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DESIGN FOR CONSTRUCTION MITIGATION ON THE CENTRAL ARTERY/TUNNEL PROJECT

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"ABSTRACT"

In an underground construction project in urban areas, it is necessary to commit to mitigation during construction. Mitigation can include:

- avoiding impacts and damage to existing buildings, utilities and facilities along the right-of-way
- reduction of construction noise, especially at night
- limiting dust and impacts to air quality
- taking steps to avoid traffic congestion

During the project's environmental impact phase, commitments in these areas are required to ensure approval of environmental documents and encourage public support for the project. However, this poses a dilemma. The public wants impact-less, pain-free construction projects. While this is not possible or realistic for underground tunneling, it is necessary to minimize the pain and to demonstrate to the public that the impacts will be minimized. It is a challenge to show how this will be so during the design phase, before any digging takes place. In a sense, increasing environmental project requirements represent a risk to underground construction projects. It is not enough to parade a project's future benefits to the public, and expect acceptance and accolades during the years of dust and disruption that can be part of construction. Failure to educate the public, specify the mitigation of negative construction impacts, and then control the impacts during construction, can lead to the downfall of the tunnel project.

The Central Artery/Tunnel Project in Boston, Massachusetts, has focused on dealing with these issues. The project includes kilometers of cut-and-cover tunnel and underground construction built in the heart of downtown Boston. The CA/T project's approach to meet the challenge is specified in Design Policy Memorandum #1 (DPM #1). The purpose of DPM #1 is to provide specific criteria on how the designs were to address construction impact mitigation.

This article provides a description of some of the project's efforts to evaluate and manage construction impacts.

1. Impacts to Existing Buildings and Facilities

Existing structures and utilities can be damaged by soil movement from tunneling beyond the excavation walls (in the case of cut-and-cover) or movement in the zone of influence of a bored tunnel. For the cut-and-cover tunnels, which comprise the land tunnels on the CA/T, two modes of soil movement can be expected:

- Vertical movement below building foundations due to lateral excavation support wall movement
- Vertical movement due to consolidation from dewatering

DPM #1 provides limits for impacts to existing facilities that designers must analyze for and meet. The limits, in part are defined in a paper by Boscardin and Cording (1989). The limits state that impacts to historic structures must be no greater than "slight" for historic buildings, and "moderate" for non-historic buildings. The distinction between the two is that historic buildings in downtown Boston are more fragile, and are more susceptible to damage during construction. Thus, they require a higher level of specified construction mitigation.

To evaluate construction impacts, the following approach has been used:

Analysis. During design, a soil-structure interaction analysis of the tunnel excavation and dewatering section is preformed. This analysis includes design construction sequence, estimated soil parameters, analysis of the support of excavation system stiffness and performance, and impacts of required dewatering. The analysis predicts soil movements beyond the limits of excavation. The soil movements are due to the support of excavation walls deflecting into the excavation, and consolidation due to dewatering.

Effects on Existing Structures. Predicted soil movements are superimposed on existing building foundations and structures. These movements are used to estimate impacts to the buildings. For example, if the analysis estimates that the front of the building will deflect an inch down, and the back of the building a half an inch down, impacts due to this predicted differential settlement can be evaluated.

Mitigation Measures. In cases where predicted impacts are greater than what can be tolerated, mitigation measures are specified. Mitigation measures can include:

- A stiffer support-of-excavation wall system with closer strut spacing and tiebacks, and a stiffer wall type. The CA/T project has specified very stiff slurry walls. In some cases, "T" wall sections were designed to further limit deflections.
- Grouting beneath SOE walls to further limit impacts of construction dewatering, and thus reduce effects of consolidation.
- In some cases, recharge of groundwater outside SOE walls.
- In severe cases, underpinning of buildings and existing structures.

