EDUCATING ABOUT TRANSPORT HISTORY: DEVELOPING OBJECT-LEARNING PROGRAMS AT THE LONDON TRANSPORT MUSEUM

An Interactive Qualifying Project Report submitted to the
Faculty of the Worcester Polytechnic Institute, in partial fulfillment
of the Bachelor of Science degree
in cooperation with the London Transport Museum

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Abstract

Incorporating engineering objects into educational outreach programs is a proven means to excite students about transport engineering. Grounded in theories of museum education and object-based learning, we offer means to help the London Transport Museum (LTM) achieve this mission: narratives on various disciplines of transport engineering, an engineering object catalog, and "toolkits" for using objects in engineering education programs. These resources and suggestions for acquiring new engineering objects are designed to enhance current and future program development.

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Executive Summary

London, England, is experiencing considerable population growth, and its transportation needs are increasing. The need for skilled transportation engineers to manage public transportation, and the importance of a solid STEM (Science, Technology, Engineering, and Mathematics) education curriculum has never been clearer. To help meet this need, the London Transport Museum (LTM) and its parent government organization, Transport for London (TfL), have developed educational programs designed to inspire students to explore transport engineering careers.

One educational initiative run by LTM, titled "Inspire Engineering", promotes engineering among London school students through activities at the London Transport Museum, and its secondary location, the Acton Depot, where antique buses and trains are stored for posterity. Assisting LTM in this effort are volunteer TfL engineers, known as Engineering Ambassadors, who engage with students and teach them about their jobs. The program has seen a positive response since its inception, but LTM desires to expand it further by integrating engineering objects into the program to supplement its engineering educational curriculum. Research into museum education in recent decades has shown that students respond positively to interactive, inquiry-based learning, particular when they are able to engage with objects and artifacts. For this reason, LTM wishes to incorporate this type of object-based learning (OBL) into Inspire Engineering and its other educational initiatives.

To do so, LTM has developed a collection of engineering objects in its object-handling collection and its Engineering Artifact Library (an object collection developed primarily for "Inspire Engineering"). While these collections are available for student engagements, they are not always fully used. The museum seeks to further tap these resources and refine this object-based learning component of the initiative. This project designed OBL-based engineering education materials for LTM to use, guided by four main objectives:

- Developing narrative histories on engineering branches in TfL.
- Categorize objects from LTM's Engineering Artifact library and object-handling collection, in addition to relevant items located in LTM's main collection.
- Develop OBL tools for LTM educational programs.

- Identify sources of and recommend new artifacts for object-based learning activities.

The methods used to achieve these goals included in-depth research into object-based learning and the history of transport engineering within London. Interviews with museum education experts, and observations of OBL programs supplemented this research, which culminated in a museum education training session attended by the project group. These methods provided the resources necessary to develop OBL components for LTM educational programs. TfL engineering narratives composed during this project provide the context necessary to use engineering objects to educate, and integrate engineering objects into the museum's collection to provide a connection between the history of transport engineering in London and LTM's engineering artifact collection.

Engineering artifacts from the museum's main collection, object-handling collection, and Engineering Artifact database are compiled in a comprehensive catalog, organized by the engineering topics focused on in narratives. The narratives and Engineering Object Catalog together provide LTM with resources for building OBL activities in the future. These resources were also used to develop object-based learning components for the Inspire Engineering: Primary Inspire program, and an object-handling trolley for an upcoming museum exhibit (called "Tomorrow's Journeys") about current upgrades to the London Underground. A final assessment of these deliverables provided the information necessary for recommendations for expansion of LTM's engineering object collection, based on sources identified during the project. Specifically, many duplicates of engineering objects exist within the museum's main collection, which could potentially be requisitioned into a handling collection, while other objects can be obtained from engineers and staff members of Transport for London eager to help LTM's educational ambitions.

Discussions with both engineers and museum professionals, and the research and development involved in developing the deliverables of this project, yielded many conclusions about the use of object-based learning for engineering. Museum professionals were largely in agreement that objects can help convey the truth behind difficult and abstract concepts like engineering by providing a tangible example of those concepts. In addition, those objects with interesting backgrounds can be used as a basis to "tell a story" and instigate insightful discussions.

The deliverables of this project are designed to reflect those ideas. The engineering narratives were greatly supplemented with photographs of engineering objects. By presenting objects in those contexts, the relationships of historical objects with their contemporary counterparts (for example, a lever-based signaling component, and a microchip from a computerized signaling apparatus) helped to convey the evolution of transport technology over time. In addition, the object-based learning components of this project are designed with recommendations for objects to be used in engineering education programs, and guidelines for the concepts they can help teach, and discussion topics around which to focus student activities involving object exploration and interaction.

We recommend that LTM continue their expansion of the OBL components within "Inspire Engineering" and other engineering education initiatives. Additionally, if LTM were to focus on the acquisition of more engineering objects, they might better reflect the history of LTM. This, in turn, would assist in the development of more specialized object-based learning activities. Similarly, the museum might consider acquiring more "engineering materials" and objects related to materials science. Materials samples would be easy to procure, and excellent examples to help convey engineering concepts to young students.

LTM may also consider expanding their engineering information by developing new engineering narratives on water transportation and cycling in London, two topics our group did not focus on in our project. Finally, we suggest recruiting the involvement of Engineering Ambassadors in activity development. These engineers possess a great deal of information regarding transport engineering and are eager to assist in engineering education, in the development of future object-handling activities may also prove to be beneficial to the expansion of these initiatives.

1. Introduction

Society is moving into the digital age at a rapid rate, with innovations like smart phones and tablet computers permitting instantaneous access to information at the touch of a button, threatening to replace everyday objects and tools. Education is naturally following suit, moving into an age of digital learning where knowledge is increasingly within the reach of our fingertips. Despite this digital shift, people retain an appreciation for museums. These preservers of world culture and human history remain relevant to education for the opportunities they present students to engage with pieces of the real world. However, to stay relevant in an age where the convenience of digital learning is becoming the norm, museums are challenged to develop innovative methods of promoting learning and engaging the public (Lasky, 2009).

The London Transport Museum (LTM) continually develops innovative programs to remain relevant in a changing time, implementing initiatives that utilize the artifacts in their collection to help educate visitors and students about transportation in London. LTM seeks to use object-based learning to help bridge the gap between students and the complicated, in-depth concepts in transport engineering. Object-based learning methods, which involve tactile and visual stimuli to enhance learning, have yielded greater success in stimulating students' interest in abstract topics than lecture or reading-based learning methods (Borun, 2002).

To incorporate object-based learning into their current initiatives, LTM seeks to develop activities to supplement both an exhibit on the extensive upgrades currently underway on the London Underground, and its innovative Inspire Engineering program. Inspire Engineering is a large-scale outreach program to educate students about transport engineering and history operated in conjunction with LTM's government sponsor, Transport for London (TfL), which manages public transportation in London. Transport engineers, all volunteers to the program, engage students at schools and at LTM in discussions about transportation. While a collection of handling objects for these student engagements is available, they are not always fully used. The museum seeks to further tap these resources and refine this object-based learning component of the initiative.

This report presents plans and guidelines for using transport engineering artifacts to supplement object-based programs for the London Transport Museum, in order to engage students and present the history of transport engineering within TfL. In developing activities, we

have categorized available objects from museum handling collections based on their representation of the diverse engineering fields in TfL. To provide contextual information surrounding the objects for museum staff who use them in programs, our group has also authored narrative histories of engineering branches involved in London's transportation systems that incorporate specific, relevant objects presented at the museum. Finally, we collaborated with several education and museum experts through interviews, undertook background research into methods of object-based learning, and worked with LTM staff and TfL engineers to guide the development of object-based components for LTM's "Inspire Engineering" program and an interactive object-handling trolley for the upcoming "Tomorrow's Journey" exhibit, utilizing artifacts available in the LTM collections.

2. Background

The day-to-day activities of London, England, are wholly dependent upon a complex and reliable transportation network. In London, the responsibility for managing all public transportation falls to the government organization Transport for London (TfL) (London Transport Museum, 2012b). TfL manages public transportation for London, integrating itself into the daily lives of citizens and visitors that make use of its services. Founded as the London Passenger Transport Board (LPTB) in 1933, TfL has expanded many times over the years to incorporate London's buses, the underground rail system, the over-ground rail system, river transportation, taxicabs and other road transport, and cycling routes (London Transport Museum, 2012a). In order to facilitate the administration and operation of these transportation systems, TfL is organized into several branches of specific transportation disciplines.

The London Underground is the most famous of TfL's transport branches, dating back to 1863 when the first underground railway opened in London. The Underground is responsible for the transportation of over 3.5 million passengers a day, its 11 lines covering approximately 402km (Transport for London, 2012e). Much of the infrastructure in the Underground is exceptionally old, with some dating back 150 years to its opening. Consequently, the Underground is currently undergoing major upgrades, and will soon feature new trains, new track, and an advanced signaling system, along with renovated stations with improved handicap accessibility (Transport for London, 2011a). Its counterpart, the London Overground, physically encircles the city and manages over-ground rail transportation, carrying 120 million passengers in 2012 (four times the number recorded for 2007) (Transport for London, 2012b).

In addition to rail, a tram network is operated by London Tramlink (founded in 2000), which maintains 28km of track and 30 trams, and transports nearly 29 million passengers a year, an increase of 45 percent since Tramlink's inception (Transport for London, 2012d).

Road transportation is organized into two different TfL branches. London Taxi & Private Hire (TPH) is responsible for managing the 22,000 taxis in the city, and training and licensing London's 25,000 taxi drivers (Transport for London, 2012c), while London Buses operates the fleet of 8,500 buses, one of the largest bus networks in the world (Transport for London, 2012a).

Aware of the considerable importance that continued and reliable public transportation has in the city of London, TfL is dedicated to educating the public about London transportation

history and transport engineering, in order to inspire future generations to take on transportation careers and keep the infrastructure of the city alive (Transport for London, 2011). In partnership with the London Transport Museum, a non-profit organization devoted to preserving and educating about transport history, TfL aims to portray the evolution of transportation in London over the past 200 years. With its diverse and focused collection of transport related artifacts, the museum offers a unique perspective on London's history (London Transport Museum, 2013a). Now, seeking to continually improve and innovate, the museum is shifting its focus to find new ways to educate the public about transport history.

To do so, LTM, with support from TfL, is reaching out to schools to bring transport education to younger generations. The museum aims to educate students about transport engineering and to spark their interest in scientific subjects by presenting the history and science behind London transportation. Through programs developed by LTM, students will learn more about STEM (Science, Technology, Engineering, and Mathematics) subjects and London transport history, developing team-building and analytical skills in the process. The museum collaborates with schools on these programs in the hope that the interactive educational methods the museum can provide will motivate and excite students to consider careers in STEM subjects, and thereby maintain the science and engineering skill sets in the workforce that London requires to maintain its vast infrastructure (Transport for London, 2011).

2.1. Education in Museums

Supplementing the science curriculum of London schools via interaction with the London Transport Museum is a concept rooted in academic research. Museums have consistently provided society scholastic benefits by presenting an informal education. While an informal education can be obtained from various sources, including books, the Internet, and television, museums have a unique advantage. Past president of the American Association of Museums Joel N. Bloom and archaeologist Ann Mintz asserted that, unlike other education sources, museums provide "direct, one-to-one experience with real objects" (1990, p. 13). Museum curators have long been of the opinion that exhibits can encourage people to "keep digging," and provide an "additional connection with history" generated by real artifacts—a distinguishing feature of museums that gives them an edge in an era of easily accessible information and digital media (Museum Professional 1, 2013).

However, the methods by which the museum teaches its visitors have not always been as engaging. In the 19th century it was believed that a museum should present its information similarly to a school – a lecture format with little interaction between educator and learner (Bloom & Mintz, 1990). Educational researcher Dorothea Lasky (2009) noted that early museums were simply a collection of items on display. Visitors could peruse collections and read the descriptions of items, but were often unable to form unique connections with the objects.

Museums are beginning to move from this format and move towards a more engaging one. Museum educators Jennifer Wild Czajkowski and Shiralee Hudson Hill (2008) believe that the museum should provoke a dialogue between itself and its visitors. For example, this may involve people physically engaging with the museum by listening to voice recordings of a reading from someone's diary or a newspaper. A person who is physically engaged will be able to associate sights, sounds, smells, and feelings with the artifacts or ideas they are learning about (Lasky, 2009). Ideally, this interactive dialogue will inspire visitors to come up with questions and develop a connection with the artifacts or ideas presented by the museum, leading to a deeper understanding and appreciation of the topics presented (Bloom & Mintz, 1990).

The Detroit Institute of Arts (DIA) is attempting to increase direct engagement with visitors. Tracking and timing studies revealed that museum patrons were not connecting with the exhibits (Czajkowski & Hill, 2008). In response, the museum staff redesigned their galleries to ensure that visitors "form deeper, more intimate relationships with works of art by deepening their skills of looking and interpretation" (Czajkowski & Hill, 2008, p. 257). The redesigned DIA succeeded at connecting with the visitors by providing creative stimulation and promoting conversation (Czajkowski & Hill, 2008). This allowed the visitors to get their own meaning from the art, making it a more personal, memorable, and meaningful experience.

Like the DIA, LTM is opening up to these new ideas. They are providing the public with unique opportunities for learning, allowing students of any and all ages, ethnicities and genders to explore and engage with engineering and London transportation history. By letting students engage with objects from the museum through the Inspire Engineering Program, students will be able to develop connections with the concepts these artifacts represent.

2.2. Inquiry-Based Learning

Interaction with objects can have a significant impact on our thought processes. Historically this has been noted in healthcare. In the 1860s Florence Nightingale stated: "The effect in sickness of beautiful objects, of variety of objects, and especially of brilliancy of color is hardly at all appreciated…. [The] objects presented to patients are actual means of recovery" (Nightingale, 2004). More recently it was shown that elderly patients at London's Newham University Hospital responded very positively to a 1940s "Nostalgia Room," meant to augment memories with a prop-filled room complete with a pianist playing wartime songs. Museum curator Helen Chatterjee (2007) relates the example of a patient at the hospital who had not spoken comprehensibly in five years, but sang along with the piano perfectly and became more cognizant of her surroundings, much to the elation of her family and doctor. Such a reaction shows the benefit in providing a tangible point for the mind to focus on.

The classical lecture where an instructor stands in front of a class presenting facts in a way that educator and philosopher Paulo Freire calls "motionless, static, compartmentalized, and predictable," (1993, p. 71) can be as similarly stimulating as a stay in a hospital bed with little to do and no window to look out of. As Freire noted, it is reduced to the chore of banking, whereby all the students do is receive the knowledge to file and store for later. On the other hand, when there is interactivity – some component of a physical relationship to the subject – more stimulation occurs. It has been shown that upon being involved in an unfamiliar educational setting, students will begin to formulate ideas on their own as well as develop interest in future learning about a subject, similarly to how patients are stimulated by familiar surroundings to make them happier and more invested in the external world (Chatterjee, 2007).

Inquiry-based learning was first introduced in the educational world in the 1960s by learning theorists and psychologists, particularly Jerome Bruner, the most often credited originator of "discovery learning" (1961). Bruner argued that "practice in discovering for oneself teaches one to acquire information in a way that makes that information more readily viable in problem solving" (1961, p. 26). In scientific discovery, all knowledge is based upon observation, experience, and inquiry. Inquiry-based learning is meant to mirror that natural process, flowing from hypothesis to experiment to conclusion and back to more hypotheses. It differs from learning facts to recall later, in that it is about experiencing the scientific process so that the

student can use it again and again, in school and life, to self-teach (Bell, Urhahne, Schanze, & Ploetzner, 2010).

According to a list compiled by science education researcher Thorsten Bell and his colleagues (2010), many inquiry learning models exist and nearly all of them begin with students first formulating and articulating questions. These reflect a personal interest that the student has in learning. Next, the students will gather evidence on their own or in a guided procedure. They must explain what the evidence could point to and draw conclusions. Furthermore, the students have the opportunity to argue their conclusion with their gathered evidence. This process develops the ability to self-teach (Bell et al., 2010).

This form of learning, when introduced to a classroom setting, naturally induces collaboration, particularly when interest is stimulated by group-based activities. Differing opinions arise and often positive, fact-oriented arguments convene and students are brought around to others' ways of thinking (Chatterjee, 2007). As opposed to the monotony and tedium of lectures, students are engaged in a personal learning process with their peers and begin to develop interpersonal skills on a scholastic level that is often crucial in higher education and will continue to be used in their careers.

As previously stated, museums can be a great asset to learning. Inquiry-based learning has been implemented in these places of education by physically engaging someone with interactive exhibits. This sort of inquiry learning in a casual setting is enjoyable rather than forced (Borun, 2002). In recent years this inquiry-based method has been explored in depth by museums with the goal of making education more interactive and enjoyable.

2.3. Object-Based Learning

The type of inquiry-based learning explained above, which encourages "guided participation" (Borun, 2002, p. 242), is a teaching method that museums can apply naturally by presenting objects in a compelling way. When objects are presented in a context that stimulates interest, they can by themselves be a catalyst of education (Borun, 2002). Indeed, interacting with and investigating objects, particularly the unique assortment museums possess, can present opportunities for guided inquiry that render objects effective, and powerful, learning tools (Durbin, Morris, & Wilkinson, 1990).

In order for an object to be an efficient learning tool, it must first possess the ability to convey information and meaning. Having such qualities allows an object to connect people to abstract concepts, like historical settings or different cultures, that people may have difficulty grasping otherwise. Dorothea Lasky asserts that objects help people "access their imaginations" (2009, p. 73) and engage with histories, cultures, artistic and social movements, and people in a way that fosters deep understanding. Objects have the capacity to present narratives about people and cultures, and reflect the cultural, historical, and scientific in a way that textbooks and visualizations like photographs cannot provide (Lasky, 2009).

However, the capacity to reflect knowledge and inspire deeper connections is not a universal property, but a property of those objects that possess unique, thought-provoking qualities – objects that are the defining features of museums. Museum curators Martha Sear and Kirsten Wehner (2009) in the book *Museum Materialities: Objects, Engagements, Interpretations*, explore the notion of "object biography" – how an object's history and properties can help convey broader knowledge – within the framework of the development of an exhibit on the diverse culture of Australia. For example, they consider that the materials out of which an artifact was made and the methods used to create it can yield information about the "ambitions, practices, skills and material and social conditions" (Sear & Wehner, 2009, p. 146) of the person, or community, that was associated with that object. In this way, a history can be discovered and shared by inquiring about and exploring the physical properties of an object.

Often, however, the learning objects that resonate the most with people are those objects that provide substance to specific moments in time, allowing people to connect with history in a more intimate way. Sandra Dudley (2012), in her paper "Materiality Matters: Experiencing the Displayed Object," offers the example of a visitor to the Jewish Holocaust Museum in Melbourne, Australia, who happened upon a model of the Treblinka concentration camp made by a man who survived the camp, but lost his family during the ordeal. This model provoked a deep emotional response in the visitor, where other exhibits that lacked the personal history this artifact carried did not (Dudley, 2012). The model, developed in this way, was able to connect the viewer to an historical moment at a more emotional level, provoking a state of personal reflection absent when the visitor explored similar exhibits.

Objects that possess connections to history can also facilitate the sharing of a narrative about pivotal moments in the lives of people, such as a journey from one location to another. An

example featured in the *Australian Journeys* collection of the National Museum of Australia is a Latvian national dress made by an immigrant to Australia over a period between 1939 and 1957 (Sear & Wehner, 2009). The dressmaker fled Latvia for Australia during World War II, but kept and wore the dress her entire life. In the words of Sear and Wehner, an object (the dress) is able to "[encompass a woman's] entire journey through life…her childhood and old age, the dreams of her ancestors for Latvian independence and her political action" (2009, p. 149). In this way, the dress provides a concrete, visual framework to help convey a narrative about a unique piece of Australian culture.

In exploring how objects can convey knowledge, it is worthwhile to define the qualities that make an object an especially useful tool for learning, over other established learning media such as photographs, videos, and other facsimiles. Psychologist Kevin Crowley, and Professor of Education Gaea Leinhardt (2001) noted that while a detailed photograph can convey the same visual information as the object itself, only the object can convey four important physical pieces of information: resolution, scale, authenticity, and value. Often the detail of ancient cloth or a painting is lost in photographs shown in textbooks, but that resolution is realized with the real item up close. Scale can be lost in such photographic representations as well. The jaw of a Tyrannosaurus Rex, when viewed in person, allows one to imagine the real terror such a gigantic creature could generate. Being inches away from a sword belonging to Napoleon allows one to be much more connected to its authenticity than a picture would. Similarly, being in the same room as the Crown Jewels evokes a feeling of value that is removed when viewed in a text. All of these attributes add a layer of personality to the experience, and the viewer can feel much more engaged (Leinhardt & Crowley, 2001).

The idea that an object can provoke thought and dialogue in people is significant, and can readily be applied to educating students. By applying the concepts of inquiry-based and object-based learning to education, students can be guided along a path of investigation, from identifying physical features about an object to discussing hypotheses about its form or function, leading to enlightening insights and conclusions, as displayed in Figure 1 (Durbin et al., 1990).

Figure 1: "Investigating an Object" (Durbin et al., 1990).

Through object-based learning – particularly when museums, repositories of distinctive objects, and schools collaborate – a more interactive learning environment for students and a unique approach to developing lessons can be attained. Kay Stables (2001), a professor of Design Education, explores a specific example of museum and school collaboration between a primary school class and the London Design Museum. The Design Museum constructed a "Mystery Loan Box" of artifacts from its collection that teachers could use to develop lessons for students. In one lesson, students were placed in groups with a "mystery object" (such as a ceiling fan meant to connect to a light bulb socket, and a tool for clay modeling) from the box and tasked with describing its purpose by drawing on their knowledge of materials and objects. Using the object as a stimulus, group discussion and collaboration were emphasized, allowing students to work together to explore the objects in depth. The lesson enabled teachers to encourage children's problem solving skills, but also improve their ability to articulate and express ideas as they presented their thoughts on the purpose of each "mystery object."

However, museum-school partnerships can go beyond collaborations in the classroom. Visits to museums permit students access to knowledge through interaction with artifacts and objects otherwise unavailable to them. When students visit museums and interact with objects, they can experience what they are learning on a different level. A student learning the history of a specific ancient culture in class perceives this knowledge in an abstract way. When visiting a museum and gaining the opportunity to view, or even hold, an artifact of that culture, the student

is able to integrate that knowledge with something tangible and make connections that textbooks and photographs cannot contribute on their own (Lasky, 2009).

This practice can be similarly useful for STEM subjects, which are often difficult for students to connect with on a personal level. A museum education specialist and program developer interviewed for this project used the idea of engineering the original Victorian subway tunnels in London to convey the challenge in imparting STEM knowledge. He related that, "most of us aren't tunnelers. We just can't understand the actual method or experience." He went on to explain that objects can be uniquely useful in this effort, because they can help reveal "part of the truth" about experiences such as tunneling. He offered that the example of an old brick, which might "represent the thousands needed to build a tunnel," could help teach about that experience by providing "a focus for a discussion about tunneling" (Museum Professional 3, 2013). By using an object as a focal point, a STEM topic can be explored in a relatable way. The brick, in the context of a museum and the histories it can impart, lends students access to significant insights about engineering and history by providing a tangible basis for exploring a much larger topic.

2.4. Objects Engaging Inquiry: TfL Inspire & Object-Based Learning at LTM

One of TfL's most prominent educational programs is their "Inspire Engineering" program, run by LTM (London Transport Museum, 2013d). Inspire uses presentations by Engineering Ambassadors, volunteers from TfL with engineering backgrounds, as well as events offered by LTM to encourage young people to make choices leading to transport engineering careers. Currently, TfL Inspire is partnered with 10 secondary schools, has over 900 student participants, and over 350 ambassadors (London Transport Museum, 2012a). The success of this program relies heavily upon the commitment of its volunteers, and on the enthusiasm of school systems to participate in the program.

One program within TfL Inspire, "Primary Inspire", is aimed toward primary school students of ages 8-10. In Primary Inspire sessions, students interact with LTM educators in hands-on, interactive activities related to specific engineering topics (Transport for London 2013). However, the program is still a work in progress, and is growing yearly (London Transport Museum, 2012a). In the 2012-2013 fiscal year, LTM offered four activity days in

which three separate sessions were offered. An estimated 120 students were present in each of these sessions. Moving forward into 2013-2014, the museum intends to host six activity days with 180 students per session, ending the year with about 1200 student interactions (London Transport Museum 2012a). As more sessions are offered and more students attend, the program will be refined through the feedback received.

To further this growth and development, LTM seeks to expand Inspire Engineering and a new exhibit, "Tomorrow's Journeys," by integrating object-based learning components into each. To this end, LTM is developing an engineering artifact database of historical and contemporary transport artifacts to "tell the story" of transport in London and allow students the opportunity to interact directly with pieces of transport history. Students will be able use these objects during any Inspire sessions into which the museum integrates the objects. Our project has assisted in the integration of these objects into the Inspire program and the new exhibit.

We will create guidelines and material to integrate object-based learning components into two LTM programs: one to supplement the "Primary Inspire" sessions (London Transport Museum, 2012a), and one to supplement a new LTM exhibit, "Tomorrow's Journeys" currently under development, focusing on London Underground upgrades (Poulter, 2013b). The activities will require that handling objects from the engineering artifact database, the museum's object handling library (which is subject to more stringent handling rules), and some objects from LTM's main collection be organized according to the branch of transport engineering each artifact best represents. In so doing, the objects will visually represent the evolution of transport technology though the years. To supplement these objects and provide a contextual basis for their use, we will also provide written narratives of the history of different strands of transport engineering in TfL. This project as a whole aims to use object-based learning methods to make transportation engineering more engaging and interesting for students, thereby providing for a more interactive and successful TfL Inspire program.

3. Methodology

The goal of this project was to assist the London Transport Museum (LTM) and its sponsor, Transport for London (TfL), in the integration of hands-on, object-based learning (OBL) components for educational programs about transportation engineering and history.

Our group aimed to:

- Developing narrative histories on engineering branches in TfL.
- Categorize objects from LTM's Engineering Artifact library and object-handling collection, in addition to relevant items located in LTM's main collection.
- Develop OBL tools for LTM educational programs.
- Identify sources of and recommend new artifacts for object-based learning activities.

