3	REAL ESTATE COSTS AND NECESSARY EASEMENTS.....	33
10.4	NEPA.....	34
11.	SUMMARY OF KEY RISKS	35
11.1	GEOTECHNICAL AND TUNNEL CONSIDERATIONS	35
11.2	STATION CONSIDERATIONS.....	36
12.	CONCLUSIONS	36
	APPENDIX 1 - LBT PROJECTS' PLANNED AND ACTUAL ADVANCE RATES.....	39
	APPENDIX 2 –CB SCHEDULES AND TUNNEL AT TYSONS JV CONSTRUCTION SCHEDULE.....	40
	APPENDIX 3 – LETTERS REVIEWED	49
	APPENDIX 4 - CORPORATE INFORMATION	80
	FIGURE 1 – TOTAL COST OF BORED TUNNEL ELEMENTS VERSUS ADVANCE RATE	14
	FIGURE 2 – METRORAIL STATION PHOTOS ERROR! BOOKMARK NOT DEFINED.....	32
	TABLE 1 – SCHEDULE IMPACT OF ADVANCE RATES AND PRODUCTION WEEKS.....	15
	TABLE 2 – OVERALL SCHEDULE ANALYSIS	27
	TABLE 3 – LBT STATION DEPTHS	333

GLOSSARY OF ACRONYMS

bpf	blows per foot	kW	Kilowatts
CB	Carter & Burgess, Inc.	LBT	Large Bore Tunnel
CEQ	Council on Environmental Quality	LPA	Locally Preferred Alternative
cfm	cubic feet per minute	MOT	Maintenance of Traffic
DRPT	Department of Rail and Public Transportation	MWAA	Metropolitan Washington Airports Authority
DIAAH	Dulles International Airport Access Highway	NATM	New Austrian Tunneling Method
DTE	Dulles Transit Engineers	NEPA	National Environmental Policy Act
DTP	Dulles Transit Partners	NFPA	National Fire Protection Association
EA	Environmental Assessment	psi	Pounds per square inch
EIS	Environmental Impact Statement	ROD	Record of Decision
EPB	Earth Pressure Balance	ROW	Right of Way
EPBM	Earth Pressure Balance Machine	RQD	Rock Quality Designation
FEIS	Final Environmental Impact Statement	SEIS	Supplemental Environmental Impact Statement
fpm	feet per minute	SMART	Stormwater Management and Road Tunnel
FTA	Federal Transit Administration	TBM	Tunnel Boring Machine
GFRC	Glass Fiber Reinforced Concrete	UCS	Uniaxial Compression Strength
GIR	Geotechnical Interpretive Report	UPE	Under Platform Exhaust
HVAC	Heating, Ventilation, and Air Conditioning	VDOT	Virginia Department of Transportation
JV	Joint Venture	w.g.	water gauge
		WMATA	Washington Metropolitan Area Transit Authority

EXECUTIVE SUMMARY

On January 22, 2007, Tysons Tunnel, Inc. submitted a Proposal consisting of engineering and environmental studies for construction of an approximately 3.4 mile-long, Large Bore Tunnel (LBT) through Tysons Corner for the Dulles Corridor Metrorail Project. The proposed LBT would be in lieu of an aerial route previously approved as the Locally Preferred Alternative (LPA). The Proposal concludes, among other items, that:

- The single-bore tunnel is cost-competitive with the aerial option, or possibly less expensive, and
- The single-bore tunnel can be constructed within 54 months, or six months faster than the aerial option.

At the request of the Virginia Department of Rail and Public Transit, a review of the Proposal and associated studies has been carried out by Carter & Burgess, Inc. (CB), including subconsultants Hatch Mott MacDonald, LLC, Lea+Elliott, Inc., and Gannett Fleming, Inc. The purpose of the review was to evaluate if the Proposal's conclusions are supportable based on the studies completed, and based on data from other TBM projects.

Due to insufficient geotechnical data, the areas of design requiring additional development, acknowledged areas where standards are not met, areas where life safety codes are not met, and the lack of detail supporting the cost and schedule estimates, the documents as presented are not considered at the 100% Preliminary Engineering level of completeness and are not biddable per Federal Transit Administration (FTA) or industry requirements.

Proposed Schedule

The LBT alternative has not been through the required public selection processes for consultants and bidders, environmental studies, public hearings, design completion and independent reviews, nor ongoing FTA reviews and sign-offs to be eligible for federal support. The 54-month project schedule indicated in the Proposal does not include these activities, nor does it incorporate the time required for additional drilling and geotechnical analyses.

In addition, the 54-month schedule is highly compressed. It is based on an overly optimistic average advance rate for the tunnel work and a 7-day work week. Using a more reasonable average advance rate and considering a 5-day work week produces a significantly longer construction schedule of 70 months. The 54-month schedule assumes concurrent tunneling activities for the stations, which represents a major risk to the proposed construction schedule.

Proposed Costs

The Proposal does not have a detailed, bottom-up cost estimate. It uses portions of the April 2006 estimate for the aerial alignment, which are not current. Therefore, the results cannot provide an "apples-to-apples" comparison of the aerial and large bore tunnel alternatives.

The cost information provided indicates assumptions of contingencies of 15% for the New Austrian Tunneling Method (NATM) Tunnel and 10% for the TBM Tunnel, which are low for this stage of project design. In addition, using a more reasonable average advance rate could increase tunneling costs by 14%, not including additional escalation from the longer construction schedule.

The overall conclusion is that the proposed single-bore tunnel through Tysons Corner may be technically feasible; however there are significant risks that the construction costs and schedule durations stated by Tysons Tunnel, Inc. will be exceeded. Underground construction presents

unique risks that are not typically encountered on other types of heavy civil construction. It is industry practice to evaluate any tunnel project's viability within a risk-based framework. This has not been done for the Tyson's LBT and it is not accounted for in Tysons Tunnel Inc.'s project planning and scheduling.

Additional effort is required to:

- Carry out additional subsurface exploration and testing
- Revisit designs, construction sequences, and associated costs and schedules to mitigate the risks reflected in the anticipated subsurface conditions, and
- Identify other elements including agency, owner/operator or local requirements, which could cause major scope increases during final design or construction.

1. INTRODUCTION

The Dulles Corridor Metrorail Project is a 23-mile-long extension of the existing Orange Line of the Metrorail system from just east of the West Falls Church Station to Route 772. Phase 1 of the project is 11.5 miles long and covers the section from east of West Falls Station to a station to be constructed along the median of the Dulles Access Road at Wiehle Avenue. Phase 2 is 11.6 miles long, extending from Wiehle Avenue to Route 772 and includes service to the Washington Dulles International Airport. A Final Environmental Impact Statement (EIS) approving the project was issued by the FTA in December 2004.

The Final EIS identified a Locally Preferred Alternative (LPA) for the transit project. The section of the LPA through Tysons Corner is mainly aerial and includes a relatively short (0.4 mile) tunnel under the Route 7 and Route 123 interchange and four elevated and at-grade stations. The Commonwealth recently oversaw completion of 100% preliminary engineering for the Phase 1 alignment and is in negotiations for final design and construction of Phase 1.

In fall of 2006, Tysons Tunnel, Inc., a non-partisan, not-for-profit, grass-roots organization consisting of civic organizations, businesses, homeowner associations and private citizens, funded a team of architectural and engineering firms to advance the design of a longer tunnel through Tysons Corner using a large-bore tunneling machine. The effort started in October 2006 and culminated with a submission of a Proposal including letters, drawings, reports and calculations on January 22, 2007. The Large Bore Tunnel (LBT) alternative proposed by Tysons Tunnel, Inc. has a length of 3.4 miles and covers the portion of the Phase 1 alignment through Tysons Corner.

At the request of the Director of the Virginia Department of Rail and Public Transit, a review of the Proposal and associated studies has been carried out by Carter & Burgess, Inc. (CB), including sub consultants Hatch Mott MacDonald LLC, Lea+Elliott, Inc., and Gannett Fleming, Inc. The purpose of the review was to evaluate if the Proposal's conclusions are supportable based on the studies completed, and based on data from other TBM projects.

2. DOCUMENTS REVIEWED

The reports and drawings reviewed were presented by Tysons Tunnel, Inc. as documents at the Preliminary Engineering level. Tysons Tunnel, Inc. has carried out a substantial effort in support of their 3.4 mile LBT alternative, including 786 engineering and architectural drawings, supplemental technical specifications, and related technical studies. They retained Tunnel At Tysons, JV, consisting of ARUP, Dr. G. Sauer Corp., KGP Design Studio, and a number of sub consultants.

The documents provided by Tysons Tunnel, Inc. and reviewed are as follows:

Drawings: Preliminary Engineering Drawings - Volume 1
Preliminary Engineering Drawings - Volume 2

Reports: Environmental Analysis Report
Basis of Design Report for Preliminary Engineering
TBM Tunnel Report
Mined (NATM) Tunnel Design Report
Geotechnical Interpretative Report (GIR)
Instrumentation and Monitoring Program Report
Structural Report for Cut & Cover Facilities
Maintenance of Traffic (MOT) Report
Utility Assessment Report
Life/Fire/Safety Report
Tunnel Ventilation and Smoke Report
Accessibility Compliance Report

Calculations: Structural Calculations for Cut & Cover Stations
Structural Design Calculations for E and W Boat Section & Portal
Structural Calculation for Elliptical Shaft Design

Specifications: Addendum to WMATA and DTE Standard Technical Specifications

Letters (copies included in Appendix 4):

West Group to Gov. Kaine, January 31, 2007
Tunnel at Tysons JV to Scott Monett, Tysons Tunnel, Inc., Jan. 30, 2007
Dragados USA and ACS Infrastructure to Gov. Kaine, February 1, 2007
Tunnel at Tysons JV memo to Sam Carnaggio, February 1, 2007
FTA letter to Reps. Moran and Davis, January 26, 2007

3. SUMMARY OF PROPOSED LBT ALTERNATIVE

The LBT alternative covers a 3.38-mile long segment of Phase 1 of the Dulles Corridor Metrorail project. It is currently designed with an outside diameter of 43.3 ft and is supported by a single pass pre-cast segmental lining of 18 inches thickness, which leaves an inner diameter of 40.3 ft. This large diameter allows station platforms and transit crossover structures to be contained within the tunnel cross section. The design does not comply with WMATA's past practice of

requiring a two-pass tunnel liner system that provides enhanced protection against tunnel leakage.

The horizontal alignment is similar to that proposed for the LPA. Station locations along the alignment will be similar to those contemplated in the FEIS for the LPA. Station entrances are planned to be at street level and vertical access will be provided by a mezzanine below grade. Access from the mezzanine to the platforms within the large bore tunnel will be provided by escalators and elevators. Each station has two entranceways providing access from both sides of Route 7 for the Tysons West and Tysons Central 7 Stations, and from both sides of Route 123 for the Tysons Central 123 and Tysons East Stations, respectively. The stations have a stacked geometry, with the platform serving the outbound track below the inbound platform. The depth of the stations measured from top of ground to the outbound platform ranges from 61 to over 107 feet.

Rooms for systems operating equipment are proposed to be located beneath the mezzanine level, as well as in subsurface facilities at the combined emergency access/egress and ventilation shafts planned at both ends of each station. The concept also suggests that the only discernible evidence of the Metro station at street level would be the canopies at the two entranceways to the mezzanine and the shuttle bus loops. Vent shafts would also be visible.

The Proposal describes several differences between the LBT alternative and the LPA. The Proposal concludes, among other items, that:

- The single-bore tunnel is cost-competitive with the aerial option, and
- The single-bore tunnel can be constructed within 54 months, or six months faster than the aerial option.

