TBM DATA MANAGEMENT AND QUALITY ASSURANCE FOR THE BRIGHTWATER CONVEYANCE PROJECT

Jeffrey Mitsopoulos ■ Jacobs Engineering

Frank Stahl ■ Babendererde Engineers GmbH

James Wonneberg ■ Jacobs Engineering

Kenneth Rossi ■ EPC Consultants, Inc.

ABSTRACT

King County's (KC) Brightwater Conveyance Project in Seattle, Washington involves the construction of approximately 21 kilometers (13 miles) of bored tunnel, in three contracts, with four TBM's which produce large amounts of real-time digital mining data. To facilitate the management of TBM data with a single interface and assist in project Quality Assurance, KC's Construction Manager (Jacobs Engineering) recommended the use of the software TPC (Tunneling Process Control), developed by Babendererde Engineers GmbH.

The paper demonstrates how TPC was used for oversight, analysis and QA on a complex tunneling project and how contemporaneous review and management of data results in a better understanding of TBM performance than can be obtained by retrospective analysis of data.

INTRODUCTION

King County's Brightwater Conveyance System will be a sewage collection and outfall system that ultimately directs treated wastewater by gravity approximately 21 Km (12.5 miles) from a treatment plant in Woodinville, Washington to the system's outfall nearly due west in Puget Sound. Tunnel construction is divided amongst three essentially simultaneously constructed contracts totaling approximately $444 B for four separate tunnels (Figure 1).

The tunnels being constructed have outside diameters ranging from 4.5 m (14′-8″) to 5.6 m (18′-4″) with a bolted, gasketed, segmental pre-cast concrete design (Figure 2). The BT-1 and BT4 tunnels are being mined by EPB TBM's where as the BT-2 and BT-3 tunnels are being mined by slurry TBM's. The drives are through a highly varied geological region that encounter maximum face pressures from 3.2 Bar (47 psi) to 6.8 Bar (98 psi) through a region of soil that is primarily highly varied glacial till (Figure 3). King County faced with this scenario inherent to the complexities of multiple-Contract Construction Management and technical challenge wrote into its Specification 02310, Tunnel Excavation, provisions for a Contractor provided TBM Data Monitoring System (DMS) that would supply the Construction Management Teams for each project the three following provisions:

1. Record data at maximum time intervals of ten seconds and display in real-time.
2. Store and record data via an automated acquisition system in digital form for later use and retrieval.

