Transportation, Energy, and Technology in the 21st Century

GCEP Advanced Transportation Workshop
October 10-11, 2005
Stanford University

Andreas Schäfer
Department of Architecture and
Institute for Aviation and the Environment
University of Cambridge
as601@cam.ac.uk
Sector shifts due to:
1. Different income elasticities for goods and services produced by each of the three sectors
2. Competitive advantage for each of the sector’s industries
3. Changing needs of society

11 World-Regional Data series: 1971 - 1998

AND IN THE ENERGY SYSTEM

GREENHOUSE GAS EMISSIONS: IDENTITY

\[
GGE = \frac{GGE}{E} \cdot \frac{E}{VKT} \cdot \frac{VKT}{PKT} \cdot PKT
\]

\[
\frac{E}{PKT} = \text{Energy Intensity}
\]
GLOBAL TRAVEL DEMAND MODEL

• Driving forces: growth in population and GDP/cap
• Schäfer/Victor (2000):
  – Historical dataset: 1960 - 1990
  – Constraints: fixed budgets of money and time, others
  – Balancing equations of travel time and speeds
  – Aggregate of urban and intercity transport
• Currently under development:
  – Historical dataset: 1950 - 2000
  – Multinominal LOGIT model for mode choice simulation
• Next generation:
  – Separation of urban and intercity travel
  – Mixed LOGIT model for mode choice simulation
AND MACROBEHAVIOR: TTB

African Villages in:
I Tanzania, 1986
II Ghana, 1988

City Surveys:
1 Tianjin (China), 1993
2 Kazanlik (Bulgaria), 1965/66
3 Lima-Callao (Peru), 1965/66
4 Pskov (Former USSR), 1965/66
5 Maribor (Former Yugoslavia), 1965/66
6 Kragujevac (F. Yugoslavia), 1965/66
7 Torun (Poland), 1965/66
8 Győr (Hungary), 1965/66
9 Olomouc (Former CSFR), 1965/66
10 Hoyerswerde (Former GDR), 1965/66
11 Sao Paulo (Brazil), 1993
12 Sao Paulo (Brazil), 1977
13 Warsaw (Poland), 1993
14 6 Cities (France), 1965/66
15 Osnabrück (Germany), 1965/66
16 44 Cities (USA), 1965/66
17 Jackson (USA), 1965/66
18 Paris (France), 1976
19 Paris (France), 1983
20 Paris (France), 1991
21 Sendai (Japan), 1972
22 Sapporo (Japan), 1972
23 Kanazawa (Japan), 1974
24 Kagoshima (Japan), 1974
25 Kumamoto (Japan), 1973
26 Hamamatsu (Japan), 1975
27 Fukui (Japan), 1977
28 Niigata (Japan), 1978
29 Hiroshima (Japan), 1978
30 Osaka (Japan), 1980
31 Tokyo (Japan), 1980
32 Osaka (Japan), 1985
33 Tokyo (Japan), 1985
34 Cities No. 21-29 in 1987
35 Tokyo (Japan), 1990
36 Osaka (Japan), 1990

National Travel Surveys:
A Belgium, 1965/66
B Austria, 1983
C Great Britain, 1985/86
D Germany, 1976
E Netherlands, 1979
F Great Britain, 1989/91
G Finland, 1986
H Netherlands, 1987
I France, 1984
J Germany, 1982
K Netherlands, 1989
L USA, 1990
M Germany, 1989
N Switzerland, 1984
O Switzerland, 1989
P Australia, 1986
Q Singapore, 1991
R Norway, 1985
S Norway, 1992
T Japan, 1987

NOTE: increase in time dedicated to sleep and leisure statistically significant @ 95% confidence, as opposed to change in other time allocations.
Data source: Szalai et al.(1972), data from 11 countries, population between 18 and 65 years of age.
AGGREGATE TRAVEL BEHAVIOR: TMB

Hypothetical Target Point at:
600 km/h x 1.2 h/d x 365 d/yr = 262,800 km/yr

Source: A. Schäfer, Global Passenger Mobility Data Set, Version 1.0, University of Cambridge, Sept. 2005
Source: A. Schäfer, Global Passenger Mobility Data Set, Version 1.0, University of Cambridge, Sept. 2005
Source: A. Schäfer, Global Passenger Mobility Data Set, Version 1.0, University of Cambridge, Sept. 2005
HIGH-SPEED TRANSPORT (1950-2000)

Source: A. Schäfer, Global Passenger Mobility Data Set, Version 1.0, University of Cambridge, Sept. 2005
HOWEVER: More careful separation between urban and intercity travel necessary!

Source: A. Schäfer, Global Passenger Mobility Data Set, Version 1.0, University of Cambridge, Sept. 2005
GLOBAL MOBILITY: PAST, PRESENT, FUTURE

Based upon a travel time budget of 1.1 h/cap/d

CAN GROWTH IN WORLD PKT ENDURE?

• Availability of high-speed transport technology (⇒ supersonic transport)
• Traffic congestion (⇒ innovation and adaptation)
• Transportation substitutes (⇒ complement vs. substitute)
• Energy resources (⇒ geographic location of reserves)
• Environment (⇒ impact of global warming policies)
GREENHOUSE GAS EMISSIONS: IDENTITY

\[
GGE = \frac{GGE}{E} \cdot \frac{E}{VKT} \cdot \frac{VKT}{PKT} \cdot PKT
\]

\[
\frac{E}{PKT} = \text{Energy Intensity}
\]
TRENDS IN ENERGY INTENSITY

Source: Schäfer A., work in progress
OFFSETTING TRENDS

+ E/PKT
Shift toward faster and more energy-intensive modes
Trend toward larger and more powerful light-duty vehicles
Declining occupancy rates in light-duty vehicles

- E/PKT
Fuel efficiency improvements of all modes
Rising occupancy rates (passenger load factors) in air traffic
DETERMINANTS OF LDV ENERGY INTENSITY

United States

Source: Schäfer A., work in progress
HOW TO REDUCE LDV ENERGY USE?

