Using a Systems Approach to Unravel Feedback Mechanisms Affecting Urban Transport Choices

Mark Bachels, John Peet[1] and Peter Newman[2]
Canterbury Regional Council (and University of Canterbury)
PO Box 345, Christchurch, New Zealand
Ph 643-365-3828x7184, Fax 643-365-3194
email: markb@crc.govt.nz.

ABSTRACT
Systems thinking and systems influence diagrams are used to gain insight into policy planning practices affecting urban transport choices and transport energy use. Data on land use, transport, economic and environmental indicators from 49 international cities (including cities in the USA, Australia/New Zealand, Europe and Asia) are used to evaluate proposed transport and land use system interactions. Correlation analysis is conducted to determine the validity of the proposed influences and as a first step in examining the strength of these interactions. Positive feedback results are found which increase car use for some planning policies in urban land use planning, transport planning and public transport service provision; indicative results are also found for transport safety influences. Some measures of transport demand management are assessed and found to reduce car dependence. Traditional planning approaches may be overly simplistic and relatively linear, and thus miss many important feedback mechanisms affecting urban transport choices resulting in unintended increases in car use. An holistic systems approach to transport and land use planning appears to capture some of these feedback mechanisms and may shed light on ways to reduce car dependence.

1. Introduction – Transport and Land Use Policies Affecting Car Dependence

This paper explores potential positive feedback mechanisms from transport and land use planning policies which might be reinforcing urban car dependence. The interactions between transport and land use policies and transport outcomes and effects are complex. Traditional planning approaches may be overly simplistic and relatively linear, and thus miss many important feedback mechanisms affecting urban transport choices; without taking account of such feedback mechanisms, such a linear approach may in fact result in unintended increases in car use. Systems modelling is used to attempt to clarify some of this complexity, identify some possible feedback mechanisms which might be hidden in a linear planning approach, and provide insights into what policies might be pursued to reduce growing car dependence.

The interaction between land use and transport has been a topic of long-standing research and debate (see Jacobs, 1961; May and Gardner, 1990; Pushkarev and Zupan, 1977; Bernick and Cervero, 1997; Newman and Kenworthy, 1989 and 1998; Bachels, 1996 and 1998).

Recent regulations in a number of countries point to the need to directly integrate transport and land use planning and development (ISTEA, 1991; TEA-21, 1998; CAAA, 1990; DOE/DOT, 1994). As a result of increasing transport pressures on limited world and urban resources, the transport-land use debate will undoubtedly continue to be of considerable interest.

Problems associated with increasing car dependence are indeed vast (see Newman and Kenworthy, 1998; OECD/IEA, 1997), including: threats to long-term fossil fuel reserves (and particularly national supply where many countries currently import far more oil than they produce domestically); local and global air pollution problems resulting from transport energy consumption; significant increases in urban congestion; increasing social isolation in some suburban communities lacking a "sense of place"; there are also growing concerns about the social affordability of meeting what at times appears to be an insatiable appetite for faster further travel (Hillman, 1996). All of these issues contribute to a growing tide of concern that alternatives to car dependence need to be provided. As Bernick and Cervero (1997) in America suggest there is a "growing recognition of the limits of automobility in America" (p 13).

In an attempt to unravel some of this complexity, and as a means of reducing car dependence, this paper reports on the use of qualitative systems modelling as a tool for identifying potential feedback from planning policies, which affect urban transport choices.

2. Applying Systems Modelling Approaches in Urban Transport Interactions

Following Bossel (1994), a systems approach for the development of qualitative models has been applied, and qualitative systems models are developed to identify potential interactions between various urban transport and land use policies, and potential effects on car use or modal split decisions. A number of interactions between transport and land use policies are investigated including:

- urban form (population density and urban area);
- transport provision (road infrastructure and public transport provision);
- traffic management (traffic speeds and safety); and
- traffic demand management measures (parking, vehicle pricing and traffic priority for alternatives).