3.1 HISTORICAL PROGRESSION OF TRANSIT DEVELOPMENT AND HOW IT RELATES TO TYSONS CORNER

In a developing urban center such as Tysons Corner, space has a premium value. Working and living areas compete with transportation and utilities networks. As the population density increases, the need to use the ground level for local vehicular and pedestrian traffic tends to push other transportation modes above or below the street. As an urban center evolves, the best transportation system is likely to change.

In most urban centers, the initial public transit mode employs buses operating in mixed traffic. As traffic increases in the urban center, this mixed-traffic operation becomes slow and unreliable. The solution to this increased congestion requires some reduction of the interference between the transit system and other travel modes. While there are “at grade” systems, the most effective approaches require relocation of the transit system above or below the street level, especially in narrower corridors.

There is a consensus among urban and transit planners, that relocating the transit system underground is desirable if cost is not a primary issue. Once construction is completed, a subway’s impact on the growth and development of the city relates only to the surface locations of station entrances. Visual and noise impacts as well as the physical barrier created by the aerial guideway are essentially eliminated.

As in the case of the Dulles Corridor Metrorail Project, cost is almost always a primary issue. Construction of a subway has historically been more expensive than an elevated guideway. For that reason, the evolution of many transit systems has been from surface to elevated to below grade. In recent decades, numerous rail transit systems have been built at-grade with features to mitigate traffic impact rather than incur the cost of bored or cut-and-cover tunnel. In a few cities such as Washington, D.C., Atlanta, and Los Angeles grade-separated alignments have been used for the initial phase of the transit system. In these systems, subways were constructed primarily in the urban centers, with elevated and surface travelways in other areas.

The decision to build an underground transit system, or to replace an elevated guideway with a subway, is driven by many factors. Many of these are external to the transit system, such as roadway capacity and interchange needs or the desire to achieve open “urban landscapes.” Cities such as Boston, New York, Pittsburgh, and San Francisco have relocated surface and/or elevated transit lines into subways to ease surface congestion and to enhance the appearance of the city.

Tunneling technology has made substantial advances in recent years, with improved control of ground movements, larger diameter excavations, improved mechanization, and more cost effective one-pass segmental lining systems. Bored and mined tunnels generally have limited impact on the surface, making them more desirable for construction in dense urban centers. In spite of these developments, tunneling continues to be more expensive than surface or elevated guideways.

The cost of constructing a subway is justified in areas where congestion is severe and other solutions are not feasible. The benefits of choosing to build a subway instead of an at-grade or aerial alignment must be weighed against the added cost and increased risk associated with a tunneling solution.

3.2 BENEFITS OF THE LARGE BORE TUNNEL ALTERNATIVE THROUGH TYSONS CORNER

The LBT alternative has several advantages over the aerial LPA. A partial list of benefits includes:

- Less noise from the operating transit system
- Less disruption and somewhat less noise during construction
- Potential for no conflict with I-495 High Occupancy Travel lanes and the Route 123 Interchange
- Greater flexibility for local changes to the Leesburg Pike (Route 7) cross-section or relocation of its vertical alignment
- Fewer utility relocations
- Slight re-alignment of guideway that eliminates tight radius curves and lessens the maximum vertical grades
- Controllable environment for passengers
- Elimination of sight line obstructions except at station headhouses, ventilation shafts and possibly traction power substations depending on the design
- Eliminates the visual impact of the aerial guideway and elevated stations on the landscape.

4. GEOLOGIC CHARACTERIZATION

Tyson Tunnel, Inc. did not perform any borings as part of this engineering and environmental study. They relied on the analysis of existing borings that were performed for the LPA alignment.

The Geotechnical Interpretive Report (GIR) submitted by Tunnel at Tysons, JV “provides general interpretations of the available geotechnical data, subsurface conditions, groundwater conditions, a summary of how these assumed conditions affect the project design, and discussions of other design and construction considerations that will affect the work. The interpretations are based on the Geotechnical Evaluation Report submitted by Dulles Transit Engineers (DTE), JV on February 17, 2006.”

The current extent of subsurface exploration and laboratory testing is insufficient for a project of this magnitude and complexity. Additional exploration and testing are required to fill the gaps that currently exist along the tunnel alignment and down through the tunnel horizon.

4.1 GENERAL UNDERSTANDING OF GEOLOGY

The site geology consists of the Piedmont formation which is composed of schist, granite, and phyllonite bedrock. Overlying the bedrock is a gradational zone of decomposed rock and residual soils, and then varying combinations of silt, sand and clay near the ground surface. Fill, which consists primarily of granular material, is present at the surface in nearly all borings.

Geotechnical borings have been performed throughout the project site during the NEPA phase and during preliminary engineering of the LPA. These borings are considered insufficient to complete a level of tunnel design that can be used to conclude the selection of a tunnel boring machine (TBM) and arrive at a credible estimate of the TBM advance rate. The major geological and geotechnical factors that pose a high level of uncertainty to the current design and estimates of schedule and cost are described later in this section.

4.2 GROUND CONDITIONS NOTED IN THE BORINGS AND PROFILE

The ground conditions along the alignment can be characterized according to the following materials:

- Fills are prevalent overlying the soils. Described as clayey silts, gravels, crushed stone, rock fragments, and organic materials having erratic SPT values ranging from 2 to 42 blows per foot. This is of particular relevance in the area of the Tyson East Station where limited cover and the presence of the Scotts Run culvert require careful consideration of the geology.
- Alluvial sands and gravels: *not noted in borings or profile*. The potential for old stream valleys intersecting the tunnel envelope that might contain such materials should be evaluated. For example, Scotts Run culvert is located close to the tunnel crown and there is the potential for alluvial materials to extend into the tunnel profile.
- Residual soil: predominantly described as silt, typically ranging from silty sand to clayey silt. Percentage of fines for most samples is high, typically above 40%.

- Decomposed rock (D): The decomposed rock is gradational, varying from near-soil like materials in upper zones to near-rock like materials at greater depths. The geotechnical information indicates that hard, un-weathered rock zones remain within the decomposed material. (Standard penetration resistance > 100 blows per foot (bpf)) (D1 to D3).
- Rock (R) and Rock Quality Designation (RQD): foliated schists, gneisses and phyllonites, ranging from weathered and closely jointed or sheared Rock (R1 - RQD < 25) to rock that is unweathered and not closely jointed or sheared (R3 – RQD > 75). Borings show that weathered (R1) and unweathered rock (R3) are both commonly found within the upper 10 feet of rock.

4.3 PROFILE OF GROUND CONDITIONS ALONG ALIGNMENT

One of the characteristics of a ground profile created by in situ weathering is that the materials, including residual soil, decomposed rock, weathered rock, and rock, can change abruptly from one extreme to the other within a few feet. For example, pre-existing shear zones and concentrations of joints allow the passage of groundwater, and therefore weathering and decomposition, to extend to greater depths than would occur in the adjacent, more intact bedrock. The result is that so-called decomposed rock zones can contain corestones or remnants of un-weathered rock.

Most of the tunnel will be driven in a mixed face of some combination of residual soil, decomposed rock, and rock, whose proportions can change rapidly within a few feet. Based on the information presented in the Proposal, the CB Team divided the LBT alignment into a series of “reaches”. Each reach is described according to their approximate stationing, their discernable characteristics, and likely tunneling conditions and concerns:

Reaches of Residual Soil Overlying Decomposed Rock (D) Overlying Rock (R)

Station 1035+00 to 969+00 (6600 ft), Station 922+00 to 857+00 (6500 ft).

The most common condition that will be encountered in the tunnel face is decomposed rock, often in a mixed face with residual soil above and weathered to unweathered rock below the decomposed rock. Through at least half of these reaches residual soil will be present at the crown, in some cases extending down to springline. Additionally, approximately half of the ground in these reaches is expected to contain relatively unweathered, hard rock in and above the tunnel invert, in some cases extending above tunnel springline.

In these ground conditions, the ability to develop a paste from the muck suitable for Earth Pressure Balance (EPB) operation will depend on the percentage of residual soil and decomposed rock capable of being broken down into soil. For significant portions of the reaches, residual soil will be absent, so that the decomposed rock must be relied on to provide the fines.

Rock encountered in the profile will contain zones of sufficient strength and RQD that the cutterhead will require disk cutters to excavate the rock. The rock will be predominantly found below the springline, but in some cases will extend over most of the tunnel cross-section. These locations cannot be determined due to the wide spacing and shallow depth of many of the borings. In these reaches, it is anticipated that penetration rates will be reduced, particularly where the rock is of greater unconfined compressive strength, and the foliation of the rock-mass is oriented sub-parallel to the direction of TBM advance.

Reaches Consisting Predominantly of Rock (R)

Station 969+00 to 922+00 (4700 ft) and shorter sections within the reaches described above.

Many of the borings along the alignment terminate above the proposed tunnel envelope. In particular, the tunnel reach between Station 969+00 and 922+00 has few borings that extend into the tunnel profile. In this reach, the crown of the tunnel is deeper (70 to 130 ft below the surface), and borings show that decomposed rock extends to the bottom of borings that terminate 0 to 40 ft above the tunnel crown. At this time, the absence of borings that extend to tunnel depth causes uncertainty regarding the ground conditions to be encountered during tunneling in these areas.

Based on the thicknesses of decomposed rock (D) above rock (R) (up to approximately 60 ft) that is observed in other sections of the alignment, it is anticipated that the tunnel in this reach will largely be in partially weathered to unweathered rock, with local zones of decomposed rock, generally near the tunnel crown, but absent over significant portions of the reach. Most of the muck will likely be in the form of chips of hard rock. The absence of significant amounts of residual soil or decomposed rock in the muck will make it difficult to develop a paste from the chips using only the standard foam/polymer conditioners.

With these conditions, it will be difficult to pressurize the face and to fluidize the muck sufficiently to reduce friction and wear in the TBM's plenum and screw conveyor. Such conditions will increase maintenance and the potential for breakdowns, will slow advance rates because of the inability to deliver sufficient conditioners to the face, and will result in TBM stoppage or slowdown, and schedule impacts. Where unstable soils are present on top of the rock, the lack of face pressure may result in runs, excessive excavation, and ground settlement.

To mitigate these adverse affects, it will be prudent to install a system for storing and injecting slurry and conditioners at the cutterhead and plenum with sufficient capacity to fluidize the rock muck as the conditions are encountered during TBM advance.

Potential Valleys of Fill or Coarse Alluvial Soils

(Station 890+00: Scotts Run)

The vertical alignment is shallow, often within one tunnel diameter of the ground surface, and the potential for encountering buried valleys containing coarse, permeable alluvial soil or fill during tunnel excavation is a concern. This requires additional investigation using topographic information and additional borings. Loss of conditioner through the permeable materials will cause difficulty in maintaining fluid pressures on the face, and could result in excessive ground loss.

4.4 AMOUNT AND DISTRIBUTION OF EXPLORATION

Of the 226 borings referenced in the documents, 149 borings were performed within the limits of the LBT alternative. There are large gaps between these borings (as acknowledged in the Tunnel at Tysons, JV reports). About 200 borings do not extend to the tunnel invert, and 18 borings do not extend to the tunnel crown (the latter group are mostly concentrated along a 2300 ft zone from Station 934+00 to Station 957+00). There are several areas where the LPA borings are more than 150 feet from the tunnel centerline. The Tunnel at Tysons GIR states "Within the hill area...no borings penetrated the tunnel and were terminated well above the crown leaving approximately 90 feet of material above the tunnel crown unknown."

