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| **Institution:** | Imperial College London |
| **Unit of Assessment:** | 12 Engineering |
| **Title of case study:** | Improvements to the Operation, Planning and Design of Mass Transit Systems via Performance Analytics |
| **Period when the underpinning research was undertaken:** | 2000 - 2020 |

**Details of staff conducting the underpinning research from the submitting unit**

| Name(s): | Role(s) (e.g. job title): | Period(s) employed: |
|---|---|---|
| Prof. Daniel Graham | Professor of Statistical Modelling and Director of Transport Strategy Centre (TSC) | 1st January 2000 – present |
| Richard Anderson | TSC Managing Director | 1st June 2000 - present |

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| **Period when the claimed impact occurred:** | 1 Aug 2013 – 31 Dec 2020 |
| **Is this case study continued from a case study submitted in 2014?** | No |

## 1. Summary of the impact

Research on public transport system performance, undertaken by the Transport Strategy Centre (TSC) within the Department of Civil and Environmental Engineering, has led to direct improvements in the design, management and operations of mass transit systems in the world's largest cities.

The TSC pioneered the development and application of an analytical platform for the measurement and evaluation of system performance across multiple domains. Continuous collaboration was established with over 110 major transport operators serving over 500,000,000 citizens. In addition to the obvious societal impact in improving transport in many countries, the financial impact of our research is estimated to be over GBP1,000,000,000 over the current REF period, including:

- CAD500,000,000 in capital cost savings to the Montreal Metro.
- GBP350,000,000 per annum increase in passenger revenue in Beijing.
- A 33% increase in design capacity for new metro lines in Guangzhou.

## 2. Underpinning research

An analytical platform to measure and evaluate the relative performance of mass transit systems has been pioneered jointly by Transport Strategy Centre (TSC) (formerly called RTSC) co-Directors Professor Daniel Graham and Richard Anderson in the Civil and Environmental Engineering Department at Imperial. It is based on continuous cooperative industrial collaboration, organised in the form of operator consortia, to generate the data and information necessary for fundamental statistical analysis, along with the funding required to support underpinning research and its translation into practice. Throughout the current REF period, TSC has managed 9 consortia comprising over 100 major public transport operators around the world (modal coverage: urban metros, light railways, mainline railways, buses, airports and infrastructure providers). Since 2000, Graham, Anderson and their colleagues have developed data collection systems, benchmarking methodologies, analytical approaches, statistical models and processes to facilitate the application and impact of research to industry. The TSC is the sole researcher and facilitator of the consortia and, due to its unique ability to procure data across a global network, no other organisation worldwide undertakes similar research for the mass transport sector.

The underpinning research comprises three key strands:

**U1. Development of an analytical framework to measure and evaluate performance [R4]** – Continuous development of robust and rigorous data definitions and systems to evaluate public transport performance, with formalised data capture, validation and collection on an annualised basis across consortia. The data generated via industrial collaboration provide a unique longitudinal source that form the basis of our performance analytics platform.

**U2. Statistical modelling to identify performance drivers [R1, R2, R3]** – Statistical modelling tools have been developed to evaluate public transport performance and uniquely identify the determinants of performance across multiple domains of operation. For example, modelling of service provision [R1] quantified the role of operational and exogenous characteristics in efficient resource usage, resulting in an improved understanding of optimal capacity provision. The modelling of incidents causing delays to train service [R3] identified key factors influencing reliability, and has been used by operators such as the Shanghai Metro to contribute to a 5-fold improvement in reliability. Empirical analysis of metro ridership [R2] quantified the responsiveness of demand to changes in fare levels, income and quality of service, which has been used to directly influence fares policy in a number of global cities including extensive application in Beijing.

**U3. Systematic analysis of operator-specific performance and underlying policies, processes and practices [R5, R6]** – Empirical evidence on capacity utilisation and passenger responsiveness to crowding [R5] has been complemented with further quantitative and qualitative investigative research relating to the design and operation of high-capacity metro systems [R6]. This work has been used to make the case for higher levels of investment and capacity in mass transit systems.