Qualitative feedback loops are proposed below for a number of these interactions, and data from 49 international cities are used to test these systems models.

It should be made clear that these proposed systems models (and the testing techniques developed) should be considered a first cut in identifying and developing possible quantitative models. A great deal more analytical work would need to be conducted to adequately verify these proposed interactions, and to develop the models further for quantitatively assessing possible policy choices and potential outcomes.

3. 49 City Data Set - Indicators and Regression Analysis

This analysis utilises a set of data collected on urban transport and land use indicators. The indicator framework was developed for the Global Cities Study at ISTP[3], Murdoch University, Perth Western, Australia (Newman and Kenworthy 1989, 1998; and Kenworthy et al, 1997). The framework focuses on land transport characteristics of urban areas, including specific indicators on transport systems and their use, land use, economic activity and transport investment, and consequent environmental effects in terms of energy consumption and estimated air emissions.

Over 40 indicators were collected for 49 metropolitan areas for cities in the USA, Australia/New Zealand, Europe, Canada and Asia for 1990.[4] The 49 city data set is referred to as the Global Cities Data in this research. The data fall into the following general categories:

> *Land Use, Demographic and Economic Data* - For three distinct areas (central business district, inner city and metropolitan area) data were collected for population, jobs and urbanised land use; for the metropolitan area economic data were collected on gross regional product.
>
> *Transport Characteristics* - For the metropolitan area data were collected on such figures as the number of vehicles, use of vehicles, road network speed, kilometres of roadway, modal share, public transport data (patronage, vehicle service provisions, costs of operation, etc.), and the costs and performance of the transport systems including investment in roading and public transport, costs of transport use, energy use and estimated emissions to air.

Systems models (described below) are developed to qualitatively capture proposed influences between transport and land use policies, and transport choices. The Global Cities Data set is used to test the correlation relationships between the variables of these proposed influences.

4. Proposed Systems Models – Development and Test Results

Due to the brevity of this paper, only the summary results of this research are presented.[5] Qualitative feedback models were developed for a number of planning policy issues including urban area and population density, road building, public transport provision and use, traffic safety and slow mode use, and traffic demand management measures. Variables for each of these system models were developed from the Global Cities Data. Regression analysis was then conducted for the "strength" of relationship between variables as a means of "testing" the validity of proposed qualitative feedback models.

The results of the tests on each proposed systems model are presented below.

For each of the systems models shown, influences were proposed between variables and each influence was assigned an equation number (eg, 1a, 1b, 2, 3, etc.). Using the indicators collected in the Global Cities Data, each of the influence variables were assigned relevant indicators. Correlation analysis was then conducted on the relationship between variables of each systems model in order to test:

- the strength of the relationship between variables (the correlation of determination (r^2) value);
- the statistical validity of the relationship (P value); and
- the "polarity" of the proposed relationship (the positive or negative influence between variables).

Note higher values of the correlation of determination (r^2) indicate a stronger relationship between variables; P values less than 0.005 were generally obtained suggesting statistically valid results.

Figures for each of the proposed systems models are presented below in an influence diagram, where influence between variables is indicated by an arrow and a sign of polarity (+ or -). Statistical correlation results from testing the relationships (r^2, P values and mathematical "polarity") are then presented in tables for each of the proposed systems models.

4.1. The Urban Form (Area and Density) Systems Model

The "urban form" systems model was developed proposing a number of interactions between urban land use policies and transport choices, shown in Figure 1. The proposed systems model suggests that increasing urban area and decreasing population density results in increasing trip length and travel per annum, decreasing use of alternative transport, and overall, positive unchecked feedback for increasing car use.

Figure 1 includes the relative "weighting" of influence where a heavier line indicates a higher r^2 value – the result of the correlation analysis shown below in Table 1 (e.g., the influence (r^2) of density and urban area on travel km per capita (equations 1a and 6a) both had reasonably high r^2 values and thus receive heavy lines, whereas the relationship between trip length and car use (equation 2a) showed a statistically significant but much lower r^2 value and is indicated by a dotted line).