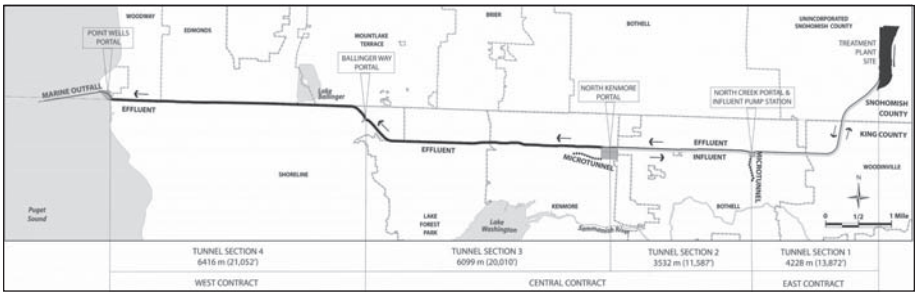

Figure 1. Brightwater conveyance system

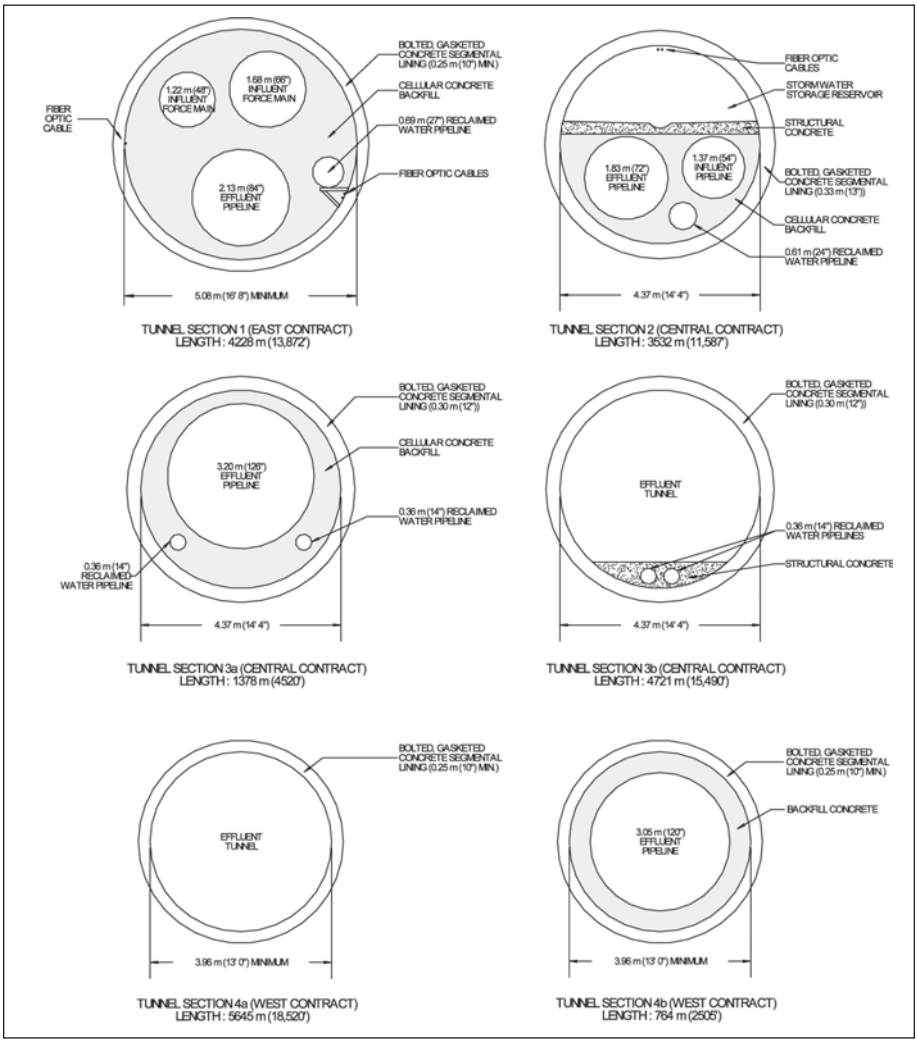

Figure 2. Brightwater conveyance tunnel sections

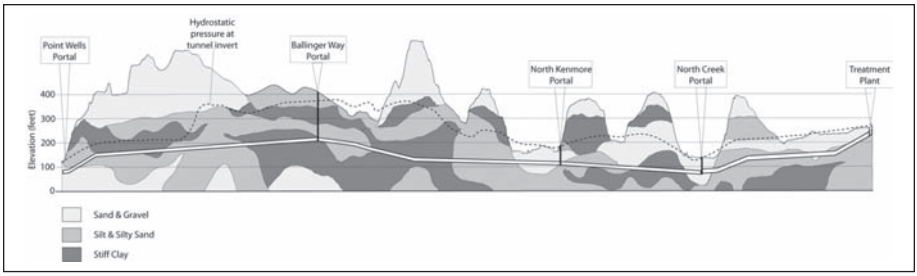

Figure 3. Brightwater conveyance system geologic profile

3. Provide secure Internet-based access to real time data for use by the Project Representative in the Project Representative office.

Given the inevitable Contractor compliance of these provisions the Jacobs Engineering CM (JECM) was to decide on the tool, a TBM Data Manager and Reporter (DMR), to archive, recall, and graphically present the data of the TBM DMS. Number one above required that the project acquire systems and hardware that could at a minimum record 10 second incremental data points, tracking approximately 130 parameters, on three shifts per day, for four separate TBM's; a massive amount of data. In total, the data could populate a database with 1,639,872,000 entries annually. Item two required that JECM obtain a DMR with the capability to accept and subsequently store continuous real-time digital data from the three separate Brightwater Contractors. Finally, the third provision suggested to the JECM to ensure the DMR provide a means to distribute data among the three planned project offices to a central hub server. Chosen by the KCCM to address the three provisions for data acquisition and processing was a software proprietary to Babendererde Engineers GmbH, Germany, called Tunneling Process Control (TPC).