Specifications and Measurement. Construction contracts include specified limits of different types of soil and building movements, and impacts to groundwater. The limits are measured by an array of instrumentation: extensometers, piezometers, measuring points on buildings, and many others. Contracts in include "threshold" and "limiting" values for each instrument. The threshold is a warning point for a particular measurement. The limiting value requires corrective action.

2. Construction Noise Control

The CA/T Project developed noise criteria limits and best management practices to mitigate construction noise. The noise limits are included as performance requirements in each construction contract (i.e. Construction Noise Control Specification 721.560). A comprehensive noise specification has been essential for proactively avoiding excessive construction noise, as well as allowing for proper reaction to noisy work without incurring costly claims from contractors. The approach used during the design phase of construction packages at the CA/T Project has been as follows:

Receptor Locations. During the design phase, noise "receptor" locations were identified throughout the contract area. These are noise-sensitive locations along the construction right-of-way where potential noise consequences are estimated and then later measured. The receptor locations can be residences, apartment buildings, office buildings, hospitals, or other sensitive locations where excessive construction noise might interfere with peoples' activities. Not surprisingly, when building a wide cut-and-cover tunnel through the heart of downtown Boston, there were hundreds of noise receptor locations identified.

Noise Measurement for Baseline. Background noise levels were measured at each receptor location in order to establish baseline noise conditions prior to any construction activities. Noise monitors were deployed and programmed to collect ambient noise data over several days and nights at each receptor location. These baseline noise readings were reduced into daytime (7am-6pm), evening (6pm-10pm) and nighttime (10pm-7am) average results and subsequently used to establish site-specific noise limits (see Table 1).

Analysis. A predictive analysis of construction noise was performed. The analysis was based on evaluation of construction work zones, types of equipment likely to be used, distances from work zones to noise receptor locations, day and night construction schedules, ambient noise conditions, and other factors. Estimates for types of construction equipment were based on expected construction activities for various phases of work. For example, cut-and-cover tunnel excavation work could be expected to use cranes, loaders, backhoes, dump trucks, hoe rams and jackhammers; all relatively noisy pieces of equipment. Noise model calculations and acoustical assumptions were conservative. For example, it was assumed that all the construction equipment would be generating noise simultaneously in a particular work zone; an unlikely but conservative approach that allows for design of noise control measures to manage worst-case potential noise.

Noise Criteria Limits. Results of the analysis were evaluated against allowable noise criteria limits at the exterior lot-line for each receptor location. In general, these “relative increase” noise criteria were established to allow the contractor to produce up to 5 decibels (+5 dBA) more noise than existed prior to construction. As shown in Table 1, the noise specification differentiates between daytime, evening and nighttime noise. The nighttime noise criteria, understandably, is more restrictive due to the quieter background noise conditions at night and the fact that residents are trying to sleep. Both L10 and Lmax noise metrics are contained in the specification to limit steady and impulsive noise events, respectively. These criteria limits have proven themselves over time (10 years now) to successfully allow work to progress while avoiding noise hardship in the community.

Mitigation Measures. In those cases where the calculated noise was predicted to exceed allowable limits, noise mitigation was warranted and designed into the contract before it went out to bid. Noise mitigation measures could include the following options:

- Impose operational constraints such as restricting the use of very noisy equipment to daytime hours only. For example, specify in the construction contracts that pile drivers, jackhammers and hoe rams can only be allowed for use during the daytime. Since the daytime noise limits are higher, noisier work could be allowed and more easily tolerated by nearby residents and business owners.

- Use noise barriers and noise curtain systems. For certain types of work, noise barriers and curtains can effectively reduce noise providing that the line-of-sight to the equipment can be blocked. Free-standing 14 ft tall portable noise barriers can be built from plywood on jersey bases. The downtown I-93 Central Artery elevated viaduct provided a convenient structure from which to hang noise curtains and enclose work sites, at least before its demolition scheduled in 2004.