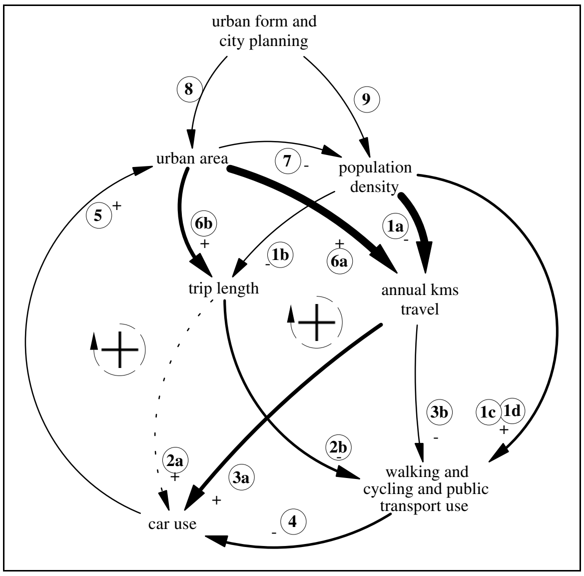

Figure 1: Urban Form Systems Model

The results of the correlation analysis on each influence factor are shown in Table 1. The results of the "test" suggest that there is in fact a very definite positive and unchecked feedback between urban form (urban area and urban density) and increasing car use using the Global Cities Data.

Table 1: Testing Urban Form Systems Model - Correlation Analysis Results

Systems Model Equation #	Correlation of Determination r^2 (or % change in Y explained by change in X)	Statistical Significance (P Value)	Mathematical Relationship
1a	0.816	0.000	negative power
1b	0.477	0.000	negative power
1c	0.572	0.000	positive power
1c	0.548	0.000	positive power
1c	0.644	0.000	positive power
1d	0.636	0.000	positive power
2a	0.165	0.015	positive power
2b	0.277	0.001	negative power
2b	0.418	0.000	negative power
2b	0.376	0.000	negative power
3a	0.674	0.000	positive power
3b	0.551	0.000	negative power
4	0.696	0.000	negative power
5	0.221	0.003	positive power
6a	0.912	0.000	positive linear
6b	0.437	0.000	positive power
7	0.226	0.001	negative power
8	policy		
9	policy		

The correlation analysis conducted to test the urban form systems model clearly indicates that positive and potentially unintended increases in private car use (and subsequent transport energy use) can occur due to land use planning policies.

4.2. "Road Building" Systems Model Test

The road building systems model is shown Figure 2, and proposes that building more roads (and road capacity) results in increasing car use, which with current planning policies results in increasing demand for road infrastructure, and overall a positive unchecked feedback.[6]