TBM DATA ACQUISITION AND DATABASE MANAGEMENT

DMR Hardware

The recommended hardware implementation strategy for TPC was to set up a separate, off-the-shelf, secure network to host the system. Figure 4 shows a schematic with the key features of the system hardware used for Brightwater. The TPC network captures data from the four separate Contractor maintained TBM DMS systems.

Upon receipt of mining data from the individual TBM's, data is streamed from the two SQL servers and one ftp server to the Main Server via a high speed (T1) internet connection. The Main Server is located at the Construction Management Project Office. Using a Virtual Private Network (VPN) connection, the Main Server can be used to view real time TBM data for any of the four TBMs from a computer anywhere in the world. This is how JECM staff utilize TPC.

Key hardware parameters for the Brightwater TPC system include:

- Servers with 2.0GHzCPUs
- 4GB RAM,
- 100/1000 Base T Ethernet cards,
- wireless networking capability,
- T1 internet connection,
- 5×250GB RAID hard drive configuration.

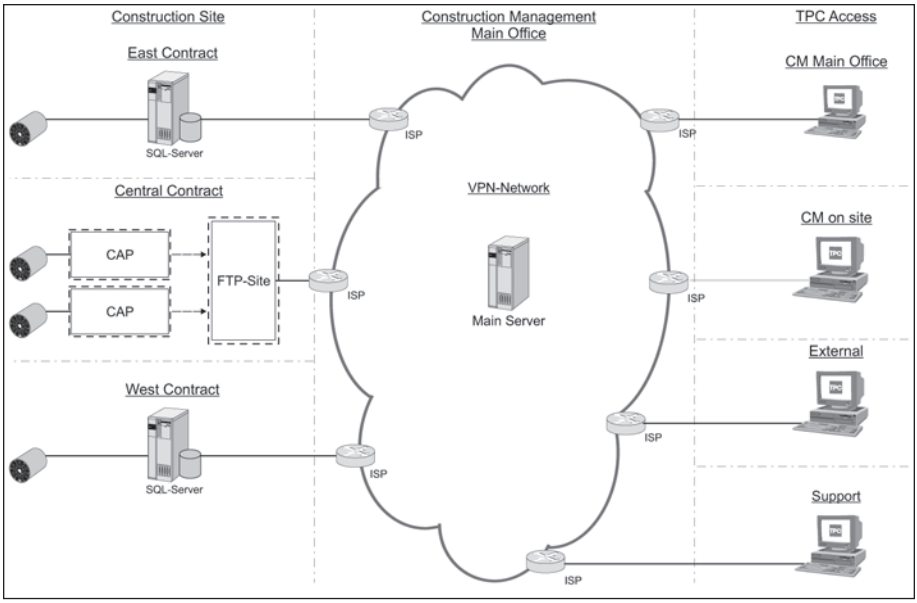

Figure 4. Brightwater DMR hardware

The Central Contract tunnels, BT-2 and BT-3, had a unique situation in that their data access was provided by periodic (20 min) posting of data to an ftp site. TPC was customized for this application to extract data from the ftp site.

DMR Software

TPC has provided the JECM with the ability to log, observe in real time, and review large quantities of multidimensional data, with reasonable processing times and powerful built-in reporting tools. Another key advantage of the system is that it allows data from different TBM types and manufacturers to be collected, managed and analyzed using a single application and interface.

The software eliminates the need for time-consuming data manipulation to review TBM performance. Instead, TPCs customizable querying and reporting tools are used to quickly generate useful and presentable information on an ongoing basis throughout each tunnel drive. These reports can be exported to pdf format, automatically sent by email, or as printed hardcopy through a LAN printer.

The software also allows manually collected data to be added to the digital data retrieved from the TBMs. This data includes, ring damage and repair information, photographs, geotechnical instrumentation data, and classification of TBM down time from field inspectors' observations. All of this data is useful in assessing TBM performance.

OVERSIGHT, CONTEMPORANEOUS REVIEW, AND REPORTING

JECM's goal for the DMR of Oversight, Contemporaneous Review, and Reporting was realized by use of the following features of TPC that allows the simultaneous and continuous monitoring of daily TBM activity on the four Brightwater tunnel drives.

