MEGAPROJECT Whole Action Workshop, MC & Joint Working Group Meetings, - IFB, Liverpool

Time & Cost Overruns in the Edinburgh Tram Network (ETN) Project: Causes and Scientific modelling

Prince Boateng
Dr Z. Chen
Prof. S.O. Ogunlana

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Contents

- Overview of the new ETN project
- Causes of time and cost overruns
- Scientific modelling
- Summary
The new Edinburgh Tram Network (ETN) Project

- Tracklaying works are progressing well on Haymarket Yards (top picture) and the Haymarket Terrace viaduct (middle picture).
- Princes Street track works and the associated diversions started in September. Surface planing has been completed and reinstatement works are underway.
- At Gogar Depot the interior fit-out of the Depot Building is complete and power connections (Energisation) are now live. The mini test track is under construction. The Depot welcomed its first tram, from the CAF factory in Spain, on 17 Oct.
- Earth works in preparation for tracklaying are currently underway on the tram corridor between Haymarket and Edinburgh Park.
Overview

- 2001 – Feasibility studies of the Tram system
- 30 options drawn up
- May 2002 – Formation of Transport Initiatives Edinburgh (Tie) plc by the City of Edinburgh Council (CEC)
  - Tasked to deliver major transport projects for CEC, its owner.
Main Problems

- Expanding population
- Vehicular congestion
  - 160,000 vehicles enter city every day
  - 180,000 by 2016 - CEC forecast
- Frequent road repairs
Consultation & Response

- 24\textsuperscript{th} March-18\textsuperscript{th} May 2003
  - 125,000 leaflets distributed
  - Several public meetings & Exhibitions
  - Sectors consulted: Transport, Business, Environment, Tourism, Conservative/Heritage, Disability groups, Utilities, etc.

- Over 3,000 responses (83.6% in support of the new tram network)

- January 2004 - Proposal submitted to the Scottish Parliament to reintroduce tram in Edinburgh
Objectives ETN Project

• Support the local economy by improving accessibility
• Promote sustainability and reduce environmental damage caused by traffic
• Reduce traffic congestion
• Make the transport system safer and more secure
• Promote social benefits.
Contractual Framework

- Development Partnering and Operating Franchise Agreement (DPOFA)
- System Design Services (SDS)
- Multi Utilities Diversion Framework Agreement (MUDFA)
- Infrastructure provider and maintenance (Infraco) and
- Vehicle supply and maintenance (Tramco)
System Design Services (SDS)

- 2005 – Appointment of design consultants
- Originally, 3 lines were proposed


- Phase 1a = 18.5km, is being developed (Case study)
- Phase 1b = 5.5 km, to be developed later.
Political Treat

- March 2006 – Tram Bill passed & granted Royal Assent

- 2007- Scottish National Party (SNP) was elected
  - Pledged to cancel project to same money
  - Voted by Parliament to continue project
  - SNP agreed, but will not give extra public money
Construction

- Spring 2007 – Beginning of Multi-Utility Diversions Works (MUDFA)

One of the many bodies discovered during utility diversion work on Constitution Street
October 2007 - Vehicle supply and maintenance contract (Tramco) awarded to Spanish company CAF

- £ 40 million
- 27 vehicles
- 250 capacity
Construction (cont’d)

- May 2008 – Turnkey Infrastructure Construction contract (INFRACO) awarded to Bilfinger Berger & Siemens (BBS) Consortium
  - Initial estimated costs £498 million
Project Time Performance
(Planned infrastructure construction programme)

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<td>2011</td>
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- Newhaven to Foot of Leith Walk
- Foot of Leith to St. Andrew Square
- St. Andrew Square to Haymarket
- Haymarket to Edinburgh Park Station
- Edinburgh Park station to Airport

Legend:
- Green: Utilities
- Red: Road and Tramworks
- Blue: Overhead line equipment

Source: Audit Scotland
Project Time Performance (cont’d)
(Delivery against key milestones)

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Business Case

Design and Traffic Regulation order

Utilities

Tram construction (Tramco)

Infrastructure construction (Infraco)