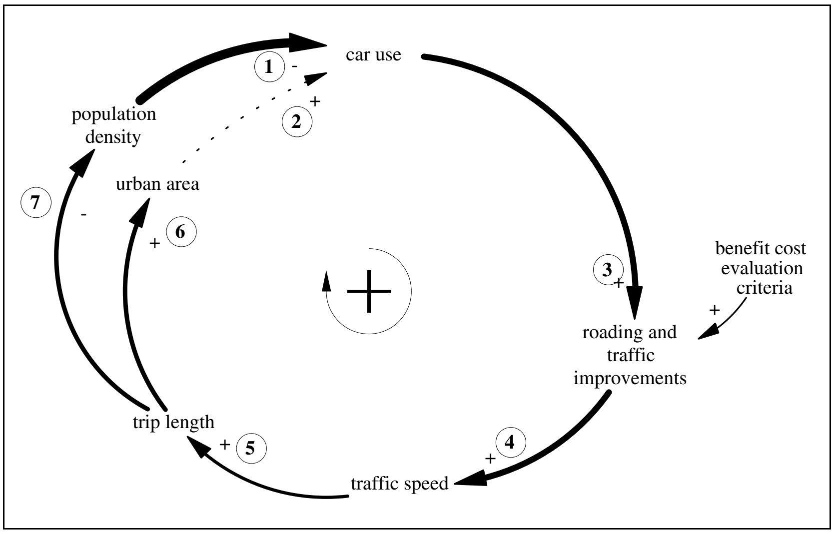

Figure 2: Road Building Systems Model

The results of correlation analysis on each influence factor of the road building systems model are shown in Table 2. The correlation results indicate a strong mechanism for positive unchecked feedback increasing car use from independent planning policies – where increasing roading provision increases travel speed and trip length, increasing the urban area and decreasing population density which both lead to increasing car use, which again leads to a need to build more road capacity. Importantly, all of the polarity signs of influence of the systems model are supported by the mathematical functional relationships (negative/positive power functions), supporting the premise of unchecked positive system feedback of the "road building" model.

Table 2: Testing Road Building Systems Model - Correlation Analysis Results

Systems Model Equation #	Correlation of Determination r^2 (or % change in Y explained by change in X)	Statistical Significance (P Value)	Mathematical Relationship
1	0.816	0.000	negative power
2	0.177	0.003	positive power
3	0.751	0.000	positive power
4	0.671	0.000	positive power
5	0.431	0.000	positive power
6	0.437	0.000	positive power
7	0.477	0.000	negative power

4.3. Public Transport Systems Model - Service Provision and Use

The proposed public transport systems model shown in Figure 3 suggests that increasing service quality results in increasing use and increasing fares revenue, which when combined with funding policies, can result in increasing service provision and generally a positive feedback loop (or conversely, decreasing public transport use results in less service and in turn less use).

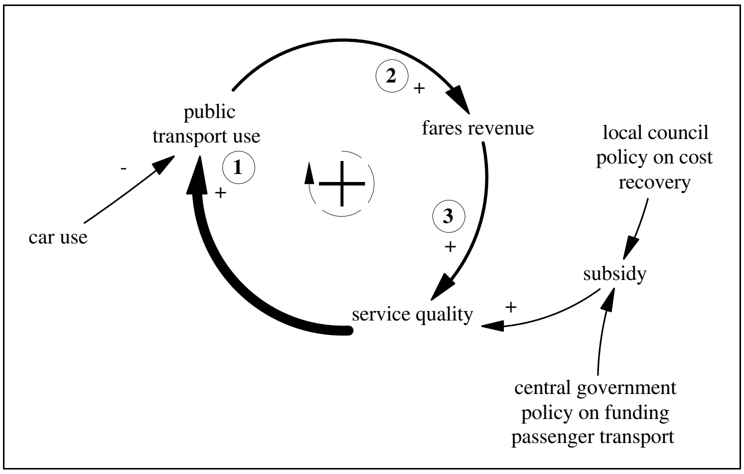

Figure 3: Public Transport Systems Model

The correlation analysis for each proposed influence is shown in Table 3. Overall, the correlation analyses of the Global Cities Data set confirm the public transport systems model developed, where increasing service delivery yields both increasing public transport use (trips per capita) and increasing fare revenue (where cost recovery was used as a proxy for fares revenue), with highly significant statistical correlations for all relationships modelled.

Table 3: Testing Public Transport Systems Model - Correlation Analysis Results

Systems Model Equation #	Correlation of Determination r^2 (or % change in Y explained by change in X)	Statistical Significance (P Value)	Mathematical Relationship
1	0.825	0.000	positive power
2	0.450	0.000	positive power
3	0.423	0.000	positive power
4	0.635	0.000	negative power

Importantly, the results of the correlation analysis support a positive feedback mechanism for public transport, which when affected by increasing car use, quickly turns to a vicious cycle of reducing public transport use.