1. Real-time TBM Overview and Mining Parameter Monitoring.
2. Shift Reports

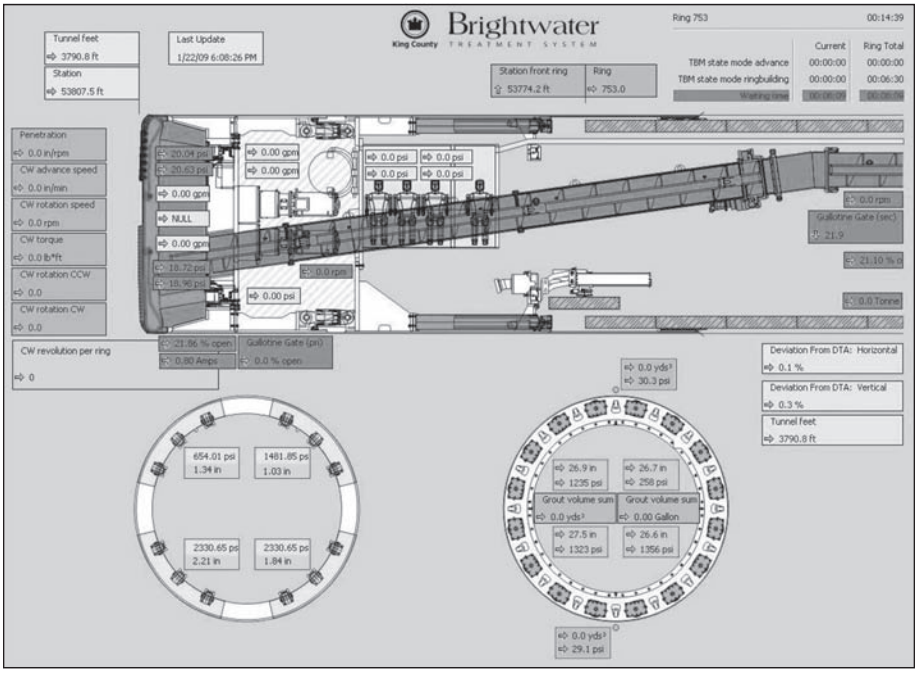

Figure 5. DMR real time viewer—BT-4 TBM

3. Productivity Analysis
4. Ring Reports
5. Multiple Analysis Plotting and Reporting.
6. Project Advance

This DMR's platform provides multiple user accounts offering the above features to all JECM personnel levels, and their specific uses for the project from Tunnel Inspectors to Assistant Resident Engineers to Project Managers. This attribute of the DMR allows for systematic monitoring and reporting activities inherent to a quality assurance program.

Real Time TBM Overview and Mining Parameter Monitoring

TPC gives the JECM User the ability to view, in real-time, at ten second intervals any of the mining parameters that the DMT is cataloging. This User can be the Inspector, the Resident Engineer, the Owner or whoever is enabled as a User, anywhere on the planet with internet access. Figure 5 shows real-time views as the User sees them for the TBM Overview. Views in this feature are refreshed in ten second intervals with the most currently reported data and are customizable to the TBM parameters of specific interest. The real time viewer for Brightwater is configured to show a TBM overview, guidance system, conveying circuit, geology, atmospheric gas monitoring, and User selected parameters.