Table 1. Lot-Line Construction Noise Limits at CA/T Project

Noise Receptor Locations and Land-Uses	**Lot-Line Construction Noise Criteria Limits in dBA, RMS slow**					
	Daytime (7am – 6pm)		**Evening (6pm – 10pm)**		**Nighttime (10pm – 7am)**	
	L10	**Lmax**	**L10**	**Lmax**	**L10**	**Lmax**
Residential Locations: (Residences, Institutions, Hotels, etc.)	75 or Baseline + 5	85 or 90 (impact)	Baseline + 5	85	Baseline + 5 *(if Baseline<70)* or Baseline + 3 *(if Baseline>70)*	80 80
Commercial Areas: (Businesses, Offices, Stores, Schools, etc.)	80 or Baseline + 5	None	None	None	None	None
Industrial Areas: (Factories, Plants, etc.)	85 or Baseline + 5	None	None	None	None	None

Table 1 Notes: Where both relative and absolute noise limits are provided, the louder condition shall dictate the applicable noise limit. L10 noise compliance readings are averaged over 20 minute intervals. Lmax noise compliance readings can occur instantaneously. Baseline L10 noise conditions must be measured and established prior to construction work commencing.

- In more severe cases, reinforce or replace windows at receptor buildings with acoustically treated windows (either interior sashes or new double-paned windows). This option is relatively inexpensive and allows noise mitigation to be applied to specific receptor locations where it can do the most benefit.
- Also in severe cases, perform some noisy work on weekend days instead of at night. Traffic concerns and the need to occupy roadway lanes often leads to the need to schedule work at night. Shifting some night work to weekends carries with it potential schedule delays and labor cost premiums, so careful consideration must be provided by project schedulers and traffic regulators.
- Prohibit the use of audible backup alarms at night for construction vehicles. This was found to be feasible because CA/T work sites are confined in size, ambient noise levels are reduced at night, and there are alternatives to the backup alarms which still meet safety requirements. OSHA regulations can still be met by using an observer to direct a vehicle's rearward motion in lieu of a backup alarm. This single concession represents a noteworthy solution towards alleviating the biggest source of nighttime noise complaints from a construction site.

Since construction began, construction noise has been actively monitored and noise limits and operational restrictions have been enforced. Contractors must submit "Noise Control Plans" which proactively evaluates potentially noisy work and commits to suitable mitigation measures. The project has a nighttime "noise patrol" and a 24-hour complaint hotline. Noise technicians are available to immediately react to any noise complaint and are authorized to shut down unmitigatably loud work which may be violating applicable noise criteria limits or noise plan commitments. However, the goal for all project staff is to "keep the work going" so practical noise control solutions are always preferred to stopping the work.

One final element of a successful noise control program that should not be under-appreciated is that of community outreach and involvement. Project staff need to organize and host public meetings at which work schedules and noise mitigation plans can be shared with the affected public. A community's collective tolerance to noise will increase if people feel informed and part of "the process". CA/T design teams actively participate in these community meetings whenever a given construction contract is being formulated.

The CA/T noise control program has been effective in managing the risks of construction noise. It provides a balance of proactive conservative design strategies with realistic construction noise limits, yet still provides enough flexibility for contractor's means and methods so that the job can be bid and built. The program can be counted among the CA/T Project's success stories.

3. Air Monitoring/Dust Control

In constructing the CA/T Project, approximately 16 million cubic yards of earth material will be excavated and moved by more than a half of million truckload trips. In building a project of this magnitude, hundreds of pieces of heavy construction equipment are being used 24-hours a day such as large excavators, front-end loaders, bulldozers, cranes, cement trucks, and both 10-wheel and 18-wheel dump trucks. Because construction activities would be in close proximity to residential communities, medical facilities, businesses, and other sensitive abutters along the project alignment, the need for CA/T dust control was very apparent in order to maintain the air quality in Boston.