With the lack of samples available from these locations, the geological conditions are unknown below these borings and a high degree of unreliability may result when extrapolating known information. Providing additional subsurface information within the tunnel horizon in these areas is considered necessary to support a prudent Preliminary Engineering design and realistic estimates of project cost and schedule.

4.5 MIXED FACE CONDITIONS

The subsurface materials encountered in the borings result in an undulating profile at the material interfaces. Across the tunnel cross section, these subsurface conditions can be characterized as “mixed face” conditions – where soil, decomposed rock, and unweathered bedrock coexist in the tunnel face. In addition, the tunnel crown will be below groundwater elevation for nearly the entire alignment.

Depending on the contrasting consistencies and strengths of these materials, mixed face conditions can be troublesome for EPBM operation, particularly for the large diameter proposed. The unbalanced reactions of the TBM cutterhead across a non-homogeneous excavation face – with relatively strong rock in the lower portions of the tunnel face, and weaker decomposed rock or soil (or both) in the upper portions of the tunnel face, can potentially damage the machine and cause accelerated wear of the disk cutters. The upper looser materials also can tend to flow in faster than the lower harder materials can be excavated. This allows for the possibility of larger than anticipated ground losses at the tunnel face. If this condition is allowed to continue, ground instability could extend to the ground surface and cause significant settlement. Avoiding these problems requires accurate monitoring and maintenance of the face support pressure, and proper balance between the advance rate and rate of material removal at all times. While this approach is technically viable, it brings with it the consequence of a slower advance rate.

4.6 ROCK TYPE, STRENGTH AND STRUCTURE

The rock type, rock strength, and rock structure (i.e., joint spacing/dip/strike, rock block sizes, etc.) are the most fundamental factors governing the drillability of the rock material and hence TBM rate of advance. The main laboratory tests on rock specimens required for proper estimate of TBM advance rate and cutter wear include rock lithology, uniaxial compression strength (UCS), tensile strength, and abrasivity. Structural defects such as joints and foliation, including their spacing, strike, dip, and orientation in relation to the TBM tunneling direction, will also affect the rate of advance. A “blocky” rock face will inhibit the ability to efficiently cut the rock, and will cause vibrations and accelerated cutter wear if full thrust pressures are maintained. The GIR contains the results of only 11 UCS tests on rock cores samples, and the TBM Tunneling Report assumes the maximum rock strength of 16,560 psi. It is considered that the 11 test results represent an insufficient database upon which to estimate either the maximum or average UCS of the bedrock along the tunnel alignment. For example, the borings located between Station 934+00 and Station 957+00 do not extend to the tunnel horizon, thus any samples would have been from above the tunnel horizon. The absence of test data on a representative number of rock core samples from the tunnel horizon raises uncertainty in the assumed TBM rate of advance. This lack of data is acknowledged in the GIR.

4.7 SOIL MATERIALS

Sandy materials are shown to lie above the weathered rock and will be encountered within the tunnel face or above the tunnel crown. Since the tunnel crown is below the groundwater table, the following conditions are likely to develop which may impose a negative impact on the rate of advance. If there are gravels in the soil formations, they can run into the TBM even though balancing pressures are being applied to the general soil mass. These and other conditions in the mixed face could cause unanticipated loss of ground and consequential settlement. Pre-empting such conditions could require ground modifications from the ground surface, from within the TBM in advance of the face, or a combination of the two. There is a concern that the schedule and cost estimates do not reflect the mixed face conditions that are described above.

5. LARGE BORE TUNNEL

5.1 THE DEVELOPMENT OF MECHANIZED EXCAVATION

The Early Years

Prior to the 1960s tunnels were typically constructed using drill and blast methods in rock and hand excavation from within a shield in soft ground. Grouting, compressed air and/or dewatering were used as complementary methods in soft ground tunneling to help stabilize the ground.

During the 1960s the development of mechanized tunneling or TBMs began in earnest. The design of these machines was ground specific, generally being capable of excavating uniform strata such as rock or firm clays.

The era of closed face TBMs began in the early 1970s, when slurry TBMs were developed in Europe and Japan. These machines used bentonite or clay slurry contained within a pressurized (plenum) chamber at the face of the TBM to provide support to the ground. The slurry also acted as a transport medium to carry the excavated material to the surface. At the surface, the spoil was separated from the slurry in large separation plants and then the “cleaned” slurry was circulated back to the tunnel face. The early slurry machines were generally 10 to 25 ft in diameter. Due to the limitations on separation plant technology these machines worked best in gravels and sandy soils.

In the late 1970s the Japanese introduced the EPB machine. This technology involved a plenum at the face of the TBM in conjunction with a helical screw conveyor by which spoils would be removed from the plenum. The spoils would form a “plug” in the screw conveyor, thereby forming a pressure in the plenum that supported the unexcavated ground. The early EPB machines were used in soft clays or silts with water being added to soften the firmer clays. The early EPB machines were in the 8 to 20 ft diameter range. Development of both machine types continued through the 1980s, with their capability being progressively increased in terms of size, to around 30 ft in diameter, and in the range of ground types handled. Improvements in separation plants allowed the slurry machines to handle the silt fractions and the introduction of conditioning materials allowed the EPB machines to handle the coarser grained soils. Other developments included the introduction of crushers in the plenum chamber of slurry machines which allowed the excavation of mixed rock / soft faces.

Recent Developments

In the early 1990s the Japanese made a major step in machine size when they designed and built a 46 ft diameter slurry machine for the construction of the Konda River Tunnel in Tokyo, which was excavated through sands and gravels. Working 2 x 8 hour shifts per day (for environmental reasons the third shift was not worked), 5 days per week, the 6,500 ft long tunnel was advanced consistently at 80 feet per week. This project was the forerunner of the ambitious Trans Tokyo Bay Tunnel constructed between 1995 and 1999, where eight 46 ft diameter machines were used to construct the 8 miles of twin tunnels for the channel crossing section of the project.

Two years later Herrenknecht built a marginally larger 46.5 ft diameter slurry machine for the construction of the 3rd Elbe tunnel in Hamburg, Germany. This 8,400 ft long tunnel was driven through sands, glacial drift material, silt, gravel and boulders with less than 30 feet cover to the bed of the overlying river. While peak production rates of up to 160 feet/week were achieved, the overall average was nearer to half this rate. This machine was subsequently refurbished and used on two highway tunnel projects in Moscow, the Lefortovo Road Tunnel and the Silberwald Tunnel.

The mid-1990s also saw the introduction of a wider range of conditioning materials and in particular the use of foams. These allowed the EPBs to handle coarser materials such as sands and gravels thus further enhancing their capability. However, the maximum diameter of the EPBs was limited by the increasing torque requirement as diameter increased. Up until 1999, the largest EPB machines were 31 feet in diameter, one of which was the Lovat machine used on the St. Clair River Tunnel.

The new century saw the continuation of the development of larger and more powerful TBMs. A significant technical development has been the introduction of ever larger and more powerful machines and processes. Diameters and tunnel depths (and hence pressures) are increasing. Tunnels are getting longer and construction schedules ever more demanding. The Table presented in Appendix 1 gives details for a number of the larger diameter tunnels constructed in the past 10 years.

Of particular note has been the increase in size of EPB machines, with the machines constructed for Barcelona Line 9 measuring 39.6 ft diameter, followed in 2006 by the introduction of the first 50 ft diameter machines manufactured for the construction of the M30 Ring Road in Madrid. These particular machines have benefited from tunneling through very consistent strata, reflected in unprecedented performance with the tunnel advance rates averaging 50 feet/day.

By comparison, the two 43 ft diameter machines used to construct the SMART (Stormwater Management and Road Tunnel) project in Kuala Lumpur, Malaysia had to bore through mixed face conditions (sands and silts overlying limestone) and achieved an overall average of 22 to 23 feet/day.

Given that the tunneling conditions at Tysons Corner are expected to comprise mixed face conditions (see discussion above), an average progress rate closer to that achieved at Kuala Lumpur is considered more applicable to this project.

5.2 TUNNEL DESIGN APPROACH

The Basis of Design Report prepared for the LBT indicates proposed deviations from the WMATA Manual of Design Criteria. These issues which have potential to impact alignment, profile and geometry of the tunnel which could in turn impact both cost and schedule include:

- No deviation from standard criteria are identified for tunnel construction, however previous WMATA tunnel projects have specified a two pass lining system which can provide a higher quality waterproofing system. While one pass lining systems have been used successfully on previous rail transit projects, where the gaskets between the precast concrete segments have been relied upon for waterproofing, there is a higher risk of occasional leakage. In order to comply with the two-pass lining requirement imposed on previous WMATA projects, a larger excavated diameter would be required.
- A tighter curve required to accommodate the double cross over between Tysons Central 7 Station and Tysons Central 123 Station.

5.3 TBM GROUND BEHAVIOR

Rapid changes in ground conditions, for example from rock to decomposed rock to silty residual soil or sandy soils, will make it difficult to maintain adequate face pressure at all times. The large diameter of the cutterhead and the variable, mixed conditions in the face will contribute to the difficulties in maintaining face pressures. The following mitigation measures may be warranted:

- Emphasis should be placed on the supply and control of conditioners and the monitoring systems to prevent temporary loss of fluidity and face pressure as variable conditions are encountered across the mixed face and as conditions change with face advance.
- A system should be in place to drill up to and place sand/cement replacement grout to locate and fill voids above the segments, and, if necessary, above the shield. The setup will be most efficient if it can be operated without delaying machine advance and segment installation. Although muck car counts and other means of comparing volume excavated to theoretical volume/heading advance should be employed, they are not precise enough to determine if ground loss is occurring. The grouting provides a means of both checking for and replacing ground loss. If such a system is not instituted, ground loss will have surface impacts and will affect TBM progress.
- In areas where there is a risk of impacting major structures, ground modification measures, structure modification, underpinning or special tunnel controls at those specific locations will need to be implemented.

Large, local ground loss will occur at the face if the muck is not fluidized and pressures are not maintained. Voids will form above the cutterhead and propagate toward the surface, forming a sinkhole. The speed with which they reach the surface will be a function of tunnel depth and diameter, the volume of the ground loss, and the presence of stiffer materials. Over approximately 38% of the tunnel alignment, where the ground cover is less than or equal to one tunnel diameter, such voids will have a greater influence on near surface and surface utilities and structures.

The tunnel face is large enough that raveling should be expected in the silts if face pressure is not maintained. Water pressures will cause flowing behavior, in particular in the less cohesive silts, sandy silts and in any coarse alluvial soils or fill.

5.4 POTENTIAL FOR GROUND SETTLEMENT

The TBM Report indicates that settlement can be controlled to 0.52 inch (13.29mm) along the tunnel alignment. This estimate seems low, considering the following factors:

- An annulus of 1/2 inch at the overcutter is a likely minimum and can be expected to cause 1/2 to 1 inch of surface settlement (the larger values for lower cover).
- It will be difficult to effectively grout the tail void in soil and decomposed rock. Ground losses at the tail of the machine could easily contribute another inch.

Assuming no other volumetric face loss occurs, and over-excavation is kept in check, the above factors suggest that surface settlements will be on the order of 1 to 2 inches. It is also noted that the maximum settlement for the Scotts Run Culvert is stated in the report as 2 inches.