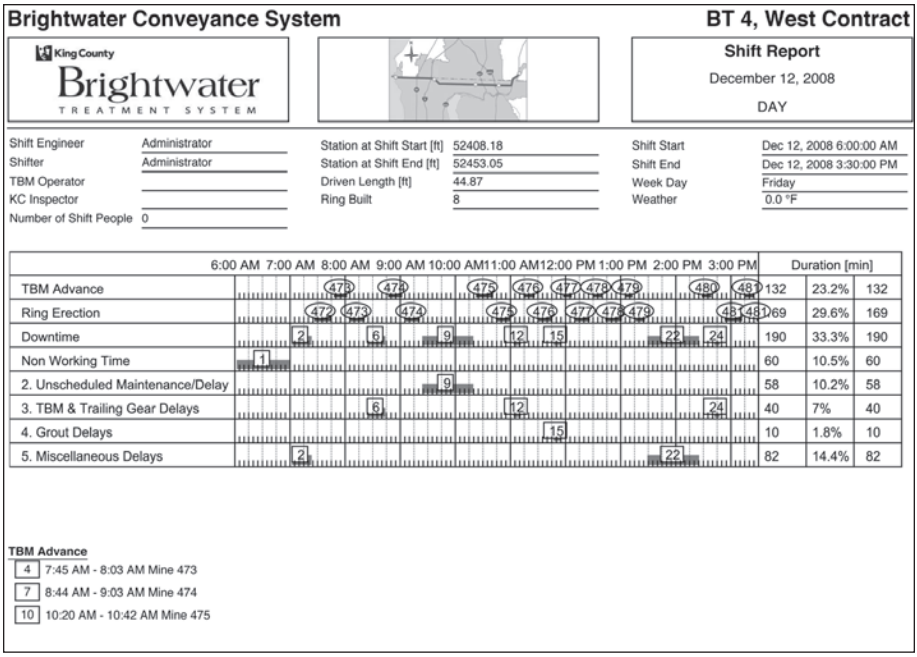

Figure 6. DMR shift report

Shift Reporting

The Brightwater Conveyance Project DMR tracks and categorizes TBM activity as Advancing, Ring Building, Nonworking Time, or Downtime over a mining operation shift which was defined by the JECM TPC User. The TPC User aided by an Inspector's daily hand written shift reports would further differentiate Downtime into subcategories pertaining to tunnel mining activity. This step became necessary to discern between Contractor error and tunneling logistics. These subcategories and the associated periods of time become part of the DMRs query-able database. Significant to the separate Brightwater contracts, these descriptions of subcategories were further tailored by the separate contracts as their machines, EPB and Slurry, have different associated causes for delay. Figure 6 shows resultant shift report showing time utilization as percentage of the shift's period. This activity was instituted as JECM daily procedure and has provided a database that is useful when evaluating Contractor mining operation efficiency.

Productivity Analysis

Directly resulting from the Shift Reporting procedure above was the DMRs capability to produce an analysis of Contractor productivity, the Productivity Analysis. Previously mentioned the shift reporting procedure provided a database of mining activity representing shift efficiency based on the categorization of Downtime. At intervals periodic and specific to the separate tunneling contracts, the JECM would produce analysis of the TBM productivity extracted from the query-able database of the DMR. TPC allows the filtering of the data fields for this feature over durations of time specified by the User. Figure 7 and demonstrate an automatically generated report of such

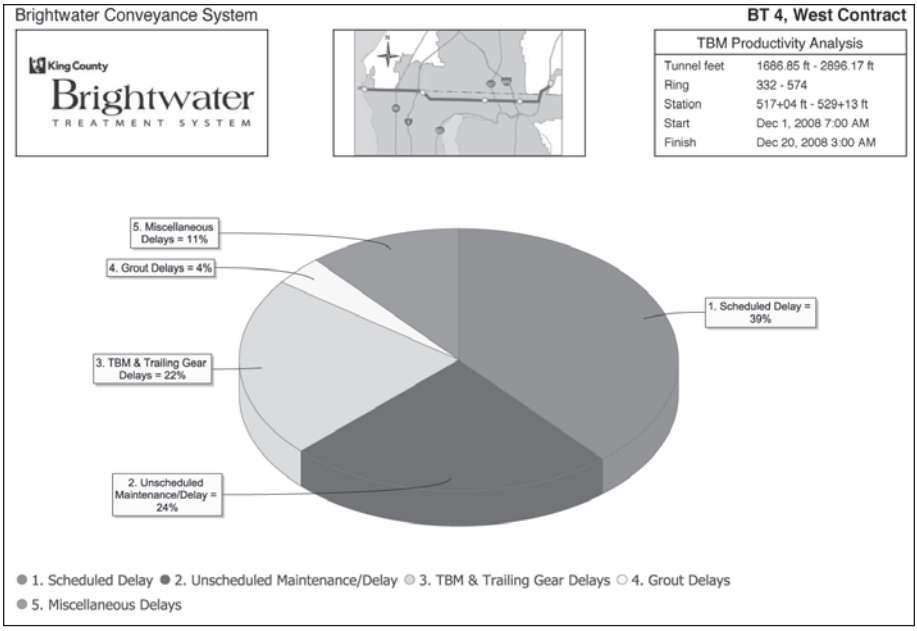

Figure 7. DMR TBM productivity analysis

an analysis over a period defined by the User. Of note in Figure 11 is the breakdown of mining activity downtime for the BT-4 TBM.