Presented below (Figure 2) is the methodology used to conduct meet these goals. Included, for reference, is a schedule of tasks, from our initial preparation in March to the conclusion of our project in June, used to coordinate this project:

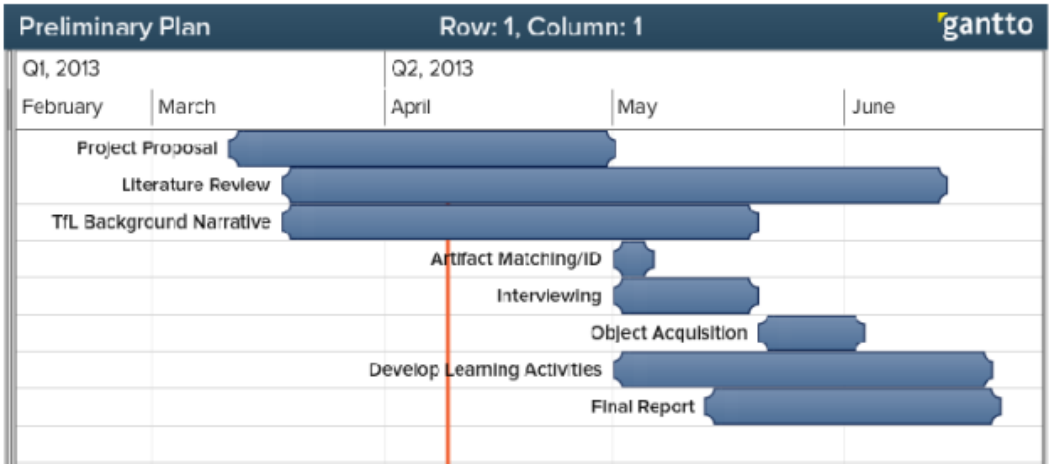


Figure 2: Preliminary Project Plan

3.1. Objective I

Develop narrative histories on engineering branches in TfL.

The central focus of this project, and the preceding project done by Worcester Polytechnic Institute (WPI) students during March and April of 2013 (Davis, Haughn, Mutty, & Thibault, 2013), was the integration of handling artifacts into the Inspire program and other LTM initiatives to support LTM's educational goals. In order to help integrate artifacts into programs in a way useful for engineering education, some organization and background information on the engineering branches that make up TfL was needed by the museum. To this end, our research into the engineering disciplines within TfL guided the composition of narrative histories of TfL engineering divisions.

As per LTM's specifications, these narratives are internal documents, not available to the general public. They are meant to provide museum staff, many of whom do not have scientific backgrounds, with the historical and scientific context needed to present transport engineering topics to student groups (Poulter, 2013a). Histories of TfL engineering branches provide context needed to use artifacts to educate about engineering. Additionally, research for the narratives provided a basis for categorizing objects and a framework for using them to educate.

The seven narratives, organized by TfL engineering branches, are: *Buses & Trams, Civil Engineering: Tunneling, Civil Engineering: Roads, Civil Engineering: Bridges, Electrical Engineering, Signal Engineering*, and *Track Engineering*. We formatted the narratives as short historical summaries about each engineering branch, and divided them into sections devoted to explaining transport technology in the past, current innovations and practices, and future developments. Museum artifacts, integrated into the narratives where applicable, provided visual illustrations of the evolution of the engineering branches. For example, some narratives feature both historical artifacts and their contemporary counterparts, to show development of the engineering field over time. Complementing narratives is a catalog of relevant engineering objects, organized by engineering disciplines featured in the narratives, to provide a basis for the development of future activities.

Background research into academic sources supported the development of the narratives. The museum provided a wealth of research material, through access to TfL's internal web network Source (a database of news articles, policy information, and company resources), and LTM's specialty library, an abundant collection of material on British transportation history. Our

research focused on finding technological highlights, major innovations, and tracking the development of engineering disciplines over time (i.e., evolution of tunneling and major triumphs of London Transport like the building of the Underground tunnels).

Information obtained from TfL engineers contributed to the research for the narratives. Interviews with representatives from Transport for London's track, electrical, and civil engineering divisions provided information about the history and development of TfL, current practices in the transport industry, interesting anecdotes and stories, and suggestions of places to collect more information. Although some correspondence was conducted via email, most communication with TfL engineers was done through in-person interviews. The template used to guide these interviews is presented in Appendix A. While interviewee identities are kept anonymous in this report, interview transcripts can be referenced in Appendix B.

Informality in these consultations permitted adjustment to the types and order of the questions asked and the directions the interviews took, depending on the information the Ambassador offered. Standardization was unnecessary in these interviews, as the goal was not to obtain and analyze structured data, but rather collect anecdotal information to supplement engineering narratives. A semi-structured interview template was most efficient for coordinating which questions to ask, while permitting flexibility in discussions (Handwerker, 2001, p. 121), and was selected for this purpose. This flexibility facilitated other questions to be discussed or omitted if necessary and/or beneficial to inquiries (Berg & Lune, 2004, p. 113) and obtaining the engineers' insight.

During interviews, one group member, designated as the lead, ran the interview. Other members, including the lead, took notes. Notes from each person were compiled into interview transcriptions, in which interview details, observations, and quotes from the person we communicated with were placed under the relevant questions. This collection method permitted quick reference of interview information when needed.

It was necessary to generate two copies of the narratives: one formatted as an academic paper with in-text citations to indicate where information was obtained (presented in Appendix D), and a copy without in-text citations to be submitted to LTM. We removed the in-text citations in the copies presented to LTM at the request of the museum, which will be using them as quick-reference material and did not wish them to be formatted in an academic style. The in-

text citations and references are included in the copies we present in Appendix D, in keeping with the academic purposes of this report.

3.2. Objective II

Categorize objects from LTM's Engineering Artifact database and object-handling library, in addition to relevant items located in LTM's main collection.

Cataloging artifacts from available LTM collections according to the engineering disciplines they belonged to was an integral part of this project. Doing so enabled our group to later incorporate artifacts into the "Primary Inspire" program and the object-handling trolley. Beyond this, the catalog provided an organized list of objects in the museum's possession with connections to engineering topics, for future reference.

LTM's Engineering Artifact library and the museum's object-handling collection, along with some objects from the museum's main collection, yielded 115 objects related to transportation engineering. LTM has accumulated over 70 artifacts in the Engineering Artifact library currently published in a WikiSpaces webpage (London Transport Museum, 2013). The object-handling collection, also meant for education, has more curatorial restrictions than the Engineering Artifact database and any objects accessed from it must be kept on-site at the museum. These objects were incorporated into the Engineering Object Catalog, organized by the transport engineering branches covered in the engineering narratives. By supplementing engineering narratives with organized lists of objects important to the topics they cover, LTM educational staff and Engineering Ambassadors can easily access objects to develop lessons on transportation engineering.

We formatted the catalog as a color-coded spreadsheet, organized into the seven TfL engineering topics covered in the narratives. Each entry includes an object's name, a brief description of the object, the collection or facility in which it was located, a photograph, and its LTM ID number. The spreadsheet, titled "Engineering Object Catalog," is found in Appendix C.

Once objects had been recorded into the catalog and organized by engineering branch, our group was able to determine which engineering topics were adequately represented in the museum's object collection, and which topics were not. With this information, recommendations for future additions to the collection could be provided to LTM.

3.3. Objective III

Integrate OBL components into LTM educational programs

The information from the engineering narratives and catalog of objects facilitated the development of object-based learning components for LTM. Specifically, we focused on the creating OBL components for the "Inspire Engineering" program's "Primary Inspire" sessions, and an object-handling trolley for LTM's new "Tomorrow's Journeys" exhibit. These programs are designed not only to help educate students on the history of TfL, but also to help students develop an understanding of transport engineering and its evolution over time in a collaborative, engaging environment.

The first step to developing these activities was to identify other successful object-based learning programs in relevant published literature, and via interviews with museum professionals with experience in developing object-based programs. The Worcester Historical Society in Worcester, Massachusetts, USA and the Horniman Museum in London, England, both have a history of planning and running educational outreach programs to schools, and particularly programs with object-handling components. Interviews with education specialists at these museums garnered information about activity development. These interviews, which include notes taken during the Horniman Museum observation session, are included in Appendix D.

Interviews with educational staff at the London Transport Museum, and an observation of an object-handling educational session at the Horniman Museum were also useful. Appendix A presents the interview template used in discussions with museum staff to derive information on developing object-based activities. Additionally, documents we used as reference material, which present criteria for object-learning activities, and guidelines from the London Science Museum regarding the development of activities for student groups, are included in Appendix E.

OBL research for this project culminated in a two-day training session run by LTM for freelance educators and educational staff. In the session, our group gained insight into real teaching skills, including how to speak to both primary and secondary school students, hold their attention, manage a class, and how to use objects and props to supplement an educational session and help meet learning goals. This object-based learning training also demonstrated (and gave the opportunity to practice) how to use objects to engage students about transportation engineering topics by using the objects as a centerpiece for discussions. These training sessions put the information and research accumulated about object-based learning and education during

this project into effect, providing a better direction to develop the object-based learning components of the programs with which we were assisting.

The information acquired on activity development provided the background needed to create the object-based learning components. Museum staff involved in the "Primary Inspire" program and the "Tomorrow's Journeys" exhibit assisted in assessing how best to incorporate objects into these programs. Considerations for object use was taken into account, guided by OBL research. Senior lecturer of the History and Philosophy of Biology at University College London Dr. Joe Cain (2010), presented considerations when using object-based learning: specifically, restricting access to objects that may be rare or valuable, and gauging how much time is required to examine objects. These issues can be addressed by finding multiples of objects that can teach the same ideas. We also considered how to involve each student in the activities, assessing the learning goals for each object and building in time for open-ended discovery (Cain, 2010).

Presented below is the methodology for our development of object-based learning components for both programs.

"Primary Inspire"

The "Primary Inspire" session is a part of LTM's larger "Inspire Engineering" program held at the museum. The aim of the session is to introduce primary school students to transport engineering, and particularly the challenges faced by engineers in designing the London Underground in the 1860s. LTM sought to integrate object-based learning components into "Primary Inspire" in order to better meet its educational goals.

Adding object-based learning activities to "Primary Inspire" required an understanding of the current status of the program's development. Collaborations with LTM staff involved in the program, and our observations of two "Primary Inspire" sessions contributed insights into the status of the program. Observations of sessions gave insights into topics covered in the program, such as problem solving, the properties of building materials, and the physics behind constructing the original Underground tunnels. These findings guided the development of object-based learning "toolkit" to contribute to the "Primary Inspire" session.

This toolkit (which can be found in Appendix F) features a list of objects from the object-handling collection and Engineering Artifact library that provides detailed information about useful objects for the "Primary Inspire" program. It includes information on the objects' identities, which collections they were located in, and photographs of the objects, and is supplemented by suggestions on how these objects might be used to demonstrate engineering concepts during program sessions. Consisting mainly of small objects that could be easily handled by primary school students, this list also includes some photos of large objects from the museum's collection that could be useful as visual aids.

The toolkit also includes guidelines for discussing engineering, along with explanations of engineering topics included in the "Primary Inspire" program. Since many of the instructors giving these sessions do not have science backgrounds, we included explanations of how engineering concepts work within these guidelines: in particular, the physics behind the strength of arches. This complements a particular learning goal of the session – part of an activity done by students, in which they created an arch by leaning upon each other and pressing the palms of their hands together, creating a sturdier "structure" much harder for the instructor to move. Added diagrams and figures, made to supplement a preexisting PowerPoint presentation in the session, provide a visual demonstration of the engineering concepts. We presented this informational material to the LTM education staff at the conclusion of the term, as supplementary material for the "Primary Inspire" session.

Object-Handling Trolley for the "Tomorrow's Journeys" Exhibition

LTM is in the process of implementing a new exhibit portraying upgrades to the London Undergound. Specifically, the museum wants to present innovations being made on the Underground, particularly the concepts of regenerative train braking, advanced signaling techniques, and the implementation of aluminum core rails. The exhibit will feature interactive, educational displays in which the visitor can push a button or lever to control the contents of the exhibit, which will teach about the various upgrades.

Part of this project was to plan and create an object-handling trolley - a cart with numerous handling objects that a museum guest can interact with - that supplements the exhibit and additionally teaches visitors through hands-on learning activities. Objects we selected for this trolley reflect, or can be used to educate about, the improvements in signaling that the

exhibit is portraying. We selected objects that were interesting and interactive, while still conveying the engineering concepts the exhibit presents.

Artifacts selected were small and light enough to fit on the trolley, while safe enough to be handled by small children. The criterion for selecting artifacts was that any visitors to the museum, including young children or adults, could pick up and touch these objects, and through a short hands-on activity, better understand how they work and what they do. Comprehensive questions developed for each artifact can be used by museum volunteers to establish a dialogue with visitors to teach about how each object applies to engineering, and in particular, the London Underground upgrades.

Assistance from our sponsor and museum curatorial staff to research these exhibit topics enabled the compilation of a list of four artifacts best suited for the trolley. Several TfL engineers provided professional opinions of essential artifacts and suggestions on how to incorporate engineering objects into the exhibit through email correspondence. The subsequent object list, which features objects recommended by our group for trolley use, includes pictures and identification numbers of each included object.

A narrative based around the objects, consisting of potential questions to ask, interesting facts, and tips for object education and interaction supplements the object list. We varied questions in focus and type to encourage visitors to physically interact with the object, consider the form and function of it, and compare it to other objects of the past. Additionally, due to the diversity of the museum guests, questions range from those appropriate for children, to those geared to adults. The narrative also features challenge questions for engineering enthusiasts as well. Detailed fact sheets on each object supplement the narratives and tie in elements of signaling history each object represents. These items allow the trolley supervisor to adjust the detail and depth of discussions surrounding each object, based on the audience. With the combination of an interactive exhibit and an interesting handling trolley, museum visitors should have a better understanding of signaling technology, and the new improvements to the Underground. The materials made for the trolley can be referenced in Appendix G.

3.4. Objective IV

Identify sources of and recommend new artifacts for object-based learning activities.

LTM already possesses a large collection of artifacts accumulated by the WPI project group and LTM personnel from March and April 2013 in London. However, through our work on the engineering object catalog and the OBL activities, it became evident that LTM would have to acquire more engineering objects. Duplicates of objects from the Engineering Artifact library needed for museum activities had to be identified for future inclusion into museum's object-handling collection. Our sponsor sought to keep both object collections separate due to museum policy: if an object from the Engineering Artifact library was primarily used in museum educational sessions, it would have to be requisitioned into the object-handling collection (Poulter, 2013b). To accomplish these goals, it was necessary to identify new objects, and sources of objects the museum could access.

Background research for this project provided the criteria used for object selection: a set of qualities that make objects useful for education. The selection process made use of the object qualities defined by Crowley and Leinhardt (2001) in the background (resolution, scale, authenticity, and value) and other important qualities identified from literature on object-based learning (Appendix E). The properties of selected objects reflected the object-based learning, interactive uses they would have. For instance, objects with low value – commonplace objects which could be easily replaced – were the only type considered, as children will handle them frequently and risk of damage is high.

Investigation of new object sources began with the initial assessment of the collection, conducted at the beginning of the project. Gaps in the collection became more apparent through the development of the engineering object catalog, which provided a visual indication of engineering branches the museum's collections did not strongly represent. Communication with LTM staff and Engineering Ambassadors about the current status of LTM's engineering education programs also helped assess appropriate collection additions, and potential sources of new engineering objects. Engineering Ambassadors, all being TfL engineers, with their knowledge and professional contacts, possessed insights into where additional artifacts could be located. Through personal correspondence, they provided contacts and sources outside LTM where more object could be located in the future.

Due to the time constraints of this project, we could not requisition new objects from sources outside the London Transport Museum into the collection. However, investigation of museum databases and correspondence with Engineering Ambassadors yielded objects within the museum's main collection that could potentially be requisitioned into the object handling collection, and sources outside LTM that the museum can contact in the future. Recommendations for the requisition of new objects are included in the Results and Recommendations section.

3.5. Summary

This project produced historical narratives of strands of engineering in comprise TfL, identified relevant objects to incorporate into these narratives, and used this information to develop object-based learning components of LTM programs currently under development. The assistance of LTM staff, TfL Engineering Ambassadors, and experts from museums in Worcester, Massachusetts, USA, and London, England, supported this project and guided the use of object-based learning to educate about transport engineering. Sources of new engineering objects identified over the course of this project support future expansion of LTM's OBL programs. These sources are included in the following Results and Recommendations section of this report.

4. Results & Recommendations

This section details the results and recommendations developed in this project, based on the objectives defined in the previous section.

4.1. Engineering Narratives

The integration of object-based learning (OBL) to London Transport Museum (LTM) educational programs provides an excellent resource for LTM to reach its overarching goal: developing programs and methods to teach students about transport engineering. The museum has the resources to use OBL in its educational programs through its vast main collection, sizable object-handling collection, and Engineering Artifact library. But because engineering is such a broad, complex subject, background information about transport engineering is necessary if transport engineering objects are to be used for educational purposes. The engineering narratives presented in this report provide this context.

These narratives are short historical summaries, 2 to 4 pages in length, which draw from literature on the history and science behind various transport engineering disciplines, and primary source material from Transport for London (TfL) engineers. We provide seven narratives: *Buses & Trams, Civil Engineering: Tunneling*, *Civil Engineering: Road*, *Civil Engineering: Bridges*, *Electrical Engineering*, *Signal Engineering*, and *Track Engineering*. Engineering narratives are presented in their entirety, each with individual "References" pages, in Appendix H.

Transport for London is a large organization that manages areas of public transport in London ranging from taxis to river transport. Because of its size, we had to assess which engineering areas would be best to write narratives about in the limited timeframe of this project. Communications with LTM staff members provided the basis needed to choose: as they were interested in using the engineering narratives to supplement their own activities and presentations, they desired the narratives to have a connection to the material covered in the museum.

The London Transport Museum itself covers the evolution of transportation in London in the last 200 years, with a visual focus on vehicles like buses and trains, and the evolution of the London Underground (Appendix I). We found that the object-handling collection and

Engineering Artifact library reflect this focus with a variety of objects from the London Underground, civil engineering, and aspects of surface transport such as road construction and bus components. The narrative topics selected are engineering disciplines that we felt represent LTM's existing holdings; this provides an "engineering focus" to topics the museum already presents. The topics selected are engineering branches of TfL, specifically electrical engineering, track engineering, signaling, and tunneling, all vital components of the London Underground and rail-based transport in London. Other narratives cover the development of buses and trams since the 1800s, and civil engineering as it applies to the evolution of roads and bridges.

The background information from the engineering narratives is useful to museum staff and volunteers running engineering education activities, but also for selecting objects and developing the OBL components of educational programs. Because of this potential to be an asset to the museum, consideration in selecting narrative topics was vital to their development. Interviews with TfL engineers helped uncover key concepts that the narratives might cover.

For example, despite being from various disciplines, ranging from civil to electrical engineering, many engineers expressed similar opinions on the evolution of transport technology in London. They considered that transport engineering, both as a whole and in their respective engineering disciplines, was shifting towards greater automation in an effort to increase efficiency, and that computers were playing progressively more important role in transportation technology (Engineer 1, 2013) (Engineer 2, 2013) (Engineer 4, 2013). Our engineering narratives reflect this overarching technological shift and the evolution of the engineering strands they cover. Major achievements of London transportation, such as the construction of the first underground railway, are especially highlighted. Providing the key achievements and structuring narratives to reflect technological evolution gives LTM educators a basis to understand how London transport has developed, and how to best use objects and activities to teach about that development.

The narratives also feature in-text images of objects from museum collections. These images not only to provide a connection to the engineering object catalog and the OBL education theme of this project, but also to provide key visual examples of topics covered in the narrative. Our group selected objects based on the background research on the qualities that make objects good for teaching (i.e., resolution, scale, authenticity, and value) presented in the Background section of this report.

For example, the *Civil Engineering: Tunneling* narrative presents the history of tunneling materials and tunneling strategies over time, paying particular attention to the Thames Tunnel of the early 1800s, and the original London Underground "deep tube" lines constructed decades later. The objects selected as examples in this narrative – a piece of ceramic tile tunnel lining from the original Thames Tunnel, and vastly stronger, improved cast iron tunnel lining from the deep tube – provide a visual example of the tunneling technology improvements made during the Victorian Era, and also bring an element of authenticity and value to the objects themselves. If museum staff members opt to use these objects in a presentation, they will have the backstory to connect the objects and an appreciation for the historical value that these artifacts of two major engineering achievements possess.

4.2. Engineering Object Catalog

The Engineering narratives provide museum professionals with a breadth of information on specific engineering strands and important artifacts that surround them. Using this information, LTM staff can determine how to structure educational sessions and how to select the best objects to use. Accessing objects in the museum's collection can be a challenge, however. LTM's internal database of artifacts is exceptionally large and difficult to navigate, making it hard to find the appropriate object for a specific lesson. With the exception of the Engineering Artifact library developed for "Inspire Engineering", the museum has no record specifically for engineering objects. In response, we recorded objects (115 in total) from the museum's main collection, object-handling library, and Engineering Artifact library to display engineering objects in one computerized database.

By sorting out any unrelated or unsuitable objects, the Engineering Object Catalog expedites the process of identifying objects suitable for education and handling by museum guests by compiling appropriate objects from the three collections mentioned above. With a source of artifacts that is compact, accessible, and visually comprehendible, museum staff can easily find objects that would be the best fit for an OBL activity.

Objects in the catalog feature properties based upon research into the qualities of suitable learning objects noted in the background of this report: low monetary value to avoid high cost to the museum in the event of damage, while being small and safe enough for children to handle. Many museum professionals regard the ideal teaching artifact as a mystery object that make "people have to guess" what the object could be, and provoke questions such as "how do you

think this works" and "what do you think it is?" (Museum Professional 2, 2013). We searched the museum's internal artifact database for any artifacts matching this set of requirements. Even if an object was too large to handle, or was a rarity from the main collection unsuitable for educational activities, it was highlighted in the catalog. Many of these objects feature interesting backstories or are examples of major engineering innovations, and can make the presentation of important engineering concepts easier and more engaging to students or other museum guests. One example is the lever frame featured in the signaling section of the catalog (see Appendix C): this artifact, despite being extremely valuable, very large, and unsuitable for object-handling purposes, can still be used for education by tying it into educational sessions about the development of signaling in the London Underground. We wove photographs of these key objects into the text of engineering narratives, providing continuity between the narratives and the catalog. The photographic aid in the narratives will help LTM staff determine the best objects to assist in education.

Every entry in the catalog features an object's name, a brief description, its location, its LTM ID number, its picture whenever possible, and additional notes such as if the object is unsuitable for handling, or has duplicates available. Our search uncovered several duplicate objects, indicated in the catalog in bolded, underlined text, which could be easily requisitioned by LTM educators into LTM's object-handling collection. The catalog also notes a general estimate of the number of these duplicates available. These objects are small, handheld, of low long-term value, and are good examples of engineering concepts. For example, there is a surplus of insulator pots, ceramic pots on which live rails from the underground are mounted to prevent the electricity from travelling into the ground. With any new requisitions from these duplicate objects, there is the potential to better tell the story of engineering through a more diverse collection of objects for OBL curriculum.

carburettor	Spare carburettor for AEC petrol engine probably for pre-war bus used in London.	Acton Depot			1998/99169
gearbox	Spare gearbox for RM type bus from RM1562.	Acton Depot			2002/13550
Tram rail section	London County Council tram rail section, 1922	Acton Depot			1995/2583
Tram rail section	London Transport tram rail section, 1936	Acton Depot			1995/2587
Porcelain loop strain insulators [1]	Light brown porcelain loop strain insulator used in trolleybus overhead, pre 1962. Insulated power lines from the trolley and power line poles, preventing the electricity from grounding.	Acton Depot	Duplicates available (24 in total)		1998/110821
Porcelain loop strain insulators [2]	Green insulators used in trolleybus overhead, pre 1962	Acton Depot			1995/170

Figure 3: Sample from the Engineering Object Catalog.

For better organization and continuity in the museum's collection, the catalog is organized according to the engineering strands presented in the engineering narratives. By showing which artifacts relate to each engineering branch, LTM staff can easily select objects that would be most useful in an object-based learning activity. The link between the catalog and the narratives provides LTM staff with an integrated resource for engineering education and activity development.

Additionally, with objects recorded in the catalog according to engineering branches, it is easy to see potential gaps in the museum's engineering artifact collection. We contacted several TfL engineers in an attempt to locate additional objects to fill these gaps. Included in the recommendations to LTM is which engineering branches need additional artifacts to strengthen their collection, as well as suggestions on where to get those artifacts.

The catalog in its present state serves as a foundation for any museum professionals creating OBL activities. The catalog is only representative of the engineering artifacts the museum currently has in its collection. As the collection expands, the catalog can easily be updated to include new additions. With this expandable list, museum professionals will more easily be able to create a handling activity in the future.

As an early indication of the usefulness of the list, the final phase of our project used the catalog to select items for object-based learning components that we developed. The catalog enabled us to select and recommend objects for the "Primary Inspire" session on tunneling as well as to propose signaling objects for the Object-Handling Trolley for LTM's new "Tomorrow's Journeys" exhibit. It was essential that the catalog phase in the project was completed before working on these activities, as it gave us a clear visual of which objects were available. The successful creation of these activities is an example of the practicality of the catalog and its value to LTM in the future.

4.3. "Primary Inspire" Object-Based Learning Material

The "Primary Inspire" program at the London Transport Museum is aimed at instructing and exciting primary school students about engineering. In particular, it focuses on the challenges engineers faced while building the world's first underground railroad in London. The session already has some object handling activities, providing a good foundation for the development of more interactive components to augment the program.

We worked with the "Primary Inspire" program's developer to determine the goals of the project and how we could contribute to them with object-based learning. We also observed two sessions of the program, during which we made notes on the merits of the engineering education aspects, and which parts of the session might need more engineering objects to assist in teaching this information.

Part of developing OBL learning components for the session was assessing the engineering topics being conveyed, and whether they were being addressed satisfactorily. The session, as stated in the Methodology, paid significant attention to material science topics such as the different properties of materials like wood or metals, and explores the development of the London Underground through a problem-solving approach that encourages students to explore the decisions the engineers made in building London's first train tunnels. However, from our observations and discussions with "Primary Inspire" staff, we found that the engineering topics, such as the exploration of material science, would benefit from further elaboration and additional support from object-based examples. For instance, we determined that the forces in an arch presented a significant educational challenge. This topic is integral to the entire "Primary Inspire" program for its relevance to the original London Underground structures, and was not presented in the most efficient way. Though they emphasized the strength of an arch shape,

educators did not compare it to any other structural shapes or present the topic in a way that accurately highlighted the forces at work upon an arched tunnel.