In order to ensure that dust control mitigation measures will be implemented, the Federal Highway Administration in its 1991 Record of Decision for the CA/T Project incorporated a Memorandum of Understanding (MOU), which established a CA/T Project Construction Air Quality Committee (CAQC). The CAQC consists of representatives from the Massachusetts Turnpike Authority, the U.S. Environmental Protection Agency, the Massachusetts Department of Environmental Protection and the City of Boston Environment Department. Through the CAQC, a comprehensive dust monitoring and construction site inspection program has been developed to monitor dust levels throughout each phase of the CA/T Project and when necessary, modifications or additions to the measures are made to reduce dust levels.

To minimize air quality dust impacts from CA/T construction activities, the project developed Construction Dust Control Specification 721.561. This specification requires each contractor working on the CA/T Project to implement a set of strict dust mitigation measures in a manner that will not result in excessive particulate matter emissions, nuisance dust conditions, or particulate matter (PM_{10}) concentrations exceeding the Massachusetts and National Ambient Air Quality Standard of 150 micrograms per cubic meter ($\mu g/m^3$) on a 24-hour average.

The CA/T Project's construction dust control specification is one of the most comprehensive dust control specifications developed for a public works project. Before any work can begin on a CA/T site, a contractor must first develop and submit for approval a "Dust Control Plan" which follows the requirements of the dust specification. By implementing this plan, every CA/T contractor will work proactively in controlling dust emissions while they perform their construction activities.

The requirements contractors must follow to control construction generated dust include:

- Wet suppression alone, or with approved binding agents, to be used on-site on a routine basis using a water truck.
- Wet spray power vacuum street sweeper to be used on paved roadways.
- Use of calcium chloride instead of wet suppression when freezing conditions exist.
- Use of wind screen fabric or solid wood barriers around the perimeter of construction sites.
- Use of wheel-wash stations or crushed stone at construction ingress/egress areas.
- Covering active stockpiles with plastic tarps, and seeding or using approved soil stabilizers on inactive stockpiles.
- Covering dump trucks during material transport on public roadways.

Due to the unique characteristics of each contract in terms of location and scope of work, particular methods to control dust in addition to the dust control specification were implemented. These methods included reducing the number of truck entrances and exits from a site within the contract; providing a crushed stone base for the dump truck in the on-site loading area; and creating embankments between stockpiles and haul roads. These particular measures were implemented to manage and reduce the dirt that was tracking off work sites and onto city streets.

In addition, emissions from diesel equipment were controlled by requiring all diesel powered construction equipment to be retrofitted with oxidation catalysts since the start of year 2000, and limiting the idling time of the equipment to less than five minutes if the equipment is not being actively used. This requirement is covered in a separate CA/T Odor Control Specification 721.562.

To evaluate the effectiveness of the dust control measures, a PM_{10} monitoring and field dust inspection program was implemented in 1997. The program measured PM_{10} levels and inspected nuisance dust at close to 20 sidewalk locations along the alignment during the summer months for the past five years. More than 2,000 daily samples were collected using portable MiniVol monitors.

The field inspection component of this program included direct observation of CA/T construction activities in areas surrounding the monitoring sites up to three times per week. The inspections recorded conditions of mitigation compliance and non-compliance against specific mitigation measures outlined in the contractor's dust control plan.

The results of five years of monitoring data indicated that the mean PM_{10} levels for all sites ranged from a low of 30 ug/m^3 to a high of 115 ug/m^3, with a few isolated cases reporting PM_{10} levels exceeding the 24-hour PM_{10} standard of 150 ug/m^3. The effects of construction activities (assessed from a statistical basis) resulted in mean PM_{10} increments over the background in the range of 10 to 81 ug/m^3 for sites within 100 feet from the main construction/stockpile areas, and up to 41 ug/m^3 for sites between 100 and 250 feet further downwind from the construction areas.