• Demand and Supply Management
  – Car pooling, telecommuting, pricing measures to induce time and/or mode shift, land-use planning, etc.
  – Comparatively small potential, even if combined in packages

• Technology-Solutions
  – Increase energy efficiency
  – Single largest potential
THE PROMISE OF ZERO-CARBON FUELS

BARRIERS TO TECHNOLOGY SOLUTIONS

- Long time scales for “sensible” fleet impact of new, fuel-saving technology (20 – 35 years, depending on technology; 50+ years for zero-carbon fuels)
- High implicit consumer discount rates (≈ 3 year amortization period for fuel-saving technology)
- Thus, need for policy measures: Optimum introduction of technology (U.S. case study)
MARKAL cost-minimization similar to utility-maximization if vehicle attributes other than energy use and costs don’t change.

## ALTERNATIVE AUTO-TECHNOLOGIES (US)

<table>
<thead>
<tr>
<th>Tech.Name</th>
<th>Characteristic</th>
<th>Fuel Efficiency / Use</th>
<th>Investments, US$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MPG</td>
<td>L/100km</td>
</tr>
<tr>
<td>Zero-Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>22.1</td>
<td>10.6</td>
</tr>
<tr>
<td>Packaging Improvements</td>
<td></td>
<td>27.2</td>
<td>8.66</td>
</tr>
<tr>
<td>Engine Management</td>
<td></td>
<td>27.9</td>
<td>8.45</td>
</tr>
<tr>
<td>Lower Cd, RRC</td>
<td></td>
<td>29.0</td>
<td>8.12</td>
</tr>
<tr>
<td>LoCost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CVT</td>
<td></td>
<td>32.2</td>
<td>7.30</td>
</tr>
<tr>
<td>Material Substitution, interior</td>
<td></td>
<td>32.6</td>
<td>7.21</td>
</tr>
<tr>
<td>HSSt, unibody</td>
<td></td>
<td>33.6</td>
<td>7.00</td>
</tr>
<tr>
<td>PowTrain1</td>
<td>Higher Compression Ratio</td>
<td>34.1</td>
<td>6.91</td>
</tr>
<tr>
<td>PowTrain2</td>
<td>VVLT &amp; Cylinder Deactivation</td>
<td>36.0</td>
<td>6.54</td>
</tr>
<tr>
<td>EPS, Red. of parasitic Losses</td>
<td></td>
<td>36.8</td>
<td>6.39</td>
</tr>
<tr>
<td>Alum</td>
<td>Al-intensive</td>
<td>42.1</td>
<td>5.58</td>
</tr>
<tr>
<td>Hybrid</td>
<td>VVLT &amp; Cyl. D., no Brake Drag</td>
<td>45.2</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>Hybrid Vehicle</td>
<td>53.6</td>
<td>4.39</td>
</tr>
</tbody>
</table>

Fuel efficiency based upon real driving conditions, i.e. U.S. FTP-75 Driving Cycle / 1.21
Based upon Capital Recovery Factor of 34%/yr, a gasoline price of U.S.$ 1.20/GAL, and an annual driving distance of 10,960 mi (17,630 km).

A BRIEF LOOK AT AIR TRAFFIC

**ENERGY INTENSITY VS. DEMAND**

% Energy intensity change by 2050:

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft Technology †</td>
<td>-25</td>
<td>-45</td>
</tr>
<tr>
<td>PAX Load Factor</td>
<td>-10</td>
<td>-10</td>
</tr>
<tr>
<td>High-Speed Rail ‡</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Direct Flight Routings</td>
<td>0</td>
<td>-11</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>-33</td>
<td>-56</td>
</tr>
</tbody>
</table>

† Due to fleet turnover, average aircraft technology in 2050 corresponds to average new aircraft technology in 2025 (ultimately dependent on fleet growth)
‡ High-speed rail substitutes 50% of A/C-PKT in 10 U.S. high-density corridors with a cumulative great circle distance of 16,700km

Projected (global) growth in A/C-PKT: 3 – 12 X yr 2000-level

Summary

• As a direct consequence of economic development, transportation is becoming the major final energy consumer and carbon dioxide emitter.

• Strong forces in transportation system: rising income translates into rising travel demand and shift toward faster, more energy-intensive modes ⇒ rising significance of air travel.

• Decoupling of travel demand from economic growth unlikely, at least during the next decades.

• Zero-carbon fuels necessary to decouple carbon emissions from transport demand; however, time scales are 50+ years for significant fleet impact.
• Significant fuel efficiency improvements are expensive and consumer amortization periods for fuel-saving technology are short $\Rightarrow$ public policy measures to move more fuel-efficient vehicles into the market.

• If accomplished via fuel price increases (e.g., through a uniform carbon tax across all sectors – the economically most efficient way), then:
  – Very high fuel prices (taxes) are necessary to achieve a sensible emission reduction ($\Rightarrow$ public acceptance)
  – Marginal emission reduction costs may be lower in other sectors than transportation; thus further increase in the relative importance of transportation in energy use and emissions
  – Thus, some combination of policy measures necessary