To address these concerns, we developed an object-based learning "toolkit" for "Primary Inspire": a single document, featuring information on engineering topics presented in the session and all additions recommended for this program (Appendix F). It includes a table of photos of seven different objects that can be added to the program either as handling objects or (in the case of main collection objects or large objects unfit for handling) as visual examples. This allows museum staff to reference relevant objects and information before integrating them into an activity. The table also includes descriptions of an object's purpose and notable features that make it useful for object-based learning. This accompanying text gives a simple background in the engineering concepts behind the object without the need for staff to research it themselves.

The objects were chosen specifically to aid this program, and reflect the requirements of the age group and material taught. Safety of the students was important. Young children would be handling these objects, and if an object was considered dangerous for them, it was not considered for inclusion. Objects that are merely heavy and as such pose a lesser threat were still included with a warning about the issue advising caution while handling. For example, one of the steel rail slices is a small yet heavy object, and we included a note in its entry advising students to use two hands to hold it. The subject matter of the program narrowed the scope of objects to those applying to rail and tunneling and our group selected objects based on their relevance to tunneling, rail engineering, and materials science. Consequently, objects chosen are primarily derived from London Underground sources, with the exception of concrete and brick samples, which were added for material science education.

Our group supplemented the object list with ideas and suggestions for discussion topics and activities in which the objects could be used, drawing upon our research into inquiry-based learning and object-based learning, and the education strategies imparted to us in the training program LTM sponsored. These suggestions are comprised largely of questions (and associated answers) that museum staff could pose to children about the objects. These questions encourage students to be active in their learning, interacting with the objects to explore their physical properties to draw conclusions about concepts in material science such as the properties of wood versus metal, and learning about engineering innovations such as the shift from steel to aluminum power rails.

To supplement the physics concepts in the “building an arch” activity done during the “Primary Inspire” session, in the document we included a short explanation of the concepts discussed in the activity. It compares the downward physical forces acting on an arched roof to that of a flat roof, and the difference between how the two shapes react to those forces. This activity supplement also links the instructor’s explanations and the actual activity done by students. In this activity, groups of two students “become arches” by joining hands with another student to make an arch and can feel the forces in action for themselves while an adult pushes down on them. We also provided two “force arrows” for students to use in the activity, so they can show where and how the forces might be acting upon tunnel structures by using a correct placement and rotation of them. The accurate representation of the physics going on in an arch is an important topic particularly in civil engineering, and it gives students a sample of an important engineering concept an engaging way.

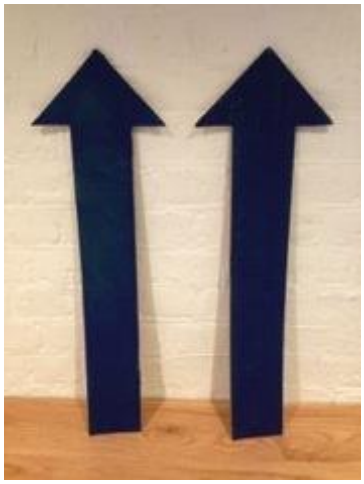


Figure 4: "Force Arrows" for use in the “Primary Inspire” arch activity.

4.4. Educational Material for Object-Handling Trolley

In order to reflect the most current developments in Transport for London, LTM is designing an exhibit to feature the major upgrades currently being implemented in the London Underground. The exhibit, titled “Tomorrow’s Journeys,” focuses on the concepts of regenerative braking, moving block signaling, and aluminum conductor rails. For reference, regenerative braking and aluminum rails are defined in the Electrical Engineering narrative, while moving block signaling is explained in the Signaling Engineering narrative (both found in

Appendix H). To supplement "Tomorrow's Journeys", LTM desires to have an object-handling trolley at the exhibit. This cart can be wheeled out onto the museum floor, presenting museum patrons with the opportunity to interact with real engineering objects that represent the subjects of the exhibit.

One of the most important considerations when choosing objects for the trolley was that these objects stay relevant to the "Tomorrow's Journeys" exhibit. A meeting with the curatorial staff responsible for the exhibit and the trolley's development led us to decide that the objects on the trolley should demonstrate the evolution and concepts of signaling engineering leading up to the moving block system. The exhibit incorporates an interactive demonstration of moving block signaling, but we found that regenerative braking and the aluminum rail upgrades were not good candidates for the trolley. Regenerative braking relies on the concepts of converting energy from one form into another. Aluminum is being used in power rails because of its higher conductivity than steel and lower weight. These concepts, both dependent upon methods of energy transfer, are intangible (except for the weight of the rail) and therefore difficult to demonstrate with stationary objects and not suitable for object-based learning purposes. Consequently, with the agreement of LTM staff members, we decided to focus exclusively on signaling objects for the trolley. Considering the abundance of signaling objects available to the London Transport Museum and the physical differences between objects that clearly show the evolution of the technology, signaling was the most feasible topic for an object-based learning component for the exhibit.

We chose four objects, based on the research that had been done into the evolution of signaling for the engineering narratives and the objects available to the museum. These objects, drawn from different "eras" of signaling, to represent the evolution of the technology over time: a signal flag, a signal lantern, rolls of program machine paper, and a microprocessor. We presented these objects and the associated materials to LTM staff as suggestions for the handling trolley. Many of these objects are from the museum's main collection, and duplicates will have to be acquired (or replicas made) if they are to be included on the trolley. Our group was unable to locate duplicates of these objects in the timeframe of this project.

The signal flag and signal lantern represent the earliest forms of signaling in railroad travel. Not only do they show the history of signaling, but they are also familiar items that people will recognize and connect with, making them ideal for interactive learning. We selected the

program machine paper and the microprocessor to demonstrate the automation of the signaling process over time. People can look at the paper and, guided by museum volunteers working on the trolley, see how the holes punched into it represent timetable-controlled signals for the trains to stop and go. The paper rolls comprising the program machine paper are exceptionally bulky, but represent an early form of automated processes. In contrast, the microprocessor is a small computer chip, significantly smaller and more compact than the program machine paper. Still, both had the same purpose. By allowing museum visitors to examine the large, complex program machine paper in contrast to the compact microprocessor, they can see just how impressive and useful the microprocessor is and how far the technology has advanced.

We developed a document that features the items suggested for use above as well as pictures to supplement them (found in Appendix G). The pictures demonstrate how and where the object was used and/or who used it. For example, to provide an interactive learning component featuring the signal flags, we included photos of the hand signals used with signal flags, which could be used in an activity. Visitors could use the flags to perform the signals themselves, and learn about early forms of signaling. To supplement the list of suggestions, a narrative document and fact sheets were written for each item (found in Appendix G). The narratives supply the volunteers running the trolley with questions they can ask people about the objects along with quick-reference information about the objects and ideas on how to have people interact with them. The questions are designed to lead people to their own conclusions about the different concepts pertaining to each object such as how the object was used, why it was needed, or what technology they think replaced the object.

We varied the complexity of questions so that the trolley activities and objects can be engaging to people ranging from inquisitive primary school children to adult engineering enthusiasts. Fact sheets provide volunteers with background knowledge about the objects to enable the volunteers to be knowledgeable about the subject matter. Through this information, they can tailor their presentation of materials to the knowledge level and interests of individual visitors. Everybody will have different needs and levels of interest in the objects on the trolley. Having their specific needs satisfied will make the experience more valuable and memorable.

4.5. Recommendations

During the course of this project, our group has produced deliverables, specifically the seven engineering narratives, Engineering Object Catalog, and OBL supplementary material, for

the London Transport Museum. Through the process of developing this material and working with LTM staff, our group also sought to provide recommendations to assist LTM in the future expansion of their engineering education programs. Our recommendations include suggestions to assist in the acquisition of new engineering objects, but also our thoughts on how LTM can expand their engineering education programs in the future.

In the interest of continued development of the "Inspire Engineering" program and other museum initiatives, we strongly recommend that the museum continue developing the Engineering Artifact library, and gathering engineering objects for this collection and other handling collections in the museum. In particular, the museum should focus its efforts on expanding areas of the existing engineering object collection that are currently weak.

In developing the Engineering Object Catalog, we found that, while there are abundant objects related to track engineering, electrical engineering, and signaling, the collection lacks handling objects for civil engineering topics like tunneling and surface transport, and objects related to buses and trams. Expanding the engineering object collection to better represent these areas of transport will provide the museum with a more well-rounded collection. This, in turn, will be useful in developing more activities and sessions on engineering at the museum. We found through our correspondence that Transport for London engineers, and particularly Engineering Ambassadors, are very willing to use their professional resources to acquire these objects. Additionally, LTM may consider investing in more advertising for the "Inspire Engineering" program and other engineering education programs available at the museum. Increased public exposure would boost support for the project, attract benefactors who could donate objects or funds to extend the program, and promote the engineering education opportunities available at the London Transport Museum.

We suggest that, in addition to expanding the collection through outside sources, LTM staff examine our recommendations for main collection objects that could be requisitioned into one of the handling-object collections. These objects, such as glass insulators, wooden keys, pandrol clips, and insulator pots, described in the Engineering Object Catalog (Appendix C) and denoted with bold, underlined text, are potentially useful educational objects with several duplicates (some with as many as 10 or more copies) in the collection. They are safe, compact, and can be used to convey scientific and engineering concepts while introducing students to the history of London Transport. Because these objects are replaceable, kept in storage, and not used

for museum presentation, the museum is not actively using them at this time, and educators at LTM can make a strong case for requisitioning samples of these objects into a handling collection for educational purposes. Adding these objects would also open up their use in the OBL activities drawn up for "Primary Inspire" and the Object-Handling Trolley. The wooden key and pandrol clip, in particular, are two objects recommended for use in the "Primary Inspire" session, and duplicates are needed if these objects are to be included for use in the session.

The museum may also benefit by supplementing the engineering object collection with more examples of objects related to materials science and samples of materials. Materials used in the Underground like metal for rails, civil engineering materials like concrete, and insulator materials (like ceramics) required for electrical engineering purposes such as rail insulator pots present key engineering concepts. Moreover, studying the evolution of materials in transport engineering over time (such as wood materials being phased out of the Underground because of the fire hazards they presented, and the switch from steel conductor rails to aluminum-based conductor rails) presents another aspect of the history of London transportation. Many of these materials would be easy to access through Engineering Ambassadors, or easily purchased from sources outside LTM.

Our group also recommends expanding upon the work done in the course of this project to cover more transportation topics. While we developed engineering narratives on topics directly pertaining to subject matter LTM presents in its exhibits, some aspects of TfL, particularly water transportation and cycling, were not covered. Having a future project group develop narratives pertaining to these areas would assist LTM in building a stronger database of engineering information for use in program development at the museum.

With respect to the OBL learning components and activities developed by our group for "Primary Inspire" and the Object-Handling Trolley, we have several recommendations. The supplementary engineering information presented in these documents, along with the engineering narratives, should be used as background information for educators before they present sessions. This information will provide educators with a breadth of knowledge needed to hold discussions about transport engineering with students and museum visitors. Still, as programs expand and new programs are developed, it may become necessary to develop new activities about engineering. Future project groups might focus on developing a list of potential engineering activities and educational sessions for various engineering topics. Collaborating with

Engineering Ambassadors, who have professional expertise in their respective engineering fields, to develop these new activities and sessions would be very useful, and it may be worth recruiting their involvement in development.

Beyond the scope of this project, we hope and strongly recommend that the London Transport Museum and Transport for London continue to expand their involvement in STEM education, and inspiring young students to explore science and engineering. Strong science education is critical to the success and continued development of London, already a leading player on the world stage. Without continuing support for science and engineering, the city risks diminishing its power to develop and advance, and the quality of life of its citizens will suffer. With resources and engineering objects, and a group of professionals dedicated to teaching about science and engineering, Transport for London and the London Transport Museum are in a unique position to inspire the minds of students. It is important that they use this position to motivate this new generation to aspire towards science and engineering, and keep London on the cutting edge of technology well into the future.

5. Appendices

5.1. Appendix A – Interview Script and Guidelines

Interview Template

London Project Center, London Transport Museum IQP

Students: Andrew Barth, Luke Perreault, Woodrow Shattuck, Ryan Santos

Advisors: Prof. Wesley Mott & Prof. Zhikun Hou

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. We would like to obtain your insight into what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Identifying Objects – Museum Staff, TfL Ambassadors

- What are the gaps in the collection as it stands? Can you recommend objects to fill in those gaps?
- Do you have any suggestions for locations to find additional objects, or any suggestions for objects that would be useful for the collection?
- What was this object used for?
- When was the object in use?
- Can you give us an idea of the object's history?
    - What was its original purpose and what advances rendered it obsolete?
    - Is this object currently in use or will be in the future?
- What engineering branch would you say this artifact belongs to?

Object-based Learning – Teachers, Museum Professionals, TfL Ambassadors

- *For Teachers:* How might a museum professional or TfL Ambassador present this object to students?
- What do you think are difficult concepts to convey to students, and how can object-based learning help teach these concepts?
    - What kinds of objects, or features of objects, are most useful in particular?
- We are working to convey the history of Transport for London through object-based activities. How would you use objects to present a history of an organization or a science over time?

Object-based Programming – Teachers, Museum Professionals

- What types of object-based programming have you done, either in your museum or at schools?
- How long has your program been running?
- What was the motivation for starting it?
- How is it going so far?
    - Any consistent reactions from students, parents, or teachers?
    - How have you evaluated the program's success, if at all?
    - Has anything changed in the program, based on your evaluations?
- How are staff members trained in object-based learning, and how do you typically use objects in presentations?
    - What's working well or needs improvement?
- What types of activities do you notice students engage with or are stimulated by the most?
- What types of activities do students engage with the least?
- How do you develop programs for students of different ages and educational level?
- *For Museum Staff:* How do you ensure a class is both excited and educated by a visit?
- Can you suggest potential sources of information for object-based programming, either from literature or your own work? Where do you typically get your material for programs and would you be willing to provide us with ideas?

Discussion Topics for Transport for London (TfL) Engineers:

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. In order to do so, we are seeking your professional engineering knowledge to help us develop a background of the history and innovations made within your engineering field by Transport for London. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

1. Is there anything you can tell us on the advances in materials science within transport engineering?

2. What generally leads to technological changes? Are there any particular accidents/disasters/major challenges in TfL history that led to technological developments or recalls?

3. Can you talk to us about current advancements/future transportation developments that aren't in use yet but may be in the near future? Where is transportation technology going?

4. How does your engineering field function within TfL and what can you tell us about it?

5. What are the health and safety requirements, or technical fail-safes, which TfL engineers in your field must abide by when working on transport improvements? Why are they in place?

6. Can you suggest other sources we can derive information on TfL engineering history and developments?

5.2. Appendix B – Engineer Interview Transcripts

Appendix B includes all transcripts from our interviews with Transport for London engineers. Names and identifying information have been removed from the transcripts to protect the anonymity of the interviewees. These transcripts detail notes and key information from conversations, and not quotes from the people interviewed, unless otherwise indicated.

Engineer 1

Transcript Editor: Luke Perreault

Scribes: Luke Perreault & Ryan Santos

Date: Tuesday, 7 May 2013

[Note: This document details notes from the conversation, and not quotes from person interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. In order to do so, we are seeking your professional engineering knowledge to help us develop a background of the history and innovations made within your engineering field by Transport for London. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Identifying Objects – Museum Staff, TfL Ambassadors

- What are the gaps in the collection as it stands? Can you recommend objects to fill in those gaps?
  Not covered in discussion.

- Do you have any suggestions for locations to find additional objects, or any suggestions for objects that would be useful for the collection?
  Not covered in discussion.

- What was this object [**link box**] used for?
  - **Link box: switch from an old set of signaling arrangements and a new one. Binds systems together with a common element. Allows you to change from one system to another, or interchange power supply sources.**

- When was the object in use?

This particular object was in use until it failed (see artifact library fact sheet)

- Can you give us an idea of the object's history?
    - What was its original purpose and what advances rendered it obsolete?

      See above

    - Is this object currently in use or will be in the future?

      Not covered in conversation

- What engineering branch would you say this artifact belongs to?

  Signaling

Discussion Topics for Transport for London (TfL) Engineers:

7. Is there anything you can tell us on the advances in materials science within transport engineering?

   <u>Example of a material transition:</u> ***1987 – Fenwick Inquiry: big fire underground, devastating. Escalators originally made of wood and smoking was still allowed in the underground – fire generated. 37 people were killed. Tend to avoid plastics unless they are fire retardant. A lot of materials in different transport industries; example, carbon fiber. Very expensive. Weight reduction not necessary in underground transportation and rail, so metals are typically fine. Use a lot of aluminum, which is replacing iron and steel for its strength, light weight, and conductivity (can be used in place of copper). Trains historically wood, steel until 1960s. Shift to aluminum as a conductor rail is significant. Copper is extremely valuable. They do look at ways to reduce weight and energy consumption.***

8. What generally leads to technological changes? Are there any particular accidents/disasters/major challenges in TfL history that led to technological developments or recalls?

   <u>See question 1 example on Fenwick Inquiry for a primary example.</u> ***Large accidents and disasters usually drive the public to push for change, which can lead to major technological shifts and improvements. Example: Back in the 70s, signaling error***

caused a train to crash directly into the end of the line. There are now failsafes to prevent this from happening again.

9. Can you talk to us about current advancements/future transportation developments that aren't in use yet but may be in the near future? Where is transportation technology going?
   -Challenges to upgrade current technology because some of it is so old, and difficult to augment. People fear change, especially big changes.

   -Automation is really becoming the norm as computers are better at dealing at computational, repetitive tasks than humans. Manpower/subway drivers still necessary for quick response time and hazards/accidents (someone falling on track). Additionally, computers can determine how long a train needs to come to a full stop, reducing the "fixed block" distance between trains necessary to break safely and allowing more trains to be placed on a track at any given time. Addresses a key challenge: how to move the population of London as it grows. Either make more space or build over/above/below existing railways.

   -Modern technology allows us to reduce energy consumption. Newer train breaks are in development that can convert kinetic energy to electrical energy (regenerative breaking technology). Doesn't take much energy to maintain a train's velocity once up to speed. Significant energy saved.

10. How does signaling work/can you tell us about it?
    Signalling engineering – stopping trains from crashing into each other, sending them in the right direction, not derailing them. Ensures that unsafe conditions cannot be generated. Stop them from crashing and falling. When you reach the end of the line, there are signaling controls to stop you from crashing.

    Computing/processing is taking over for levers and analog technologies. Relays are middle-ground technology.

    Train Detection: Message passing, originally; token machines; automatic train detection from electrical track circuits & radio communication now the norm.

11. What are the health and safety requirements, or technical fail-safes, which TfL engineers in your field must abide by when working on transport improvements? Why are they in place?

    "As low as reasonably practical." Finance and safety argument: TfL computes the value of a life is (technically) 1.2 million pounds, to justify improvement or rejection of certain augmentations to the underground. Generally, engineers want to come back to a failsafe principle, but not everything can fail safely (i.e., planes). Failsafes very important to the underground, which transports 4 million people a day.

12. Can you suggest other sources we can derive information on TfL engineering history and developments?

    Try to access TfL's Engineering Standards via LTM, or the District Dave website. Feel free to get in touch with Ian or Liz for additional information or to be put in touch with other engineers.

Engineer 2

Transcript Editor: Luke Perreault

Scribes: Drew Barth & Luke Perreault

Date: Wednesday, 8 May 3013

[Note: This document details notes from the conversation, and not quotes from person interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of historical engineering narratives relating to Transport for London, and object-based learning activities. We would like to obtain your professional insight on Transport for London engineering, what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Discussion Topics for Transport for London (TfL) Engineers:

1. Anything you can tell us on the transition from metals to plastics and advances in materials science in transport engineering?
   Wood to metal transition was due to health and safety concerns (fire hazard).
   New conductor rails have steel caps to protect the lighter aluminum rails from damage.

2. What generally leads to changes? Accidents/disasters/major failures that led to technological developments or recalls?
   [Mentioned King's Cross fire incident]
   Corrosion: Having to shut parts of the Jubilee line down – clay/water from river is acidic and corrodes wire casing.

3. Can you talk to us about current advancements/future developments that aren't in use yet but may be in the near future? Where is the transportation technology going?

The King's Cross fire was an electrical accident involving wooden escalators. Machines got so hot they set fire to the equipment.

Electric buses are under development and may see public usage in the near future.

Regenerative breaking; there are still resistors for heat dissipation breaking, and friction breaking (less magnetic resistance as the train comes to a stop) – new technologies are being added to old ones.

"S-Stock" train launching this year; more standardized trains for deep tube tunnels.

TfL must upgrade power voltage level because there's a great deal of new equipment on these trains, and AC, in the s-stock trains.

Signalling: Driver originally looked for red or green visual signal. Moving toward automatic signaling by uniting train operations with a computer. More efficiency is achieved by cutting out human error. The rational for signaling improvements is the growth in the population. "People used to move in when they were young and leave London when they got older. Now more people are settling here."

Automatic Train Control: ATO (Operation) and ATP (Protection). New trains will have an antenna that picks up needed information (how fast it can go, if it needs to break, target speed. Operation communicates with motors/breaks, Protection ("the brain") communicates with signaling and detection components (i.e. is someone jammed in the door).

4. How does electrical engineering function within TfL/can you tell us about it?

   Three main strands of the power grid: <u>Power to the rails</u> (high [for power] and low voltage [for signaling]); <u>cooling</u> – keeping electrical components of stations & trains cool (i.e., with underground reservoirs and pumps to cool the trains); <u>station</u>s (lighting & communications, & lifts and escalators.

   [side note]: stations shoot for goal power consumptions, while railing and cooling is more fixed.

   Streets and surface: Low and high voltage going to street signals.

5. Health and safety requirements?

   Doors are now electronically controlled, so development going into trying to avoid people getting trapped in doors. There have been some accidents related to that.

6. Other sources of information?

   Note: Engineer 2 donated to this project a transcript on TfL electrical supply for the London Underground.

Engineer 3

Transcript Editors: Ryan Santos & Drew Barth

Scribes: Drew Barth & Ryan Santos

Date: Tuesday, 21 May 2013

[Note: This document details notes from the conversation, and not quotes from person interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities. We would like to obtain your insight into what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Discussion Topics for Transport for London (TfL) Engineers:

1. Is there anything you can tell us on the advances in materials science within transport engineering?

   Finding stronger materials that can hold more weight and need less maintenance. Maintenance is a big thing, maintenance-less tools and materials save a lot of time and money.

2. What generally leads to technological changes? Are there any particular accidents/disasters/major challenges in TfL history that led to technological developments or recalls?

   Problems with wheels vs. track, the lasting length for both is different. Need materials that last longer.

The best journey on the tube is one that you don't remember. Finding new ways to make the tube run smoothly with nothing out of the ordinary.
Hitting a max number of passengers, about at 4.5 million which is much more than expected. Need more ways to transport more people. Three ways to do that:
1: More reliable trains/track
2: Longer tube stations
3: Better signaling

Need good maintenance, fix problems before they arise
Finding more innovative ways to fix and clean the tube.
For example, have a trolley on the tracks that has a magnet attached. Used to pick up debris.

3. Can you talk to us about current advancements/future transportation developments that aren't in use yet but may be in the near future? Where is transportation technology going?

Going towards complete automation, no driver needed. Already no driver on the DLR. Some trains are getting Bluetooth in the operator cabs. This will link with the red/green signals outside the train and appear on the command board of the operator cab. Mainly in case the operator can't see the external signal or there is some other problem with it.

4. How does your engineering field function within TfL and what can you tell us about it?

He is the head of the track manufacturing division of TfL.
He and his crew inspect components of the track and approves them by TfL, as well as produce the track components.
Most of the track on the tube is produced at the Lillie Bridge Depot.
They also have the resources for lots of calibrating for components.

5. What are the health and safety requirements, or technical fail-safes, which TfL engineers in your field must abide by when working on transport improvements? Why are they in place?

   All of the tools and heavy machinery in the Depot has major safety assurances (for example, many buttons around a person's head, arms, and feet that will stop the machine).
   Some machine can sense a finger and will automatically stop.
   Provided gloves, earplugs, pneumatic lifters, etc…
   Can only operate on the tube from 1-4 or 5.
   Must bring all of the tools and materials in, do as much of the job as they can do, then move it all out before the tube opens again.

6. Can you suggest other sources we can derive information on TfL engineering history and developments?

TfL engineers could provide us with some track artifacts. There are usually little bits and pieces of components lying around.

Engineer 4

Transcript Editor: Luke Perreault

Scribes: Luke Perreault & Woodrow Shattuck

Date: Friday, 31 May 2013

[Note: This document details notes from the conversation, and not quotes from person interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. In order to do so, we are seeking your professional engineering knowledge to help us develop a background of the history and innovations made within your engineering field by Transport for London. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Discussion Topics for Transport for London (TfL) Engineers:

1. Is there anything you can tell us on the advances in materials science within surface transport engineering?
   Not aware of any, not in this interviewee's field of study.

2. What generally leads to technological changes? Are there any particular accidents/disasters/major challenges in TfL history that led to technological developments or recalls?
   - CC-TV cameras to monitor an accident area and keep traffic flowing in the event of an accident or breakdown.
   - Working in the Olympics, people had to work around the clock to keep traffic running and make sure athletes got to competition zones on time.

3. Can you talk to us about current advancements/future transportation developments that aren't in use yet but may be in the near future? Where is transportation technology going?
   - SCOOT system: automates the traffic and can detect traffic rates and optimize traffic.

- SCOOT system is upgrading to go wireless to avoid damage.

4. How does your engineering field function within TfL and what can you tell us about it?
   Not covered in this interview.

5. What are the health and safety requirements, or technical fail-safes, which TfL engineers in your field must abide by when working on transport improvements? Why are they in place?
   Safety measures are put into the system – if they put plans into a traffic signal, and it's bringing up alarms.
   Engineers can make realtime changes to the traffic as they see fit.
   Traffic signals are linked into lines – if a line goes down, it goes to local control.
   Monitored 24 hours at a control center to make sure everything is safe.
   TfL does collaborate with the police to make sure things are running smoothly.

6. Can you suggest other sources we can derive information on TfL engineering history and developments?
   TfL documents on website, sometimes produce documents on specific products.