Legend:
- Green: Plan
- Yellow: Actual
**Project Cost Performance**

Spend to the end of December 2010

- Budget as at May 2008
- Expenditure to end December 2010

**Note:**
- 2008 - Initial cost was £498
- December 2009 – Cost revised to £545 mil
- December 2010 – Cost passed £545 mil
- Final Cost unknown

- **Infrastructure construction**: £67m
- **Tram construction**: £49m
- **Utilities diversion**: £27m
- **Design**: £33m
- **Project management**: £85m
- **Land and compensation**: £27m
- **Contingency**: £33m
Causes of Time & Cost Overruns

- **Social risks**
  - Dispute
  - Legal actions
  - Multi-level decision making bodies
  - Stakeholders’ pressure

![Diagram showing internal and external stakeholders](image)
Causes of Time & Cost Overruns (cont’d)

- Technical risks
  - Utility diversion/ground condition problems

Wartime tunnels under Haymarket

- Construction disruption
Causes of Time & Cost Overruns

- Economic risks
  - Economic downturn
  - Delays of all types
  - Changes in project governing body
  - Quality deficiency/rework
Causes of Time & Cost Overruns (cont’d)

- Environmental risks
Causes of Time & Cost Overruns (cont’d)

- **Political risks**
  - Lack of political support
  - Political indecision
  - **Contractual disputes**
    - 2009- BBS demand additional £50-£80 mil before beginning work on Princes Street.
    - Tie refused
    - 2010- BBS announced 30 months delay to 2014
  - 2011- **Tie** released from managing project
  - 2011 - Cost revised from **£545 to £776 mil**
  - 2012- **T&T** appointed to manage project
Changes and Disputes to date.

- **816 notice of Claims**
  - 677 continued with
  - 139 withdrawn

- **426 Estimates submitted**
  - 228 not settled
  - 198 settled
    - 20 settled thru’ FDRP
    - 178 settled thru’ IDRP
    - 7 resolved thru’ negotiation
    - 2 resolved thru’ external mediation
    - 11 resolved thru’ adjudication

- **Cost of disputes to date** £23.8 m
  - £12.6 m
  - £3.7 m
  - £3.5 m
  - £4.0 m

- **251 – Still hanging**
Hierarchy of Identified Risk Areas in ETN Project

Based on desktop search, ETNP source documents and Interviews.
Scientific Modelling

- **SDANP**
  - Analytical Network Process (ANP) model for prioritising risk factors

- System Dynamics (SD) for simulating risks over time
SDANP Framework

Data source
- Literature on STEEP
- Data from source documents of past similar projects
- Case studies

ANP route
- List of potential risks
- Conduct prioritization survey based on experts’ decisions
- Perform Mean Scores of importance
  \[ MV = \frac{1}{n} \left( \sum_{i=1}^{n} E_{(C,T,D)} \right) \]
- Develop and structure the ANP model
- Conduct pairwise Comparison
  \[ PR_{ij} = \begin{bmatrix} 1 & R_{i1} & \ldots & R_{in} \\ R_{1i} & 1 & \ldots & R_{nj} \\ \vdots & \vdots & \ddots & \vdots \\ R_{ni} & R_{nj} & \ldots & 1 \end{bmatrix} \]
- Normalized criteria
  \[ \sum_{j=1}^{n} R_{ij} W_j = \lambda_{\text{max}} W_i \]
  \[ \sum_{i=1}^{n} W_i = 1 \]
- Perform Risk Priority Index (RPI) Calculation
  \[ RPI_{ij} = \sum_{j=1}^{n} W_{(RC)_j} * R_{ij} \]
- List of Top n “priority risks”

Database
- Risks identification and categorization

SD route
- Initial model development
  - Reference modes
  - Model boundary chart
  - Feedback structure
  - Casual flow diagram
- Model verification
  - Expert opinion
- Model development
  - Develop formulae for flow diagrams
- Model Testing
  - Dimensional consistency
  - Structure consistency
- Test passed/Test not passed
- Model simulation
- Model validation
  - Testing of model structure & behaviour
  - Software application
  - Test passed
- Policy analysis, design and improvement and implementation
## Data Collection Methods