5.5 COST CONSIDERATIONS

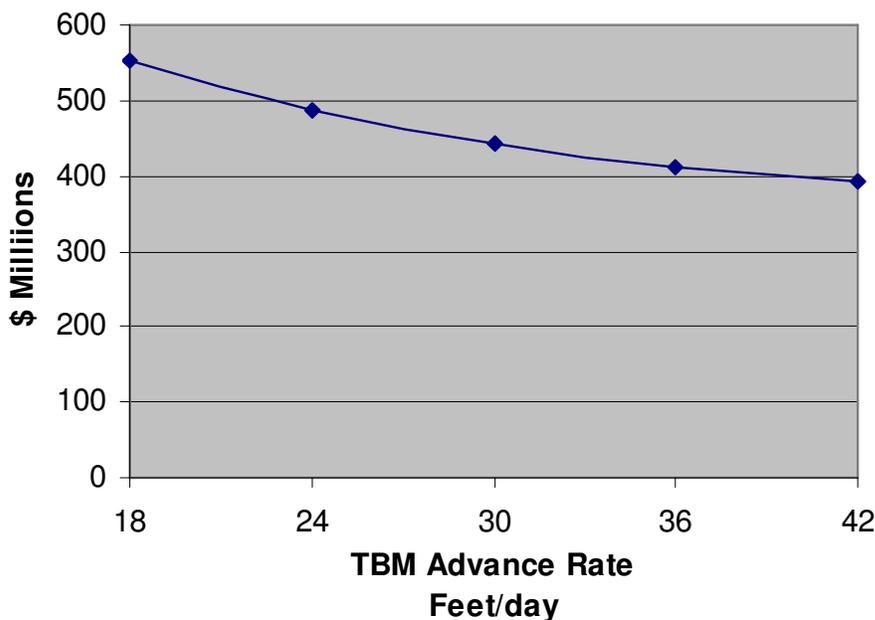
In the absence of a detailed cost estimate in the Proposal, construction costs for TBM excavation were independently assessed. The costs assigned by Tysons Tunnel, Inc. in their summary estimate for the TBM tunneling item agree reasonably with this assessment. However, this appears to be largely due to the over-estimation (by a factor of 2 or 3) of the cost of the segmental lining. This would suggest that the excavation costs have been under-estimated by a similar factor.

The NATM tunnel costs seem to be underestimated by a factor of almost 2, but it is uncertain from the summary estimate how costs have been apportioned between NATM tunnels and Structural for the stations.

The schedule for the NATM tunnels at 13.5 months per station seems reasonable for 400 feet of NATM tunnels but seems to belie the cost estimate. It is also noted that this work is sequenced to be performed concurrently between stations requiring 12 trained crews (or 16 for 7-day working). This may represent a significant challenge due to the limited availability of experienced local labor.

For TBM tunneling the most important factor influencing construction cost is the overall advance rate achieved by the TBM. In order to demonstrate the influence of tunnel advance rate on construction cost, CB developed contractor-style “bottom-up” cost estimates assuming a number of different advance rates. These estimates are based on a 24 hr construction period 5 days/week, with machine maintenance carried out on the weekend, and an overall 30% contingency.

Figure 1: Total Cost of Bored Tunnel Elements Versus Advance Rate



At 32.5 feet/day (the basis for the LBT Proposal) the cost would be \$429.7 million, whereas at 24 ft/day, which is a realistic advance rate for this size machine in ground conditions expected at Tyson’s Corner, the cost would be \$488 million, an increase of 14%. However, based on worldwide large TBM tunnel experience, in particular, the 22-23 feet/day advance rates achieved on the SMART project in Kuala Lumpur, an average advance rate of 24 feet/day is considered more appropriate. It should be noted that these costs do not include escalation due to an approximately 7-month extension of the overall construction duration.

The January 30, 2007 letter to Mr. Scott Monett from the Tunnel at Tysons team includes a table that shows possible savings of up to \$209 million. Two of the items that make up this total, “Tysons Segment Direct Cost” at \$51 million and “Systems Direct Cost” at \$24 million, have no supporting justification or explanation.

5.6 SCHEDULE CONSIDERATIONS

The overall construction period of 54 months, stated by Tyson Tunnel, Inc., suggests a 7 day-per-week full production schedule for TBM excavation. Conventional planning for TBM drives normally assumes a 5 day-per-week production schedule with TBM maintenance and other regular activities such as advanced probe drilling being performed during the weekend stoppage. Table 1 shows the impact of these different assumptions on the overall TBM construction period.

Table 1: Schedule Impact of Advance Rates and Production Weeks

TBM Advance per Day	Total Duration for TBM Construction (weeks)		Difference in Production Duration (weeks)
	5-day production week	7-day production week	
32.5 feet/day	110	78	32
24 feet/day	148	106	42
Difference between assumed TBM rates	38	28	

The difference between a 5-day and 7-day production week for an assumed advance rate of 32.5 feet/day adds 32 weeks to the construction schedule. This difference increases to 42 weeks, not including the increased duration mentioned above for the lower production, if the assumed advance rate of 24 feet/day is considered. The difference between a 7-day 32.5 feet/day TBM advance rate and a 5-day 24 feet/day advance rate is 70 weeks (148 weeks minus 78 weeks). This will extend the overall project schedule by approximately 16 months.

These durations consider the bored tunnel only, with no inclusion of impacts from other activities such as the excavation of the stations. It is expected that the stations would be excavated concurrently with the tunnel excavation where possible, and that the actual connections to the bored tunnel will be delayed such that they do not impact the bored tunnel schedule. The earliest these connections could be made would be following the completion of TBM excavation, once its trailing gear had sufficiently cleared the break-out working area, and prior to the installation of the interior concrete.

The interface between TBM tunneling for the main tunnel and construction of the stations (which are excavated with another type of tunnel technology) is complex. Even though the large bore tunnel concept serves to minimize this interface, the construction schedule presented by Tunnel at Tysons, JV indicates that the stations are proposed to be excavated concurrently with TBM tunneling. This represents a major risk to the construction schedule.

The 54-month schedule in the Proposal appears highly compressed. The Tunnel at Tysons, JV schedule shows station excavation occurring prior to the TBM excavation, which could lead to ground stability problems due to ground loosening in the station areas prior to TBM arrival. The normal sequence of activities would be to mine the main tunnel, install and secure the structural lining, excavate the station from the top, stabilize loose material on the outside of the main tunnel shaft, and then remove a section of the lining to finish the station excavation connecting to the main tunnel. Given the safety concerns stated below for construction of the pedestrian tunnel, re-sequencing of this work so that this activity follows rather than precedes TBM

excavation, is warranted. Unfortunately, this might lead to a further extension of the overall construction schedule.

The construction schedule states an 18-month duration for start up testing and commissioning, which is considered a reasonable duration. However, only a 12-month portion of this activity is included in the 54-month schedule (July 2011 to July 2012). The printed schedule appears to be truncated at July 2012, with this activity extending 6 months beyond.

The letter to Mr. Scott Monett from the Tunnel at Tysons, JV team, dated January 30, 2007, highlights:

“...major opportunities and potential costs savings in the following:

- Early delivery of a refurbished TBM (for instance, the Malaysia SMART tunnel TBM is available and can be shipped within several months) saving nearly a year from the schedule.”

As the submitted construction schedule indicates only a 10-month total duration assumed for TBM procurement, a savings of nearly a year from the schedule cannot be achieved.

As explained in section 3, the outside diameter of the segmental lining is required to be 43.3 feet. For any one pass lining process, the TBM must be of a greater outside diameter than the outside diameter of the segmental lining erected within it. For this project, the machine diameter required to construct a segmental liner with an outside diameter of 43.3 feet, would need to be on the order of 44.5 feet. Because the SMART TBMs are 43.3 feet in diameter, they are approximately 1.2 to 1.4 feet too small. (Outside diameter of the SMART machine is 13.21 m, or 43 ft 4.07 in; tunnel lining o.d. is 12.83 m or 42’ 1.11” and i.d. is 11.83 m , 38’ 9.74”.) The design documents indicate that EPB technology is appropriate for the project yet the SMART TBMs are slurry machines. In light of this, if conversion to an EPB machine is intended, the refurbishment effort would need to include:

- Reskinning the TBM shield to increase its diameter
- Cutterhead rebuild to increase its diameter
- New drives (the current power of these TBMs is 4000kW whereas approximately 6000kW would likely be required)
- New screw conveyor
- Modifications to the machine bulkhead
- TBM back-up modifications for muck and segment handling

The SMART TBMs were originally built for the Westerschelde project in the Netherlands where the machines worked in pressures up to 7 bar. The TBM manufacturer, Herrenknecht, bought back the machines at the end of the project and rebuilt them for the SMART project, which required an increase in diameter. Having to upsize the diameter once again for this project, it must be questioned whether the machines would be required to perform to limits exceeding their original design. This could impact the reliability of key TBM components such as the main bearing. A main bearing failure during construction would result in a significant delay to the construction schedule.

It is noted that the letter referencing the use of the SMART TBMs is dated about a week later than the Proposal. If a slurry type TBM is now preferred by the Tunnel at Tysons, JV team, the design documents will require modification to cover the significant changes in operation, such

as: surface logistics; slurry separation plant location and access; muck separation and removal; environmental issues e.g. disposal; etc.

The average advance rate achieved by the SMART TBMs in Kuala Lumpur was 160 feet per week with 7 day/week mining. This equates to approximately 23 feet/day. The submitted construction schedule shows the activity for TBM tunneling taking 18 months to complete. For 7-day/week mining with no holiday stoppages, this is equivalent to 32.5 feet/day; for 6-day/week working this is 35 feet/day; and for 5-day/week working this is 45.5 feet/day. The assumed construction schedule rates of progress for TBM advance are therefore considered to be very optimistic.

It is considered that the schedule savings of 6 months (compared to the aerial option), as suggested in the January 22, 2007 letter from Tysons Tunnel, Inc., depends upon the following being achieved:

- an optimistic TBM procurement duration;
- overly optimistic rates of TBM progress; and
- concurrent excavation of the stations and TBM tunnel that could present stability and safety concerns.

These three factors suggest that the 6-month schedule savings is unlikely, and that a significantly longer construction period will be necessary.

6. STATIONS

6.1 DESIGN APPROACH

The Basis of Design Report prepared for the LBT indicates where there are proposed deviations from the WMATA Manual of Design Criteria. The following is a summary of those issues which have potential to impact geometry of the stations which could impact both cost and schedule:

- One of the more developed elements of the Tysons Tunnel, Inc. proposal is the station geometry and mechanical design. The study documents stated that certain key WMATA criterion for headroom, operations in the tunnel and for ventilation shaft size may not be met. These are not insignificant issues. Refinement is likely to require increased shaft sizes, platform sizes, and possibly even tunnel size in the area of the stations.
- The ceiling heights in the mined stations (platform area) are lower than in other underground WMATA stations.
- The stations include a waterproof membrane attached to the concrete liner segments to prevent leakage into the public areas by diverting any inflows to a drain. The membrane is covered by Glass Fiber Reinforced Concrete (GFRC) panels. The attachments of the GFRC panels to the supporting concrete will need to penetrate the membrane, requiring experienced supervision during construction.

6.2 GROUND BEHAVIOR

The excavation of the station structures takes place in fill, and residual soils at the upper level and decomposed rock and bedrock for the lower sections of the shafts and access adits. The

water table is expected to be well above the crown of the TBM tunnel, which will require ground improvement during excavation of the overlying structures in soft ground. Generally the tunnel support consists of shotcrete reinforced with welded wire fabric and lattice girders.

The design shows soft ground excavation below the water table in combination with grouted pipe spiling to prevent water intrusion from the crown and shoulders and dewatering from within the tunnel with vacuum lances for expected sand lenses ahead of the tunnel heading. Residual water inflow at the tunnel walls will be captured with drainage sheets and pumped out of the tunnel. Crown support in areas where the excavated areas lie in weathered rock or bedrock consists primarily of rebar spiles.