Notes:

Information on Bridges:

- **Hammersmith Flyover – bridge, started to curl, salt broke down the rebar and it had to be shut down for repair. Repair projects have been quite successful.**
- **Pretension: Pull a rebar cable, fill with concrete and compress to force the beam into a shape.**
- **Post-tension: apply tension force to the beam as well.**
- **Current or future bridge projects: Western side of London has a large amount of crossings, but not many on the Eastern side.**
    - **Plan (very recent) for the Thames gateway bridge, but Crossrail was favored and the project was scrapped.**
    - **Still push for crossings in East London.**

Roads: Traffic Control Engineering

- **Modeling of traffic in London**
- **Olympic Road network**
- **Control traffic signals**
- **Reducing journey times and keeping a reliable network.**

5.3. Appendix C – Engineering Object Catalog

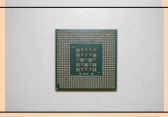
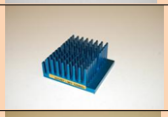
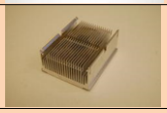
This catalog presents engineering objects from the London Transport Museum's main collection, object-handling collection, and Engineering Artifact library. The name of an object, its general description, the object's location, a photograph (if available), and the object's LTM ID number are included in each entry. In addition, objects from the main collection with duplicates available are flagged with bolded and underlined text. These objects may be good for requisition into a handling collection, as they are generally small objects safe for handling by children, and can be used to help teach about transport engineering concepts.

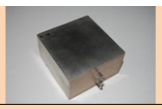
London Transport Museum Engineering Object Catalog

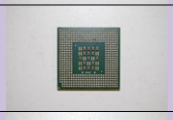
[Note: Bolded & Underlined items indicate Main Collection objects with several duplicates and/or are good for object-handling purposes. Recommended for use in Handling Collection.]

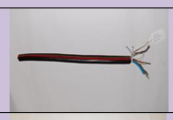
Artefact Name	Description	Location	Notes	Photograph	ID
Buses & Trams					
bus blind	Bus blinds, RM type, full set. Displays destination of bus.	Acton Depot			2011/2618
destination key	Destination blind key (used for Feltham tram No 355). Operates the blinds.	Acton Depot			2004/691
pedal	Gong pedal (for Feltham tram No 355)	Acton Depot			2004/689
sand pedal	Sand pedal (for Feltham tram No 355)	Acton Depot			2004/687
Ticket machine	Bell Punch ticket punch number 76477, with backplate and strap.	Handling Collection			1997/6947
exhaust pipe	Steel pipe, probably part of exhaust pipe for unknown bus	Acton Depot			1999/854
exhaust pipe	Part of exhaust pipe for unknown type bus	Acton Depot			1999/853
former	Former for producing laminated wings for K -type or S -type bus	Acton Depot			1999/852
carburettor	Updraught carburettor probably for T, ST or LT-type petrol engine bus. Mixes air with petrol that will be injected into the cylinders.	Acton Depot			2003/4471
carburettor	Spare carburettor for AEC petrol engine probably for pre-war bus used in London.	Acton Depot			1998/99169
gearbox	Spare gearbox for RM type bus from RM1562.	Acton Depot			2002/13550
Tram rail section	London County Council tram rail section, 1922	Acton Depot			1995/2583
Tram rail section	London Transport tram rail section, 1936	Acton Depot			1995/2587
Porcelain loop strain insulators [1]	Light brown porcelain loop strain insulator used in trolleybus overhead, pre 1962. Insulated power lines from the trolley and power line poles, preventing the electricity from grounding.	Acton Depot	Duplicates available (24 in total)		1998/110821
Porcelain loop strain insulators [2]	Green insulators used in trolleybus overhead, pre 1962	Acton Depot			1995/170

Porcelain loop strain insulators [3]	Brown porcelain loop strain insulator used in trolleybus overhead, pre 1962	Acton Depot			1998/110 817
Overhead line insulator	Trolleybus overhead loose bolt porcelain insulator, 1930s	Acton Depot	duplicates available (12 total)		1996/498 6
Electrical					
Rail insulator	LPTB positive current conductor rail insulator, tube type, c1930s, salvaged from vicinity of Down St. Station. Prevents current from conductor rails from grounding.	Acton Depot	duplicates available (5, possibly more)		1998/128 55
Rail insulator	Glass rail insulator, 1890, salvaged from King William Street Station. Glass does not conduct electricity, and prevented current from rails from leaking to ground.	Acton Depot	duplicates available (9)		1985/46

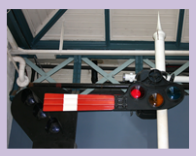
Microprocessor	The "brain" of a computer	Buckingham Palace Road - Artefact Library			E01
Microprocessor	The "brain" of a computer	Albany House, 55 Broadway - Artefact Library			E02
Microprocessor	The "brain" of a computer	London Transport Museum - Artefact Library			E03
Heatsink	Disperse heat generated by microchips	Buckingham Palace Road - Artefact Library			E04
Heatsink	Disperse heat generated by microchips	Albany House, 55 Broadway - Artefact Library			E05
Heatsink	Disperse heat generated by microchips	London Transport Museum - Artefact Library			E06
Capacitor	Device that stores electric charge	Albany House, 55 Broadway - Artefact Library			E07

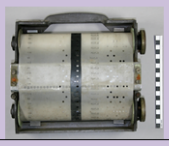
Capacitor	Device that stores electric charge	Buckingham Palace Road - Artefact Library			E08
Fuses	Used to protect circuits from drawing too much current	Buckingham Palace Road - Artefact Library, London Transport Museum - Artefact Library			E11.1-9
White Electrical Cable	Wire used to carry electricity	London Transport Museum - Artefact Library			E14
Blue Electrical Cable	Wire used to carry electricity	Albany House, 55 Broadway - Artefact Library			E15
Ceramic Insulating Buffer	Insulates the current running through the rails	Handling Collection			2010/21481
Roads and Bridges					
Concrete core	Concrete sample from Hammersmith flyover	Buckingham Palace Road - Artefact Library			C01
Post tensioning cable	Reinforcing cable from Hammersmith Flyover	Buckingham Palace Road - Artefact Library			C02
Rebar	1/2 Inch high tensile steel rebar, used to reinforce buildings and other infrastructure.	London Transport Museum - Artefact Library			C03
Rebar	1 inch steel rebar	London Transport Museum - Artefact Library			C04
Formwork Reinforcing Spacer	Formwork spacer for rebar	London Transport Museum - Artefact Library			C05
Water Meter	Device that measures flow of water at a given point in time	London Transport Museum - Artefact Library			C07
Traffic Light	Traffic light with pedestrian crossing and stand, c1952	Acton Depot	Not for handling, but photo available		2010/9207
Parking Meter	Coin operated parking meter as used by Westminster City Council, c.1990 - 2009	Acton Depot	Not for handling, but photo available		2009/8874

Traffic Signal Controller	ATE traffic signals controller, type 37, from Highgate Village, c1955.	Acton Depot	Not for handling, but photo available		2001/53630
Bridge Bearing	Bearing from Putney railway bridge, 1880s - in parts	Acton Depot	Not for handling, but photo available		1997/3694
Signalling					
Microprocessor	Desktop PC Microprocessor (CPU)	Buckingham Palace Road - Artefact Library			E01
Microprocessor	Desktop PC Microprocessor (CPU)	Albany House, 55 Broadway - Artefact Library			E02
Microprocessor	Microprocessor from laptop	London Transport Museum - Artefact Library			E03
Trackside Cable	Wire used for signalling in the underground	Albany House, 55 Broadway - Artefact Library, Buckingham Palace Road - Artefact Library, London			S02.1-9

		Transport Museum - Artefact Library			
3-Core Signal Wire	Wire used for signalling in the underground	Buckingham Palace Road - Artefact Library			S04
Indicator Push Rods	Indicates the position of track	Albany House, 55 Broadway - Artefact Library			S05.1-2
Contact Switch	Switch used to send signals	Buckingham Palace Road - Artefact Library			S07
Contacts	Used to conduct electricity in a switch	Buckingham Palace Road - Artefact Library			S08.1-2
Darlington Transistor	Power switch that can regulate the amount of power going to another circuit	Buckingham Palace Road - Artefact Library			S11
Indication Contact Arrangement Piece	Part of a train stop used to apply brakes if danger signal is passed	Buckingham Palace Road - Artefact Library			S13

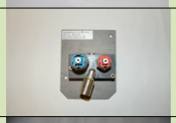
Indication Contact Arrangement Piece	Part of a train stop used to apply brakes if danger signal is passed	Buckingham Palace Road - Artefact Library			S14
Relay	Electromagnetic switch used in the London Underground	Albany House, 55 Broadway - Artefact Library			S15
Relay	Electromagnetic switch used in the London Underground	Albany House, 55 Broadway - Artefact Library			S16
Trainstop	HO type train stop, from Central Line. As a train passes into a block section, the signal turns red and the arm of the trainstop is raised. The position of the arm is carefully set, so that, when raised, it will hit a valve called a trip cock on the underside of any passing train, causing it to come to an emergency stop.	Acton Depot	Not for handling, but photo available		1996/4346
Flag	Used for hand signalling to communicate to trains.	Acton Depot	Not for handling, but photo available		1996/795

Flag	Used for hand signalling to communicate to trains.	Acton Depot	Not for handling, but photo available		1996/794
Semaphore signal arm	This early type of railway signal with a moving arm is known as a semaphore signal. Used on surface sections of the Central Line in the 1920s and 1930s it could indicate if the line ahead was clear, blocked or if the next signal was at danger.	Acton Depot	Not for handling, but photo available		1992/147
Signalling Token	Bank to Moorgate, northbound road, single line signalling token.	Acton Depot			1998/110375
Signal Rod	Operating rod for Signal	Acton Depot	Duplicates available (5)		1998/112581
Fog Repeater Signal	Used to help drivers see signals in poor visibility conditions	Acton Depot	Not for handling, but photo available		1993/53

Tunnel Signal	Two aspect tunnel signal	Acton Depot			1993/36
Programme machine part	This punched film is read in a similar manner to a pianola roll. The holes represent a sequence of trains in the working timetable and the passage of one train moves the roll on for the programme machine to signal the route for the next train.	Acton Depot	Not for handling, but photo available		1998/12013
Lever Frame	Interlocking lever frame used to control signals and points. Interlocking mechanism prevents incorrect levers from being pulled so, for example, signalmen couldn't direct a train to move into an occupied block and risk a collision.	Acton Depot	Not for handling, but photo available		1993/5
Track Relay	Relay used in track circuits, which would detect if a train was passing through a specific area.	Acton Depot	Not for handling, but photo available		1993/38

Block instrument	Spagnoletti block instrument from Metropolitan line signal box. Date range approximate: 1880-1960. To safely monitor and control the movement of trains on the railway, each line is divided operationally into block sections of track. This instrument let the signalman know if a section of line was clear or occupied by a train.	Acton Depot	Not for handling, but photo available		1995/2610
Track					
Screw Spike	Screw spike for securing track	London Transport Museum - Artefact Library			T01
Pandrol Clip	Pandrol clip for securing rail to sleeper.	London Transport Museum - Artefact Library			T02
Resilient Pad	Recycled Resilient pad	London Transport Museum - Artefact Library			T03

Resilient Pad	New Resilient Pad	London Transport Museum - Artefact Library			T04
T Piece	Track T piece to separate track	London Transport Museum - Artefact Library			T05
Track Piece	Cross section of composite conductor rail	London Transport Museum - Artefact Library			T06
Short Key	Broken short key used in points system for track changing	Albany House, 55 Broadway - Artefact Library			T07
Short Key	Short key used in points system for track changing	London Transport Museum - Artefact Library			T08
Piston	Compressor piston	London Transport Museum - Artefact Library			T09
Air Compressor Hose	Hose used for air compressors	London Transport Museum - Artefact Library			T10

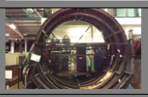
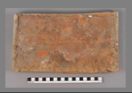
Pressure Switch	Outdated pressure switch from Piccadilly line	London Transport Museum - Artefact Library			T11
Pressure Switch	Pressure switch used on Piccadilly line	London Transport Museum - Artefact Library			T12
Bolt	Bolt and nut used for securing track	London Transport Museum - Artefact Library			T13
Washer	Washer	London Transport Museum - Artefact Library			T14
Wooden Track Key	Wooden key for securing track to sleeper	London Transport Museum - Artefact Library			T15
Biscuit	Biscuit to provide electrical insulation between track and pandrol clip	London Transport Museum - Artefact Library			T16
Door Pads	Door pads to seal doors when shut	London Transport Museum - Artefact Library			T17

Maglock	Magnetic lock	London Transport Museum - Artefact Library			T18
Spring Door Arm	Spring door arm	London Transport Museum - Artefact Library			T19
Red Button	Red emergency button	London Transport Museum - Artefact Library			T20
Phone	Phone used in train cab	London Transport Museum - Artefact Library			T21
Electrical Conducting Fish Plate	Bottom aluminium fish plate	London Transport Museum - Artefact Library			T22
Electrical Conducting Fish Plate	Top copper fish plate	London Transport Museum - Artefact Library			T23
Wooden Track Key	Hexagonal timber blocks, or "keys" are hammered between the running rail and rail chair to lock the rail in place.	Acton Depot	duplicates available (4)		1998/114 076
Steel Track Key	Sprung steel clip to lock rail into place.	Acton Depot	duplicates available (6)		1998/992 65
pandrol clip	Curved steel rod used as a rail fastening.	Acton Depot	duplicates available (2)		1998/114 195
Rail insulator pot used on London Underground.	The insulator pot has two main functions: it insulates the conductor rail from the ground and supports the conductor rail. The rail carries up to 4500 amps.	Handling Collection			2011/215 4
Steel conductor rail used on London Underground.	The conductor rail provides electricity to Underground trains. An iron 'contact shoe' on the train rubs along the rail and picks up the power. Steel rail is easy to make but is heavy and difficult to work with.	Handling Collection			2011/214 8
London Transport tube train roof strap hanger. Has roof attachment, spring and ball holder.	London Transport tube train roof strap hanger, for passengers on trains to hold on to. Has roof attachment, spring and ball holder.	Handling Collection			2009/452 1

Booklet	Rolling stock maintenance manual for tripcocks	Handling Collection			2006/6918
Booklet	Rolling stock maintenance manual for shoes and shoegear	Handling Collection			2006/6244
Booklet	Metropolitan Railway - Description of the British Thomson-Houston multiple unit control equipment and the British Westinghouse multiple unit control system, 1913	Handling Collection			2003/3791
Rail Chair	Cast iron Great Central Railway rail chair, with a two bolt holes at each end, each end having one smaller and one larger hole. Remains of wooden washer inside larger hole at one end. Two track bolts associated with chair kept in two smaller holes.	Acton Depot	Duplicates available (8, possibly more)		2004/10234
Cable Clip	Curved metal clip with attached leather strap with metal eyelets at ends. Used to secure cabling to cast iron compressed air main along underside of platform.	Acton Depot			2004/1288
Track Bolt	Track bolt for fastening rail chairs to sleepers	Acton Depot	duplicates available (at least 8, likely more)		1998/114390

Jack	Iron rail jack for use on the underground, with socket for jack handle (missing), ratchet system, and step. Inscribed on both sides in embossed text. Lifting mechanism damaged or broken, loop handle at top.	Acton Depot			2004/11263
Rail Fastening	Alloy rail fastening similar to Linadapter type	Acton Depot	Duplicates available (3)		1998/114237
Plastic Screw	Plastic screw insert for rail track fastening	Acton Depot	duplicates available (4)		1998/114244
Glass Conductor Rail Insulator	City & South London Railway conductor rail insulator, cast in green glass, c1890, recovered from King William Street Station.	Acton Depot	duplicates available (9)		1993/196
Packing Piece	Timber/Metal/Plastic packing for placing under pots or insulators on Underground track.	Acton Depot	duplicates available (4 timber, 2 metal, 2 plastic)		1998/114084
Rail Insulator Bracket	Standard fixing for insulator pot as used on Underground track to carry the current conductor or "juice" rail.	Acton Depot	duplicates available (9)		1998/114068

Track Gauge	Track level as used by Underground track workers to define the spacing of the rails. Known also as an Inspectors gauge. For use on all lines other than old CLR tunnels.	Acton Depot	duplicates available (11, possibly more)		1993/56
Spanner	Pointsmans spanner as used by Underground track workers. It consists of a head and shaft. The shaft is flattened at one end so as to be inserted under the track. The paint that remains is blue.	Acton Depot	duplicates available (3)		1998/9987
Rail Guide	Steel device with nylon roller for holding long welded flat bottom rail in position while allowing it to slide during de-stressing or stressing operations. c1990. The nylon roller bears on the rail web to allow the rail to creep more easily on curves.	Acton Depot	Duplicates available (3)		1995/393
Ferrule	Plastic ferrule used between rail chairs and track bolts as used by London Transport	Acton Depot			1998/114366

Tunnelling					
Retroreflector	Tool to detect disturbances caused by underground construction.	London Transport Museum - Artefact Library			C06
Tunnel Lining	Metal tunnel lining segments, circa 1900.	Acton Depot	Not for handling, but photo available		1999/4235
Thames Tunnel Tiles	Collection of ten tiles, forming part of the dentilation brickwork, used to line the Thames Tunnel, c1845 - 1995.	Acton Depot	Not for handling, but photo available		1998/12099
Ventilation Fan	Representative ring of 11ft 6in C&SLR cast iron tunnel lining segments from London Bridge station.	Acton Depot	Not for handling, but photo available		1999/4235

5.4. Appendix D – Museum Education Interview Transcripts

Appendix D includes all transcripts from our interviews with museum education professionals from Worcester, MA, USA, and London, England. Names and identifying information have been removed from the transcripts to protect the anonymity of the interviewees. These transcripts detail notes and key information from conversations, and not quotes from the people interviewed, unless otherwise indicated.

Museum Professional 1

Transcript Editor: Luke Perreault

Scribes: Ryan Santos, Woodrow Shattuck, Luke Perreault

Date: Thursday, 18 April 2013

[Note: This document details notes from the conversation, and not quotes from those interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities. We would like to obtain your insight into what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Object-based Learning – Teachers, Museum Professionals, TfL Ambassadors

- *For Teachers:* How might a museum professional or TfL Ambassador present this object to students?
    - ***Not covered during interview***
- What do you think are difficult concepts to convey to students, and can object-based learning help teach these concepts?
  Historical information, particularly the living or working conditions of a certain time or situation, are difficult concepts to convey. Placing students in the moment with objects that represent those conditions can assist in lending a "sense of time/putting children in the moment."

- What kinds of objects, or features of objects, are most useful in particular?
  Objects need to tell stories. Objects with personal connections to people via local stories or anecdotes they are involved in can make them particularly endearing (i.e. the pleasantly shocked reaction of young adults to seeing a GameBoy in the "Game On!" exhibit) An object that belonged to a famous person can also be useful.

- We are working to convey the history of Transport for London through object-based activities. How would you use objects to present a history of an organization or a science over time?

  Focus on why technology has developed and changed, as opposed to how. Interesting stories can be discovered - disasters, accidents - that can be compelling to students and yield more information. "Safety issues cause change," in particular. Think about environmental effects, such as how coal and steam from locomotives and subways effected the environment, and the working conditions of associated jobs.

  "Dress them up as a train conductor and put them in the train with hot cinders and such. They will think of things they never considered like 'Damn its hot in here.' They realize how difficult it was."

Object-based Programming – Teachers, Museum Professionals

- What types of object-based programming have you done, either in your museum or at schools?

  The following answers relate to exhibitions "Stories They Tell" and 'Game On!"

- How long has your program been running?

  Not covered during interview

- What was the motivation for starting it?

  Educating the people of the greater Worcester area on their local history.

- How is it going so far?
  - Any consistent reactions from students, parents, or teachers?

    More personalized objects – those with stories with connections to visitors, get more of a surprised/excited response.

  - How have you evaluated the program's success, if at all?

    N/A

- Has anything changed in the program, based on your evaluations?
  N/A

- How are staff members trained in object-based learning, and how do you typically use objects in presentations?
  Not covered during interview.

  - What's working well or needs improvement?

- What types of activities do you notice students engage with or are stimulated by the most? What types of activities do students engage with the least?
  Activities involving solid objects consistently work better than pictures. Those activities that use tools like magnifying glasses and handling gloves, which place students in a role, can be extremely stimulating for them. Exhibits where you can "keep digging" by manipulating a screen or pulling a lever are also excellent.

  Exhibits that offer no connection to the visitor and display only facts are not good at stimulating interest. Information is so easily accessible with modern media – "people are lazy, why go to museums?" – museums must offer something "extra" by presenting an additional connection to the history generated by real artifacts and exhibits.

- How do you develop programs for students of different ages and educational level?
  N/A

- *For Museum Staff:* How do you ensure a class is both excited and educated by a visit?
  Kids love moving parts and love to touch stuff. But there is a danger of "all play and no learning." Competition for objects and attention might develop, which can be bad.

- Can you suggest potential sources of information for object-based programming, either from literature or your own work? Where do you typically get your material for programs and would you be willing to provide us with ideas?
  Museum websites are excellent examples of curriculum. Check the Museum of Science or the Oakland Museum. "Look into the book 'Age of Edison' from 2013. Might be useful."

Museum Professional 2

Transcript Editor: Luke Perreault

Scribes: Full Group

Date: Monday, 13 May 2013

[Note: Observation notes from learning program session included.]

[Note: This document details notes from the conversation, and not quotes from those interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. We would like to obtain your insight into what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Object-based Learning – Teachers, Museum Professionals, TfL Ambassadors

- *For Teachers:* How might a museum professional or TfL Ambassador present this object to students?
    - **Not covered in interview.**
- What do you think are difficult concepts to convey to students, and can object-based learning help teach these concepts?
    - **Not covered in interview.**
    - What kinds of objects, or features of objects, are most useful in particular?
- We are working to convey the history of Transport for London through object-based activities. How would you use objects to present a history of an organization or a science over time?
    - ***Mystery objects, "things that people have to guess what they are, how do you think this works and what do you think it is."***

- ***"More important to let people figure out things for themselves and come up with questions."***
- ***Emphasize important topics, but take care not to generalize or give people the wrong idea.***

Object-based Programming – Teachers, Museum Professionals

- What types of object-based programming have you done, either in your museum or at schools?
  - ***Toy session: Toys from around the world***
- How long has your program been running?
  - ***30 years***
- What was the motivation for starting it?
  - ***Help students learn about the world, and handle unique objects.***
  - ***Doesn't see it as teaching them, but allowing them to start asking questions.***
  - ***Valuable educational tool to let students handle objects.***
- *How is it going so far?*
  - Any consistent reactions from students, parents, or teachers?
    - ***"A 'wow' when they come in to the room."***
    - ***"Can they try on different things" and other engaging questions.***
  - How have you evaluated the program's success, if at all?
    - ***Teacher evaluation forms***
    - ***Visitor evaluations to see what people like the best.***
    - ***Interviewed secondary school students to get their opinions on the collection.***
  - Has anything changed in the program, based on your evaluations?
    - ***Add things or take things out based on preference of students.***
    - ***Use evaluation comments to know what aspects of the activities and lessons to emphasize.***

- How are staff members trained in object-based learning, and how do you typically use objects in presentations?
    - ***Object-handling training & courses - everyone working in the museum must partake.***
    - ***Some things that are most delicate, they don't allow out during school sessions; highly supervised use, if objects are rare, is sometimes used with older children/young adults.***
    - What's working well or needs improvement?
    - ***Tailor-made sessions for older students (secondary school) work very well.***
- What types of activities do you notice students engage with or are stimulated by the most?
    - ***Most people seem to like touching things. "Even the toughest secondary school kids will find something they're interested in."***
    - ***"Let them pick it out." So they can "find links to their own lives," their own connections; really works effectively.***
- What types of activities do students engage with the least?
    - ***"Depends on the group and what they're interested in."***
    - ***Not giving them the choice or freedom to do their own exploration (i.e., linear selection & structure within a program).***
- How do you develop programs for students of different ages and educational level?
    - ***Similar format for young and old student groups.***
    - ***Primary schools come to standard sessions about museum topics.***
    - ***Secondary school topics are tailored to the topics the students are learning with at the time.***
- *For Museum Staff:* How do you ensure a class is both excited and educated by a visit?
    - ***"It can depend on the class and the topic." Toys are a "laid back and fun session."***
    - ***"Ancient Egypt programs, you have to put on gloves, and build it up as special."***
- Can you suggest potential sources of information for object-based programming, either from literature or your own work? Where do you typically get your material for programs and would you be willing to provide us with ideas?

- **Respondent can't think of anything at the time.**

Observation Session Notes:

- **6-8 year old students**
- **stage for presenter, with objects on tables, and a carpet area for students**
- **What are the objects?**
  - **"Antiques," "old," "toys."**
- **First toy she presents is Red Riding Hood/Granny/Wolf toy -> something that the students can connect with immediately and draw their attention.**
  - **Takes time to talk about the story, something they're all connecting and interacting with, they complete scenes, help tell the story.**
- **Talks about a doll that was used to teach about making clothes.**
- **"Traditional toys" – very old, often made by hand**
  - **walks around the room, to keep their attention and let everyone have a look**
- **Allows kids to demonstrate objects in front of the class up on the stage with the antique toys**
  - **Presenting, other kids engage with their peers.**
- **Talks about special features of the toys**
  - **One is made of recycled objects – talks about how they're made of old flip-flops, an object they'd be familiar with.**
- **Lets them play and explore last, as a reward for the learning components.**
  - **Splits them up into groups beforehand to allow everyone equal time with the toys.**
- **Kids interacting with each other, discussing the toys**
  - **Everything in stations, to make switching easy.**
  - **Toys in station are organized according to type.**
    - **Wire/recycled, block/ball, anique/traditional**
- **Teachers play and interact to, perhaps to set an example.**
- **Wraps up session by asking students to recall which countries the toys are from.**
  - **Educates about how some of the toys are made.**

Museum Professional 3

Transcript Editor: Luke Perreault

Scribes: Woodrow Shattuck, Luke Perreault

Date: Thursday, 16 May 2013

[Note: This document details notes from the conversation, and not quotes from those interviewed, unless otherwise indicated.]

We are students from Worcester Polytechnic Institute in the United States assisting the London Transport Museum with the development of object-based learning activities about London transport engineering history. We would like to obtain your insight into what objects would best serve this purpose, where we may be able to obtain additional objects, and what aspects of educational activities using objects are most effective. With your permission, we may use your responses in an academic paper that will be publically available. Any contribution you make will be cited accordingly. With your permission, we would like to record the interview for our reference.

