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Final Report

Design of a Scale Model to Evaluate the Dispersion of Biological and Chemical Agents in a NYC Subway Station

Prepared by

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16. Abstract

Urban subway systems remain among the most susceptible to a terrorist attack by biological or chemical agents (BCA) because they are heavily trafficked and have limited points of egress. The combination between efficient creation of casualties and anonymity afforded to terrorists make subways attractive targets. However, the disproportionate amount of passengers to subway employees, limits the ability of transit workers to identify suspicious activity. On March 20, 1995, the Aum Shinrykio religious cult demonstrated this with the release of sarin gas at five locations within a Tokyo subway. This assault resulted in twelve deaths and approximately 5,000 illnesses. An October 6, 2005 terror threat on the NYC subway system, although not realized, reminded United States residents that this possibility persists even post-September 11. This limitation was also exploited by the Al Qaeda architects of the July 7, 2005 London transit attacks in which bombs were detonated on three subway cars and a double-decker bus, resulting in 56 deaths (including the bombers) and roughly 700 injuries. Other incidents, such as a 1995 series of subway and train bombings in Paris and the March 11, 2004 commuter train bombings contribute to concerns over subway vulnerability.

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DESIGN OF A SCALE MODEL OF A NYC SUBWAY STATION

TO SUPPORT THE EVALUATION OF THE

TRANSPORT AND DISPERSION OF BIOLOGICAL AND CHEMICAL THREAT AGENTS IN NYC SUBWAY STATIONS

Background

Urban subway systems remain among the most susceptible to a terrorist attack by biological or chemical agents (BCA) because they are heavily trafficked and have limited points of egress. The combination between efficient creation of casualties and anonymity afforded to terrorists make subways attractive targets. However, the disproportionate amount of passengers to subway employees, limits the ability of transit workers to identify suspicious activity. On March 20, 1995, the Aum Shinrykio religious cult demonstrated this with the release of sarin gas at five locations within a Tokyo subway. This assault resulted in twelve deaths and approximately 5,000 illnesses. An October 6, 2005 terror threat on the NYC subway system, although not realized, reminded United States residents that this possibility persists even post-September 11. This limitation was also exploited by the Al Qaeda architects of the July 7, 2005 London transit attacks in which bombs were detonated on three subway cars and a double-decker bus, resulting in 56 deaths (including the bombers) and roughly 700 injuries. Other incidents, such as a 1995 series of subway and train bombings in Paris and the March 11, 2004 commuter train bombings contribute to concerns over subway vulnerability.

Objective

The long-term goal of this research is to improve the ability of transit authorities to respond to a release of a BCA in or outside of a subway station, by informing policy regarding:

- Placement of BCA sensors within subway stations,
- Necessary sensitivity and response time of sensors to monitor BCAs,
- Ventilation design considerations to mitigate potential exposure to BCAs, and
- Development of risk-minimizing egress strategies.

The short-term goals of this research is to acquire detailed flow field information in a series of fluid dynamics experiments intended to characterize the transport and dispersion of a surrogate BCA into, across, and out of a scale model of a New York City (NYC) subway station. The scale model will be modular, allowing for degrees of complexity in subway station design and therefore flow pattern to be characterized. The experiments will use existing in-house resources, including a wind tunnel and a particle image velocimeter (PIV). The flow field information will be used to develop and validate a Multi-Compartment Mass Balance (MCMB) model, and to evaluate the Subway Environment Simulation (SES) model. The former model will be designed to account for both transport and dispersion of the BCA in and across the station, while the latter model only accounts for transport of BCA within subway stations.

The immediate goals of the proposed work are to:

1) Identify current practices employed by the NYC MTA for ventilation in normal and 'emergency' conditions.
2) Develop detailed Autocad drawings of the 137th St and 145th St 1 line stations.
3) Identify construction materials for the scale model that will represent the texture of materials used in the actual stations.

The results of the proposed work will allow the short-term goals of the overall project to be realized. The ventilation practices will inform the placement of fans, ducts, and gratings in the station. The scale model will be constructed per the Autocad drawings.

Detailed tasks and methodology

Task 1: Identify current practices employed by the NYC MTA for ventilation in normal and 'emergency' conditions

The ventilation requirements and recommendations specified in this guideline are able to address fire safety concerns, but are not necessarily able to safeguard against the release or entrainment of a BCA into the subway environment.

Subway station and tunnel ventilation practices employed in NYC are designed to respond to fire conditions in the subway tunnels. Their design is based on the critical fan plant facilities design guideline DG302 (Reiter, 1997) which stipulates that ventilation systems be able to replace the air in each tunnel in an 'emergency' condition with a volume of air equal to the tunnel volume, taken either from the street level or exhausted from the tunnel. In addition to meeting a target capacity, the ventilation systems must have the ability to achieve a critical velocity in the tunnel of approximately 3 m/s, in accordance with National Fire Protection Association (NFPA) Code 130. Although separate ventilation fans are recommended for each tunnel section, separate fans are not required. The guidelines do not stipulate the location of the ventilation system fans or their orientation. As a result, fans are typically located in places that allow for ready access for maintenance purposes.