Expected settlements for the mined approaches at the station are not discussed in the Mined Tunnel Design Report. However, settlements can be expected during mining and dewatering. The application of multiple headings and pocket mining will reduce, but not eliminate, the settlement. The shallow pedestrian tunnels connecting the two station entrances underneath Route 7 and Route 123 will create surface settlements which will need to be monitored with surface and subsurface monitoring points. The use of a doorframe slab method, where the tunnels will be built underneath a pre-installed concrete slab, should be considered to minimize surface settlements.

6.3 BREAKOUTS FROM TUNNEL

The proposed construction sequences for shafts and adits aim to decouple these activities to the greatest extent possible from the main tunnel drive. This has the advantage of allowing concurrent construction activities. However, final breakouts should only occur following completion of the tunnel drive where access for segment removal can be achieved.

Several NATM breakouts are required in the LBT alternative. These excavations, including shaft breakouts, LBT adit breakouts, inclined escalator adits, and pedestrian connector tunnels, present a number of concerns:

- The main lining will require substantial temporary support to prevent adverse movement or the potential for collapse of the liner prior to performing the breakout of the segmental lining for the main tunnel to provide connection to the station ventilation and egress adits.
- The LBT design indicates that a partial mini-piled umbrella support will be installed above tunnel access level with no additional temporary support being provided below this level. This configuration severs full ring compression of the main lining, and ring stability must be questioned.
- It is common practice to install a permanent collar support around the opening with the main lining. The purpose of this support is to maintain ring compression of the segmental lining for all segmental rings affected by the presence of the adit opening. The largest of the station openings shown on the drawings is indicated to impact seven (7) rings of the segmental lining. The construction activity to install the compression collar behind the segmental ring will require additional time and cost.
- The four mined stations will require excavation that extends from within the bored tunnel out into soft ground conditions. The soft ground will need to be properly strengthened or otherwise stabilized prior to removal of the tunnel lining and excavation beyond the tunnel perimeter.

- Each precast concrete segment has been estimated to weigh in excess of 11 tons. The drawings indicate that a simple saw cut will allow removal of a complete segment in a single operation. Given the weight of the segment and the likely logistical constraints that exist, the excavation of the segment to create the opening will need to be performed in smaller, manageable pieces that require sufficient allowance for both time and cost.
- The station adit junctions with the main tunnel are sequenced to be performed during the main TBM drive. Performing the work in this sequence will prevent a safe means of egress for TBM personnel in the event of tunnel instability occurring during work on the adit connections. Due to these safety implications it is considered prudent to defer final connections for the openings until after completion of the TBM drive. This may add the station excavation activity to the critical path for the project and thereby extend the project duration.

6.4 NATM TUNNELING

NATM excavation to create the underground passageways and adits at the stations for three of the four stations is likely to encounter mixed face conditions of soil overlying rock. Excavation for the adits under mixed face conditions will require a combination of tunnel excavation methods. Soil and decomposed rock may be excavated by conventional mechanical means however the strength of the bedrock may be in the upper efficiency range of a roadheader. The use of controlled blasting may be necessary for part of the face excavation. In the vicinity of the main tunnel lining, hydraulic, mechanical or chemical splitting may be necessary to excavate the rock, in order to protect the structural integrity of the lining.

Some of the pedestrian passageways above the main tunnel have such low cover to the surface that the tunnel horizon passes through the underlying fill of the highways above. This represents high risk. Furthermore, the cover between the passageway and the main tunnel below will impose an adverse change to the loading conditions assumed for the segmental lining design. This change removes the overburden from above the main tunnel resulting in eccentric loading of the lining. The main tunnel will require reinforcement in this location due to the presence of the surrounding NATM excavations.

Construction of the proposed pedestrian connector tunnels should be reviewed in more detail; in all cases the proposed construction methodology carries high risk. The shallow cover, particularly in fill material, means there is likely to be insufficient confinement to maintain hoop stress in the NATM tunnel and has the potential to cause eccentric loadings on the LBT beneath. The most severe case occurs at the Tysons East Station where the proposed cover to the tunnel is on the order of 15 feet beneath Route 123 with approximately half of the overburden made up of road construction materials. The proposed shape of the pedestrian connector tunnels is not ideal for promoting good ground support interaction. In the shallow cover tunnels the use of spiling or grouted pipe spiling may interfere with overlying utilities as may the tunnel at Tysons East Station.

The sequence indicated on the construction schedule introduces a potential for both the pedestrian tunnel (and the highway above) to collapse as the TBM passes close to the invert of the NATM-excavated pedestrian tunnel. In the case of the Tyson East Station, the pedestrian tunnel has a cover of approximately 15 feet to Route 123, and approximately 2 feet of soil cover

above the TBM tunnel. TBM excavation this close beneath the pedestrian tunnel is considered impractical.

6.5 POTENTIAL FOR GROUND SETTLEMENT

The four mined stations will require excavation that extends from within the bored tunnel out into soft ground conditions. The soft ground will need to be properly strengthened or otherwise stabilized prior to removal of the tunnel lining and excavation beyond the tunnel perimeter. The cost estimate may not account for the full extent of this ground modification.

6.6 CASE HISTORIES

The most recent case history of a sequential or NATM excavation in North America is the Beacon Hill Station in Seattle that is presently under construction. Sequential excavation or NATM tunnels have also been recently completed at the Dulles Airport and are currently planned as part of the LPA or aerial alignment through Tysons Corner. The Beacon Hill Station is being mined in a complex mixture of soft ground conditions and has required ground modification prior to sequential excavation, which can also be expected at this project.

A key observation of the Beacon Hill excavation has been the very slow excavation progress rates as compared to planned rates at the beginning of the project in the absence of experienced mining crews. Another key observation is that despite everyone's best efforts to control unstable ground, including measures such as surface-based jet grouting and canopy tube pre-support, two face instabilities have occurred on the project. It underscores the importance of risk planning and anticipating adverse events in potentially unstable ground.

6.7 COST AND RISK CONSIDERATIONS

Due to the difficult nature of the excavations, the cost of the tunneling associated with the stations will be on the order of \$40,000/ft and lining costs about \$10,000/ft. Since each station contains about 400 ft of this work, this would represent \$20 million per station.

Risks associated with the tunneling are significant. For instance, the pedestrian tunnels have very shallow cover and are in close proximity to the other tunnels. As has been the case in Beacon Hill, extensive jet grouting will be required to provide a safe tunneling medium. Additionally, the openings through the bored tunnel are very large and require additional attention in terms of design, temporary support, and construction sequencing.

6.8 SCHEDULE CONSIDERATIONS

The station arrangements offer many opportunities for concurrent working and the limitation will be the number of crews. If it is assumed that four crews could be developed for each shift, then the station tunnel excavations could be completed in a period of 6 months. This does not include shaft excavation, ground treatment, or breakout preparation. The installation of station finishes and mechanical/electrical equipment would need to follow the structural work. These activities can be expected to take approximately 12 to 15 months. The Tunnel at Tysons schedule assumes 12 months, which is on the low end of this range.

6.9 VENTILATION/MEP

The sizing of ventilation system components does not include the contingency it should have at a Preliminary Engineering Phase. Rather, it would appear that a number of design compromises have been made from the outset.

6.9.1 Tunnel Ventilation System Sizing

The tunnel ventilation system has been sized based on smoke control requirements. While Incident Operations (a train on fire) will typically determine the mechanical ventilation capacity of the system, normal operating considerations such as air flows, pressures and temperatures can also have a significant influence on the sizing of ventilation shafts and other system components.

No Normal Operations (normal train movement) ventilation analysis has been performed for the Preliminary Engineering Phase. This would normally be expected in order to give confidence in the sizing of ventilation system components, particularly the ventilation shafts. In the absence of this analysis, ventilation shaft sizes remain unconfirmed. An increase in shaft size will have cost implications for each of the four underground stations.

The LBT configuration results in running tunnels that have a cross-section which is substantially larger than that which is necessary to accommodate a train. As a result, the ventilation capacity necessary to achieve the critical velocity for smoke control is significantly higher than it would be in a conventional twin bore tunnel. In order to minimize ventilation capacity the efficiency of the traditional push-pull ventilation system has been enhanced through the use of jet fans installed within the tunnels. This reduces the size of the main fans and the ventilation shafts, but at the expense of placing mechanical equipment within the running tunnels.

Maintenance requirements for this equipment could result in operational constraints that are unacceptable to WMATA, who should therefore verify that this is an acceptable design approach. If jet fans cannot be installed within the tunnels, the ventilation capacity of the main fans will need to be increased. This will ultimately lead to an increase in the size of the ventilation shafts, and an increase in the capital cost.

6.9.2 Ventilation Shaft Sizing

Ventilation shaft layouts have been provided showing the general configuration of the principal ventilation components at each station. From an initial review, the typical cross-sectional area of the shafts appears low when considering their multi-functional requirements.

The ventilation shafts must accommodate sufficient space for the tunnel ventilation fans (and access), blast relief from the upper and lower platforms, under platform exhaust (UPE) and a number of other intake and exhaust ducts associated with the station HVAC system. Egress stairs must also be accommodated.

The Tunnel Ventilation and Smoke Management Report (Section 6.2) identifies a fan total pressure drop of 8 inch w.g. This is relatively high and reflects the compromises in shaft size already being made at the Preliminary Engineering phase.

The current layouts are considered schematic and do not provide the level of detail and coordination between services necessary to confirm shaft sizing. Again, an increase in shaft size will have cost implications for each of the four underground stations.

6.9.3 Station Platform Space Provision

Cross-sections are provided showing the layout of HVAC and UPE ductwork within the station platforms. It is readily apparent that insufficient space exists within the current sections to accommodate the necessary mechanical and electrical systems.

The WMATA Manual of Design Criteria limits duct velocity to a maximum of 1000 feet per minute (fpm) which is consistent with industry best practice. Each of the ducts shown substantially exceeds these criteria, the most extreme example being a 44 inch x 78 inch exhaust duct with airflow of 60,000 cubic feet per minute (cfm). At an air velocity of approximately 2500 fpm, this is 2.5 times the design criterion, which is unacceptable for a normally operating (non-emergency) system. Section 6.3 of the Basis of Design Report acknowledges that the criterion is exceeded.

In general, it appears the station platform cross-section is based largely on the required cross-section in the running tunnels rather than sizing the station around the mechanical and electrical systems that must be accommodated. A more detailed examination of the spatial requirements of the stations' mechanical and electrical systems could increase the required cross-sectional area of the station platforms.

Based on the current tunnel construction methodology, an increase in station platform cross-section will require an increase in the overall tunnel size which has significant implications for project cost and constructability. Alternatively, the station platforms could be mined to create necessary enlargement beyond the TBM tunnel section. This would again have significant cost implications.

6.10 PLATFORM EMERGENCY EGRESS ANALYSIS

This section of the report analyzes the platform emergency egress for the four underground stations in the Tunnel at Tysons, JV "Preliminary Engineering Design Submittal". In particular, the Fire/Life Safety Report was analyzed along with drawings for the following stations:

- Tysons East Station, drawings NT4-A-101 through -104
- Tysons Central 123 Station, drawings NT5-A-101 through -104
- Tysons Central 7 Station, drawings NT6-A-101 through -104
- Tysons West Station, drawings NT7-A-101 through -104

All stations are similar in design with two at-grade entrances leading down to a common mezzanine level. From the underground mezzanine, a vertical circulation core consisting of two escalators and one stairway leads down to an upper level platform and then a lower level platform. Platforms are 600 feet long. Emergency egress stairs are located at each end of a platform and egress directly to grade.

Preliminary findings for the four Stations are presented as: (1) general findings, (2) maximum walk distance "leaving" the platform, (3) time to clear the platform, and (4) time to reach a point of safety.