Object-based Learning – Teachers, Museum Professionals, TfL Ambassadors

- *For Teachers:* How might a museum professional or TfL Ambassador present this object to students?
    - **Not covered in interview.**
- What do you think are difficult concepts to convey to students, and how can object-based learning help teach these concepts?
    - ***Any concept, a STEM issue, historical, etc, which is abstract or beyond a student's experience, can be difficult to convey. For example, the building of a tunnel: "Most of us aren't tunnellers; we can't understand the actual method or experience."***
    - What kinds of objects, or features of objects, are most useful in particular?
        - ***Obscure objects that make people ask questions, or that you can ask questions about, can work very well.***

        - ***Objects that reveal "part of that truth." For example, a brick can help teach about tunneling. "A brick might represent the millions of bricks needed to build a tunnel."***
        - ***"Comparable about a comedian telling a funny story to reveal the truth about human relationships." You can present an idea, but not "the totality of human experience."***
- We are working to convey the history of Transport for London through object-based activities. How would you use objects to present a history of an organization or a science over time?
    - ***As noted above: Can be used to reveal "part of that truth." For example, a brick can help teach about tunneling. "A brick might represent the millions of bricks needed to build a tunnel."***
    - ***Can make points about structural engineering, make points about construction, provides "focus" for discussion.***

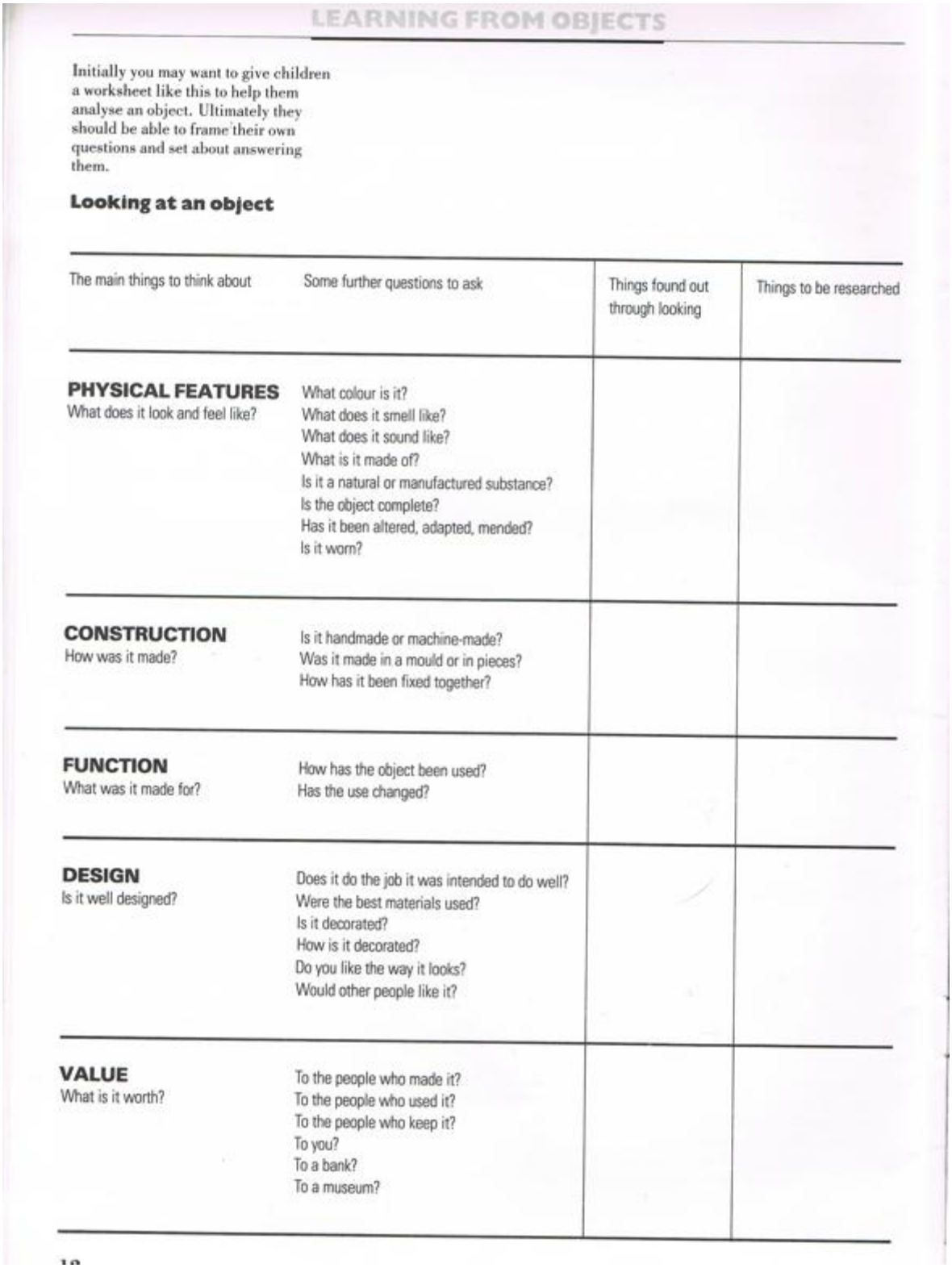
Object-based Programming – Teachers, Museum Professionals

- What types of object-based programming have you done, either in your museum or at schools?
    - ***Respondent worked in heritage and cultural organizations for nearly 16 years. Worked in the Imperial war museum, painting called "Gassed," about First World War soldiers… a stark image, which they developed an entire learning program around.***
    - ***Gave a focus to ask questions.***
    - ***"What do you see?"***
    - ***An educator needs to have a learning goal in mind.***
- How long has your program been running?
    - **N/A**
- What was the motivation for starting it?
    - **N/A**
- How is it going so far?
    - **N/A**

    - Any consistent reactions from students, parents, or teachers?
        - **N/A**
    - How have you evaluated the program's success, if at all?
        - **N/A**
    - Has anything changed in the program, based on your evaluations?
        - **N/A**
- How are staff members trained in object-based learning, and how do you typically use objects in presentations?
    - ***"We do have training for educators and training days for ambassadors."***
    - ***One of the most important things for training is imparting key messages regarding why the program running is important.***
    - What's working well or needs improvement?
        - ***Needs to be reinforced and built up, so that, when teaching about resources, we give them clear things to remember regarding what they need to do.***
- What types of activities do you notice students engage with or are stimulated by the most?
    - ***Best activities are where they get to "do something," and be active.***
    - ***Students like to be asked, "What do you think?" and subsequently are engaging with questions.***
    - ***Warm-up with an object; then give them a task to complete.***
- What types of activities do students engage with the least?
    - ***Those where they're sat down and spoken at, and not engaged.***
- How do you develop programs for students of different ages and educational level?
    - ***Objects are useful for all ages and educational levels.***
    - ***The approach isn't always hugely different; learners to be active.***
    - ***Differences stem mainly from the educational requirements at primary and secondary level.***
    - ***Find out "what do they already know?"***

        - ***Objects can help make that answer specific and focused: "what does this do?" or "what is this made out of" to find out a starting point, and begin, a discussion.***
- *For Museum Staff:* How do you ensure a class is both excited and educated by a visit?
    - ***Knowing what the overall goals for the session are ahead of time. Educator skills in behavior management.***
    - ***Collaborate with kids for behavior management rules.***
- Can you suggest potential sources of information for object-based programming, either from literature or your own work? Where do you typically get your material for programs and would you be willing to provide us with ideas?
    - ***Book, author is Gale Durbin, on object-based learning.***
    - ***North, South, East, West method:***
        - ***N = Natural (is it natural?)***
        - ***E = Economic (what's it's value?)***
        - ***S = Social (what's it's purpose?)***
        - ***W = Who Decides? (Who decided to make or do this?)***
        - ***Might use these questions to make a focus for an educational session.***

5.5. Appendix E – Museum Education Reference Documents



LEARNING FROM OBJECTS

Initially you may want to give children a worksheet like this to help them analyse an object. Ultimately they should be able to frame their own questions and set about answering them.

Looking at an object

The main things to think about	Some further questions to ask	Things found out through looking	Things to be researched
PHYSICAL FEATURES What does it look and feel like?	What colour is it? What does it smell like? What does it sound like? What is it made of? Is it a natural or manufactured substance? Is the object complete? Has it been altered, adapted, mended? Is it worn?		
CONSTRUCTION How was it made?	Is it handmade or machine-made? Was it made in a mould or in pieces? How has it been fixed together?		
FUNCTION What was it made for?	How has the object been used? Has the use changed?		
DESIGN Is it well designed?	Does it do the job it was intended to do well? Were the best materials used? Is it decorated? How is it decorated? Do you like the way it looks? Would other people like it?		
VALUE What is it worth?	To the people who made it? To the people who used it? To the people who keep it? To you? To a bank? To a museum?		

Figure 5: Learning from objects (Durbin et al., 1990)

What we've learned about developing educational resources

Practical ideas on how to create activities for teachers to use off-site

When you're planning the new resource...

Think about **why** you want to develop the resource and **for whom**. Is it something teachers need and want? Does it support your organisation's aims, and national education strategies? Is it a unique idea or do similar things already exist? Is it linked to **something your museum does best** or is known for? Will it suit your particular audience?

When you are coming up with new ideas...

Generate **lots of ideas** initially. Talk to teachers and students to check on the subject and format of resources they would welcome and really use. When you have a firmer idea of the topics you intend to cover, research **National Curriculum links** and the **vocabulary** used to teach the topic. You may have a regular teacher panel or other contacts you can use, or you can get new teachers involved. Make sure there is an incentive for being involved, and always send a nice thank you letter.

When you are developing the resource...

One really good resource is better than several average ones, so only develop as many resources as you can do well. Project-plan your process, creating a **timeline** and **checklist** of what you need to do, and a rough **budget** for each stage. Communicate your **milestones** to colleagues, especially those whose input you will need, and any external parties like designers or photographers.

Use staff time effectively by developing resources during quieter times. Volunteers may be able to help, and **teachers** may welcome the chance to contribute during holiday periods as part of their CPD.

Keep good records of your development process, including what worked and didn't work, how long things took, unexpected findings etc, so that you develop a **robust framework for next time**.

When formatting your resource materials...

Develop a consistent **house style** for your materials so that teachers recognise a familiar and trustworthy format. Use the same font each time, short chunks of text and numbered stages or pages. To create a resource sheet for students, use **limited words**, lots of **pictures** and plenty of white space. To create notes for teachers, use a consistent order and format, with sub-headings and short paragraphs. Provide top-line links to the National Curriculum, and consider including **real-life** careers links drawn from interviews with relevant contacts.

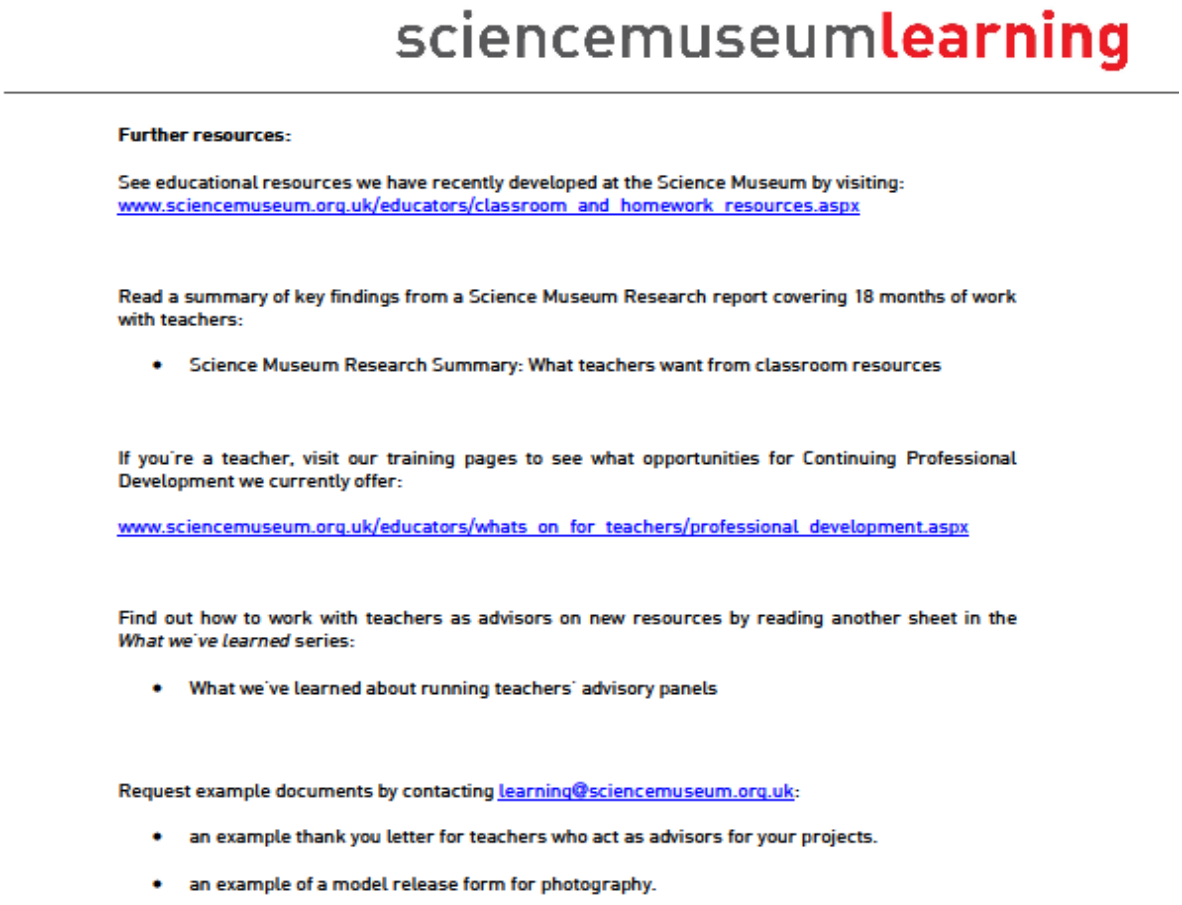
Photos are very useful in instructions – make sure they print and photocopy well. **Video** is even better for complex instructions, and can be produced using a cheap video camera (and presented in an informal way, for example, 'going behind the scenes' of a particular demonstration). In all photography and video, make sure props are clean and staff are dressed consistently and chosen to show diversity (age, gender, ethnicity).

When you are testing the resource...

Trial the resource at several stages – initial ideas, during development and final draft. When you feel each stage is complete, show it to a few people who've never seen it before to check it makes sense. Test resources with both **teachers and students**, and find a range of ages, gender, types of schools, levels of experience etc. You won't please everyone but it will give you enormous **insight** into real users. Be aware that some of your advisors may be wary of unfamiliar ideas, and consider this before abandoning something innovative.

A note on photography...

Images and video of under-18s need parental/guardian permission in advance to be used in resources. If you want to use pictures or video of over-18s in which individuals can be identified, you still need permission, even if they are museum volunteers.



sciencemuseumlearning

Further resources:

See educational resources we have recently developed at the Science Museum by visiting:
www.sciencemuseum.org.uk/educators/classroom_and_homework_resources.aspx

Read a summary of key findings from a Science Museum Research report covering 18 months of work with teachers:

- Science Museum Research Summary: What teachers want from classroom resources

If you're a teacher, visit our training pages to see what opportunities for Continuing Professional Development we currently offer:

www.sciencemuseum.org.uk/educators/whats_on_for_teachers/professional_development.aspx

Find out how to work with teachers as advisors on new resources by reading another sheet in the *What we've learned* series:

- What we've learned about running teachers' advisory panels

Request example documents by contacting learning@sciencemuseum.org.uk:

- an example thank you letter for teachers who act as advisors for your projects.
- an example of a model release form for photography.

Figure 6: Science Museum on Developing Educational Resources (*Developing Resources*, n.d.).

5.6. Appendix F – "Primary Inspire" Object-Based Learning Materials

Appendix F features the materials our group developed for the London Transport Museum's "Primary Inspire" session. Included is a table of objects recommended for use in the program. Each entry features the object's photo, location, what material it is made of, its function, ID number, and notes regarding its purpose. We also include explanations of engineering concepts presented in the presentation, and guidelines for teaching with the recommended engineering objects.

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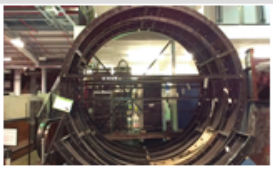
Primary Inspire Engineering Artefact Resources & Guidelines

Engineering Artefacts for Primary Inspire:

Name	Photo	Location	Material	Function/Purpose	Notes	ID Number
Pandrol Clip		Engineering Artefact Library	Steel	Secures rails to the beams (called "sleepers" they rest upon.	Small, handheld, relatively lightweight	T02
Wooden Key		Engineering Artefact Library	Wood	Predecessor to pandrol clip. Secures rails to sleepers.	Significant wear, including a burn-mark	T15
Aluminum conductor rail piece		Engineering Artefact Library	Aluminium with steel cap	Cross-section of conductor rail used to carry electricity that powers Underground trains	Lightweight compared to steel rail.	T06
Concrete Core		Engineering Artefact Library	Concrete	Concrete core from Hammersmith Flyover – similar concrete would be used in building modern tunnels, as opposed to bricks of the Victorian Era	Heavy, use two hands, emphasize caution if passed around.	C01

Name	Photo	Location	Material	Function/Purpose	Notes	ID Number
Tunnel Lining segments, circa 1900	 	Acton Depot	Cast-Iron	Segments used to line Underground tunnels. Note the cylindrical shape, which provides best support.	Very large – Acton Depot, not available for handling	1999/4235
Steel conductor rail piece		Object-Handling Library	Steel	Powers underground trains. An iron 'contact shoe' on the train rubs along the rail to pick up power. Steel rail is easy to make but is heavy and difficult to work with.	Heavy – Use for a comparison of metal properties and weight with Aluminum rail.	2011/2148
Brick		Learning Department	Brick	A standard brick, the material that would have been used to construct the original Victorian underground tunnels	Rather heavy, hard. Have students use two hands when handling.	N/A

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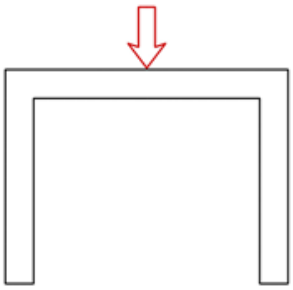
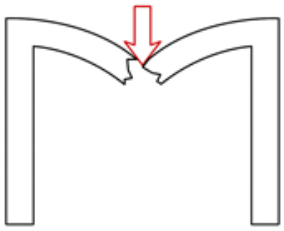
Primary Inspire: All about Engineering Concepts

Tunnel Shapes: Arch/Circle vs. Rectangle:

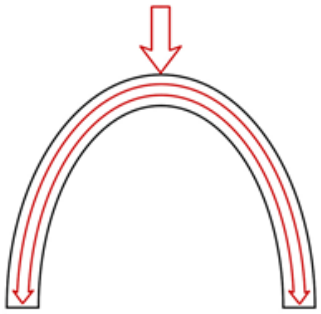
When trying to teach about tunnelling to primary school students, it's important to convey information about forces at work on the tunnel wall. From a discussion about forces and energy, an understanding of why most Underground tunnels are designed with arched or cylindrical roofs can be easy to convey:



In the case of brick or rock tunnels with flat roofs, the centre of the roof is not supported and cannot withstand the force of the earth; consequently, it buckles.[1]



This problem is avoided in an arch, which naturally distributes pressures exerted by the earth around the tunnel structure: a force exerted at the top of the arch pushes against the bricks along the roof and walls, rather than being concentrated in an unsupported centre. The structure is rendered much more stable and holds its shape.[1]



This can be made clearer with a demonstration. Let's look at the activity done during Primary Inspire:

[1] Wahlstrom, Ernest. *Tunneling in Rocks*. Elsevier Scientific Publishing Company. Amsterdam, Netherlands. 1973.

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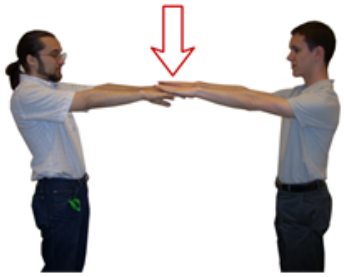
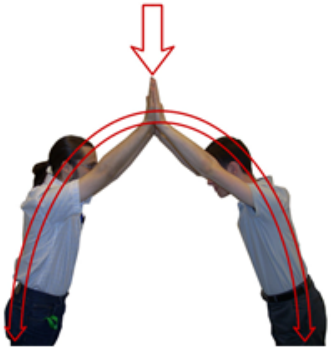
"Human Arch" Activity:

During the Primary Inspire session, students pair up in groups of two and make an arch to feel the strength of that shape, and better understand why it was selected in the construction of the Metropolitan Railway in the 1860s. Let's look at the physics behind it:



Have students pair up to make a rectangular "roof," locking their hands together and firmly supporting one another. Demonstrate the weakness at the centre of this shape by pushing hard on their hands: the students will have to lean in to remain connected, showing that a flat roof is at risk of collapse if placed under great duress.

Next, have students make an arch by placing their palms together and leaning into one another. Demonstrate the strength of this shape by pushing hard on their hands: a great deal of force can be exerted, and the students will be able to stay in the arch shape. Ask them if they can feel the force of the push down to their feet – this demonstrates how forces are distributed through the arch.



Suggestions for Using Engineering Artefacts:

Demonstrating Differences between Metals:

- Use a Steel Conductor Rail, and a new Aluminium Conductor Rail, to show similarities and differences between metals.
- Have students hold both in their hands – the difference in weight, despite the similarities in size and shape, should become readily apparent.
    - Ask them to comment on the weight of the aluminium vs. the weight of the steel. Steel is much heavier.
- *Problem Solving*: Have students try to guess why TfL is changing from steel to aluminium.
    - Answer: Aluminium is a better conductor than steel, so more electrical energy is saved and trains are less costly to run.
- *Problem Solving*: Have students try to figure out what challenges there might be with aluminium, which is a lighter, weaker metal than steel.
    - Answer: Aluminium is weak (and expensive), which is why the conductor rail is **protected by a steel cap**!

Talking About Materials

- *Metal vs. Wood*: Using the wood block and pandrol clip (wood and metal samples) can help convey why metals, and not wood materials, are used on the Underground.
- *Exploring:* Ask students to guess what both objects might have been used for on the Underground.
    - Explain that the wood block and pandrol clip were used for the same purpose – to anchor tracks to the sleepers they were placed on.
- Talk about why the metal pandrol clip might be better than the wood block.
    - Note any damage to the wood block, cracks, etc.
    - Have students feel how strong and smooth the clip is.
- *Talk about friction*
    - Explain that friction, caused by rubbing between two different objects, generates heat (have them rub their hands together rapidly to feel this)

- Ask students whether more friction and heat, would be generated between a rail and the wood block, or a rail and a metal pandrol clip.
    - The rough wood block would cause more friction with the rail – the heat might even set it on fire!
    - Metal, however, are smooth, and smooth surfaces generate less friction, so less energy is lost to heat.

5.7. Appendix G – Handling Trolley Object-Based Learning Materials

Appendix G features the materials our group developed for the London Transport Museum's "Tomorrow's Journeys" exhibit object-handling trolley. Included is a list of objects recommended for use in the program, along with fact sheets about the objects, and guidelines for using them to teach. The list of objects is supplemented with information about each object, pictures of the objects, and their LTM ID numbers.