### Summary:
- **Questionnaire Survey**
- **Structured Interview**

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### Project Objectives (Po)

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### STEEP Risks Impact on (Po)

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Modelling in ANP for Risk Prioritization

ANP Network Models for STEEP Risks Prioritization
## Comparison Matrices

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<th>P&lt;sub&gt;R2&lt;/sub&gt;</th>
<th>P&lt;sub&gt;R3&lt;/sub&gt;</th>
<th>P&lt;sub&gt;R4&lt;/sub&gt;</th>
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Legend: λ<sub>max</sub> = maximum eigenvalue, CI = Consistency Index, RI = Random Index, CR = Consistency ratio, TPV = Total priority value, NPV = Normal priority value, IPV = Ideal priority value R = Ranking
### Results of Final Mode ANP Decision Making Priorities

<table>
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<th>Potential Risks (P_R)</th>
<th>Priorities for Potential Risks</th>
<th>Final Priorities</th>
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<td>P_R4: Environmental</td>
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<td>P_R5: Political</td>
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<tr>
<td>Total</td>
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</table>

TRPI - Total risk priority index  
IRPV - Ideal risk priority indexes  
R - Ranking
Using SD to model behaviour overtime

- STEEP risks in ETN project
Causal Loop Diagram for STEEP Risks in ETN Project
SD models for STEEP risks in ETN project

Model structure

MegaDS

Social Subsystem

Political Subsystem

Technical Subsystem

Environmental Subsystem

Economic Subsystem

Environ. Factors

- Effects of Project
  - Air emission
  - Habitat destruction
  - Waste generation
  - Pollution (air/ water)
  - Comfort disturbances
  - Health & safety

- Effects on Project
  - Critical weather conditions (snow, rain, wind etc.)
  - Temperature
  - Landslide, etc.
# Model Boundary

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</tr>
</tbody>
</table>
System Dynamics: Dynamic Hypothesis (CLD)

Information flow, e.g. how environmental uncertainties affect project time

Legend:
- A casual relationship
+ (-) signs at the arrowheads indicate that the effect is positively (negatively) related to the cause.
R denotes reinforcing loop
Dynamic Patterns for Stock Entities in the Environmental risks model

Environmental risks

0.2
0.15
0.1
0.05
0

Time (Year)

Max. P_{R4} @ 0% E_{NV2} impact level in year 2010 = 18.7%

Dynamic pattern (Actual)

Max. P_{R4} impact level @ year 2010 = 18.7%

Dynamic pattern @ E_{NV2} = 0% impact level

a: Baserun and actual scenario simulation patterns for environmental risks

Risks of project time overrun

0.6
0.45
0.3
0.15
0

Level of E_{NV15} in 2008 = 0%

Behaviour pattern for E_{NV15} based on 20% of E_{NV1} and 0% of E_{NV2} impact levels

Actual dynamic pattern for Risks of project time overrun

Max. E_{NV15} @ 20%
E_{NV1} and 79%
impact level = 55.4%

Max. E_{NV15} @ 20%
E_{NV1} and 0% E_{NV2}
impact level = 41%

Max. E_{NV15} @ 20%
E_{NV1} and 79%
impact level = 55.4%

Max. E_{NV15} @ 20%
E_{NV1} and 0% E_{NV2}
impact level = 41%

Project completion time - 10/2013

b: Baserun and actual scenario simulation patterns for risks of project time overrun
c: Baserun and actual scenario simulation patterns for risks of project cost overrun

**Dynamic Patterns for Stock Entities in the Environmental risks model**

**Risks of project cost overrun**

- **Actual dynamic behaviour pattern**
  - Level of $E_{NV14}$ in 2008 = 0%
  - Max. $E_{NV14}$ @ 20% $E_{NV1}$ and 79% impact level = 35%
  - Max. $E_{NV14}$ @ 20% $E_{NV1}$ and 79% impact level = 28%

**Behaviour pattern for 0% impact level**

- $E_{NV13}$ based on 20% of $E_{NV1}$ and 0% of $E_{NV2}$ impact levels
- Level of $E_{NV13}$ in 2008 = 0%