6.10.1 General Findings

The analysis uses the 2003 edition of NFPA 130. It is suggested that the latest (2007) edition be used instead. The NFPA Occupant Load calculations appear to meet the 2007 code.

While the design appears to mostly meet the requirements of NFPA 130, from a practical design standpoint the East and West Stations' upper platforms' "passenger entrance to the station and platforms", consisting of two escalators and one 10-foot wide stair, does not provide sufficient capacity and should be more centrally located in accessing the platforms.

Emergency stairs at one end of all platforms, the opened doors from the platform to the emergency stairs appear to restrict access to the full width of the emergency stair. The reduced accessible stair width would result in a Time to Clear Platform of over 4.00 minutes - violating code section 5.5.3.1 for all stations.

6.10.2 Maximum Walk Distance "Leaving" the Platform

The maximum distance from the platform to the point where the means of egress leaves the platform appears to technically meet code (less than 300 feet). The upper platforms at the East and West stations have potential problems as discussed below.

6.10.3 Time to Clear Platform

For all stations and all platforms, related to the emergency stairs at either end (north or south) of the platform, it is not clear that the most restrictive element is used in calculating egress capacity. The emergency stairs are used as the most restrictive element, however the door leading to the stairs is more narrow and may be more restrictive and therefore be the element used in the egress capacity calculation. The door width to these emergency stairs should be stated to allow the "most restrictive element" to be determined.

Also for the emergency stairs at one end of all platforms (drawings NT#-A-104 and -105), the opened doors from the platform to the emergency stairs appear to restrict access to the full width of the emergency stair. According to NFPA 101, "movable objects" (like these doors) should not encroach on the path of travel. As currently designed, the reduced accessible stair width would result in a Time to Clear Platform of over 4.00 minutes - violating code section 5.5.3.1 for all stations.

- The Time to Clear Platform is just under the 4.00 minute limit (3.96 minutes for Tyson's East and West Stations) assuming egress demand is distributed evenly among the various egress capacity elements. While this meets the letter of the code, the platform/egress design from a practical standpoint would fail either the walk distance limit or the platform clear time limit for the East and West Stations for the following reasons:
- Such an even distribution implies that approximately 75% of the occupant load will flow to one end of the platform (where stair, escalator and one emergency stair are all located) and 25% of occupant load will flow to the other end (where one emergency stair is located), thus the quarter point (150 ft) of the 600-foot platform would be the "dividing line". Such an uneven distribution (from a platform length standpoint) implies that some of the 75% will walk up to 350 feet before leaving the platform - violating code section 5.5.3.1.1 (maximum walk distance of 300 feet).

- If passengers were divided more evenly from a platform standpoint, say 67% to 33%, so that the longest walk would be 300 feet, then a greater proportional egress demand would flow to the single emergency stair and the time to clear the platform at that element would be 4.8 minutes - violating code section 5.5.3.1 (maximum time to clear platform of 4.0 minutes).
- The Time to Clear Platform is under the 4.00 minute limit (3.84 and 3.86 minutes for Tyson's Central 123 and Central 7 Stations, respectively) assuming egress demand is distributed evenly among the various egress capacity elements. This meets the letter of the code and the platform/egress design from a practical standpoint would appear to meet the platform clear time (and walk distance) limit for the Central 123 and Central 7 Stations.

6.10.4 Time to Reach a Point of Safety

The point of safety is defined as the mezzanine level of these underground stations; above the upper level platform and below the grade level. To be defined as a point of safety, this mezzanine has to be equipped with an emergency ventilation system designed in accordance with Chapter 7 of NFPA 130. Section 6.9.1 of this report raises concerns and questions about the design of the ventilation system.

The Time to Reach a Point of Safety is calculated to be under the 6.00 minute limit (4.97 to 5.09 minute range over the four stations) however, these calculations appear to miss the pedestrian tunnel distance (between the upper level platform and the vertical circulation) and do not take into account passengers entering the queue for these vertical circulation elements (stair and one escalator) coming from the lower level platform. Adding these to the calculation would appear to add 0.60 to 0.70 minute for a total time of 5.6 to 5.8 minutes.

While this meets the letter of the code, the platform/egress design from a practical standpoint would fail the Time to Reach a Point of Safety limit for the Tyson's East and Tyson's West Stations. If passengers divided more evenly from a platform standpoint, say 67% to 33%, in egressing the platform so that the longest walk would be 300 feet, then a greater proportional egress demand would flow to the stair/escalator means of egress which would add to the wait component of the overall time. This longer wait and the additional passengers flowing up from the lower level platform to use the same stair/escalator means of egress would result in a time to reach a point of safety of over 7 minutes - violating code section 5.5.3.2 (6.0 minutes).

7. CONSTRUCTABILITY/STAGING

7.1 SEGMENT STORAGE

The constraints of storing precast concrete segments in the median need to be considered. There is a common rule of thumb that "double the average advance rate will be achieved sometime during the project". For an average advance rate of 24 ft/day, a peak production rate of 48 ft/day would be achieved. Assuming that approximately 1 week's worth of segments would need to be stored at any one time, this would translate to 40 full rings of segments, which would require a minimum footprint of approximately 7500 square feet at the portal, plus an allowance for a gantry crane.

Getting to and from the portal in the Dulles Access Highway is a challenge. Given that the weight of each segment will exceed 11 tons, it will take 4 trucks to deliver one ring. Although

the volume of deliveries is small, when combined with muck removal trucks, the volume of traffic merging in and out of the Dulles Access Highway will pose traffic risks.

7.2 MUCK/STORAGE REMOVAL

The Proposal anticipates that muck removal will be via the Dulles Toll Road to a spoil storage area on Dulles Airport property. An area for treatment of the spoils has not been identified, though it is likely required. The airport has not agreed to make this acreage available for storage. The volume of muck hauled from the site for the 3.4 mile long tunnel is estimated to be approx. 1.5 million cubic yards assuming a 1.5 bulking factor. The assumed peak production rate of 48 ft/day equates to 4,167 cubic yards or 433 trucks per day. Assuming that this peak production is achievable, the project should anticipate having to store up to one day's peak muck production at the West Portal, i.e. 4,167 cubic yards.

If the muck is conditioned from an EPBM operation the muck would need to be spread for approximately 1 week to allow for the muck to "dry". At the assumed peak production rate of 48 ft/day, an assumed 5-day work week, and a 3 feet thick spreading operation, the spoil area would need to be approximately 127,000 square feet to an agreed height. The muck pit at the portal would need to be sized to accommodate the multiple loading points and to provide sufficient storage for downtimes when hauling operations are not permitted.

The Virginia Department of Transportation (VDOT) identified issues regarding the assumed number of truck loadings and site storage/stockpiling capacity assumed, the acceleration and deceleration lane distances, round trip times to the disposal/storage site, size of the muck pit, nighttime noise impacts, tunnel liner delivery and movement, need for truck bed liners to prevent seepage, and damage to public roadway pavement.

The delivery and movement of precast tunnel liners to the portal will have similar truck and space limitations. The number of liner segments required, assuming three to four liners per truckload, will mean an average of 18 to 24 truck deliveries per day. The documents do not appear to show a sufficient acceleration/deceleration lane or truck unloading lane length for the tunnel liner deliveries.

Additional truck traffic will be required for the construction of the structures inside the tunnel including the invert, the floor of the upper level, and station platforms. These will be either precast or cast-in-place, which will require delivery of a large amount of material and/or a batch plant at the same portal used for muck removal and tunnel liner delivery operations. The logistical sequence of tunnel and station construction activities must be considered early in design and tightly controlled to maintain construction efficiency.

Since a lane of a freeway such as the Access Highway or Connector Road can carry at least 1,500 vehicles per hour at an acceptable level of service, the impact to traffic adjacent to the muck removal portal could be substantial. These impacts would include:

- Restricted lane and shoulder widths adjacent to the portal
- Temporary lane closures
- Traffic flow disruptions due to the arriving and departing trucks
- Noise impacts to the adjacent land uses

There would also be impacts of a greater geographic scope due to the wear and tear on the roadway pavement under the 250,000 fully loaded truck trips and 300,000 empty truck trips. There may be additional costs/fees required to reimburse VDOT and MWAA for the damage to the pavement.

There are also muck removal requirements related to the excavations at the station entrances that should be considered in assessing the total truck impacts of the LBT. A presentation dated June 28, 2006 estimates about 6,500 truck trips per station during a one year excavation period. This equates to about 18 empty trucks per day to the site and 18 loaded trips from the site during an 8 hour shift for each station. The total truck trips for the four stations within Tysons Corner would be about 26,000 trips each way using Route 7 and/or Route 123 to reach I-495 on their way to Lorton. There would also be the additional truck trips for the delivery of station construction materials to the site.

Typically, the single greatest cost element in earthwork construction, regardless of the technology employed, is the removal, hauling and dumping costs. These costs are directly proportional to the volume of material and the distance/time for the round trip. For the LBT alternative, the volume of excavated material and potential hauling times are a major impact to be considered both in the environmental process and in construction.

7.3 TRUCK ACCESS

Access to the East Portal will be via the Dulles International Airport Access Highway (DIAAH). However, the DIAAH has limited accessibility, particularly from the west. VDOT has stated that there cannot be trucking during peak traffic periods, weekends, or holidays. Additional connections between the Dulles Toll Road and DIAAH will be required which could present problems with toll evasion on the Dulles Toll Road.

The ability of trucks to queue up using the DIAAH median is a risk. Having this volume of traffic merging in and out of the DIAAH poses a traffic risk. More likely, conveyors would be used to take the muck to another location outside the median.

8. OVERALL SCHEDULE ISSUES

8.1 DESCRIPTION OF LBT SCHEDULE

The LBT alternative contains a 54-month construction-only schedule. It assumes that the NATM tunneling for the stations is completed almost concurrently and prior to the TBM Drive sequence. The last activity, Commissioning/ Startup and Testing is noted as having an 18-month duration but only 12 months are included in the 54-month schedule and descriptions of the schedule. The 54-month schedule appears to be highly compressed. Overall the schedule has far fewer activities than would be expected at the full Preliminary Engineering stage of design.

Interface with the above grade sections has not been accomplished. Critical path activities at the end of system development would need to be planned and scheduled.

The LBT schedule is missing the following items which are required to meet FTA eligibility:

- Public selection processes for consultants and bidders
- Environmental studies and public hearings

- Drilling, geotechnical analyses and related design completion
- Independent engineering reviews
- Independent project-wide risk assessment
- Ongoing FTA reviews and sign-offs, to be eligible for federal support.

8.2 SCHEDULE ANALYSIS

In order to give an idea of the duration of time needed for the LBT option to have the same status according to FTA criteria as the LPA, we have prepared schedules that include these activities and included them in Appendix 3. The “front end” for all our scenarios is the same. We estimate that the earliest date that FTA could recommend federal funding for the LBT alternative would be March 2009.

Assuming time for an Environmental Assessment, drilling, competitive Design-Build procurement and related activities, and assuming that the 54 months for construction stated by Tunnel at Tysons, JV is correct, the minimum overall duration for the LBT alternative is 8 years and 1 month. This “baseline comparison” analysis assumes the EA has no hold ups, that no supplemental EIS is needed, and that the 32.5 feet/day TBM advance rate indicated in the Proposal can be achieved, and that the proposed concurrently sequencing of NATM and TBM is validated during final design.