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Tomorrow's Journeys Narrative Sheet

Signal Flag:

- **Questions:**
  - **What is it used for?**
    - Signalmen would hold the flags at the edge of the platform to signal the oncoming trains.
  - **What signals did the signalmen send to the trains and what did they mean?**
    - "All Clear" meant that the train was clear to move ahead.
    - "Danger" meant that there is an obstacle in the way and it is not safe to continue.
    - "Caution" meant there is a train close by, but it is safe to proceed with caution.
  - **What do you think this evolved into today?**
    - The concept of using flags and arms to signal trains evolved into semaphore towers that had mechanical arms that would move and signal the trains passing by.
- **Facts:**
  - Using flags to signal to conductors was the first and crudest method of signalling between the train and the station.
  - Signalmen would sometimes get distracted or leave their post, making this method of signalling very unreliable.
  - As trains got faster and stations became more crowded it got harder to see the signals. Mechanical semaphore arms served as flags and were put on towers next to the track to ensure they would be more visible.
- **Let the guests hold and use the flags to try various flag positions.**
- **Show them the picture of the modern mechanical semaphore arm to show how the concept as evolved.**

Signal Lantern:

- **Questions:**
  - **Have a person examine the lens and ask why they think it's a certain colour.**
    - Each colour represented a different signal. Red meant "Danger", Green meant "Caution", and white meant "All Clear".
  - **Where do you think the lanterns were used?**
    - The lanterns were held by signalmen or put on the end of trains to signal the next trains.
  - **Why do you think trains used signal lanterns?**
    - The tunnels were very dark; flags were very difficult to see in the dark. It was much easier to see a light in the darkness.
  - **Why do trains no longer use signal lanterns?**
    - Electric lighting was much more reliable and easier to maintain. Also, signal lights fixed on the track ensured that the driver didn't accidentally miss a signal.
- **Facts:**
  - Lanterns were used originally on the back of trains to signal to trains behind them, and by signalmen to signal trains from the platform.
  - The lanterns first used candles and whale oil, but after 1870, starting using Paraffin (now known as kerosene).
  - Lanterns would sometime blow out and needed to be constantly refuelled by "Lamp Men."
  - Multi-coloured lanterns evolved into the electric signal lights we see today. The maintenance and risk of failure is much lower (lamps had to be refuelled and would sometimes be blown out).
- **Show that the glass is a certain colour and explain that when the lantern is lit, it make that colour light.**
- **Let people hold the lantern and pretend to be a signalman.**
- **Show guests the picture of the modern electric signal light. Compare it to the lanterns and explain why lanterns evolved.**

Programme Machines:

- **Questions:**
  - **Feel the programme machine paper, what do the holes represent?**
    - The holes represent a train schedule. Each hole sends a signal to the train telling it, for example, to stop or to continue.
  - **How does the paper work with the programme machine?**
    - The daily details of the train activity for a particular set of points along the track are hole punched into the paper and put into the programme machine. As the paper rolled through the machine it would open and close electrical switches that controlled the points and sent the appropriate signals.
  - **Why don't we use programme machines today?**
    - While being mostly automated, the programme machine still required a degree of human attention. Holes had to be manually punched for each changing train schedule, paper had to be manually loaded, and moving parts had the chance to jam or to fail, requiring maintenance. Today we use computers which solve most of these problems.
- **Facts:**
  - First introduced in the late 1950s, the programme machine allowed for the automation of signal control and reduced the risk of accidents due to human error.
  - In 1968 they were used on the Victoria Line to implement the first automatic railway.
  - It is gradually being replaced by computers, which are much more reliable and requires much less maintanance.
- **Let guests examine and feel the paper and each hole.**
- **Show the picture of a man using the programme machine so guests can see how the paper is used with the programme machine.**
- **Show the picture of the programme machine so guests can see what the machine looks like and how large it is. Compare it to the microprocessor chip.**

Microprocessors:

- **Questions:**
  - **What is this object?**
    - It is a microprocessor chip that can automatically and instantaneously send signals to trains when they approach the stations. They are capable of dealing with any changes in the track. It helps run the entire signalling network today.
  - **Why do you think computers replaced the programme machine?**
    - Computers generally don't need supervision like the programme machines; they would automatically do any signal calculations. They are also much more powerful, compact, and faster.
  - **How does computerized signalling improve the transportation network?**
    - Since computers can make very fast decisions, they improve safety and transportation speed on the tube. Also, since computers are so consistent, they help the entire system run smoothly and timely.
- **Facts:**
  - Computers began to replace the programme machines in controlling the signal process in the 1970s. They are more adaptable and able to carry out a variety of tasks including analyzing data from trains and performing complex calculations.
  - Signals sent through the rails are picked up and analyzed by computers on the trains. This allows for driverless trains like the ones on the District Light Railway (DLR) that were introduced in 1987.
  - The use of computer processors allows for the communication-based train control that is the standard for railway in London.
- **Let guests hold the chip to feel how small and light it is.**
- **Compare the chip to the programme machine picture to see how much smaller the chip is, even though it is more powerful.**
- **Compare the chip to the picture of the old signalling computers. This shows how compact and efficient computer equiptment has gotten.**

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Tomorrow's Journeys Signal Flag Fact Sheet[1]

- The first form of signalling between the trains and the platforms involved having railway employees, known as signalmen, stand at the edge of the platform and use their arms to gesture to the train driver.
    - The only way to communicate between stations is to have a signalman travel from one station to the next.
- Trains operated on a timetable. The railway ahead of a station was assumed to be clear after a certain amount of time.
    - Amount of time it took before another train would be signalled on varied between stations
    - There was no way for signalmen to know if something happened to a train after it left the station. This led to the increased possibility of a collision.
- Signalmen soon started using flags instead of their arms for better visibility.
- In the early 1800's, different colours and flag positions would represent different messages for the train driver.
    - One arm/flag horizontally outstretched meant that the line was clear.[2]
    - One arm/flag raised vertically meant proceed with caution.
    - Both arms/flags raised vertically meant danger ahead or stop.
- Signalmen would switch to signal lanterns during the night time, following the same signalling standard.
- Signalmen would sometimes get distracted or leave their post, making this method of signalling very unreliable.
- Towers with large arms replaced the signalmen on platforms
    - These semaphores were mechanical and electrical, making them easier for the train driver to see, as well as more reliable.
- "Distant Signals" were placed between stations to let conductors know the state of the station down the line.
- The semaphores with mechanical arms we see today evolved from this flag notation.

[1] Some information taken from Mike Smith at http://myweb.tiscali.co.uk/gansg/3-sigs/sigs-1.htm
[2] Flag signals taken from Geoffrey Kichenside and Alan Williams in *Two Centuries of Railway Signalling.*

Tomorrow's Journeys Signal Lantern Fact Sheet[1]

- Signal lamps have been used since 1800's as a form of signalling along with flags.
- Originally, candles or whale oil was used to light these lanterns.
- In 1870, Paraffin (now known as kerosene) was invented and lanterns began using that as a fuel source
- Underground tunnels were too dark at times; drivers could not always see the signalmen's flags.
    - A light is much more visible in darkness.
- Lamps would be attached to the backs of trains so the next train would be aware.
- The lamps had different coloured lenses to give signals to the upcoming train.
    - Red meant caution and that the train was stopped.
    - Green meant proceed with caution.
    - White meant the train was moving and the path is all clear.
- Since the Paraffin burned so bright, they used a blue lens to produce a green light.
- Lamps would often blow out because of the wind or it would run out of fuel.
    - Long-lasting Paraffin lamps lasted eight days until needing to be refuelled.
- "Lamp Men" would go around to each train and stations to refill every lamp.
- The lamps were sometimes difficult to see if they were badly positioned.
- There was also a risk if the signalman or lamp men were not doing their job correctly.
- The lamps were mostly replaced by electric powered lights that were in fixed positions along the tube.
    - Paraffin lamps are still used today on some older lines and as emergency lighting.
- The multi-coloured lights evolved into the electric signal lights we see today in the tube.
- The maintenance and risk of failure is much lower on electric lighting.

[1] Information gathered from Mike Smith at http://myweb.tiscali.co.uk/gansg/3-sigs/sigs-1.htm

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Tomorrow's Journeys Programme Machine Fact Sheet[1]

- The programme machine was used to control the signalling of a train at specific points along the track.
    - First introduced in the late 1950's, it allowed for the automation of signal control and reduced the risk of accidents due to human error.
    - Used on the Victoria Line to implement the first automatic railway in 1968.
- Holes were punched into a roll of plastic to represent the timetable for the day.
    - If the schedule changed a new roll had to be made.
- As the roll is fed through the machine it will open and close electrical contacts which control the points and signals.
    - Each hole sends a signal to the train telling it, for example, to stop or to continue.
- A train passing over the track will trigger an electrical switch that will advance the roll through the machine.
    - When the machine reaches the end of a roll it will automatically rewind the roll.
- The programme machine was a big step towards the automation of the railway; however it still needed occasional maintenance and human attention.
    - Holes needed to be punched manually for each new schedule.
    - The paper could possibly get jammed or one of the mechanical parts could be broken.
- In case of an emergency the signals could be controlled manually.
    - When the programme machine starts over again it will continue to read off the timetable where it left off
- Still in use today, but is mostly replaced by computers and electrical equipment.
    - Computers are more reliable, no moving parts reduce the chance of something failing.
    - Much easier to maintain, the entire railway network could be stored and run in a single computer.

[1] Some information taken from http://www.squarewheels.org.uk/rly/programme-machine/

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Tomorrow's Journeys Microprocessor Fact Sheet

- Microprocessors, found inside computers, will receive, process, and send signals automatically.
- Computers began to replace the programme machine in the control of signals in the 1970s.
    - Computers were able to automatically perform the function of multiple devices, including the programme machine.
- Computers are much smaller and compact, more processing power in a smaller package.
    - Few moving parts make computer more reliable and less prone to failure.
    - Less maintenance is required keep the signal system running.
    - The entire train system moves faster because of the fast response time.
- Computers are reprogrammable and more versatile.
    - If there was a change to the track layout or schedule the computer code could be rewritten instead of changing the programme machine paper or redesigning and replacing the circuit of relays.
- Driverless trains were introduced on the District Light Railway (DLR) in 1987 using on-board computers.
    - The computer can control the speed, acceleration and deceleration as well as stop the train at stations.
    - Signals are sent through the rails by another computer that tell the train information about the condition of the rails.
- Computers are essential in implementing the moving block system.
    - In the fixed block system, the railway is broken up into equally sized blocks.
        - No more than one train can occupy a block at the same time.
        - This ensures that trains do not collide on the track by entering the block of another train.
    - In the moving block system, the blocks are moving along with the train.
        - This allows trains to get as close as possible to another train while still being safe. This allows trains to transport passengers more quickly.

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Tomorrow's Journeys Recommended Object List

Object 1: Signal Flag and Pictures

- Picture of signal flag arm positions:

Figure 1: Line Clear
One hand horizontally outstretched meant the line was clear

Figure 2: Caution
One hand raised vertically meant proceed with caution

Figure 3: Danger
Both hands raised vertically meant danger ahead or stop

- Duplicate of Flag: 1996/794
  - 
- And/or duplicate of flag: 1996/795
  - 
- Picture of semaphore arm signal: 1992/147
  - 

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Object 2: Signal Lantern and Picture

- Picture of electric signal light: 1993/54
  - 

One or more of the following objects:

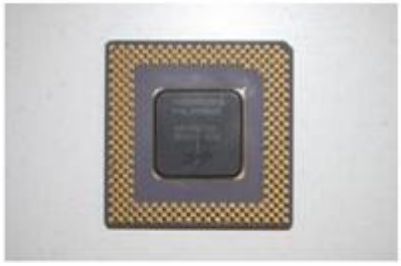
- Statutory Objects:
  - 2003/4024
    - 
  - 1995/2447
    - 

- Lamps in Handling Collection:
  - 2010/5278
  - 2010/5269

Object 3: Programme Machine Paper and Pictures

- Programme Machine Paper (Contact Caroline MacVay)
- Picture of a man using the programme machine: 1998/47724
  - 
- Picture of Programme Machine: 1998/87378
  - 

Object 4: Microprocessor Chip and Picture

- Duplicate of Microprocessor Chip: E01
  - 

- Picture of Control Monitors: 2011/3104
  - 

5.8. Appendix H – Engineering Narratives

Appendix H presents the engineering narratives developed during this project. These narratives focus on the history of engineering branches of Transport for London. The narratives, in the order presented in this Appendix, are titled: *Track Engineering, Electrical Engineering, Civil Engineering: Tunneling, Civil Engineering: Roads, Civil Engineering: Bridges, Buses & Trams,* and *Signaling Engineering*. Narratives cover the evolution of these areas of transport engineering in London from the Victorian Era to the present day, mirroring the topics and time period the London Transport Museum covers in its exhibits. The narratives include key engineering achievements of Transport for London, along with relevant pictures and objects from the museum's collections, to provide examples and contextual information LTM staff can use in educational sessions about transport history and engineering.

Engineering Histories & Achievements in London Transportation

Track Engineering

Track Engineering is the engineering of London's transportation railways, including train cars and rails. Under Transport for London, this comprises what is now the London Overground, London Underground (or Tube), and the Docklands Light Railway (DLR). These railways keep the economy and society of London running, and engineers are constantly looking for ways to make transportation faster, safer, and more reliable.

Early Successes & Inventions: Victorian Era & Early 20th Century (1863 - 1945)

Figure 1: Metropolitan Line Steam Train (1981/535)

National railroads have been present in London since the early 1800's, but the existing railroads were slow and dissatisfying to the city's population. Londoners required a fast, reliable method of transportation that connected major railways and provided transportation to London's business districts (London Transport Museum, 2013b). The Metropolitan Railway, created in 1864 for this purpose, was the world's first underground railroad. Since the railroad was tunnelled underground, it could cut straight through the city, avoiding traffic and minimizing travel times (Croome & Jackson, 1993). However, the train was steam powered and the tunnels were inundated in pollution and fumes. Most passengers had trouble breathing and described the railway as "a mild form of torture" (London Transport Museum, 2013c). Nonetheless, the rail did not defer passengers from riding once better ventilation was implemented.

In 1890 the City & South London Railway created the first deep-level tube line and electric railway (Transport for London, 2013b). Electric power, which requires no on-board fuel for the train and therefore no exhaust, is cleaner, safer, more efficient, and permits a smoother ride. The City & South London Railway used a three rail system to power the electric motors, two running rails and one to power the train (Elliott, 2012). Modern upgrades have expanded on this system: the Underground is currently one of the only major transportation networks to use a four rail system. From 1904 to 1924 many railroads around the world, including the Metro Railway, began gradually converting their trains to electric power (London Transport Museum, 2013a). With the electrification of trains, more safety measures began to be implemented. Originally, trains had manual door locks that had to be operated by train passengers. These

locks were unreliable and dangerous; there were many cases of locks failing and doors opening during the ride (London Transport Museum, 2013a). The invention of automated air-operated door locks in 1929 was one of the first major steps in making railroad transportation safer for the public (Transport for London, 2013b).

Modern Advancements (1930 - Present)

Moving into the modern era, London's transportation network aims to make transportation as quick, efficient, and as safe as possible. To accomplish this, the London transportation network began to become more standardized and more modernized. For example, signalling technology advanced, as signals could now be sent to and from the train electrically through the rails, enabling the trains to respond faster and more reliably (Lockyear, 1996). In addition, newer materials and better designs were being used on the rails and train cars. This led to many different train stocks to be developed over the years and to be used on various Tube lines.

The stock designs of trains became more sophisticated as engineers found more comfortable and efficient ways to transport passengers. Traditionally, all tube stocks were named after the year they were created, and the 1972, 1973, 1992, 1995, 1996, and 2009 stocks are running on the tube currently. These stocks are meant to run in the deep underground and are designed to fit the tunnels efficiently. Some notable tube stocks are the 1935, 1986, and 2009 stocks. In 1935 tube stocks, the electrical motor and equipment were compacted underneath the cab instead of taking up an entire cab, adding one more cab for the passengers. In 1986 stocks, the wheels of the train were made smaller, allowing the floor of the cab to be flat and for the doors to be placed anywhere in the cab (London Underground Limited, 2009). The most recent tube stock, the 2009 stock, was the first stock to move from pneumatic power to electric powered doors, as well as first stock to fully comply with the Rail Vehicle Accessibility Regulations to accommodate the colour blind and disabled (Transport for London, 2013a). Generally, the trend for tube stocks is to find more ways to make the train compact and safe, while accommodating and leaving as much room as possible for passengers.

To complement tube stocks, there are surface stocks, which are traditionally named after a letter. C, D, and S stock trains are still operating on the tube. A Stock trains had sliding doors controlled by a guard for safety and speed and had a more efficient seating plan to maximize space. This stock was updated to the C stock which had four wide doors on each side, the same number of seats per cab, and wider cabs to accommodate this. The D Stock was produced next, having four equally spaced doors on each side of the cab along with inward

sloping flat body sides that allowed for more room and easier door construction. Finally, the S7/S8 Stock was created and combined the best design components of previous stocks, having comfortable spacing, full air-conditioning, and regenerative braking (London Underground Limited, 2009). Now, the standard for future trains is the S-Stock and they are gradually replacing other stocks

New and better materials were being introduced in this modern era. The railway made the leap from steel trains to aluminium trains in 1952 when the first aluminium train, the R Stock, was opened on the District Line (Transport for London, 2013b). Aluminium was cheaper, more resistant to vibrations, and lighter than steel, allowing trains to be built more easily, travel more quickly, and give passengers a smoother ride. Instead of steel, rails with aluminium components were used for conductor rails because of their conductivity properties (Engineer 1, 2013). Concrete sleepers were being used in the Tube instead of wooden because of their strength and rigidity. Also, the underground began switching from Bullhead rails to flat-bottom rails because of their strength and durability (Engineer 3, 2013).

Figure 2: R-Stock aluminium train (1982/35)

In addition to material and stock advances, safety also improved and became more standardised in London transportation. In 1975 on the Northern line at Moorgate, a driver failed to break when entering the station and the train crashed into the end of the line, killing forty-three people. This led to the introduction of more safety measures to prevent another such accident from happening. Trains now automatically stop when entering a station, greatly reducing the chance of any crashes (Jenkins, 2009). To complement this, trains were also fitted with magnetic door locks and railway employees were better trained for emergencies in the future.

Moving Forward:

Because of the increasing demand for public transportation, engineers must find new ways to transport more people. To accomplish this, train lines are constantly being opened and extended to more parts of London until, eventually, all of London will be easily accessed through a train station. Transport for London is in the process of opening a new major railroad system known as Crossrail that will integrate the existing transportation network and directly connect all of London's main business centres. When opened in 2018, the Crossrail is estimated to increase London's railway capacity by an impressive 10 per cent (Crossrail, 2013).

References

Comfort, N. (2013). Strong backing for new Crossrail 2 route. *Today's Railways UK, 136*, 82.

Croome, D. F., & Jackson, A. A. (1993). *Rails Through the Clay* (2nd ed.). 38 Long Elmes, Harrow Weald, Middlesex, England: Capital Transport Publishing.

Crossrail. (2013). Benefits. 2013, from http://www.crossrail.co.uk/benefits/

Elliott, R. (2012). 3rd and 4th rail dimensions and settings. Retrieved 16 May, 2013, from http://homepage.ntlworld.com/russelliott/3rd-4th.html

Engineer 1. (7 May 2013). [Engineering Interviews].

Engineer 3. (21 May 2013). [Engineering Interviews].

Jenkins, J. (Producer). (2009). The 1975 Moorgate tube disaster. *In Living Memory*. Retrieved from http://www.bbc.co.uk/iplayer/episode/b00p2hy4/In_Living_Memory_Series_11_The_1975_Moorgate_tube_disaster/

Lockyear, M. J. (1996). Changing track: moving-block railway signalling. *IEE review, 42*(1), 21. http://au4sb9ax7m.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info%3Aofi%2Fenc%3AUTF-8&rfr_id=info:sid/summon.serialssolutions.com&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.genre=article&rft.atitle=Changing+track%3A+moving-block+railway+signalling&rft.jtitle=IEE+Review&rft.au=Lockyear%2C+M.J&rft.date=1996&rft.issn=0953-5683&rft.volume=42&rft.issue=1&rft.spage=21&rft_id=info:doi/10.1049%2Fir%3A19960110&rft.externalDBID=n%2Fa&rft.externalDocID=10_1049_ir_19960110¶mdict=en-US

London Transport Museum. (2013a). From the City to the Country: Metropolitan Railway Coach. London Transport Museum, Covent Garden Piazza, London WC2E 7BB.

London Transport Museum. (2013b). Steam Underground 1863-1905. London Transport Museum, Covent Garden Piazza, London WC2E 7BB.

London Transport Museum. (2013c). World's First Underground Railway: Metropolitan Railway Steam Locomotive. London Transport Museum, Covent Garden Piazza, London WC2E 7BB.

London Underground Limited. (2009). *Passenger Rolling Stock* R. M. Shemlit (Ed.) (pp. 132).

Transport for London. (2013a). 2009. Retrieved 30 May, 2013, from http://www.tfl.gov.uk/corporate/modesoftransport/londonunderground/rollingstock/1620.aspx

Transport for London. (2013b). Milestones. Retrieved May 13, 2013, from http://www.tfl.gov.uk/corporate/modesoftransport/londonunderground/history/1606.aspx

Engineering Histories & Achievements in London Transportation

Electrical Engineering

Electrical Engineering includes any transportation that runs on or uses electric power, as well as how that power is supplied. Under Transport for London, this includes the London Overground, London Underground (Or Tube), the District Light Railway (DLR), the Tramlink, and more recently, London's buses. Electric power is the desired power supply of the future because it is cheap, clean, and efficient. Many transportation networks, including London's, are working to become fully electrified and as efficient as possible.

Early Successes & Inventions: The Introduction of the Electric Railway (1890 – 1945):

Until 1890, London's rail transportation relied on steam power to run its trains. Steam power was acceptable for overground rail transportation, but in the underground it posed a large problem. The enclosed underground area kept most of the smoke in, making it very unpleasant and harmful for passengers to ride (London Transport Museum, 2013b). In 1890, the City & South London Railway solved this problem when it opened as the first deep-level electric train (Transport for London, 2013). Electric trains are much cleaner, faster, and cheaper when compared to steam powered trains. Now passengers could ride underground without the burden of smoke. The electric railway was powered by a power station at Stockwell that used steam power to provide electricity to the rails. Many power stations, including the Stockwell plant, quickly figured out that they couldn't provide nearly enough power for multiple trains, so these stations had to expand their capacity. The Lots Road power station at Chelsea became the largest power plant in Europe and supplied power to the entire network of London trains (London Transport Museum, 2013a). Even so, that plant also had to expand, and the problem of not being able to supply enough power to the train network became a common challenge for London's electrical engineers as the transportation network grew.

Figure 1: Electric powered motor from a City & South London Railway train. (1996/4695).
Manufactured by Crompton 1899/1900

Most overground electrified rail systems of the time used an overhead electrified line to power the train. This required building guidelines throughout the path of the railway and hanging electrified wires from them. The train had a conductive arm that would touch the wires

and supply power to the rest of the train from it (American Railway Engineering and Maintanence-of-way Association, 2003). However, since the City & South London Railway was underground, engineers needed a method that was much easier to construct, smaller to make the tunnels as compact as possible, and safer to avoid accidents. To fulfil these requirements, the City & South London Railway ran on what is known as the three rail system. The wheels of the train rode on the two "running rails" and the electric motor received its power from a contact plate touching a third rail, or the "conductor rail" (Elliott, 2012). This third rail was easy to construct, was much safer than hanging overhead lines, and was compact since it lay underneath the train along with the two running rails. As time passed, the London Underground found even better ways to power their railways.

Modern Innovations: Electrical Standardization (1945 - Present):

Today London transportation uses a variety of methods to power their transportation networks. The London Overground uses a mix of overhead wire and third rail systems, the DLR uses a third rail system, the Tramlink uses overhead wires, and even London's buses are converting to a hybrid half-electric system (Engineer 1, 2013). The London Underground has since converted from third rail technology and is now one of the few railway networks to use the four rail system. The four rail system, like the third, has two running rails and a conductor rail. However, a fourth rail is added that allows a return current to flow through it. Essentially, in the three rail system, since all of the current was through a single rail, the return current would jump to train or track parts and then dissipate into the ground. This could cause electric corrosion of those parts (Elliott, 2012). With a fourth rail, the return current would safely flow, causing less damage to the railway system.

Today as the capability of engineers to provide more electric power increases, more electrical advances are possible. Where, in the past, new technology was limited by the amount of power that could be provided to the train, now trains receive all of the power they need. When the London transportation network switched from self-providing power stations to receiving power from the National Grid in the mid-20th, railway limitations were pushed (London Transport Museum, 2013a). Now, the network could provide much more power to their many trains in a much cheaper and more efficient way than expanding their power stations.

Now with much more power available, railways began to improve their trains. Safety was always a major concern throughout the development of the railway, and now with electric powered doors, magnetic locks, and advanced signalling techniques there is a significantly lower chance of doors opening unexpectedly or similar incidents occurring. In addition, as a

safety feature, all trains were equipped with battery backups that could power essential functions until the train reached the next station (London Underground Limited, 2009). Today there is not only a positive trend in efficiency and safety on trains, but also in passenger luxury. Lighting on trains has improved now that they are electric and not powered by gas, as in most trains in the past. The trains pull the power from the conductor rail by a conductive plate riding underneath the train. In 2010, the first fully air-conditioned train, the S-Stock, opened on the Metropolitan Line. These trains also took power from the conductor rails to power the air conditioning when needed (London Underground Limited, 2009). Since then, air-conditioning became the standard for new trains and future S-Stock models.

Now that the transportation network has all of the power it could possibly want, it is looking for ways to increase the efficiency of this power and to save money. In order to do this, engineers have started making rails with more conductive materials, such as aluminium. Aluminium core rails were chosen to be used as the third and fourth rails to replace the older steel rails because of their conductivity properties (Engineer 1, 2013). More conductivity means less power lost during transit, which means less money spent on power. In addition, engineers have found ways of recycling or reusing electric power that is lost while the train brakes. The concept of regenerative braking was introduced in the modern era as a way to capture the energy usually turned into heat when braking, and convert it back into electric energy. This electric energy is now sent through rails to any other trail that is in the same tracks. It is not a perfect transfer, and some energy is still lost to heat, still, this concept conserves a large amount of energy (Engineer 1, 2013).

Figure 2: Cross section of an aluminium core railway track (T06). The darker grey part is made out of stainless steel while the rest is aluminium. This rail uses the high conductivity of aluminium to avoid large power losses and the durability of stainless steel to withstand constant wear from the train. When the steel is worn out, it can easily be replaced without removing the entire rail.

Futures in Engineering: Power Efficiency:

As we move forward, engineers are still trying to find more ways to make power consumption more efficient. More conductive materials than aluminium such as silver or copper could be used on tracks. They aren't used now because they are very expensive materials, but it may be possible at some point in the future. Also, it is possible to make regenerative braking more efficient. Currently, there is no conventional method of storing the electrical energy braking converts. If there is no other train on the track or no other train needs the electricity, then the electricity is dissipated and it would be as if there was no regenerative braking at all.

With a storage method, this electrical energy could be sent out to trains at will without the need to buy extra power from the National Grid.

Transport for London is committed to making the entire network electricity dependent and efficient. Passengers will have a smooth, quick, and clean ride to their destinations. As time goes on, London's transportation network will continue to expand as engineers find new and better ways to save and reuse power, as well as to satisfy the massive demand for transportation.

References

American Railway Engineering and Maintanence-of-way Association. (2003). Railway Electrification. *Practical Guide to Railway Engineering* (9), 7.

Elliott, R. (2012). 3rd and 4th rail dimensions and settings. Retrieved 16 May, 2013, from http://homepage.ntlworld.com/russelliott/3rd-4th.html

Engineer 1. (7 May 2013). [Engineering Interviews].

London Transport Museum. (2013a). Engineering Wondors (pp. 8).

London Transport Museum. (2013b). Providing the Power. London Transport Museum.

London Underground Limited. (2009). *Passenger Rolling Stock* R. M. Shemlit (Ed.) (pp. 132).

Transport for London. (2013). Milestones. Retrieved May 13, 2013, from http://www.tfl.gov.uk/corporate/modesoftransport/londonunderground/history/1606.aspx

Engineering Histories & Achievements in London Transport

Civil Engineering: Tunnelling

Civil engineering, which deals with the design and construction of infrastructure like roads, bridges, and buildings (American Society of Civil Engineers, 2006) plays a large role in London's transportation systems, particularly in tunnelling the Underground. The London Underground has been the setting for many major innovations in Civil engineering.

Early Successes & Inventions: Tunnel Shields & Other Tunnelling Methods (1817-1890)

Early attempts to tunnel beneath the Thames were done to ease traffic congestion across the river, but tunnelling under the river was risky. Tunnel walls were at constant risk of collapsing under pressure, flooding the tunnel – the fate of the first tunnel under the Thames in 1817, which was never completed (Sandstrom, 1963, p. 209).

Civil engineer Marc Brunel, who constructed the Thames Tunnel in 1825, solved this problem by developing the first tunnelling shield, made to protect workers as they excavated and built tunnel walls. The rectangular shield was sectioned into 12 cast-iron cells – each containing one worker – that could be jacked forward in centimetre increments as workers dug deeper. This shielding provided the structural support to withstand the pressures on the tunnel walls, and Brunel completed the tunnel in 1843, despite numerous accidents and financial setbacks (Clayton, 2010, pp. 109 - 112).