**Project quality deficiency**

- **Actual dynamic pattern for Risks of project time**
  - Level of $E_{NV13}$ in 2008 = 0%
  - Max. $E_{NV13}$ @ 20% $E_{NV1}$ and 79% impact level = 11.37%
  - Max. $E_{NV13}$ @ 20% $E_{NV1}$ and 0% $E_{NV2}$ impact level = 8.28%

- **7.29% (max)**

**d: Baserun and actual scenario simulation patterns for project quality deficiency**
b: Baserun and actual scenario simulation patterns for economic risks

Economic risks

Max. $P_{R3}$ impact level @ year 2010.13 = 33.03%

Initial RPI for $P_{R3} = 25\%$ impact level.

Min risk impact level for $P_{R3} = 1.72\%$

DSBP = Dynamic simulation behaviour pattern

b: Dynamic simulation scenario graphs for social risks

Social risks

DSBP = Dynamic simulation behaviour pattern

b: Dynamic simulation scenario graphs for social risks
Dynamic Confidence Bounds Sensitivity Graph for Political Risks

- Simulation interval continues to grow larger overtime
- **50% chance** that the level of political risks will be between **15% and 55%**
- **75% and the 95%** confidence bounds suggest that the level of political risks could range from **10% to 65% and 5% to 80%** respectively.
### Research findings/Data Validity

<table>
<thead>
<tr>
<th>Original Project Information (OPI)</th>
<th>SDANP Simulation Project Information (SPI)</th>
<th>Validated Project Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost (£ Million)</strong></td>
<td>Planned Project Budget (PPB)</td>
<td>545</td>
</tr>
<tr>
<td>Revised Project Budget (RPB)</td>
<td>776</td>
<td></td>
</tr>
<tr>
<td>Project Cost Variation (PCV)</td>
<td>231</td>
<td></td>
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<tr>
<td><strong>Year of Completion</strong></td>
<td>Original Planned Date (OPD)</td>
<td>2011 (3 Years)</td>
</tr>
<tr>
<td>Expected New Date (END)</td>
<td>2014 (6 Years)</td>
<td></td>
</tr>
<tr>
<td>Completion Date Variation (CDV)</td>
<td>3 Years (30 month)</td>
<td></td>
</tr>
</tbody>
</table>

### Risks

<table>
<thead>
<tr>
<th>Risks</th>
<th>Level of Risk Impact on Project Performance –LRIPP (%)</th>
<th>Validated Project Information</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(OPI X SPI)</td>
<td>Cost (£ million)</td>
</tr>
<tr>
<td></td>
<td>(SPI_C)</td>
<td>(SPI_T)</td>
</tr>
<tr>
<td>Social</td>
<td>12.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Technical</td>
<td>1.24</td>
<td>0.43</td>
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<tr>
<td>Economic</td>
<td>22.36</td>
<td>30.74</td>
</tr>
<tr>
<td>Environmental</td>
<td>11.43</td>
<td>29.3</td>
</tr>
<tr>
<td>Political</td>
<td>2.56</td>
<td>5.14</td>
</tr>
<tr>
<td><strong>Total Impact</strong></td>
<td>49.59</td>
<td>71.61</td>
</tr>
</tbody>
</table>

Source: Field Work 2013
Further discussion

<table>
<thead>
<tr>
<th></th>
<th>SDANP model</th>
<th>Statistical research *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cost escalation (%)</td>
<td>49.59</td>
<td>44.70</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>85.47</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Using SDANP for Risk Planning

Work schedule

Production-dep. Risks

High Risk Period

- clear site
- rough grade
- drill well
- water tank foundation
- excavate for sewer
- excavate for electrical manholes
- install well pump
- erect water tank
- install sewer and backfill
- install manhole

Time-dep. Risks
Conclusions and further research

- Well defined research methodology
- A study into **STEEP risks** impacts on ETN project at the construction phase
- A **SDANP model** for planning against the impact of STEEP on ETN project
- More case studies for accurate prediction
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- Edinburgh Trams
Thank You