The analysis of the data concluded that most of the PM_{10} increases were localized, and confined to areas close to the major CA/T construction activities. The observations of the inspection program also concluded that the single most significant source of the high PM_{10} levels was re-suspended dust from construction trucks entering and exiting the construction areas. The results from the monitoring program indicated that the highest PM_{10} levels decreased almost 50% once dust control efforts were implemented.

Overall, given the enormous magnitude of activities that are taking place during the peak construction period of the CA/T Project, the project has been highly successful in minimizing dust emissions and PM_{10} levels. Significant lessons learned on this project to control dust include:

- To be truly effective, dust control measures need to be consistently applied throughout all construction phases and locations of the construction site.
- The community plays a vital role in judging and influencing dust mitigation policies. Because of this, the option of refining dust mitigation controls to respond to community concerns should remain available after construction has commenced.
- It has been demonstrated that dust mitigation control can be effectively implemented in a highly urbanized environment without adversely affecting project progress.

4. Traffic Management

The CA/T project requires construction of deep, wide cut-and-cover tunnels in the middle of a dense, busy urban area. One of the biggest fears prior to construction was that the city would come to a grinding halt during a decade of construction. As great an achievement as the final product would be, such an interim condition would devastate the city. To address this concern, the project developed a detailed construction staging and traffic mitigation measures prior to any shovel hitting the ground.

The Project's Environmental filings contained many commitments to address this concern. Two key traffic commitments were:

- maintaining traffic and transportation service with minimum disruption during the construction period as the cornerstone of project planning, and
- focusing mitigation measures on improving traffic and pedestrian circulation at or near temporary detours or disruptions.

Despite these commitments and the efforts detailed below, the community's perception that disastrous disruption was unavoidable persisted throughout the design phase and well into the first few years of construction. Although traffic management efforts have been extensive compared to a more typical construction project, the results have proven to be a great success.

Traffic Reduction. Efforts to mitigate traffic impacts started in the planning and preliminary design stages with statewide steps to provide alternatives to highway transportation and reduce traffic through the city. Capacity of the region's existing subway, commuter rail, transit and water transportation systems was expanded before construction of the tunnel project began. Also, park and ride capacity was expanded at points along the region's highway system. South of the city, the Old Colony Rail Road, whose owners had stopped service in 1959, was restored from Plymouth and Middleboro by the Massachusetts Bay Transportation Authority (MBTA) and is now carrying an estimated 7500 commuters in the morning peak. The MBTA also extended rail lines to the west and north with an increase in ridership for the morning peak expected to be 3000 to 5000 commuters. The MBTA had created 10,000 new parking spaces at its rail and subway stations by 1996 and another 10,000 spaces were added by 1999 by joint effort of MBTA, Massport, Massachusetts Highway Department and Massachusetts Turnpike Authority. The city's three bus terminals which had been in the heart of the downtown and reached by local streets were relocated and combined into one modern transit facility at the interchange of I-90 and I-93 thus removing many bus trips from local streets.

Major Milestones. Central Artery/Tunnel project designers were careful to orchestrate traffic friendly construction staging through the identification of major milestones, which would result in improved traffic mobility through the CA/T corridor as the project progressed. The basic planning assumption was to open the I-90 highway to traffic first followed about 6 months later by the new I-93 NB tunnel and then 12 months later the I-93 SB tunnel. Early milestones provided only for commercial traffic, and later milestones provided increased capacity for connections between major arterials and finally increased capacity for regional connections. The key elements of the major milestone planning involved:

- Constructing and opening the new harbor tunnel along with a dedicated truck route between the tunnel and I-93 known as the South Boston Bypass Road. These roads, while open only to commercial traffic during peak periods, provided more capacity across the harbor and removed significant truck traffic from the downtown construction corridor as well as from the South Boston residential neighborhoods. The new harbor tunnel, named after the famous Red Sox player, Ted Williams was opened in December of 1995, connecting Industrial South Boston to Logan Airport. The South Boston Bypass Road opened in two stages, the first in 1995.
- Constructing and opening the new Leverett Circle Connector from I-93 to Storrow Drive in 1999 which provide two more lanes of capacity over the Charles River and separated approximately 500 vehicles per hour headed to Storrow Drive from the rest of the I-93 SB traffic which experienced severe congestion in the morning peak hour. This will increase to 1000 vehicles per hour in mid 2002 when the connection from the Tobin Bridge (US Route 1) to Storrow Drive opens, further reducing traffic on a section of I-93SB.
- Opening of I-90, now scheduled for fall 2002, providing a direction regional connection for general traffic from I-93 south of the city and I-90 west of the city to Logan Airport and Route 1A, which serves the North Shore area of eastern Massachusetts.
- Opening of I-93 NB, scheduled for late 2002. This milestone allows demolition of portions of the old elevated central artery structure and reduces through traffic on city streets making way for finishing construction of I-93 SB tunnel.

- Opening I-93 SB tunnel, which allows demolition of the remainder of the old elevated central artery structure and restoration of the surface streets in the project corridor.

Managing Interstate Traffic. In the I-93 corridor existing interstate facilities were in the same general footprint as the proposed new tunnels and viaducts. There were commitments to maintain 3 lanes of traffic both north and south bound on the interstate during construction. Through the central portion (downtown) designers were challenged to plan for tunnel construction directly beneath the elevated artery while it still carried the full interstate demand volume. The solution required underpinning the elevated artery and supporting it on the walls of the new tunnels that were constructed by slurry wall techniques. Load transfer was done at night, maintaining one lane in each direction on I-93. Once the underpinning was complete, the remainder of the tunnel construction could take place between the slurry walls and traffic could continue to safely operate on the elevated roadway.

In viaduct portions of the I-93 corridor and in the interchange between existing I-90 and I-93, the design planned for many temporary roadways both at grade and on structure to shift traffic around the active the construction areas. The most significant of these were the interim viaduct over Albany Street which has carried I-93 SB traffic since 1997, the loop ramps on temporary bridges in the Central Artery North Area which provide connections from the Tobin Bridge (US Route 1) to I-93 NB & SB, and most recently the Northbound Bypass which shifted I-93 NB traffic east onto a temporary viaduct over Atlantic Ave so that the I-93 SB could be shifted onto the I-93 NB structure to allow construction of the new I-93 SB tunnel.

The old elevated highway had many on and off ramps through the downtown area that actually contributed to traffic congestion since distances between ramps averaged only 1000 feet. The new interstate tunnels were to have fewer on and off ramps with longer distances between exits thus maximizing the through capacity of the mainline. However, elimination of ramps before the new tunnels were open for traffic was imprudent, because local collectors and arterials, still burdened by through traffic trying to avoid congestion on the old central artery, could not accommodate the traffic from the closed ramps. As a result, designers worked out solutions to leave ramps in place until the last possible construction stages.

As construction progressed, the staging was reviewed by project traffic engineers a few months before implementation to ensure that traffic maintenance goals were being met.

Managing Local Traffic. In 1994 the Commonwealth of Massachusetts signed an agreement with the City of Boston providing for the joint coordination of construction and management of traffic. The agreement covered provisions for a myriad of traffic management issues including such things as traffic monitoring with cameras and other electronic means, signal maintenance responsibilities, traffic and parking enforcement. It also provide for joint review of all project design documents including:

- Corridor-wide Traffic Management Plans
- Traffic Management Plans for each design/construction contract
- Traffic Management Plans provided by contractors corresponding to their staged work plans
- Mitigation measures impacting vehicular and pedestrian traffic circulation, construction sequencing and staging