4.4. Slow Mode Safety Systems Model

The "slow mode safety" systems model shown in Figure 4, proposes that increasing car traffic speeds and volumes deter cyclist and pedestrian activities.

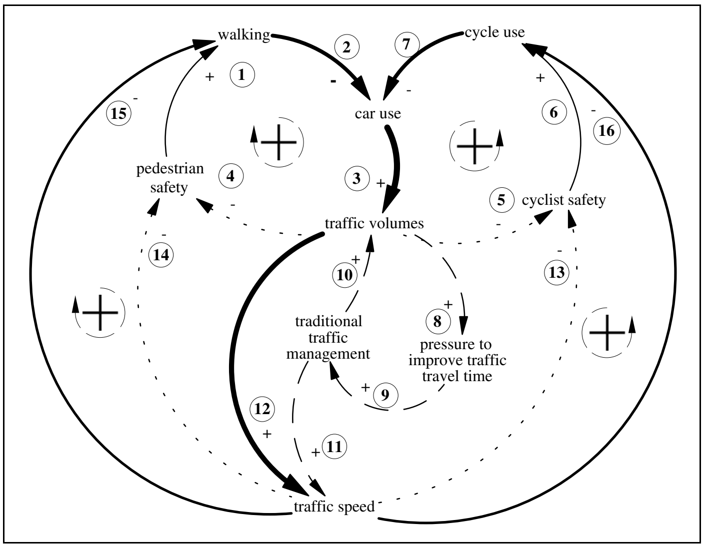

Figure 4: Slow Mode Safety Systems Model

The results of the correlation analysis are shown in Table 4. The results generally confirm that positive feedback is exhibited where increasing traffic decreases safety for slower modes which decreases their use. And importantly all of the polarities of influence tested were confirmed, supporting the positive feedback suggested by the "slow mode safety" systems model.[7]

Table 4: Testing Safety Systems Model - Correlation Analysis Results

Systems Model Equation #	Correlation of Determination r^2 (or % change in Y explained by change in X)	Statistical Significance (P Value)	Mathematical Relationship
1	0.244	0.001	positive power
2	0.532	0.000	negative power
3	0.674	0.000	positive power
4	0.146	0.016	negative power
5	0.146	0.016	negative power
6	0.244	0.001	positive power
7	0.532	0.000	negative power
8	policy		
9	policy		
10	policy		
11	policy		
12	0.586	0.000	positive power
13	0.158	0.018	positive power
14	0.158	0.018	positive power
15	0.334	0.000	negative power
16	0.334	0.000	negative power

4.5. Traffic Demand Management–Balancing Feedback

The introduction of traffic demand management (TDM) measures as possible "balancing" or negative feedback policies are the final systems model tested using the Global Cities Data set.

Using the Global Cities Data a number of traffic demand management approaches are tested including:[8]

- Priority for public transport using a ratio between public transport and private transport speeds;
- Pricing externalities using the variable (or marginal) cost of car use;
- Parking controls using the variable for the central business district (CBD) parking provisions ("1000 CBD Worker per parking space").