The physical properties of some BCAs (ex. density much greater than air) make them more likely to accumulate in below ground environments. However, even if the properties of the BCA were not considered, it is unlikely that ventilation systems designed according to DG302 can adequately safeguard against the release or entrainment of a BCA into the subway environment. For example, tunnels without separate fans may prolong exposure by retaining BCA in tunnel. Fan placement and orientation may allow for some BCA to settle and accumulate in the tunnels. Systems that ventilate the tunnel with street level air could actually draw BCAs released above ground into the subway environment. Systems that ventilate the tunnel by exhausting tunnel air, could actually release BCAs to the above ground environment.

Task 2: Develop detailed Autocad drawings of the 137th St and 145th St 1 line stations

Both stations are underground and have no mezzanine level. The 137th Street station has a side platform design, while the 145th Street station has both a center platform design, as illustrated and photographed in Figure F2. The stations also differ, in the number of tracks, the platform depth, and the column design and frequency.

Printouts of the Autocad drawings of the two stations were obtained from the City of New York Metropolitan Transit Authority, eliminating the need to develop these drawings. The drawings were analyzed to identify the dimensions of station components, as shown in Table 1.

Table 1. Dimensions of actual and scale station components.

	Actual size	**Scale model (1:48)**
Train width	8' 9"	2.2"
Half station width	24' 6" – 49'	6" – 1' 0.2"
Distance between track and ceiling between platform and ceiling	20' 13' 2"	5.0" 3.3"
Station length	410' 6" for station plus 528' before and after station	8.6" for station plus 11' before and after station

The actual station components will be scaled to 1/48th of the size (i.e., "O" scale), to accommodate commercially available scale model subway cars and building components. Other factors that were considered in the development of the scale model of the station that were identified include:

- The relative dimensions of the platform, ceiling, track, and train will be based on the actual dimensions of the 137th St and 145th St stations. Considering the actual station dimensions and the scale of the model scale, the resulting height of the platform and ceiling will be consistent with other scales studies of subway transport (Ke et al., 2002).
- Although many stations (including the 137th and 145th St stations) have two or more tracks and platforms, each model will represent only a half of the station, as if cut along an axis parallel to the tracks. The motivation for this simplification is to allow airflow patterns over the track to be observed by PIV. A dual-platform model station obscures the view of the track area below the platform from either side, whereas a single-track model allows for image capture from the track side of the station. This configuration also simplifies the number of experimental variables.
- Each model will include a 0.1 mile length of track preceding the station, a station length equal to that of an eight-car train, and a 0.1 mile length of track following the station.
- The scale design will be modular, allowing complexity in structural details of the two stations (ex. columns, ceiling details, and stairwells) to be gradually added.
- The train motion will be automated for realism of BCA suspension.

Task 3: Identify construction materials for the scale model that will represent the texture of materials used in the actual stations

The scale model will be used to evaluate the transport and dispersion of a surrogate BCA, released outside of or in a subway station. Since surfaces have inherent roughness, it is important to construct the scale model from materials with similar texture as the actual station.

The texture of the structural features of the 137th Street and 145th Street stations were classified and used to identify scale model construction materials that mimic the actual texture of the NYC subway platforms, middle divider, columns, stairwells, train and track.

I: Waiting Platforms

The waiting platforms are located alongside the two tracks. They are made of three layered sections of plywood in the following arrangement, on top of the ¾" base platform as shown in **figure 1**.

Item	Number	Quantity	Supplier
1/8"x 16"x 54" finished ply	-	1	Mike's Lumber
3/8" x 24"x 48" finished ply	-	1	The Home Depot

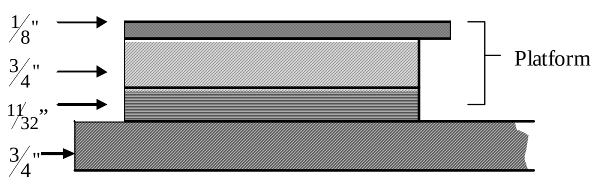

Figure 1

These three pieces were layered and nailed together. These platform "units" can then be attached and removed from the base piece through the use of screws.

The four platforms were attached to the base sections **A1-B1** and **A3-B3** in an arrangement depicted by **figures 2 and 3**.