Ring Reports

Customized by the JECM to show the selected tunneling parameter summaries for each of the separate mining contracts were the Ring Mining Summaries (Ring Reports). Figure 8 represents a typical Ring Report that is generated at any time for any ring of the tunnel alignment based on the DMR User's search criteria. These graphic representations of a traditional reporting of TBM mining parameters were immediately retrievable for all rings at any point in the project.

Multiple Analysis and Reporting (Special Reports)

The complexities for the TPC system regarding its computational representation of data is too broad for the scope of this paper, however, of note is its ability to conduct compound queries of all compiled mining data over a range defined by time, ring, or station. The results of such queries are the Special Reports which allow the evaluation of essentially any TBM performance or compliance specification. This element of TPC's reporting gives the JECM analysis and graphic representation of multiple mining parameters over a common range. Figure 9 shows such an analysis for tail shield grouting.

Project Advance

At perhaps the highest level of reporting capabilities of this particular TBM DMR was the Project Advance report. Figure 10 exhibits a screen capture of such a report and its demonstration of the plotted comparisons of actual project TBM advance versus the Contractor's planned advance. The feature was primarily used to demonstrate TBM

Brightwater Conveyance System

BT 4, West Contract

King County Brightwater TREATMENT SYSTEM

Ring Mining Summary

No. 725

Station	53672.42
Tunnel feet	3655.72
Advance time	01/16/2009 13:38
	01/16/2009 13:53

1. Cutting wheel (Maximum Values)

RPM	2.67 rpm	CW Rotation	94.2% 5.8%
Thrust	375.58 Ton	Advance Rate	7.0 in/min
Total Advance Pressure	9485.94 psi	Penetration	2.7 in/rpm

2. Face Pressure

	BL	BR	TL	TR			
AVERAGE	32.0	31.0	20.4	27.4	psi	Advance time	7 min/ring
MAXIMUM	49.3	44.1	36.6	41.2	psi	Ring erection time	1 min/ring
MINIMUM	20.2	20.7	14.8	19.3	psi	Waiting time	5 min/ring

3. Jacking Units

Group	max. Advance Pressure	Extension [in]	Extension Start [in]	Extension Difference [in]
A	2,257	87	27	59
B	2,480	86	27	59
C	2,463	87	27	59
D	2,286	87	0	87

4. Grout Injection (Ring n-1)

	1	2	$V_{Act.}$	V_{Target}
V [yd³]	0.88	1.09	1.98	
$P_{avg.}$ [psi]	32.62	26.01		
P_{max} [psi]	60.20	50.28		

5. TBM Guidance System

Roll in/ft	0	Deviation From DTA, Horizontal	0.4	%
Pitch in/ft	3	Deviation From DTA, Vertical	0.7	%