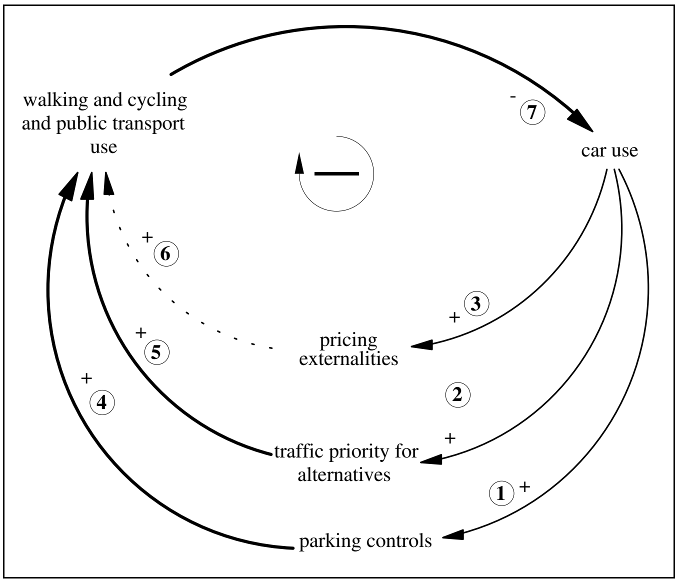

Figure 5: Traffic Demand Management Systems Model

The results of the correlation tests of the systems model are shown in Table 5. The correlation analysis results of the Global Cites Data set confirm that the traffic demand management policies tested could be used as "balancing" or negative feedback for increasing car use. Three separate feedback loops were considered including parking policies (availability), giving greater priority to public transport by improving the ratio of public transport speeds relative to car traffic speeds, and increasing the variable costs of car travel per km as a surrogate for "pricing externalities".

Table 5: Testing Traffic Demand Management Systems Model - Correlation Analysis

Systems Model Equation #	Correlation of Determination r^2 (or % change in Y explained by change in X)	Statistical Significance (P Value)	Mathematical Relationship
1	policy		
2	policy		
3	policy		
4	0.480	0.000	positive power
5	0.639	0.000	positive power
6	0.184	0.006	positive power
7	0.696	0.000	negative power

Overall the results of the regression analysis using data from 49 cities in the Global Cities Data confirm that negative feedback for car use can be introduced under the umbrella of traffic demand management measures.

5. Complexity of Interactions - Connecting Systems Models

Although not explored in detail in this brief paper, linking the various systems models explored in this research reveals the complexity of the interactions affecting transport choices. Figure 6 shows the links between various transport planning policies explored which affect transport choices. Although not pursued in this paper, the complexity of these interactions suggests that quantitative systems modelling could reveal more about the planning policy interactions affecting urban transport choices.