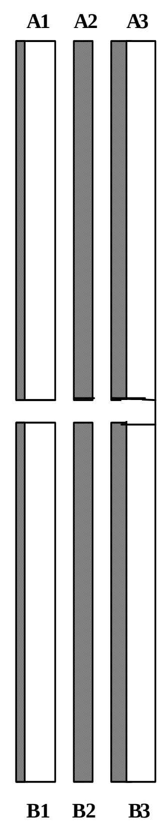

Figure 2

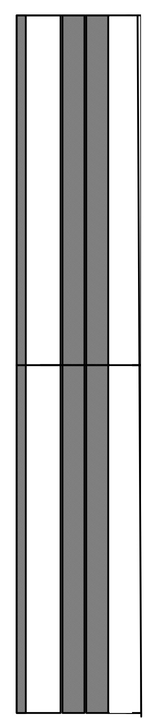

Figure 3

II: Middle Divider

On the far right side of section A2 and B2 (the removable train track), a divider was nailed that continued along the entire length of each section. This divider serves as the continuous base of the middle support columns.

For the production of the column, a quarter inch path on each platform piece was hollowed out using a router. The middle divider of the train station that continues along the length was also hollowed in the center with a quarter inch router. These paths were continued on each platform piece and each middle divider. **Figure 4** shows a cross section of the scale model depicting how portions of the model were hollowed out with a router tool.

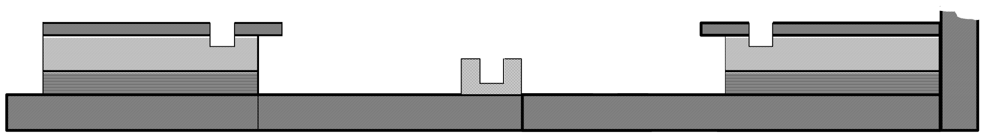

Figure 4

These quarter inch hollowed out portions of the model serve as an efficient means of installing and removing column sections from the overall model. Using ¼" x ¼" x 30" inch rods, columns can be easily inserted or removed from the sections.

III. Columns

Plans for installation of the column evolved substantially. Initially, it was decided that thin, bent brass metal rods could approximate the design for the column. However, major disagreement was over the high cost of the metal materials. Square rods were viewed as an alternative. Such rods could fit securely in place in the platform, and could be removed easily. However, concern existed over the difficulty in covering the holes once the columns were removed in an efficient manner, and whether the square column would disturb airflow in the same manner as a more accurate representation. After some research, prefabricated columns were found online at Plastruct, Inc. for an affordable price, and a number of ABS plastic H-Columns were purchased. Each column comes ¼"x ¼" x 15" in packs of five.

Item	**Number**	**Quantity**	**Supplier**
H-8 ¼" ABS H-Columns	90065	6 (5items/unit)	Plastruct
¼"x ¼" x 36" Hardwood Dowels	27456	18	Lowe's

The columns on the platforms were constructed by embedding the prefabricated ABS plastic columns (cut at the same length) in the appropriate orientation in between two long wooden dowels. Each column is "dug" into the wood 1/16" on each side, making the column a total of

2.375" tall as indicated in **figure 5**. In order to hollow out the portion of the dowel to fit the column, a ¼" router was used, set at a depth of 1/16". Each column is spaced apart 3.25"

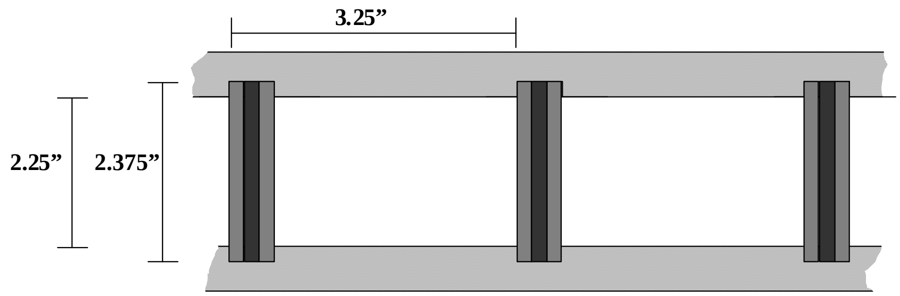

Figure 5

Columns for the middle divider were built in the same way, except that the total height of the middle columns was 3.125"

Note: Several ABS base mounts (Item number 95413 from Plastruct) were purchased for trial, but decided against being used, due to their fragility, inaccuracy, and inefficiency.

IV: Stairs

Item	Number	Quantity	Supplier
1/8" x 12" x 48" finished ply	-	1	Janoff's Stationary
1/32" x 12" x 48" finished ply	-	1	Janoff's Stationary

Two pieces of plywood were glued together to obtain one homogenous piece of 5/32" (7.5" to scale) piece. This measurement represents an accurate approximation of the "rise" of subway stairs. Careful measures must be taken when gluing the plywood pieces together, for the 1/32" ply is very fragile. The uniform ply piece of 5/32"x 12"x 48" was used to create eight staircases, by layering strips of plywood that have been decremented 1/4" in width from the previous. The largest piece (bottom step) is measured at 4", allowing for a total of 16 steps till the smallest ¼" strip of ply at the top. The entire staircase measures 2.5" from the base to the top.