Assuming the same preparatory activities for environmental and FTA reviews, but using an average advance rate of 24 feet/day vs. the Proposal’s 32.5 feet/day, an additional 7 months would be required for construction. Using a more reasonable 5-day mining production vs the 7-day production assumed in the Proposal, an additional 16 months would be required for construction. This results in an estimated 70-month construction schedule. The LPA has a 60-month construction schedule and it is much more detailed, has been reviewed numerous times and therefore is at lower risk for slippages.

In summary, the CB schedule analysis is shown in Table 2.

Table 2: Overall Schedule Analysis

Schedule **	Start	TBM Mining Duration	Finish	Duration
32.5 feet/day 7-Day Work Week	March 1, 2007	78 weeks	April, 2015	8 Years, 1 Month (97 months)
24 feet/day 7-Day Work Week	March 1, 2007	106 weeks	October, 2015	8 Years, 8 Mos (104 months)
24 feet/day 5-Day Work Week	March 1, 2007	148 weeks	July, 2016	9 Years, 5 Mos (113 months)

** If after completion of an Environmental Assessment, a Supplemental EIS is required, a longer total duration than those stated would be required.

9. COST ISSUES

9.1 DESCRIPTION OF TUNNEL AT TYSONS, JV ESTIMATE

We have not prepared an independent cost estimate or detailed cost review of the unit prices stated by Tunnel at Tysons, JV. The Summary Cost Estimate which totals to \$2,158,995,931 in 2007 dollars and \$2,386,576,809 in 2010 dollars incorporates Phase 1 costs “Outside the Portal” from the April 2006 independent cost estimate for the LPA, which are out of date. Therefore, the totals, even in summary form, are not reliable as a way of comparing the two projects.

Based on our review, the LBT proposal needs:

- A detailed, “bottom-up” cost estimate for all Phase 1 work
- Independent Engineering Review per FTA requirements
- Adequate contingencies on cost or schedule
- Detailed plans for the two large portal operations
- Plan for trucking and disposal of muck
- Risk Assessment

Insufficient time and data exist to perform a detailed reconciliation. However, some observations can be made regarding statements made about the overall probable cost of a LBT alternative, based on the documents reviewed.

Level of Contingency. A substantial contingency would be required to address the potential risks that have been identified. This is standard for underground construction, which is considered higher risk construction. A detailed cost and risk review would be needed to assess the appropriate level of contingency. However, the Tysons Tunnel contingency assumptions of 15% for the NATM Tunnel and 10% for the TBM Tunnel are low for this stage of project design. The DRPT’s Independent Engineering Consultant utilized a contingency of 24% for the Preliminary Engineering estimate of the LPA, which represents lower risk construction.

Financing Costs. The January 30, 2007 letter to Mr. Scott Monett from the Tunnel and Tysons team indicates that “Soft Costs, Finance Charges, ROW” shown as a possible reduction of \$81 million, appears to include reduced financing costs due to the 6 months overall schedule savings claimed in the initial transmittal letter and also reduced ROW requirements. Given the comments and concerns to schedule raised in this report, this item could be an additional cost to the project rather than a reduction.

Vehicle Storage. The letter also states that, “...the potential for underground storage at Tysons for up to 80 vehicles will increase operational efficiency for start up in the morning rush hour while Wiehle Ave is a terminal station...”. This idea raises questions regarding operational facilities and costs. The significant costs associated with providing numerous cross-overs between revenue and stored trains, lay-up tracks, train cleaning facilities, inspection facilities, and train operators/crew access points, all need to be considered and adequately evaluated to determine the potential savings or additional costs in assuming this concept.

Escalation Costs are based on the 54 month schedule, which we believe to be highly compressed. Therefore, the escalation costs in the \$2,386,576,809 total are low by two years (mid-point of 2012 as opposed to 2010). Escalation costs of additional delay are at least \$50 million annually.

Tunnel Cost vs. Aerial Cost. The assertion that a 3.4 mile tunnel can be built for less than an aerial structure is problematic since the aerial alignment is primarily to be constructed in a relatively undeveloped roadway area. In October 2002, the EIS estimated that a twin bore tunnel would cost 28% more, \$422 million, than the LPA. In March 2006, DRPT estimated that the LBT would cost \$526 million more than the LPA, in year of expenditure dollars.

9.2 STATED POSSIBLE SAVINGS

The January 30 letter to Scott Monett identifies possible savings to the \$2,386,576,809 estimate.

The Tysons Tunnel schedule only assumes 10 months for procurement of a TBM. So the statement that a savings of a year can be realized by using a refurbished TBM is not likely. The LPA already assumes early procurement of vehicles so this savings has already been accounted for. Annual maintenance costs for aerial and underground transit is roughly comparable. The letter mentions reuse of excavated material from the tunnel for necessary fill such as in the median of the Dulles Access Highway. However, the more than 1,000,000 cubic yards of estimated excavated materials is far more than the approximately 150,000 cubic yards of fill required in the Dulles Access Highway median for construction of the guideway. In addition, it is unclear that the excavated material from the tunnel (or more technical term, muck) is suitable for structural fill, particularly if it contains significant quantities of mica, which local metamorphic rocks are known to contain. It is also possible it will need some sort of treatment, due to mixing it with additives for tunneling operations.

9.3 POTENTIAL ADDITIONAL COSTS

Federal Funding. By far the biggest cost risk is the potential to lose all or a portion of federal support for the project. FTA's most recent comment is "as we noted in our meeting in September 2006, there are scheduling and environmental review consequences that should be considered if the Commonwealth decides to undertake additional study of a tunnel option." Once the large bore tunnel had completed all requirements to be fundable under federal guidelines in a minimum of 2 years, it could be considered for support. The risk that the costs for a Large Bore Tunnel will cause the project to exceed the FTA's required Cost Effectiveness ratio is very high.

Immediate Funding Needs. FTA and the Commonwealth of Virginia have made a substantial investment in the LPA design and approval process over the past 13 years. FTA has made it clear that they will not fund studies and design needed to bring the LBT alternative to the same state of project readiness as the LPA. Another source of funds for geotechnical investigations, environmental studies and consultant costs would be needed immediately. Any costs to terminate the existing contract with Dulles Transit Partners (DTP) would also need funding.

10. OTHER CONSIDERATIONS

10.1 OPERATION AND MAINTENANCE COSTS

Operations and maintenance costs for those portions of transit systems on aerial structure versus those in tunnels tend to be similar. However, the items included in each of these categories are substantially different for tunnels and aerial structures.

Areas of higher cost for aerial transit

- Snow and ice treatment or removal
- Snow plans involving the operation of trains
- Third rail heaters are required
- Aerial guideways generally require more frequent replacement of track, signal and communication, and power components, to include bearings and joint seals

Areas of higher cost for underground transit

- Ventilation, smoke evacuation, drainage, and pumping
- Large ventilation shafts are required for air exchange in the vicinity of each station, in addition to the requirements for smoke evacuation as required by NFPA 130
- Dry standpipe systems for fire protection are required at periodic intervals along the tunnel. These systems require regular test programs and inspections.
- Tunnel drainage systems and wastewater collection systems from the station areas are complicated, necessitating pumping (lift) stations, which require routine maintenance
- Tunnel lighting is required for any tunnel system thereby requiring routine lamp replacement and general maintenance

Areas of cost that are similar

- Maintenance of elevators and escalators
- Routine condition-assessment inspection efforts
- Regular and routine preventive maintenance and inspection for track, traction power and signal/communications

However, for system repair and replacement work that will be required to be performed during non-operating night hours or between regular service trains, there are more favorable and safer delivery of materials and erection options for aerial structures as opposed to tunnel. Delivery of materials into the work area by truck and crane placement on aerial structure can begin shortly after the last revenue train, as opposed to having to wait for the work train to clear. This usually results in some efficiency for aerial systems versus tunnel systems for these kinds of activities.

10.2 REDEVELOPING TYSONS AS A PEDESTRIAN-FRIENDLY, TRANSIT-ORIENTED TOWN CENTER

The claim has been made that the LPA will undermine redevelopment of Tysons as a more pedestrian-friendly, transit-oriented downtown. There is no body of work, nor is it a commonly held belief by industry experts, that underground systems promote transit-orientation more than

aerial systems. Both the LPA and the LBT alternative will offer access to the regional rail transit system, making the nearby properties transit adjacent.

Whether these properties become transit-oriented is up to the landowners and the community's land use, zoning, parking and traffic regulations and their ability to orient development and access (particularly for pedestrians and buses) to the transit system. King Street Station in Alexandria is an example of an elevated transit system with good transit-oriented development that is also pedestrian friendly (Figure 2).

Commonly accepted strategies for improving the environment for pedestrians mainly focus on those that address the conflict between pedestrians and vehicles and the need for a safe, comfortable and interesting experience as a pedestrian. The placement of the transit system above or below ground is not, by itself, a contributor or detractor to pedestrian-friendliness in Tysons Corner.

10.2.1 Transit-Oriented Town Center

As stated on the website for the Center for Transit Oriented Development, components of transit oriented design include the following:

- Walkable design with pedestrian as the highest priority
- Train station as prominent feature of town center
- A regional node containing a mixture of uses in close proximity including office, residential, retail, and civic uses
- High density, high-quality development within 10-minute walk circle surrounding train station
- Collector support transit systems including trolleys, streetcars, light rail, and buses, etc
- Designed to include the easy use of bicycles, scooters, and rollerblades as daily support transportation systems
- Reduced and managed parking inside 10-minute walk circle around town center / train station

Locating the system underground is not identified as a necessary component of transit oriented design and the photographic examples of transit-oriented design on the website include both at-grade and aerial transit systems. Photographs of underground and aerial WMATA stations are included in Figure 2.

Figure 2- Metrorail Station Photos



Crystal City Station Entrance



Crystal City Station Entrance



King Street Station



King Street Station Entrance

If a solution required the removal of developable land near the transit stations, then it might be argued that the solution was not fully promoting transit orientation. But given the station sites, the LPA and the LBT alternative would remove essentially the same minimal amount of developable land.

Almost the entire length of the LPA is located in street right of way or through large freeway cloverleaves, leaving developable land as it is in almost all cases. Most of the LBT tunnel runs under streets and other forms of non developable land, and placing the alignment below ground would not significantly increase the amount of developable, transit-oriented land in the downtown. Both the LPA and the LBT alternative will offer access to the regional rail transit system, making the nearby properties transit adjacent. Whether these properties become transit-oriented is up to the landowners and the community's land use, zoning, parking and traffic regulations and their ability to achieve components like those listed above.

10.2.2 Pedestrian-Friendly Town Center

Both the LPA and the LBT alternative will have stations accessible to pedestrians. Commonly accepted strategies for improving the environment for pedestrians mainly focus on those that address the conflict between pedestrians and vehicles and the need for a safe, comfortable and interesting experience as a pedestrian. They can include the removal of cars completely, or the institution of ‘traffic calming’ actions, such as lower speed limits, narrower or curved roadways, frequent pedestrian crossings, landscaped medians, priority for pedestrians over other traffic, wide sidewalks, transparent windows in buildings at street level and providing active, interesting and safe paths to transit stations. These measures are not precluded by the LPA nor are they intrinsically encouraged by the LBT alternative. The placement of the transit system above or below ground is not necessarily a contributor or detractor to pedestrian-friendliness in Tysons Corner.

The depth of the underground stations for the LBT would range from 61 to 107 feet below ground. Each station has 2 elevators at each of the two entrances. In addition, each entrance has two escalators (up and down) and a set of stairs. Therefore, there are 4 elevators and 4 escalators at each of the 4 stations.

Elevations for key features at each station are shown in Table 3.