6. Installed Ring Data

Station at Ring	53636.4 ft
Station at Ring n-1	53631.4 ft

7. Belt Conveyor

Scale 1	
Scale 2	41.2
Excavated	
Calc. WT.	
Bulk F	

8. Air Monitoring

Gas	Max	Min	Avg
CH4 (%LEL)	0.0	0.0	0.0

9. Soil Conditioning

	Total Gallons
Soap	-24.87
Polymer	11.05

Figure 8. DMR ring report

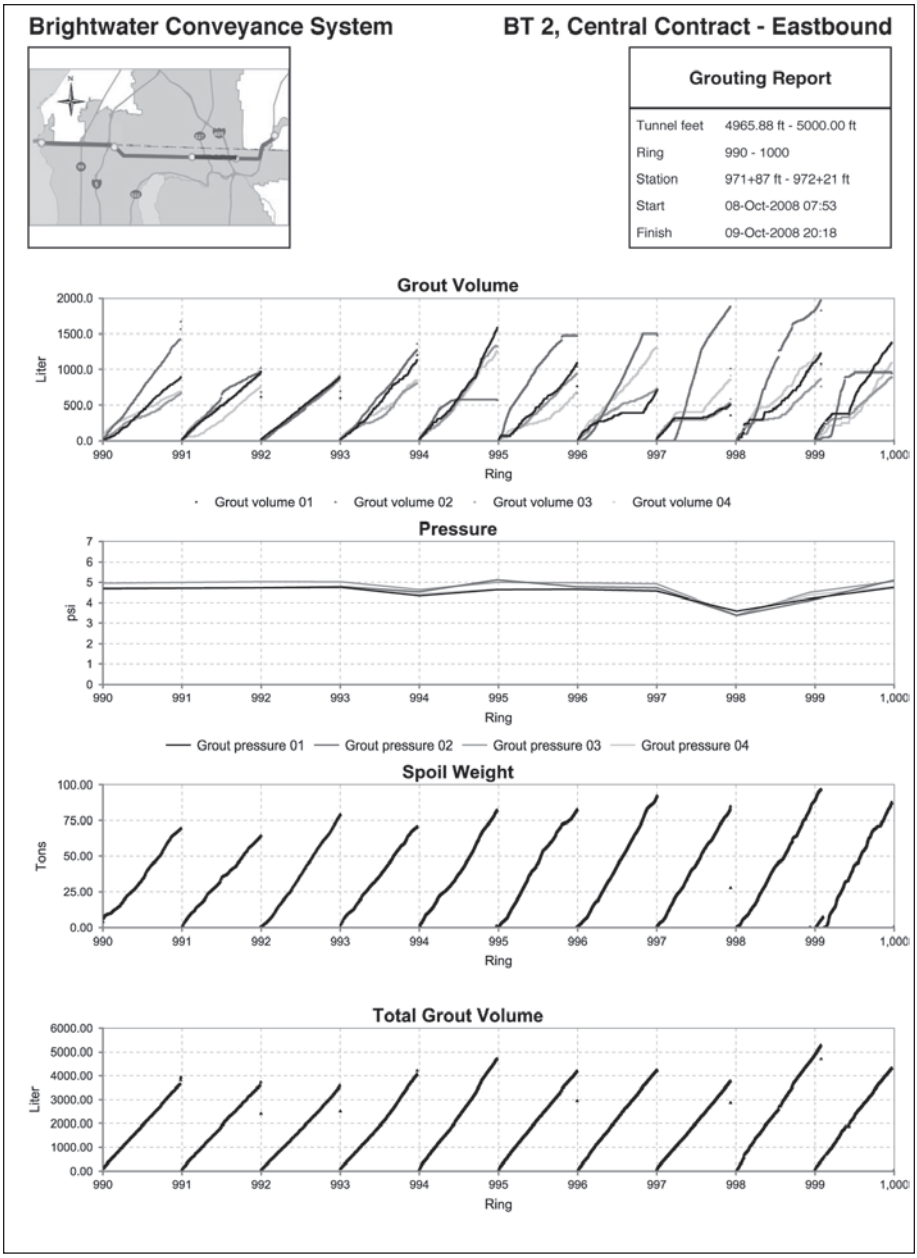

Figure 9. Special reports—grouting

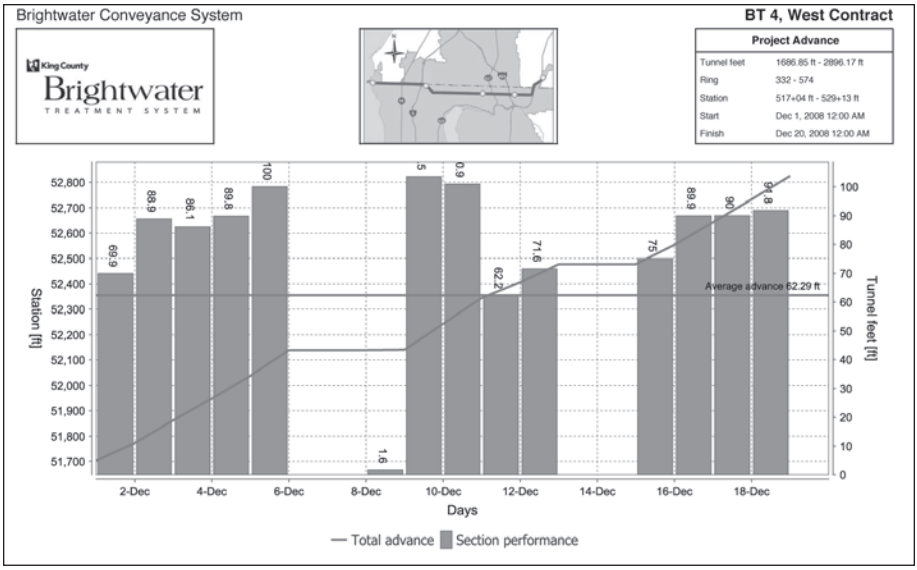

Figure 10. DMR Project Advance Report

progress in a summary level to Owner oversight audiences. Automatically generated from database query of TBM progress and the Contractor's CPM over a User selected range of time, the resulting graphic would display a succinct summary of project timeliness that was immune to debate.

AD HOC IMPLEMENTATION

During the course of the TBM drives opportunities have presented themselves for TBM activity evaluation that were not a routine part of the CM effort but rather and as-needed occurrence. Although some cases of such Ad-Hoc implementation of the Brightwater DMR are still contractually sensitive and can not yet be discussed at great length, several examples can be relayed.

Differing Site Condition

An obvious example of such a use is to evaluate a Contractor claim of Differing Site Condition (DSC) affecting TBM mining activities. Few tools for such a task will be as valuable to an Owner or Construction Manager as a query-able database of all pertinent TBM mining parameters recorded since the inception of a Contract. Ability to graphically present data that has been filtered to distill specific TBM mining parameters over a finite period of a TBM drive is valuable to Owners and the CM's.

Public Outreach/Wow Factor

During the Brightwater Conveyance Project the JECM frequently had the task of demonstrating the TPC DMR to Owner Administrators or as a public outreach. When demonstrating the real-time features of TPC, invariably the response was one tinged with a 'wow' factor. Graphically viewing the streaming data of a TBM mining activity that is ten miles away under two hundred feet of glacial till was always impressive to visitors. A project favorite anecdotal example of public outreach occurred as the JECM

was trying to validate the cause of a noise complaint of a Homeowner living above the tunnel alignment. With one JECM team member viewing TPC's Real-time viewer for an instantaneous indication of TBM activity and another JECM team member standing in the subject Homeowner's kitchen on the telephone, the team was indeed able to verify that the source of the noise complaint was the TBM.