The agreement covered both local and regional roadways, but it was primarily aimed at ensuring traffic control and mitigation on city streets. Plans were submitted to the city at each stage of design, but generally the traffic management plans were jointly reviewed between the 75% and 100% design packages. These reviews were scheduled in advance and, during the first three years of design, took place at weekly workshops in a large conference room at the Central Artery Project. The conceptual design and construction staging was presented by the Section Design Consultant along with the proposed traffic management plan to accommodate the construction staging. Workshop participants included city and project traffic personnel, the project's community liason staff and other design staff as appropriate. The meetings were scheduled and conducted by a facilitator responsible for controlling the meeting schedule while allowing all interests to express their concerns about traffic management and related construction issues. This level of centralized cross communication on traffic and construction staging was vital to achieving consensus given the size and complexity of the project and the decentralization of personnel working on the issues. The agreement with the city also provided for a Joint Coordinating Committee that was made up of senior members of the City, the State and the FHWA. One purpose of this committee was to resolve traffic management and other issues that could not be resolved by the workshop participants

The early design contracts provided a full set of detailed traffic staging plans as part of the bid documents including striping, signage and signal plans. Since the standard contract specifications required the contractor to submit detailed traffic staging plans based on his construction staging, much of the designer's work to detail the traffic management plans was not used if the contractor submitted plans based on revised staging. Subsequently, the Project was able to realize both a design dollar and a schedule savings and still ensure the quality of the maintenance of traffic plans by adopting use of the "Contractor Submittal Model" for traffic staging plans. This approach used the design consultants to carefully develop traffic staging plans for the entire contract limits (the "baseline" design for traffic staging), but left the responsibility for drafting details to the Contractor. A single plan, called the Contractor Submittal Model, was incorporated into the traffic management package. This plan showed one intersection fully designed with signs, striping, curbs, handicap ramps, signal locations etc. The contract required that the Contractor's Traffic Management Plan submittal be developed in the format and to the level of detail shown in this plan.

<u>Traffic Forecasting.</u> Traffic forecasts for use in designing milestone roadway systems and other interim construction stages were developed using the same traffic model that had been developed to analyze final design alternatives for the Environmental Impact Studies. This model, based on Tranplan software, continued to provide a useful tool for evaluating alternatives during design and for providing project wide traffic volumes for different construction stages. It was challenging to keep the model current during the project's design period. The model needed to be recalibrated each year, and there were many revisions to the street system during design. The number of design contract areas, the number of years of planned construction created a very large number of roadway network alternatives. Changes in construction sequencing or construction schedules in contracts already bid, often affected traffic projections for staging in later designs. Ironically, in our age of technological changes at the speed of light, new traffic modeling software was available before we ever started some of the final design contracts, but because of the model size and complexity its use was continued for the Central Artery Project and for environmental analysis for new development projects in the Central Artery corridor.

<u>Traffic Analysis</u>. The long design period also created challenges and opportunities for traffic analysis, which supports the designs. During the preliminary design the traffic operations analysis was done primarily with two analytical tools called Cinch and Transyt 7F. As the Project design progressed, Cynch was replaced by Highway Capacity Software (HCS). Both HCS and Transyt 7F was subsequently replaced by Syncro and Simtraffic. Each program has used increasingly sophisticated and refined traffic mathematics and computer techniques, which have increased the amount and quality of traffic operations data available for the designer. As a result, however; some portions of the project were designed based on older operations data. As we dust off some of the later design contracts, we are finding different operational characteristics on a few of the roadway segments than assumed with the original design.

The traffic staging and construction staging was difficult, tedious, and a great success, so much so that not only has the project been built with minimized impacts, but it has even turned into a tourist attraction in its own right. Tens of thousands of people visited a CA/T tunnel ramp during First Night 2000.

5. Conclusion

A common theme among all of these impacts is the need to estimate what will happen during construction before construction begins. The risk to an underground project like the Central Artery is that construction impacts can be so severe, that public outcry could lead to work stoppages, delay, or worse. Nowadays, this is an extremely serious risk. It can be managed by effective evaluation of impacts prior to construction, along with clear definition and measurement of impacts in the construction contract.

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