Table 3: LBT Station Depths

STATION NAME	Tysons East	Tysons Central 123	Tysons Central 7	Tysons West
Street Level Elevation	313	429	466	401
Mezzanine Level Elevation	291	388	419	379
Upper Platform Elevation	270	351	377	345
Lower Platform Elevation	251.75	332.75	358.75	326.75
Total Vertical Distance (ft)	61.25	96.25	107.25	74.25
Estimated Length of escalator (ft)	70.73	111.14	123.85	85.74

10.3 REAL ESTATE COSTS AND NECESSARY EASEMENTS

Tysons Tunnel, Inc. states that one of the big cost benefits is reduced real estate costs. However, they have not shown or described the large construction activities and easements and pavement easements at the two tunnels portals. Nor have they acknowledged that the LBT would require substantial additional easements for the underground alignment. Some of the construction and utility easements along Route 7 are likely needed regardless, because of VDOT plans for improvements, unrelated to either transit alignment.

The Tysons Tunnel Environmental Analysis Report states that both alternatives require the same two relocations and land takings: the Merchant Tire and Automotive Center and Cherner Kia Isuzu. In addition, the LPA requires partial takings (fee acquisition) from several properties that total approximately 29.2 acres. This acreage includes bus and parking facilities and the 4 stations. The LBT alternative would require the same acreage for bus and parking facilities and less for each of the 4 stations. The Proposal does not estimate a total acreage for their design.

The LPA anticipates 26 acres for temporary easements which includes staging for the aerial structure and also laydown areas for construction materials. The LBT alternative will require acreage for temporary easements for laydown areas and management of muck. The muck areas are potentially large and may not be readily accommodated at the spoil bank provided by the airport. The Tysons Tunnel, Inc. Environmental Analysis Report does not show temporary easements for either the West or East Portals in the Dulles Access Highway or the muck management areas. Permanent above ground easements for the two portals are also not shown. The above ground easements for the LBT option would be less than the LPA. The amount of permanent underground easements is significantly greater for the LBT alternative than for the LPA.

There is insufficient information available to assess the cost implication of these differences and it is possible that some of the construction easements for Route 123 and Route 7 might still be needed for road improvements and related utility relocations by VDOT, even under the LBT scenario.

10.4 NEPA

The National Environmental Policy Act (NEPA) of 1968 requires all federal agencies to incorporate environmental considerations in their planning and decision-making through a systematic interdisciplinary approach. Specifically, all federal agencies are to prepare detailed statements assessing the environmental impact of and alternatives to major federal actions significantly affecting the environment. These statements are commonly referred to as environmental impact statements (EISs).

Also as part of NEPA, Congress established the Council on Environmental Quality (CEQ), assigning the task of ensuring that federal agencies meet their obligations under the Act. The CEQ reports annually to the President on the state of the environment; oversees federal agency implementation of the environmental impact assessment process; and acts as a referee when agencies disagree over the adequacy of such assessments.

The current alignment for the Dulles Corridor Metrorail Project was developed as part of the required federal NEPA process over the past 13 years. An underground tunnel through Tysons consisting of twin-22 ft diameter bores was evaluated several times, but dropped from further consideration due to the costs and risks associated with underground construction. For this and other reasons, it is probable that if the LBT alternative was advanced, FTA would require preparation of a Supplemental Draft EIS and then a Supplemental Final EIS (SEIS). This effort would take at least two years and, if there are technical or community issues, could take even longer.

The FTA could not make a determination that a Supplemental EIS is not needed now. They would have to complete technical studies which include the disposal of excavated material, the location and size of the tunnel vent buildings, and tunneling under Scotts Run with minimal clearance, conduct a review, and hold public hearings. At that time, a determination could be made as to whether a Supplemental EIS is required.

The estimated time to re-do the environmental process is highly variable, due to the possibility of claims by other parties.

11. SUMMARY OF KEY RISKS

This study has identified a number of items that present substantial risks to the LBT alternative as designed; these risks may not have been taken into consideration during the development of the cost and schedule estimates. This study has not identified any risks that invalidate the technical feasibility of the proposed LBT alternative. The question is cost and schedule feasibility, not technical feasibility.

The following discussions address risks that could adversely impact the cost and/or schedule of the work as proposed.

11.1 GEOTECHNICAL AND TUNNEL CONSIDERATIONS

Ground Settlement. Approximately 38% of the tunnel alignment is positioned within one or less than one tunnel diameter below the ground surface. In these areas, the crown of the tunnel excavation will encounter soils, decomposed rock, or weathered rock materials, all below the groundwater table. In all areas the ground conditions are expected to increase in strength in the invert of the tunnel. Given these conditions, even with the EPB methods proposed, volumetric face losses during tunneling will likely exceed those inferred from the report's settlement predictions, and settlements will likely exceed those predicted. Additional methods and costs will need to be implemented to mitigate the effects of such settlement.

TBM Advance Rate. The average TBM advance rate of 32.5 ft/day, upon which the Proposal duration (and cost) are based, is at the upper end of worldwide experience, and is unprecedented for the proposed diameter in the mixed face conditions that are expected to comprise a substantial portion of the LBT's 3.4 mile alignment. Average advance rates on the order of 11 to 29 feet/day have been achieved for machines ranging from 40 to 47 feet in diameter. These advance rates have largely been achieved using slurry machines, which are better suited to dealing with the range of ground conditions anticipated. The above body of worldwide experience is compelling. Compounded by the fact that this project will need to import technology at a scale never before undertaken in the US, a lower average advance rate, on the order of 24 feet/day, seems more appropriate as a basis for estimate.

Tunneling and the Critical Path. One unique characteristic of tunnel construction is that if progress at the tunnel face is slowed, delayed or stopped, so is the Critical Path of the project. Because of this reality, schedule certainty is often improved by advancing a project with more than one tunnel heading so that if one heading is delayed, progress may still proceed elsewhere on the project. However, given the size of the TBM bore and construction staging constraints, this would be very difficult to achieve. Thus, the entire schedule of Phase 1 hinges on the ability to keep one tunnel heading moving over a 3.4-mile long alignment. This is the greatest of risks to a tunnel project, because a 1% condition can stop progress altogether.

Choice of Tunneling Methodology. Without further geotechnical data and analyses, it is considered premature to determine the appropriate type of tunneling machine for a 3.4 mile long tunnel beneath Tysons Corner at the depths specified in the Proposal. A slurry type of machine may be better suited for the underground conditions at Tysons and this determination cannot be made without further study.

Availability of Tunnel Boring Machine and Local Labor Force. Large diameter tunnel machines are rare and only a handful exist. The schedule indicated by Tysons Tunnel, Inc. assumes 10 months to procure and deliver an EPB machine. Whether a new or refurbished machine is used, a 10-month duration for procurement and delivery is considered insufficient. Beyond machine considerations, there will be a limited number of bidders for what would be the largest diameter pressurized face TBM project in the United States. The local workforce in Northern Virginia has a limited capacity for such specialized underground construction. These aspects represent potential additional cost.

11.2 STATION CONSIDERATIONS

Ground and Structure Stability. Breakouts from the segmentally lined tunnel will need to be made into potentially unstable materials that are under the water table and in close proximity to the ground surface, near-surface utilities, and adjacent structures. Mitigation measures will be required that target the risks of opening instability and settlement of the ground and overlying structures. Such mitigation measures will impact the cost and schedule of the work and do not appear to be contemplated in the current design.

Size of Excavations. The clearances within the station openings may not be in accordance with WMATA design standards. Either variations will need to be sought or larger excavations will be required.

12. CONCLUSIONS

Underground construction presents unique risks that are not typically encountered on other types of heavy civil construction. As a result, it is industry practice to evaluate any tunnel project's viability within a risk-based framework.

The proposed project involves mechanical tunnel excavation of an uncommonly large diameter in North America. The project will be mined through mixed face conditions that present more variability than most large diameter machines have encountered to date. There is insufficient subsurface information and testing to fully assess all of the risks. The project alignment involves a tunnel's diameter or less cover for approximately 38% of its alignment, where soft ground or decomposed rock will be encountered in and above the tunnel crown. The project will need to be mined its full 3.4 mile length from a single portal, and with a single machine. Station excavation will require breakouts in potentially unstable soils, and within one tunnel diameter of the ground surface.

Quantification of the attendant risks requires back-up of the cost and schedule estimates presented in the Proposal, and more study. Past projects funded by the FTA have utilized formalized Risk Register processes to quantify risks on their projects, particularly tunnel projects. Carried out at early stages of design, these Risk Registers serve to eliminate risks through pre-emptive design, or develop best practices for mitigating or managing the identified risks. Repeated at later stages of design, these procedures have helped owners and FTA representatives develop contingency budgets to capture residual risks that may remain.

Additional findings are as follows:

1. The proposed single-bore tunnel through Tysons Corner appears technically feasible, although underground construction is considered higher risk than construction above ground.
2. There is sufficient information on the Proposal schedule to assess the overall proposed sequencing and some overall activity durations. However, at the Preliminary Engineering level, a much more detailed schedule would be expected.
3. There are significant risks that the project costs and schedule durations stated by Tunnel at Tysons, JV will be exceeded.
4. While substantial, the level of effort put forth by Tysons Tunnel, Inc. does not meet the 30% level of design completion for Preliminary Engineering of a project of this scale and complexity. While this level of completion accurately describes certain sections of the documents, such as architectural drawings, other sections such as utility relocation drawings are in a conceptual stage. As such, there are many questions and issues that must be addressed before these documents can be issued to the construction industry for bid.
5. There is a significant risk that the project cost of a Large Bore Tunnel would not meet the FTA's Cost Effectiveness ratio criteria, which could compromise federal funding for the project.
6. FTA's most recent written comment is "as we noted in our meeting in September 2006, there are scheduling and environmental review consequences that should be considered if the Commonwealth decides to undertake additional study of a tunnel option." Once the large bore tunnel had completed all requirements to be fundable under federal guidelines in a minimum of 2 years, it could be considered for support.
7. The project design and construction program carry significant risks that need to be mitigated. While these can likely be addressed through additional subsurface exploration and testing, additional design, and additional construction planning, it is probable that doing so would cause the project cost and schedule estimates stated in the Proposal to be exceeded.
8. Given the many risks identified in the current project design and construction program and the inadequate geotechnical data, the contingencies incorporated in the Proposal's cost and schedule estimates are unrealistically low.
9. The Proposal's cost bases for non-tunnel components are out of date and incorrect.
10. The TBM advance rates upon which the Proposal's cost and schedule estimates are based are unlikely to be achievable given the anticipated subsurface conditions. A more realistic advance rate and production schedule would increase tunnel construction costs 14% or more, and increase the overall project construction schedule of between 7 and 16 months.
11. There are questions about the appropriate tunnel technology for this project. Once geotechnical investigations are completed, determining the technology is more feasible.
12. The Proposal assumes the use of EPBM technology but a letter states reuse of one of the SMART tunnel machines, which are slurry machines. Due to the required increase in diameter for the Tysons tunnel, and a prior rebuild of these machines, a detailed review of the feasibility is needed.

13. The Proposal design is based on a number of assumptions that do not conform with certain WMATA and national standards. A number of the assumptions, if brought into conformance, would cause an increase to the size of platforms, stations, and possibly even the main tunnel, increasing construction costs and construction schedule.
14. There are a number of additional items in the Proposal, including Visual and Noise benefits, Right of Way costs, construction staging requirements at the two tunnel portals, and transit vehicle storage savings, with which the reviewers take issue. A number of these items could cause an increase to the Proposal's stated cost and schedule, or both.

Nothing has been identified that invalidates the technical feasibility of the project. However, given the aforementioned issues, there are significant risks that the project costs and schedule durations stated by Tunnel at Tysons, JV will be exceeded.