The tunnelling shield proved to be a major achievement in civil engineering, and continued to evolve. Peter William Barlow and his apprentice, James Henry Greathead, used an improved, cast-iron cylindrical tunnel shield to construct the second Thames tunnel, the Tower Subway. By pushing the shield forward incrementally on hydraulic jacks, and while simultaneously lining the tunnel behind it in cast-iron segments (rather than the traditional masonry used by Brunel), workers built the tunnel in less than five months, without incident. Barlow and Greathead's tunnel shield emerged as a standard of tunnelling technology for decades (Sandstrom, 1963, pp. 216 - 218).

The construction of the Metropolitan Railway (between 1854 and 1863) was a monumental engineering achievement: the world's first underground railway (Clayton, 2010, p. 158). The railway was constructed using the "cut and cover" method: excavating a deep trench in which the rail line, covered with brick walls and roofing, was constructed and buried. This approach caused disarray and damage in communities surrounding the construction (pp. 161 - 164), but it was effective, and later used to construct the District and Circle lines (p. 170).

Figure 1 (Left): Cast-Iron Tunnel Lining (1999/4235)

Figure 2 (right): Thames Tunnel Brick Tile (1998/12099)

Brick tiles would have been used to line, and support, the Thames Tunnel in 1825.

By 1890, cast-iron lining segments, assembled to form a very strong, self-supporting circular ring that could forces of surrounding earth, were the norm in tunnel engineering.

Another major civil engineering achievement of the era was the development of the City & South London Railway (opened in 1890), the first of the "tube" railways (p. 175), and the first electrically powered railway. Tunnel shields were again used, this time under the direction of James Henry Greathead. Workers used his cylindrical tunnel shields to burrow deep underground, avoiding surface damage. It was a triumph for London transportation and Greathead, who had successfully used tunnel shield technology to build the first railway that ran entirely underground (Croome & Jackson, 1993, pp. 14 - 15).

Modern Innovations: Growth of the Underground (1905-1969)

The dawn of the 20th century saw much growth on the Tube. The District and Circle lines were electrified in 1905, and several extensions to the Underground were made, including the Baker Street & Waterloo Railway in 1906, and the Charing Cross, Euston & Hampstead Railway (built in 1907 and now part of the Northern Line) (Transport for London, 2013).

During World War II, the Underground tunnels served as air raid shelters for British civilians. Due to Britain's focus on the war effort, London did not see many tunnelling projects during the war years; the next major one would come nearly 20 years later, with the development of the Victoria Line. Constructed between 1964-1966, the Victoria Line project was a challenging operation, owing to the maze of subway tubes and existing infrastructure installed in the 60 years since the last major tube constructions (Clayton, 2010, p. 199). To navigate this underground labyrinth, an advanced tunnelling method was needed; the answer was in "drum diggers," huge tunnelling machines capable of excavating 400ft per week, and equipped with large, rotating drill mechanisms. Greathead tunnel shields were still used, their presence a century after their invention a testament to the efficiency of the technology (Croome & Jackson, 1993, pp. 330 - 331). Similar mechanical tunnelling machines and methods would be used to construct the Jubilee Line (1979), and Tube extensions in later years (Transport for London, 2013).

Futures in Engineering: Crossrail & High-Tech Tunnelling (2001 – present)

Crossrail is a major engineering project underway by Transport for London to develop a new subway line through London, boasting 21km of new tunnel and 118km of track from Maidenhead and Heathrow in the west, to Shenfield and Abbey Wood in the east (Crossrail, 2013b). It will connect with existing lines along its route, with the intention of easing transport congestion (Crossrail, 2013a).

Crossrail construction presents several challenges: tunnels must navigate London's congested underground and burrow through varied terrain, including clay, sand and gravel, and chalk under the Thames (Crossrail, 2013d). The project must also counteract subsidence, or ground settlement on the surface due to tunnelling, which is damaging to buildings (Crossrail, 2013c). The methods devised to face these problems are among London transportation's most impressive engineering achievements.

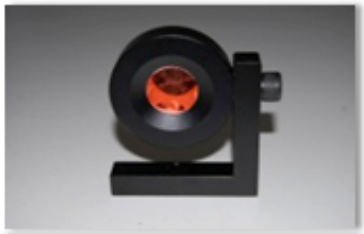


Figure 2: Retroreflector (Artefact Library: C06)

Retroreflectors are used to precisely detect distances by reflecting a laser off the reflecting centre. These can detect even subtle ground settlement from underground construction, avoiding property damage.

Tunnel Boring Machines, or TBMs, are 1000 tonne, 148m-long machines custom-built to excavate the Crossrail tunnels. The fronts of these machines are giant, cylindrical cutter heads – specially designed to tunnel through specific terrain types and capable of the ultra-precise (within a millimetre) excavation needed to navigate London's crowded underground. Managed by 12 workers working inside the TBM and 8 others managing the rear of the machine above the ground, TBMs are operated continuously to reduce the likelihood of ground settlement.

As TBMs excavate, tunnel walls are immediately lined with pre-built sections of reinforced concrete (Crossrail, 2013d). Where TBMs are not used, another innovation is put to work in the construction of the Crossrail route: spray concrete. Spray concrete lining rapidly strengthens and stabilizes tunnels, allowing for variation in shape and diameter to facilitate the construction of station tunnels (Munsi, 2012).

Crossrail is due to be completed in 2018, and tunnelling in London has a bright future: there is already strong backing for expansion of these tunnels, including a new Crossrail line in discussions to be built in the 2020s, soon after Crossrail's anticipated opening (Comfort, 2013, p. 10). As technology improves, the world can look forward to this tunnel line, and much more ambitious projects, being produced. Indeed, some engineers have drawn up ideas for a tunnel beneath the Atlantic Ocean, to connect North America and Europe – an idea that might be the envy of Marc Brunel, were he alive today (Rodman, 2002).

References

American Society of Civil Engineers. (2006). History and Heritage of Civil Engineering. Retrieved 13 May, 2013, from http://live.asce.org/hh/index.mxml?versionChecked=true

Clayton, A. (2010). *Subterrainean City: Beneath the Streets of London*. 32 Ellington Street, London: Historical Publications Ltd.

Comfort, N. (2013). Strong backing for new Crossrail 2 route. *Today's Railways UK, 136*, 82.

Croome, D. F., & Jackson, A. A. (1993). *Rails Through the Clay* (2nd ed.). 38 Long Elmes, Harrow Weald, Middlesex, England: Capital Transport Publishing.

Crossrail. (2013a). A World-Class New Railway for London and the South-East. Retrieved 13 May, 2013, from http://www.crossrail.co.uk/benefits/

Crossrail. (2013b). Benefits. 2013, from http://www.crossrail.co.uk/benefits/

Crossrail. (2013c). Ground Settlement: Managing the Effects of Tunnelling. Retrieved 13 May, 2013, from http://www.crossrail.co.uk/construction/managing-the-effects-of-construction/ground-settlement-managing-the-effects-of-tunnelling

Crossrail. (2013d). Meet Our Giant Tunnelling Machines. Retrieved 13 May, 2013, from http://www.crossrail.co.uk/construction/tunnelling/meet-our-giant-tunnelling-machines

Munsi, A. (2012). Crossrail's First Spray Concrete Lined Tunnels Completed Under Finsbury Circus. Retrieved 15 May, 2013, from http://www.crossrail.co.uk/news/articles/crossrails-first-spray-concrete-lined-tunnels-completed-under-finsbury-circus

Rodman, M. (2002). Tunnel Vision. Retrieved 15 May, 2013, from http://www.law.harvard.edu/news/bulletin/2002/summer/bf_04.html

Sandstrom, G. E. (1963). *The History of Tunnelling*. 2 Clement's Inn, London: Barrie Books, Ltd.

Transport for London. (2013). Milestones. Retrieved May 13, 2013, from http://www.tfl.gov.uk/corporate/modesoftransport/londonunderground/history/1606.aspx

Engineering Histories & Achievements in London Transportation

Civil Engineering: Roads

To explore the whole history of roads in London, it would be necessary to look back, far before the establishment of Transport for London, to the original organized roads built by the Romans, (Paterson, 1927, p. 18) or even *further* back to the Ancient Britons and their first trade routes (1927, p. 8)! London has a rich history of civil engineering advancements, and road services have adapted to meet the demands of a growing population and changing transportation systems.

Early Successes & Inventions: Accommodating Changing Traffic (1816 – 1903):

Roads are a vital component of any society, but those in England at the opening of the 19th century had not seen many major technical improvements for several hundred years. Roads were typically dirt or gravel, susceptible to the weather (mud was cumbersome to traffic), and could not support the growing traffic of the emerging 19th century (Earle, 1971, pp. 2 - 3). Change came between 1801 and 1835 (Davies, 1960, p. 286) with the development of macadam roads, crushed granite moulded together with water and mud to produce a durable, relatively waterproof road surface that could support the high volumes of traffic on main roads (Paterson, 1927, pp. 27 - 28).

Roads continued to evolve according to the traffic that utilised them. By 1870, the iron bicycle was a popular mode of travel, but was difficult to manoeuvre on bumpy macadam roads, earning the unfortunate nickname "boneshaker" (1927, p. 54). But bicycle demand continued to grow through the 1880s and 1890s, and demand for better roads with it (Earle, 1971, p. 5). By the opening of the 20th century, which brought about a boom in motorcars and bicycle use, the roads were in dire condition, and dust from traffic was reaching intolerable levels. Additionally, the heavy motorcars caused considerable wear on roads (Paterson, 1927, p. 94). Road engineers found a solution in 1903: supplementing macadam roads by laying them with tar instead of mud, producing "tarmacadam" or tarmac, a reliable, largely dust-free road material that could withstand heavy traffic (Earle, 1971, p. 94).

Modern Innovations: Traffic Engineering (1903 – present):

The age of the automobile brought entirely new challenges for road development and the management of traffic. Roads built for the days of horse traffic, still vital to the infrastructure of London, had to accommodate the demand of mass-produced motorcars

(Davies, 1960, p. 5). Unfortunately, during World War II and in the years directly after it, few improvements or additions were made to London's roads. The challenge, then, became fitting traffic to accommodate the infrastructure that was already available (1960, pp. 8 - 9).

To address these concerns, a whole new subfield of civil engineering, traffic engineering, was developed. The function of traffic engineering is, as defined in Ernest Davies' *Roads and Their Traffic*, "to fit the roads to traffic by planning and design, and the traffic to the roads by regulation and control, in order to maintain maximum capacity with safety" (1960, p. 10). London Transport traffic engineers, from the 1950s to the present day, have undertaken numerous improvements to the roads in London.

Figure 1: Traffic Signal Controller (2001/53630)

This controller, circa 1955, would have held the machinery that ran a street traffic signal.

Engineers focused on how to organize and plan routes and intersections, greatly improving traffic efficiency. To facilitate safe, structured use of roads, traffic-control devices were installed, such as signs, traffic signals, road markings, and parking meters (to discourage car use in high-traffic areas) (1960, pp. 20 - 24). Traffic engineers of the 20th century focused on making the streets of London safer, accessible, and organized for the growing number of pedestrians, cyclists, motorists, and public transport users travelling on the roads every day.

London has seen several updates to its roads and traffic control in recent years. One high-profile initiative undertaken by TfL has been the implementation of a congestion charge in high-traffic areas, which began in 2003: vehicles detected by cameras are charged a fee for driving within the centremost (and busiest) part of London, the Inner Ring Road, to discourage traffic. By doing so, TfL hopes to reduce congestion and journey times, and encourage public transport use (Transport for London, 2003).

Figure 2: Traffic Signal (2010/9207)

Traffic signals are a normal sight in daily life, and it is easy to overlook their importance in traffic control and safety.

In 2006, road materials received an upgrade when high-traffic routes were coated with a chemical preservative, commercially dubbed "rhinophalt," that works just as wood treatments do: it slows the aging, damage, and decay of the roads in order to extend times between repairs (Godber, 2006). More recently, in 2011, TfL engineers employed safety

initiatives to make roads safer for the growing number of cyclists in London, by fitting blind-spot mirrors and detection equipment on the road (Pilgrim, 2011).

Futures in Engineering: Automation on (and in) the Roads (2000 - on):

As the streets of London become more congested, traffic control devices are adapting to meet the new demands. City traffic is now operates under an integrated, computerized network: monitoring equipment and CC-TV relays information directly to TfL Surface Transport staff, who can control traffic lights and signals remotely and make the split-second decisions needed to keep traffic moving in the event of accidents or repair work (Engineer 4, 2013).

One particularly innovative technology TfL has recently begun using is SCOOT, or Split Cycle Offset Optimisation Technique, a programme of made up of sensors embedded into the road that detect the level of traffic and adjust traffic signal timings to make traffic flow more efficient and reliable. Since installing SCOOT, TfL has already seen 12.7% reduction in delays for vehicles travelling on London roads (Transport for London, 2012).

The future is bright for adaptive computerized technology in the roadways. TfL is actively upgrading SCOOT technology: traffic engineers hope to improve SCOOT reliability by going wireless, to avoid issues caused by damaged or malfunctioning wires (Engineer 4, 2013). In addition, engineers are working to upgrade the system to detect and respond to changes in pedestrian and bicycle traffic, vastly improving safety and travel times for Londoners not using automobiles (Transport for London, 2012).

References:

Davies, E. (Ed.). (1960). *Roads and Their Traffic*. London, England: Blackie & Son Limited.

Earle, J. B. F. (1971). *A Century of Road Materials*. London, England: Wiley-Blackwell.

Engineer 4 (2013, 31 May 2013). [Engineering Interview].

Godber, N. (2006). Capital's roads tough as Rhino skin. Retrieved 24 May, 2013, from http://source.tfl/News/SurfaceNews/4296.aspx

Paterson, J. (1927). *The History and Development of Road Transport*. London, England: Sir Isaac Pitman & Sons, Ltd.

Pilgrim, D. (2011). Making London's streets safer for cyclists. Retrieved 24 May, 2013, from http://source.tfl/News/SurfaceNews/12725.aspx

Transport for London. (2003). Congestion Charging 6 months on.

Transport for London. (2012). Mayor announces innovative technology is helping traffic flow more smoothly and cut disruption. Retrieved 24 May, 2013, from http://www.tfl.gov.uk/corporate/media/newscentre/archive/23061.aspx

Engineering Histories & Achievements in London Transportation

Civil Engineering: Bridges

Early Successes & Inventions: The One Bridge (AD 50 –1729):

During the second Roman invasion, the aggressors decided to build a bridge across the Thames rather than continue to ford it as they has done a hundred years earlier. They had plans to stay at the site which had just been developed by the Britons as a trading hub, and a bridge would help them. The bridge was wooden and of pontoon style; in other words, it was a very long raft that floated upon the water, secured at either side. This was the humble beginnings of bridges in London (Timelines, 2013a).

In the many centuries that followed, this same bridge was destroyed, whether by invaders or natural effects, and rebuilt over and over (Davenport, 2006, p. 36). There are few specific historical mentions of the bridge as far as design is concerned, and we know nothing of it between the 7th and 9th centuries. But we can be fairly certain that little changed (Timelines, 2013a).

In 1176, Henry II ordered a stone bridge to be built, in response to the increasing number of fires seriously damaging the wooden bridge incurring many expenses for rebuilding. Construction began, and 20 timber piers, or starlings, were placed down. The builders placed them on high points on the river floor, and as such, were very irregularly spaced. The starlings themselves were designed in a shape pointing upstream that would allow the water to flow around it without eroding. 19 stone arches were placed on top of those, making up the main body of the bridge. Due to poor financing partly because of the crusades, it took 33 years to complete (Timelines, 2013c).

Figure 1: Medieval London Bridge

The long-standing London Bridge with the buildings that helped finance it

Perhaps the most striking part of the bridge was the buildings on top of it. King John had the idea to rent out space on the bridge for shops and dwellings to add revenue. This was in addition to the three gatehouses, a chapel, and the drawbridge. Nearly 200 buildings were atop the bridge by the 14th century, and with the arrival of the horse and carriage later, this caused a massive amount of traffic that would not be mended until the 18th century (Davenport, 2006, p. 37). It was at this point, in 1722, that the Lord Mayor had decreed

that horse-drawn traffic keep to the left of oncoming traffic. This was not enough, and around 1760, all the buildings were demolished (Timelines, 2013c).

Another issue caused by the bridge was the massive currents created between starlings. These were hazards to boat drivers, and no small number of the vessels that braved the rapids were lost. Passengers would often disembark the boat above the bridge and meet them downstream if it had made it. This issue was not addressed until the bridge's replacement (Timelines, 2013c).

Modern Innovations: An Evolution of Materials (1816 –present):

One bridge suited London just fine for quite some time. There was little need of them before horse-drawn vehicles became common. Businesses in trade and ferrying benefited greatly from the lack of them. As time went on, these factors lessened in the face of more traffic, and more and more bridges were built, the business exploding in the second half of the nineteenth century (Timelines, 2013a).

A few more stone bridges were built in the eighteenth century, but in 1816, the first iron bridge across the river was completed. This was known as Regent Bridge initially, but renamed to Vauxhall Bridge. This was the predecessor to the current bridge of the same name. Thanks to the industrial revolution, the iron bridge was cheaper than a stone bridge. The iron used was cast iron, meaning liquid iron was poured into moulds, one for each part of the bridge.

One of the more impressive and certainly the most recognisable of London's river crossings is Tower Bridge. Due to development in the East End, it became obvious a crossing there was required. However, if built, it could cut off access of the port facilities to ships, so it required a drawbridge. A competition was held, and over 50 designs were submitted. In the end, the design submitted by one of the judges of the competition was chosen (Davenport, 2006).

Figure 2: Constructing Tower Bridge

Photograph of the bridge under construction, showing the iron frame

Construction of Tower Bridge began in 1886 with two 35,000 ton concrete piers as the main supports under where the towers would be. Steel was becoming cheaper to make due to advancements in the field of metallurgy and was much stronger than iron. 11,000 tons of it was put on top of the piers as the framework for the span and towers. Steam engines were installed that would run the hydraulic system to lift the massive drawbridge. The water that was used in the system was pressurised to 750 pounds per square inch, or about 50 times atmospheric

pressure. Today, a hydraulic system is still used, but the liquid is oil, rather than water. Cornish granite and Portland stone covers the steel frame. Work was completed in 1894 (Timelines, 2013b).

A big leap in bridge materials occurred in 1960 with the construction of the Hammersmith Flyover. This does not cross the river or another water body, but is still important in engineering. This is because it was one of the first bridge structures to be built with prestressed concrete. There are two kinds of prestressed concrete, and the original type used was pre-tensioned. This meant that steel cables are pulled taut by hydraulic jacks, concrete is poured around it, and as it hardens, the tension is loosened. This pushes the concrete together, making it stronger and better able to hold a load. In addition to this advancement, the flyover also has a heating system in it that would deter ice formation (Brady, 2013; Engineer 4, 2013).

It was discovered in 2011 that the flyover was deteriorating and TfL said that there was a remote possibility of collapse. This was likely due to the salt used in the winter corroding the steel cables. In early 2012 repairs began using post-tensioned concrete, which differed from pre-tensioned in that the taut cable was introduced after pouring the concrete. Both methods are still used, one being better than the other on a case-by-case basis (Engineer 4, 2013).

Figure 3: Post-Tensioning Cable

Cable that was used in the repair of the Hammersmith Flyover (C02)

A recent feat of engineering in London's bridges was the aptly named Millennium Bridge. Like other London engineering projects, it was again a competition. The winning design was a suspension bridge that had the supporting cables underneath the main body, pulling tight to either river bank (Davenport, 2006, p. 46). This interesting design allowed for unobstructed views from the bridge and minimal need for piers in water. Unfortunately, when it opened on 10 June 2000, there was a problem. The bridge naturally swayed back and forth slightly, which itself wasn't an issue, but the fact that it is a footbridge multiplied the sway. This is due to the phenomenon that people unconsciously step in time with the sway, moving their weight with the bridge and adding to the movement. It was shut down to fix the problem by using dampers that reduce oscillation, like how shock absorbers smoothen a ride in a car (Davenport, 2006, p. 47).

Futures in Engineering: Bridging the Future (present-):

Bridges will always need to be built and replaced as city infrastructure grows. And as they have in the past, the bridges of the future will continue to become more advanced. Science is always discovering new materials, and in the future we are likely to see one of them become a new bridge material, just as we advanced from wood to stone to iron to steel and prestressed concrete. Better designs will be introduced, as computers become more and more powerful and simulations more accurate. In general, bridges will become lighter in weight and have a longer distance between supports to minimize pier building in water. In addition, they will continue to get better designs that are more artistic and pleasing to the eye.

References

Davenport, N. (2006). *Thames Bridges: From Dartford to the Source*: Silver Link Publishing Ltd.

Engineer 4. (31 May 2013). [Engineering Interviews].

Engineering Timelines. (2013a). Infrastructure is Destiny. *The Bridges of London*. Retrieved 23 May, 2013, from http://www.engineering-timelines.com/why/bridgesOfLondon/bridgesLondon_02.asp

Engineering Timelines. (2013b). More Bridges at Last. *The Bridges of London*. Retrieved 23 May, 2013, from http://www.engineering-timelines.com/why/bridgesOfLondon/bridgesLondon_08.asp

Engineering Timelines. (2013c). Old London Bridge. *The Bridges of London*. Retrieved 23 May, 2013, from http://www.engineering-timelines.com/why/bridgesOfLondon/bridgesLondon_06.asp

Engineering Histories & Achievements in London Transportation

Omnibuses, Trams, and Buses

Omnibuses, trams, and buses refer to the vehicles that travel along a fixed route on London's streets with capacity for more than a few individuals. As of 2013, Transport for London has 7,500 buses that transport 6 million passengers through 19,500 stops on over 650 routes each weekday. In addition to the massive importance to London infrastructure, the red, double-decker bus is a symbol of the city and is recognised globally. Tram service in south London under the name Tramlink serves 71,000 daily through 39 stations.

Early Successes & Inventions: The Power of Horses (1829 – c.1900):

The Omnibus began in London in 1829, when George Shillibeer imitated the Paris mode implemented the year before. It was a carriage drawn by three horses on a fixed route. While the vehicle couldn't take passengers everywhere, they could take different parties at the same time. This was more efficient than coaches, and fares were lower as a result. More individuals followed Shillibeer and within the next decade the streets were full of buses of varying routes and fares. This became confusing and made a jumble of the streets, which led to a license system that required each vehicle to be registered with the government. But the increasingly populous and relatively cheap transport system began to expand the city into the countryside, as commuting became a more commonplace concept (Sommerfield, 1933, p. 7).

Figure 1: Tilling Knifeboard Bus

One of Thomas Tilling's buses from c1875 (1981/525)

In 1850, the first seats were put on the roofs of the vehicles, creating the first double decker – the Tilling Knifeboard Bus. The benches were back to back facing the sides of the vehicle in what was called a 'knifeboard' pattern. This was originally illegal because the vehicle carried more than it was licensed for, but having the extra space proved a boon, and the law was quickly changed. From this point forward, the double decker was a staple of London transport (Sommerfield, 1933, p. 9).

Engineers always look for ways to make any process more efficient, and this was no different in the case of transport. Wheels traveling over the bumpy and uneven roads of the time required more energy from the horses than if they travelled over a perfectly smooth surface. As a result, horses needed to be changed more often than was ideal and had to be fed more often. Since these buses travelled on a set path, a parallel was drawn to locomotives, and some buses were put on rails to make the first London trams. The first rails sat above ground in the streets in the late 1860s, but these were quickly replaced by flush, grooved tracks. This did prove better, as more passengers could be carried at a time on larger vehicles with no more strain put on the horses (Collins, 2001, p. 11).

Figure 2: Tram Rail

Slices of tram rail. All of this would be underground, so the top would be flush with the road (1995/2590)

Thus, the price of transport was driven down again by innovation and access to it was more open to the lower classes than ever. Because of their cheap rates, trams became associated with the poor and in 1872, a short time after trams made their first appearances, a law was passed to keep this mode out of central London (Collins, 2001, p. 11). By the 1880s, typical trams carried 46 passengers and were laterally symmetrical so that when the end of a line was reached, the horses were hitched to the opposite end for the journey back (London Transport Museum exhibit).

Modern Innovations: The Power of Engines (c.1900 – c.2010):

The advent of the automobile was a huge innovation in transport and it was only a matter of time before London's buses received an upgrade. In the first decade of the twentieth century, several manufacturers experimented with electric and petrol engines to power their large vehicles. After failures and retooling, mechanically driven buses and trams such as the B-type bus came to dominate the streets over horses, and on 25 October 1911, the last horse-drawn bus under the London General Omnibus Company went on its final journey. Petrol engines became the driving force behind buses (Sommerfield, 1933, p. 62), while electric engines were installed in trams, powered by overhead electric cables (Collins, 2001, p. 18).

In the following decades, more improvements were made to the bus and the system. Automobiles became more and more common, and so more people became knowledgeable

about engines. Advances in the bus engine naturally followed those in the car engine, such as a self-starter, so that the operator didn't have to crank the motor himself to get it to run under its own power (Christopher, 2009, p. 47).

The twenties saw the addition of air-filled tires for a much smoother ride and a low centre of gravity that allowed for a roof above the second deck seats. Both these were implemented in the NS-type bus. In 1935 the first fixed bus stops were installed (Christopher, 2009, p. 47).

It was in 1954, after many years of designing and prototyping, that the bus that defined and symbolised London transportation was introduced - the Routemaster. This series of similar models, usually seating between 64 and 72, introduced many new improvements and standardised others. These included a lightweight aluminium alloy frame, which reduced the load on engines; interchangeable body parts, making mechanic service time shorter and saved on manufacturing; power steering, which greatly reduced the effort on the drivers' part, since they no longer had to put in the energy to actually turn the wheels; an automatic gearbox so the driver didn't have to shift; power-hydraulic brakes so all of the braking power didn't have to come from the driver's leg, which for safety reasons, kept the speed of a bus under 20 mph; independent suspension and shock absorbers for a smoother ride; and, most importantly to the passengers, a heating system. All of these features helped to future-proof the bus, as the Routemaster models lasted until the end of 2005. The two big reasons for their replacement were that they were unable to accommodate those unable to step up, and boarding in the front, near the driver, eliminated the need for a conductor (Christopher, 2009, p. 54).