## 3. References to the research


R1. **Graham DJ** (2008). Productivity and efficiency in in urban railways: parametric and nonparametric estimates, Transportation Research Part E-Logistics and Transportation Review, Vol: 44, Pages: 84-99, ISSN: 1366-5545

R2. **Graham DJ**, Crotte A, **Anderson RJ.** (2011). A dynamic panel analysis of urban metro demand, Transportation Research Part E-Logistics and Transportation Review, Vol: 45, Pages: 787-794, ISSN: 1366-5545

R3. Melo PC, Harris NG, **Graham DJ**, **Anderson RJ**, Barron A, et al. (2011). Determinants of Delay Incident Occurrence in Urban Metros, Transportation Research Record, Pages: 10-18, ISSN: 0361-1981

R4. Trompet M, Liu X, **Graham DJ**.(2011). Development of a Key Performance Indicator to Compare Regularity of Service between Urban Bus Operators, Transportation Research Record: Journal of the Transportation Research Board, No 2216, pp. 33-41

R5. Horcher D, **Graham DJ**, **Anderson RJ**. (2017), Crowding cost estimation with large scale smart card and vehicle location data, Transportation Research Part B-Methodological, Vol: 95, Pages: 105-125, ISSN: 0191-2615

R6. Canavan S, Barron A, Cohen J, **Graham DJ**, **Anderson RJ**. (2019). Best Practices in Operating High Frequency Metro Services. Transportation Research Record: Journal of the Transportation Research Board. ISSN: 0361-1981


## 4. Details of the impact

The TSC designed and continuously manages an innovative, formal process to organise engagement with and dissemination to industry, providing a clear path from research to impact. A key innovation has been the establishment of industry consortia, steered by member public transport organisations and facilitated by the TSC. This continuous

engagement enables the generation of unique longitudinal data and detailed observations that form the basis of the underpinning analytical research.

The nine consortia include the Community of Metros (42 metros from major cities such as Paris and Beijing), the International Bus Benchmarking Group (16 organisations including TfL London Buses, Istanbul IETT) and the American Bus Benchmarking Group (21 operators). Other consortia encompass operators of mainline railway operators and airports.

Impact has arisen from significant improvements to the design of public transport systems, financial efficiency, fare and funding mechanisms, and the measurement and management of service quality. The impact cited, are a selection from 10 of the 110 consortia partners where the sum of per annum and one-off financial benefits cited exceeds GBP1,000,000,000. Many policy benefits, once established, generally continue for some years beyond the initial impact. We would expect further social and economic impact to arise from the improvements to service quality and enhanced design, but these are not easily quantifiable.

Five key categories of impact generated in the period August 2013 to July 2020 are as follows. Each category is supported by evidence provided by one or more transport companies in six countries: UK, China, USA, Canada, Portugal and Turkey, who benefitted directly from our research.

**I1. Change in the design and planning of new metro lines in mega-cities (underpinning research R1, R5, R6)**

The rapid development of metros in China and India has been directly influenced by TSC research that has strengthened the economic (**R1, R5**) and operational (**R6**) case for higher-capacity metro lines, enhancing the benefits that metros bring to mega-cities:

**[Source 1.1 Guangzhou Metro Company, 2017- ongoing].** 10 new metro lines or extensions have been designed with larger and longer trains representing an increase in train capacity of 33%. The evidence states that:

*"Ongoing expansion projects, including 10 new lines or extensions totalling 258.1 km between 2017 and 2023, are being directly influenced by the research carried out by the TSC at Imperial College London."*

**I2. Directly influencing funding policy (underpinning research R2)**

Statistical research (**R2**) into the responsiveness of public transport demand was combined with evidence from the longitudinal datasets and syntheses of policy and practice. The impact has been significant changes to fares and funding policies in several cities:

[**Source 2.1: Beijing Mass Transit Railway Operation Corp. Ltd., 2015-ongoing]** Fares structures were changed for the metro in Beijing, contributing to a GBP352,660,000 per annum increase in revenue from 2015. TSC presented its research to the Chinese Government in 2012.