TBM Operation Assessment

Used to a lesser extent, as cases for application on the project have thankfully been limited, are evaluations of suspect TBM Operator procedure. In the event that problems develop with the TBM, at the alignment surface, within the tunnel, etc, the DMR provides a means to thoroughly evaluate mining activity conditions and TBM Operator response. Given the dynamics of the DMR such evaluation is capable moments or months after the occurrence.

CONCLUSION

Given the current state of TBM sophistication and the inevitable increase in the application of technology to this industry's method of construction, the experiences of the Brightwater Conveyance Project's DMR can provide assistance to those planning a real-time data base management system for TBM mining parameters.

First, there is value to the Owner or Construction Manager that implements a DMR system that can evaluate data on a contemporaneous basis as opposed to a stored (retrospective) system such as one that would be periodically received in batch data from a Contractor. Primarily, value is achieved by the review of data that is current and part of a project's current state. Data does not have to be retrospectively dissected and reconstructed to show trends and events. The value to the Owner is in quality TBM data management that is efficient, that is timely, and conserves project resources.

Owners should also insist on clear succinct language in the Contract Documents that define the Contractor's requirements for interface with a project's planned DMR. This statement is painfully self explanatory and can basically be applied as a goal of all specification writing. A loophole in this project's specification did allow a Contractor to provide full TBM data access and viewing only via their own proprietary DMS.

Finally, instances in multi-contract TBM construction, such as that with Brightwater, involve individuals and CM practices of wide experience and management technique. With these conditions comes skepticism for the use of a new paradigm such as a project-wide TBM DMR like TPC. Paramount to the DMRs successful implementation is to instill the support of the project stakeholders by outlining the goals, procedures for use, and reporting well ahead of a system's implementation.