V: The Ceiling

Design of the roof of the model was a process of evolution. The roof of the modeled subway station consists of a sequence of segmental arches supported by columns in between. These arches continue along the entire length of the station as the ceiling. In order to approximate the arching pattern of the ceiling, bending plastic according to a mold, and nailing it in to force it to take appropriate shape proved ineffective. The plastic tended to flatten out near the center region where it was not supported. Since in order to force the plastic to take form would require a more intricate system of molds, the added clutter was too poor a payoff. It was decided that the ceiling could be left as a flat piece of glass, and which could easily be slid into the model via hollowed routes.

VI: Track and Train

Item	Number	Quantity	Supplier
Premier - R-40 Train (4-Car train set)	20-2717-1	1	Trainworld
Atlas - O 40" custom rigid straight	6058	9	Trainworld
Atlas - O 1.75" Straight Track Section	6052	1	Trainworld
Rail King - Z1000 Transformer	40-1000	1	Trainworld

Various model trains are available for purchase. Premier's new line of subway series trains is making its debut. The NY subway model Premier R-40 train set was chosen for its accuracy.

Reliable O-gauge (1:48 scale) track should be purchased for the operation of the train.

CONCLUSIONS

A 1:48 scale model of the 137th Street C line MTA station in New York City was constructed with materials that mimic the surface roughness of elements in the station and with dimensions based on the actual Autocad drawings for the station. The model is modular, allowing for the effect of various roughness elements in the station on BCA dispersion in the environment to be investigated. A specification sheet for the model was also developed (see attached).

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BIOCHEMICAL AGENT TRANSPORT IN SUBWAY STATIONS USING A MODULAR SCALE MODEL AND PARTICLE IMAGE VELOCIMETRY

Project goal: Measure the flow field and the dispersion of BCA surrogates in the subway station environment to estimate exposure to riders and workers. Future studies will probe the role of forced vs. natural convection in the station on exposure, and methods of BCA containment.

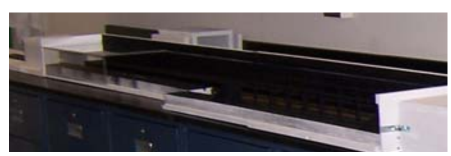
Key PIV features:

- Uses Nd:YAG laser which produces 532 nm (frequency doubled) light
- Produces 6” to 12” long laser sheet
- Allows for ~16 ms between subsequent images

Key scale model features:

- Dimensions and scale based on MTA drawings of the 135th St C line station components and includes an 8 car automated train, 2 tracks (1 removable), 2 platforms, multiple stairwells (all removable), multiple columns (all removable)
- Transparent glass (in section being studied using PIV) and plexiglass (in all other sections) are used as ceiling and side wall of scale model to allow PIV system to be used to evaluate flow field and dispersion in both profile and plan view
- Guiding track alongside and on top of model maintains alignment of PIV camera between sequential experiments
- Surrogate BCA generated using Magnum 650 Fog Machine / water-based glycerin solution and released via uptunnel flow or at singular locations along track
- Automated train is a MTH Premier R-40 8-Car train set that runs along Atlas O-40" rigid track
- Scale model base, platforms, tunnel extensions and staircases constructed using finished plywood, sealed with waterproofing, and then painted flat black; scale model columns are ABS scale model H-columns held in place using 1/4”x1/4” wood rods

Actual and 1:48 model dimensions	Actual Size	Model Size
Station dimensions		
Overall length	410’-6”	8'-6"
Distance between track & ceiling	14'-6"	3 5/8"
Distance between platform & ceiling	10'-0"	2 1/2"
Tunnel length before & after station	528’-0"	11’-0"
Track dimensions		
Train width	8'-6"	2 1/4"
Track width	10'-5"	2 5/8"
Spacing between tracks	1'-6"	3/8"x3/4"
Platform dimensions		
Height	4'-5"	1 1/8"
Width	12'-0"	3"
Column dimensions		
Outer width	1'x1'x10'-0"	1/4"x1/4"x2 1/2"
Inner width	1'x1'x15'-0"	1/4"x1/4"x3 3/4"
Spacing to adjacent column	15'-0"	3 3/4"
Staircase dimensions		
Overall height	10'-0"	2 1/2"
Footprint width	6'-6"	1 5/8"
Footprint length	15'-6"	3 7/8"
Distance to adjacent staircase	102'-0"	2'-1 1/2"



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