[**Source 2.2: Lisbon City Bus Operator, Carris, 2017-2020]** the TSC directly helped to secure up to EUR30,000,000 of government funding, supporting a more sustainable public transport system.

**[Source 2.3: Newcastle Metro, Nexus, 2017]**: states *"the assistance that Nexus received from the RTSC was instrumental in helping Nexus acquire £337 million of capital grant from the UK Government."*

**I3. Improving cost efficiency (underpinning body of related research)**

Public transport operators have used TSC research to make the case for and achieve significant improvements in cost efficiency:

**[Source 3.1: Montreal Metro, Société de Transport de Montréal, 2014-ongoing]**: *"The STM has therefore decided to extend the useful life of the MR-73 cars to 60 years. The discussions leading to this decision were based on a 2012 report by Imperial College London ("Rolling Stock Replacement vs Refurbishment")…This scenario would generate savings of nearly $500m* [CAD500million]*"*

**[Source 3.2, Istanbul City Bus Operator, IETT, 2014-2017]**: *"RTSC's research allowed us to make savings to our operating expenditure which roughly amounts to 59 million TL per year (equivalent to 50 million USD PPP) by nearly halving layover hours without impacting the service quality."*

**I4. Enhancing service quality and safety (underpinning research R3, R4, R6)**

Datasets of enhanced granularity, designed by TSC, have bolstered the modelling of public transport service quality. Statistical analysis (**R3**), the development of performance measures (**R4**) and operational research (**R6**) have directly led to quantifiable and strategic improvements to service quality with far-reaching benefits:

**[Source 4.1 Shanghai Metro, SSMG, 2009-2017]** Research application yielded a 12-fold improvement in reliability between 2009 and 2017 (a 5 fold increase between 2013 and 2017) and contributed to a 6% increase train speeds on Line 12.

[**Source 4.2: Transport for London, London Buses, 2014-2018**]: Strategic application of the TSC's research (**R4**) provided the impetus to TFL to maintain bus speeds, informed TfL's bus safety program and changed the way service quality is measured.

**I5. Providing new performance measurement tools (underpinning research R4)**

Research into improved performance measurement methods by TSC, has been adopted and used at the highest levels of operator organisations, providing new insight on performance from a customer perspective:

**[Source 5.1: New York City Transit, 2017-ongoing]**: *"The annual Key Performance Indicator research is regularly used to inform Senior Executives how NYCT compares…..NYCT introduced new customer-focused indicators…These metrics were inspired by passenger metrics at other CoMET systems, and by TSC research carried out for the IBBG.."*

**[Source 5.2: Hampton Roads Transit, 2012-ongoing]:** *"HRT decided to adopt ABBG's definition for On-Time Performance and data collection methodology as developed by TSC"*

**5. Sources to corroborate the impact**

**[1.1]** Letter of corroboration from Manager, Operation Division, Guangzhou Metro Company.

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| **[2.1]** | Letter of corroboration from Vice President, Beijing Mass Transit Railway Operation Corp. Ltd. |
| **[2.2]** | Letter of corroboration from President and CEO, CARRIS – Lisbon Bus and Tram Municipal Operator |
| **[2.3]** | Letter of corroboration from Director of Finance and Resources, Nexus, Newcastle, United Kingdom |
| **[3.1]** | Press release, Société de Transport de Montréal, 29th October, 2014. http://www.stm.info/en/press/press-releases/2014/when-should-the-mr-73-metro-cars-be-replaced--the-stm-responds Link archived here. |
| **[3.2]** | Letter of corroboration from Deputy of General Manager, Istanbul Electric Tramway and Tunnel enterprises General Directorate |
| **[4.1]** | Letter of corroboration from Shanghai Rail Transit Technical Research Centre |
| **[4.2]** | Letter of corroboration from Director of Bus Operations, Transport for London, London Buses |
| **[5.1]** | Letter of corroboration from Senior Vice President, New York City Transit |
| **[5.2]** | Letter of corroboration from Chief Operating Officer, Hampton Roads Transit |