Figure 3: Routemaster

This model of bus provided a plethora of improvements (1991/23)

In the mid-1930s, the transport authority at the time, the London Passenger Transport Board, decided to phase out trams in favour of the trolleybus, which was similar to a tram in that it was powered by overhead lines; but it did not run on rails, instead having the wheels of a bus. The routes were gradually changed over until the beginning of the Second World War. Both trams and trolleybuses had an advantage over buses in that they are quieter, more efficient, and accelerate much faster. However, if one on a line broke down, all of the vehicles in the line behind it must also stop. When the phasing out of trams continued in 1950, perhaps it was due

to that fact that trams were replaced by regular diesel buses rather than trolleybuses. By the early 1960s, all the trolleybuses had been switched to the Routemasters, ending, for a time, the era of cables over the road. In 2000 trams made a return in Croydon as Tramlink, which has expanded slightly in neighbouring boroughs since (Collins, 2001, p. 106).

Futures in Engineering: The Power of Technology (c.2010 –):

Many are excited about the "new Routemaster" or the "New Bus for London" which resembles the favourite Routemaster, including the hop-on-hop-off feature but also has accommodations for the disabled. However, in the technical world, more advances are being made. Over 350 hybrid diesel/electric buses have been added with more coming, as well as fuel cell buses that run on hydrogen and emit only water. Regenerative braking is being added as well, which generates electricity by braking, which buses certainly do frequently (Christopher, 2009, p. 96).

The iBus system is an advancement that takes advantage of modern computers and global positioning systems. In short, it allows for tracking all of London's buses accurate to less than ten seconds using a combination of GPS and motion sensors inside the vehicle. Passengers can use this information to determine exactly when a bus on a certain route will arrive at a stop. It also allows controllers of the bus system to regulate the flow of buses more efficiently. Another feature of the system inside the bus is that announcements can automatically be made about stops. Drivers can also trigger other specific announcements such as a notification of a diversion (Christopher, 2009, p. 101).

In the future we can expect to see more technological advances. Perhaps the driverless car pioneered by Google will become a reality and can be adapted to buses, though it may not be implemented in full, as people generally dislike not having a human driver on the road. Perhaps a hybrid of sorts will arise, with a computer and human driving together. We can also expect to see better and more advanced materials, continuing in the same direction as the Routemaster's aluminium alloy.

References

Christopher, J. (2009). The London Bus Story: The History Press.

Collins, P. (2001). *London's Trams: A View From the Past*. Surrey: Ian Allen Publishing.

Sommerfield, V. (1933). *London's Buses: The Story of a Hundred Years*. Waterloo: The St. Catherine Press.

Engineering Histories & Achievements in London Transportation

Signal Engineering

With thousands of trains driving around London every day, there has to be a way to communicate between trains to ensure that they don't collide. The language that is railway signalling has been evolving since the early 1800s. From men waving their hands to complex computer programs, signal engineering has been the driving force of this evolution.

Early Successes & Inventions: Semaphore Signals to Early Automation (1800 – 1970):

The first signals were very crude. In order for stations to communicate with the trains, a policeman or signalman stood on the platform holding out his arms or a flag. His position would indicate either danger, caution, or clear. Trains could communicate with each other with tail lamps on the back of the train. Different coloured lamps indicated whether the train was moving or stopped at a station. These methods proved to be unreliable. Signalmen could get distracted by the going-ons of the platform, or the train conductor may not be able to see him in time. If visibility was poor, conductors may not have been able to see the tail lamp of a train in front of them. Fixed signals such as a flag on a pole or semaphore signals were more reliable than the signalman waving his arms. These could be used to signal to the conductor not only at the platform, but down the line as well. "Distant signals," as they were called, showed the conductor the conditions at the platform ahead of him (Kichenside & Williams, 2008).

With the discovery and exploration of electricity, signalling became more and more sophisticated. The first notable was the invention of the Cooke and Wheatstone electro-magnetic telegraph in the 1830s. Used on many lines in London, it allowed messages to be sent between stations instantly instead of relaying messages through the train conductors. Many railways in Great Britain used the absolute block system, in which a block consisted of a fixed section of track and only one train was allowed in that block at a time. In order to adapt to this system the Cooke and Wheatstone telegraph was adapted to become the block telegraph. Instead of having multiple needles pointing toward a letter as before, this telegraph had only one

Figure 1: Spagnoletti Block Instrument (1995/1531)

This type of telegram machine was used to communicate between blocks. The needle can be changed to indicate either "line clear" or "train on line".

needle. The needle pointed to one of three positions: 'normal' (the default position), 'line clear', or 'train on line' (Kichenside & Williams, 2008). Each signalman would look after a fixed length of track (their block) and would send signals to the block behind him using his block telegraph (Lockyear, 1996). Before this, conductors had to pick up a token like a key or ticket at the beginning of a block in order to enter. If there were no tokens left, a train could not enter the block (Engineer 1, 2013).

As time went on, new railways were added and modified and paths became progressively more complex. Levers had always been used to direct trains, whether it be changing a signal or moving track. To ensure that the correct levers were being pulled, a system was developed to link levers that opposed each other such that they could not be pulled simultaneously. The first interlocking system, invented by John Saxby, was implemented in January of 1860. This quickly became standard on all railways (Kichenside & Williams, 2008).

Figure 2: Lever Frame (1993/5)

This set of levers would have been used to control a point. Under the levers we can see the interlocking mechanism designed allow only the appropriate lever to be pulled.

In the 1870s, railways around London began to adopt the Sykes lock and block system in an attempt to prevent a signalman from sending a train onto a block at the wrong time. Before a train could be signalled into the next block, the signalman in the block ahead had to electronically release the signal. Once that was done, the train could be signalled onto the next block. This system helped to reduce accidents caused by human error, but it was by no means a perfect system (Kichenside & Williams, 2008).

One of the most important innovations for signalling is the track circuit, which allows for the electrical detection of a train's location on the railway. Experiments and research of track circuit began in the 1840s. The system was not implemented in London, however, until the late 1880s (Duffy, 2003, p. 9). The two running rails were electrified to create a circuit controlling a switch. When a train drives along the rails the circuit gets interrupted, changing the switch. Track circuits were originally introduced to aid the signalmen in tracking a train's progress along the railway, but by the early 1900s they were being used to automatically control signals. Signals would change to indicate the state of the track based on the signal coming from the track circuit. These simple systems were not yet able to automatically control the more complex junctions (Duffy, 2003, p. 10).

The next major innovations in signalling came about in the 1920s and 1930s. Now that track circuits were able to detect where the trains were, track diagrams were able to show their locations. Lights on the diagram would illuminate to show train locations and which routes had been set up. Points and signals were now operated by electro-pneumatic systems. With this, signalmen would control a relay that would, in turn, control an air valve instead of mechanically controlling points (Kichenside & Williams, 2008).

Another advance in automation was taken in the 1950s with the introduction of the programme machine. The daily details of train activity for a particular set of points was printed and put into a machine resembling a piano roll. This would open and close electrical contacts that controlled the points and signals. This method was not perfect and often required human supervision. If the need arose, a person could take control of signals and points away from the programme machine and operate them oneself. The first automatic railway in Britain was introduced in 1968 on the Victoria Line using the programme machine. All aspects of signalling and point setting were controlled automatically; however, a driver was still needed to operate the train (Kichenside & Williams, 2008).

Figure 3: Relay (S15)

A relay like this one would have been used to control signals for a point on an underground railway.

Modern Innovations: Computers Take Over (1970 – 2013):

Figure 4: Microprocessor (E01)

A microprocessor, found inside a computer, will receive, process, and send signals automatically. Without the microprocessor, the CBTC system would not be possible.

In the 1970s the computer and solid-state circuits replaced programme machines and relays respectively (Duffy, 2003). Not only were computers able to perform the function of multiple devices, including the programme machine, but they were reprogrammable. This meant that if there were changes to track layout, the computer code could simply be rewritten to reflect those changes instead of redesigning and replacing the circuit of relays that controlled the signals. In 1987 the driverless train was introduced on the District Light Railway (DLR). Using information picked up through coded track circuits, the

train is able to control its speed, acceleration and deceleration, as well as stop at stations. The only function not handled automatically is opening and closing doors and initiating the automatic driving (Kichenside & Williams, 2008).

Information sent over the rails is used for more than just speed control. Using an on-board computer to process the data, a moving block system can now be implemented. Instead of having a block consist of fixed locations on the track, they are now a certain distance behind a train. The train will pick up data about train speeds, acceleration, position and braking conditions to calculate a safe distance from the train ahead of it and adjust its speed accordingly (Lockyear, 1996). The use of track circuits and computer processors to communicate between trains in this way is known as Communications-Based Train Control (CBTC) and is the standard for railways in London.

Futures in Engineering: Safety and Reliability:

Upgrading the railways is an expensive and time consuming. Eventually, as computers become cheaper and more powerful, communication between trains will be faster and signalling equipment will be more reliable. Driverless trains will become safer and more common. Trains will get faster and more reliable to meet the growing needs of Londoners without sacrificing safety.

References:

Duffy, M. C. (2003). *Electric Railways 1880 - 1990*. London: The Institution of Electrical Engineers.

Engineer 1 (2013, 7 May, 2013). [Engineering Interviews].

Kichenside, G., & Williams, A. (2008). *Two Centuries of Railway Signalling* (2 ed.). Surrey, England: Oxford Publishing Co.

Lockyear, M. J. (1996). Changing track: moving-block railway signalling. *IEE review, 42*(1), 21. http://au4sb9ax7m.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info%3Aofi%2Fenc%3AUTF-8&rfr_id=info:sid/summon.serialssolutions.com&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.genre=article&rft.atitle=Changing+track%3A+moving-block+railway+signalling&rft.jtitle=IEE+Review&rft.au=Lockyear%2C+M.J&rft.date=1996&rft.issn=0953-5683&rft.volume=42&rft.issue=1&rft.spage=21&rft_id=info:doi/10.1049%2Fir%3A19960110&rft.externalDBID=n%2Fa&rft.externalDocID=10_1049_ir_19960110¶mdict=en-US

5.9. Appendix I – Sponsor Description

The London Transport Museum, abbreviated LTM, is an organization devoted to the conservation and presentation of London, England's public transportation history. The goal of the museum is to show the advancement and history of transportation in London throughout the last 200 years, covering all areas of public transportation, from buses to the London Underground. In doing so, museum exhibits lend a unique perspective on the evolution of London since the 19th century. Recently, the museum has redirected its aims to focus on specific themes, such as art and design as it applies to transportation, and transportation during wartime (London Transport Museum, n.d.-a).

The museum has a long history of its own. Originally known as the Museum of British Transport, it opened during the 1960s in Clapham, South London, in a building previously used as a bus garage; this original museum itself evolved from an initial collection of three buses – two Victorian horse-drawn models and one motorbus – preserved in the 1920s by the London General Omnibus Company. In 1973 the collection moved to Syron Park, West London, and again in 1980 to its current location in Covent Garden, within a former flower market. Its collection, which in 1980 had around 1,000 objects, has expanded to include over 400,000 objects of great variety, from photographs, signs and uniforms, to trains and buses. The LTM building has been extensively renovated twice, expanding to include more gallery space and a theatre, and now receives an average of 300,000 visitors yearly. In 1997 it was designated to be of national importance by the British government (London Transport Museum, 2012b).

LTM is a charitable organization (Charity Comission, 2013), incorporated as such in 2008. It is managed by a board of trustees, chaired by businessman Sir David Bell, which meets at least four times a year to discuss business strategies. Museum management is delegated to Managing Director Sam Mullins who oversees the Senior Management Team, employees, and volunteers of LTM (London Transport Museum, n.d). The London Transport Museum organization itself is a subsidiary of Transport for London [TfL], the local government body that manages and facilitates public transportation in and around London. As the owner of the London Transport Museum, TfL provides the museum with management assistance as well as being its main financial supporter (London Transport Museum, 2012b).

As a registered charity, LTM relies heavily on donations from supporters, notably the Luke Rees-Pulley Charitable Trust and LTM Friends group (London Transport Museum, 2012b). This voluntary income accounts for nearly half of the museum's funds (Figure 1).

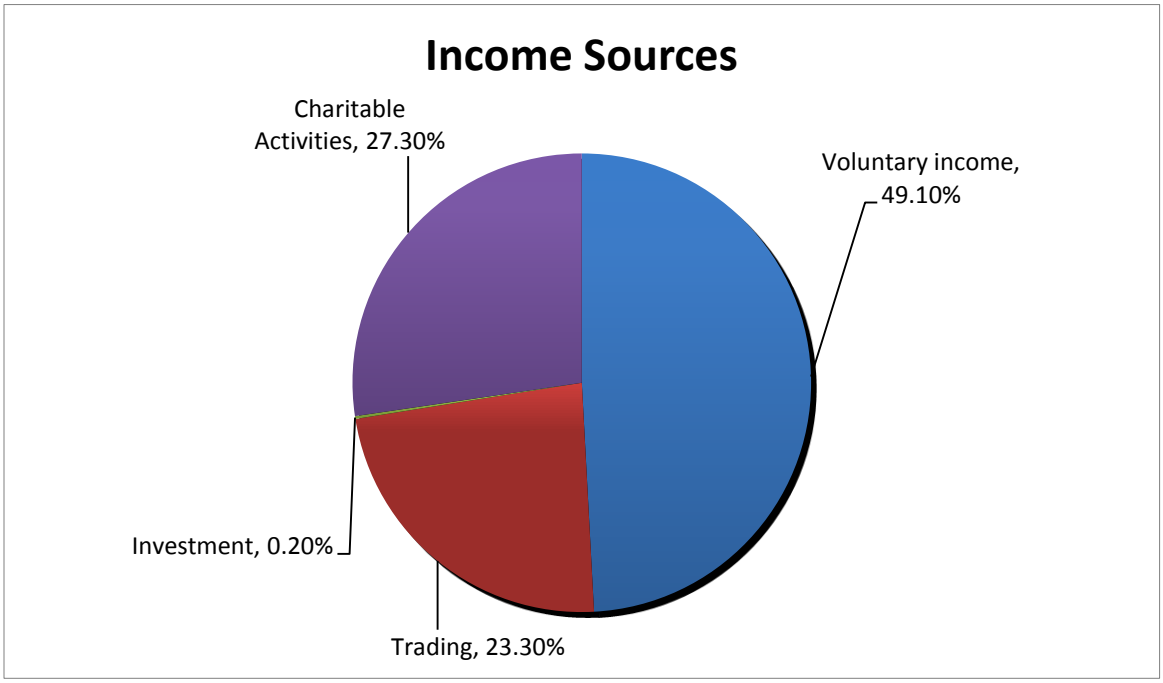


Figure 7: Income Sources for the London Transport Museum (Charity Commission, 2013)

The museum derives additional income from internal sources, including the entrance fees collected from visitors, and profits from the museum gift shop. London Transport Museum (Trading) Limited, a subsidiary of the London Transport Museum itself, manages all of the non-charitable activities that generate a profit for the museum (London Transport Museum, 2012b).

LTM primarily uses this income for maintenance and expansion. For example, a Museum Development Fund was created for any emergency repairs, as well as for the renewal of any exhibits. Additionally, income feeds into the Future Exhibitions and Education Fund, set up for the creation of new exhibits and for the development of educational programs that aim to introduce students to the history of transportation in London (London Transport Museum, 2012b). Charitable endeavors like these educational programs account for nearly 80% of the museum's yearly expenses (Figure 2), approximately 11.04 million pounds (Charity Comission, 2013).

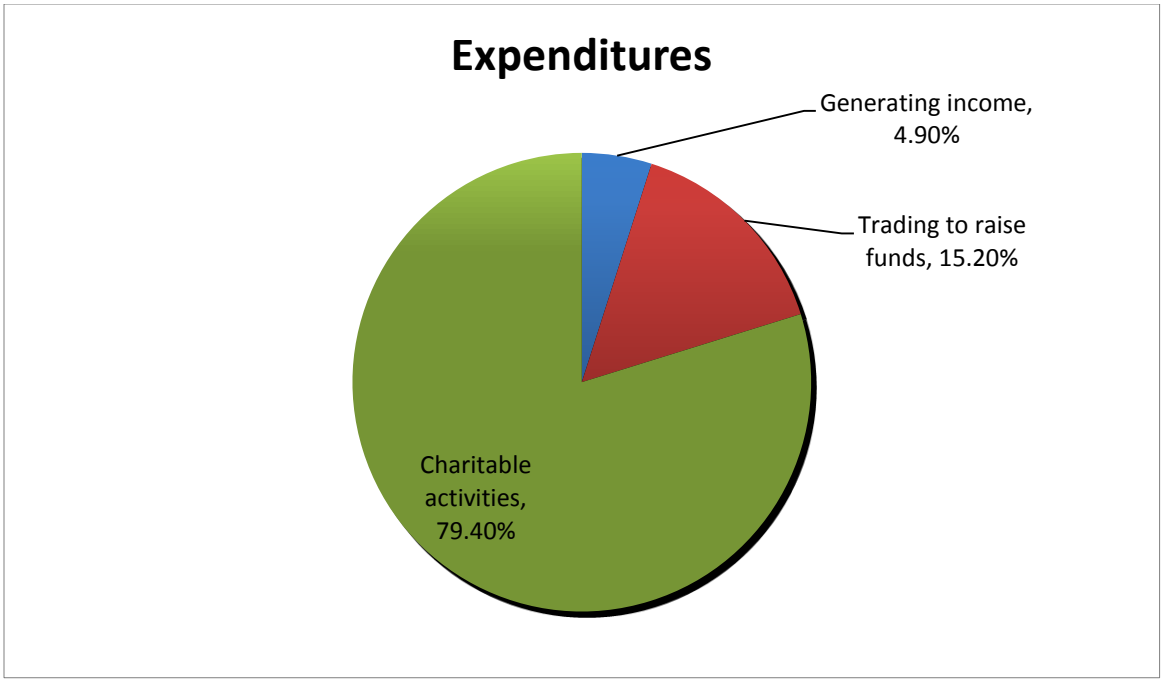


Figure 8: London Transport Museum Expenditures (Charity Commission, 2013).

The museum and Transport for London place a large degree of emphasis on educational initiatives to inform about the history of transportation in London and transportation engineering in order to encourage continued interest in these areas. To this end, Transport for London sponsors programs geared toward school-age children to encourage them to consider careers in transport, engineering, and "take science, technology, engineering and math (STEM) subjects" (Transport for London, 2011).

One particular educational program sponsored by Transport for London and the London Transport Museum is the Inspire Engineering program, or "TfL Inspire" (London Transport Museum, n.d.-b). Delivered at the London Transport Museum Depot in Acton, this program, a full day of events and "hands-on activities" (Transport for London, 2011) gives students the opportunity to meet with engineers and planners from TfL and explore the large collection of artifacts stored at the Acton Depot (London Transport Museum, n.d.-b).

The London Transport Museum and TfL supplement Inspire Engineering with the Engineering Ambassadors Program, an initiative to train engineers and planners to travel to classrooms to present on transportation careers and engage students in hands-on activities (Transport for London, n.d.). According to a 2011 Transport for London report, over 2000

attendees have taken part in Inspire Engineering programs, and TfL Ambassadors have conducted over 400 visits to classrooms (Transport for London, 2011).

Recently TfL and the London Transport Museum have sought to expand the Inspire Engineering project with a library of transport artifacts for use by Ambassadors and LTM staff. These artifacts will be accessible to Ambassadors to take on trips to schools, and for LTM staff to use in object-based learning activities. Our project will be to facilitate the development of educational activities for TfL Inspire and a new museum exhibit, that make use of these objects by creating historical narratives that present the history of engineering branches within LTM, and categorize artifacts based upon their engineering discipline. Our group will then use these narratives to develop object-based learning activities for use by the Inspire Engineering program. This work will build upon work done by another project group at LTM: this group was tasked with developing the database of handling artifacts for use by LTM. Ideally, the object-based learning components developed will supplement and improve the LTM's engineering education curriculum.

6. References

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative Inquiry Learning: Models, tools, and challenges. *International Journal of Science Education, 32*(3), 349-377.

Berg, B. L., & Lune, H. (2004). Qualitative Research Methods for the Social Sciences (8 ed.): Pearson.

Bloom, J. N., & Mintz, A. (1990). Public Mission vs. Private Allegiance: The Museum's Inner Conflict. *The Journal of Museum Education, 15*(3), 4.

Borun, M. (2002). Object-Based Learning and Family Groups. *Perspectives on object-centered learning in museums*, 245-260.

Bruner, J. S. (1961). The Act of Discovery. *Harvard Educational Review, 31*, 21-32.

Cain, J. (2010). Practical concerns when implementing object-based teaching in higher education. *University Museums and Collections journal, 3*, 197-203.

Charity Commission. (2013). London Transport Museum Limited. Retrieved March 13, 2013, from http://www.charitycommission.gov.uk/Showcharity/RegisterOfCharities/CharityWithPartB.aspx?RegisteredCharityNumber=1123122&SubsidiaryNumber=0

Chatterjee, H. (2007). Staying Essential: Articulating the Value of Object Based Learning. Retrieved from Humboldt-Universität zu Berlin website: http://edoc.hu-berlin.de/umacj/1/chatterjee-helen-1/XML/Chatterjee.xml

Crowley, K., & Leindardt, G. (2001). Objects of Learning, Objects of Talk: Changing Minds in Museums. Pittsburgh, Pennsylvania.

Czajkowski, J. W., & Hill, S. H. (2008). Transformation and Interpretation: What Is the Museums Educator's Role? . *The Journal of Museum Education, 33*(3), 9. doi: 10.2307/40479679

Davis, K., Haughn, M., Mutty, A., & Thibault, A. (2013). Developing an Artefact Library: Worcester Polytechnic Institute. Retrieved 5 June 2013, from http://www.wpi.edu/Pubs/E-project/Available/E-project-042413-131817/unrestricted/Developing_an_Artefact_Library_.pdf

Dudley, S. (2012). *Materiality Matters: Experiencing the Displayed Object*. Paper presented at the Working Papers in Museum Studies, University of Michigan. http://ummsp.lsa.umich.edu/files2/8_dudley_2012.pdf

Durbin, G., Morris, S., & Wilkinson, S. (1990) A teacher's guide to learning from objects. *Education on Site* (pp. 40). London, England: English Heritage.

Engineer 1. (7 May 2013). [Engineering Interviews].

Engineer 2. (8 May 2013). [Engineering Interviews].

Engineer 3. (21 May 2013). [Engineering Interviews].

Engineer 4. (31 May 2013). [Engineering Interviews].

Freire, P. (1993). Pedagogy of the Oppressed. New York: Continuum International Publishing Group Inc.

Greater London Authority. (n.d.). Engineering Inspiration: Promoting Engineering, Planning and the Transport Industry to Schools. Retrieved March 21, 2013, from http://www.london.gov.uk/rp/docs/casestudies/TfL_Transport_Museum.pdf

Handwerker, W. P. (2001). Quick Ethnography. Lanham, Maryland: Altamira Press.

Lasky, D. (2009). Learning from Objects: A Future for 21st Century Urban Arts Education. *Perspectives on Urban Education, 6*(2), 5.

London Transport Museum. (2012a). Inspire Engineering at London Transport Museum (pp. 21): London Transport Museum.

London Transport Museum. (2012b). Yearbook 2011/12: City Futures. Retrieved March 14, 2013, from http://www.ltmuseum.co.uk/assets/downloads/pdfs/Yearbook%202012_low_res.pdf

London Transport Museum. (2013a). About Us. Retrieved March 14, 2013, from http://www.ltmuseum.co.uk/about-us/a-brief-history

London Transport Museum. (2013b). Governance. Retrieved March 14, 2013, from http://www.ltmuseum.co.uk/about-us/a-brief-history/governance

London Transport Museum. (2013c). TfL Inspire. Retrieved March 14, 2013, from http://www.ltmuseum.co.uk/learning/schools/key-stage-3/266-tfl-inspire

Museum Professional 1. (18 April 2013). [Museum Education Interviews].

Museum Professional 2. (13 May, 2013). [Museum Education Interviews].

Museum Professional 3. (16 May, 2013). [Museum Education Interviews].

Nightingale, F. (2004). *Florence Nightingale on Public Health Care* (Vol. 6). Waterloo, Ontario: Wilfrid Laurier University Press.

Poulter, E. (2013a, 2 April). [Personal communication].

Poulter, E. (2013b, 16 May). [Personal communication].

Sear, M., & Wehner, K. (2009). Engaging the Material World: Object Knowledge and Australian Journeys. In S. H. Dudley (Ed.), *Museum Materialities: Objects, Engagements, Interpretations* (pp. 143-161). New York: Routledge.

Stables, K. (2001). Exploring Mystery Products to Develop Design and Technology Skills: Case Studies from the Design Museum's Outreach Project. *Journal of Design and Technology Education, 6*, 7.

Transport for London. (2011a). *Our Upgrade Plan*. London, England: Retrieved from http://www.tfl.gov.uk/assets/downloads/corporate/our-upgrade-plan-london-underground-february-2011.pdf.

Transport for London. (2011b). Skills and Employment Strategy. Retrieved March 14, 2013, from http://www.tfl.gov.uk/assets/downloads/skills-employment-strategy.pdf

Transport for London. (2012a). London Buses Factsheet. Retrieved April 6, 2013, from http://www.tfl.gov.uk/assets/downloads/corporate/london-buses-factsheet.pdf

Transport for London. (2012b). London Overground Factsheet. Retrieved April 6, 2013, from: http://www.tfl.gov.uk/assets/downloads/corporate/Overground_Factsheet.pdf

Transport for London. (2012c). London River Services Factsheet. Retrieved April 6, 2013, from http://www.tfl.gov.uk/assets/downloads/corporate/london-river-services-factsheet.pdf

Transport for London. (2012d). London Taxi & Private Hire Factsheet. Retrieved April 6, 2013, from http://www.tfl.gov.uk/assets/downloads/corporate/Taxi_Factsheet.pdf

Transport for London. (2012e). London Tramlink Factsheet. Retrieved April 6, 2013, from http://www.tfl.gov.uk/assets/downloads/corporate/Tramlink_Factsheet.pdf

Transport for London. (2012f). London Underground Factsheet. Retrieved April 6, 2013, from http://www.tfl.gov.uk/assets/downloads/corporate/lu-factsheet-jan2012.pdf

Transport for London. (2013). Engineering Ambassador Volunteer Programme. 1.

Transport for London. (n.d.). Ambassadorship Programme. Retrieved March 14, 2013, from http://www.tfl.gov.uk/corporate/projectsandschemes/8085.aspx