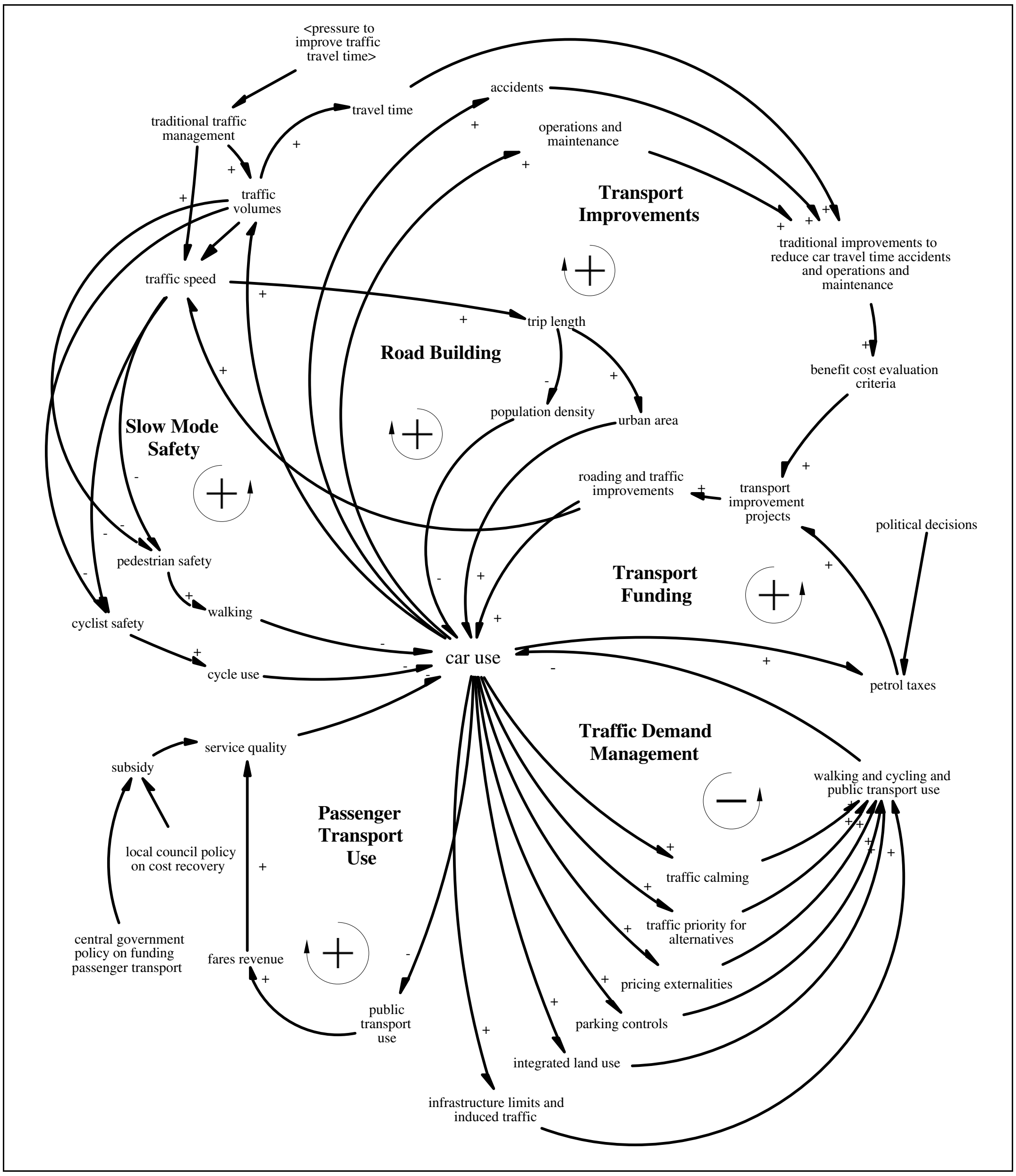

Figure 6: Interacting Transport Planning

6. Conclusions of System Model Tests

As the results of correlation analysis across data for 49 cities between dependent and independent variables indicate, there are significant positive feedback mechanisms occurring between independent planning policies and transport choices – all of which may lead to unintended increasing car use. In all cases the correlation relationships supported the contention of "polarity" between factors developed in the proposed systems models. Also importantly most of the correlation of determination results were highly statistically significant (generally with a P value less than 0.005), suggesting that the relationships were statistically accurate.

In some models the positive influence between variables appeared to be very strong (with correlation of determination results showing r^2 above 0.8), in others there were moderately strong relationships (r^2 about 0.5) and others with a weaker but still statistically significant correlation (r^2 of 0.2). Overall the correlation results supported the predicted influence polarities in the proposed systems models. As described by Bossel (1994) the development of systems models and systems loops comes from personal knowledge and to some degree intuition. As shown in the tests of systems models developed in this research, there is variation across relationships and some appear to have reasonably weak influence (with low r^2 values, depicted by lighter lines in the resulting diagrams); however, some of these influences may be stronger than this simple correlation analysis shows. To determine more accurate respective influence would require multivariate regression analysis and further research (including improving some of the identified "gaps" in the data).

Positive feedback was strongly confirmed for the "urban form", "road building" and "public transport" influence diagrams and moderately confirmed for the "slow mode safety" model. Unfortunately there were limits to the data used to adequately test some of the proposed influences in the "slow mode safety" influence diagram.

In addition, the "balancing" or negative feedback was confirmed for potential "traffic demand management" approaches tested (including central city parking supply, improving public transport speeds with respect to private traffic speeds, and increasing variable costs of cars).

Finally, it is important to note that this analysis should not be considered as definitive "policy prescriptions". Additional analysis would need to be conducted including multivariate correlation analysis, and quantitative systems modelling, to determine relative strengths between relationships and variables and to further explore the complexity of these relationships.

What the results suggest is that, typically, planning policies look at linear relationships (e.g., congestion leads to the need to increase road capacity), instead of considering a more holistic view of the consequences and complexities of feedback mechanisms affecting car use. The use of systems modelling has allowed some of this complexity to be uncovered. The results suggest that linear planning policy approaches require a more holistic appraisal if car dependence (and associated energy use) are to be reduced.

7. References

Bachels, M. 1996. "Developing Positive Feedback for Sustainable Transport: learning from car-dependence", Sustainable Energy Forum Conference, Tauranga, New Zealand, March 29-30, pp21-30 (contact primary author).

Bachels, M. 1998. "Opportunities and Threats for Sustainable Urban Transport 'Getting the Right Balance'", Urban Transport Forum, March 2-3, 1998, Wellington (contact primary author).

Bachels, M., Newman, P., and Kenworthy J., 1999. "Indicators of Urban Transport Efficiency in New Zealand's Main Cities", a study prepared for a number of New Zealand government bodies, and published by the Institute for Science and Technology Policy, Murdoch University (contact ISTP at Murdoch University).

Bernick, M.and Cervero, R. 1997. *Transit Villages in the 21st Century*. McGraw-Hill, USA.
Bossel, H. 1994. *Modeling and Simulation*, AK Peters Ltd, USA.
DOE/DOT, 1994. "Planning Policy Guidance: Transport (PPG 13)", Department of the Environment and Department of Transport, HMSO, London.
Hillman, M. 1996. "Curbing car use: The dangers of exaggerating the future role of public transport", *Traffic Engineering + Control*, January.
ISTEA 1991. 1991 Intermodal Surface Transportation Efficiency Act, USA.
Jacobs, J. 1961. *The Death and Life of Great American Cities*. Vintage Books, New York.
Kenworthy, J., Laube, F., Newman, P., Barter, P. 1997 "Indicators of Transport Efficiency in 37 Global Cities", a report produced for the World Bank, ISTP, Murdoch University, February (contact Peter Newman at ISTP).
May, A.D. and Gardener, K.E. 1990. "Transport policy for London in 2001: the case for an integrated approach". *Transportation* 16 pp257-277.
Newman, P. and Kenworthy J. 1989. *Cities and Automobile Dependence*, Gower Technical: Aldershot.
Newman, P. and Kenworthy, J. 1998. *Sustainability and Cities: Overcoming Automobile Dependence*, Island Press, Washington DC.
OECD/IEA, 1997. *Transport, Energy and Climate Change.* Energy and Environment, Policy Analysis Series, OECD, Paris, France.
TEA-21 1998. Transport Equity Act, USA.

---

[1] Senior Lecturer, University of Canterbury, Private Bag, Christchurch, New Zealand, email: j.peet@cape.canterbury.ac.nz.
[2] Professor City Policy, Director ISTP, Murdoch University, Western Australia, email: newman@murdoch.edu.au.
[3] The Institute for Science and Technology Policy (ISTP).
[4] For detailed results of city data refer to Newman and Kenworthy (1998); Kenworthy, Laube et al (1999); and Bachels, Newman and Kenworthy (1999).
[5] This research was conducted as part of a PhD at the University of Canterbury. For further information please contact the primary author of this paper.
[6] Note, one significant policy instrument is depicted - the "benefit-cost evaluation criteria" which is typically used in decisions to increase road capacity.
[7] Overall, there were some limits found in utilising the Global Cities Data set for testing the slow mode safety influence diagram. Generally, the Global Cities Data set does not capture time-sensitive indicators like traffic volume or congestion; data on cycling and walking are rather limited (only a combined indicator for the journey-to-work is available); and traffic safety data are also somewhat limited (where traffic fatality data are for the total transport system not a specific mode).
[8] The traffic demand management measures which could not be tested using the Global Cities Data set include such measures as traffic calming, induced traffic in roading project evaluations, integrated land use and transport planning, improving accessibility, and pricing other externalities like air emissions, etc.