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Waldo Tobler
Using Asymmetry to Estimate Potential
From a talk given in Redondo Beach, CA--1005.
[ed.] Readers who enjoy Professor Tobler's article may also wish to consider work by Jerrold Grossman involving Research on Collaboration in Research, http://www.oakland.edu/enp/research.html, and related topics on Professor Grossman's home page, http://personalwebs.oakland.edu/~grossman/

John D. Nystuen
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Virtual Flood in the Allen Creek Floodplain and Floodway

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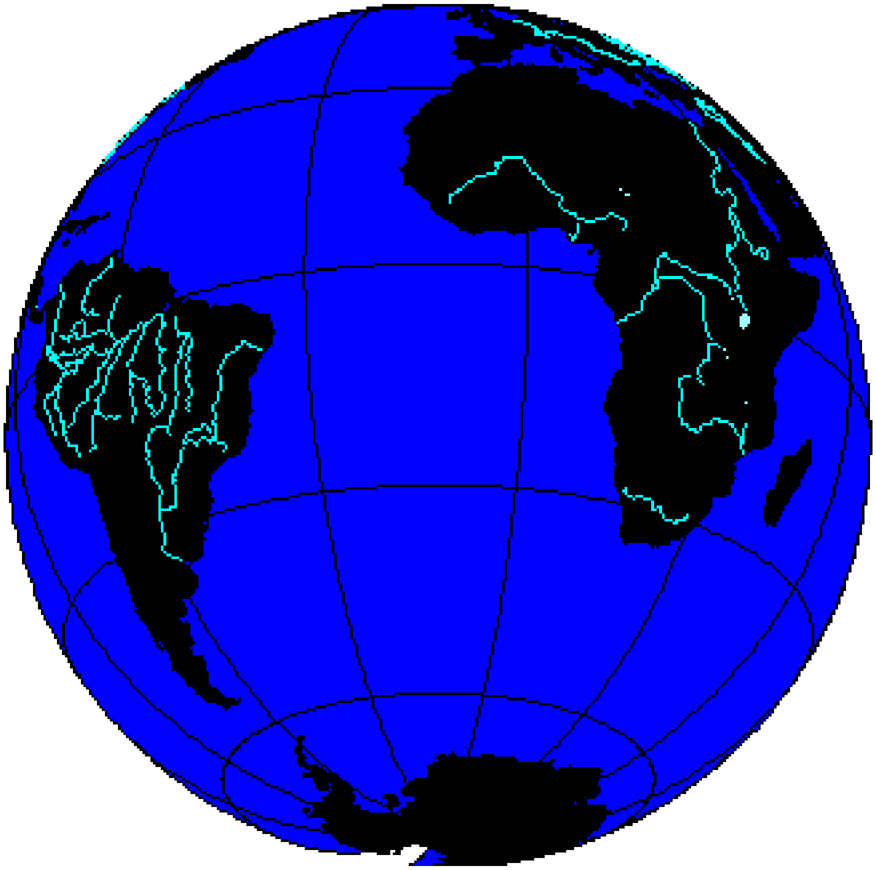

Earth: with 23.5 degrees south latitude as the central parallel.

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MISSION STATEMENT

The purpose of Solstice is to promote interaction between geography and mathematics. Articles in which elements of one discipline are used to shed light on the other are particularly sought. Also welcome are original contributions that are purely geographical or purely mathematical. These may be prefaced (by editor or author) with commentary suggesting directions that might lead toward the desired interactions.

Individuals wishing to submit articles or other material should contact an editor, or send e-mail directly to sarhaus@umich.edu.

SOLSTICE ARCHIVES

Back issues of Solstice are available on the WebSite of the Institute of Mathematical Geography, http://www.imagenet.org and at various sites that can be found by searching under "Solstice" on the World Wide Web. Thanks to Bruce Long (Arizona State University, Department of Mathematics) for taking an early initiative in archiving Solstice using GOPHER.

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Awards and Recognition

(See Press Clippings page for other.)

- Sandra L. Arlinghaus and William C. Arlinghaus, Spatial Synthesis Sampler, *Solstice*, Summer 2004. Semi-Finalist, Pirelli 2003 INTERNETional Award Competition.
- Sandra Lach Arlinghaus, recipient, The President's Volunteer Service Award, March 11, 2004.
- Jeffrey A. Nystuen, won the 2003 Medwin Prize in Acoustical Oceanography given by the Acoustical Society of America. The citation was "for the innovative use of sound to measure rainfall rate and type at sea". It is awarded to a young/mid-career scientist whose work demonstrates the effective use of sound in the discovery and understanding of physical and biological parameters and processes in the sea.
- Sandra L. Arlinghaus, William C. Arlinghaus, and Frank Harary. *Graph Theory and Geography: an Interactive View (eBook)*, published by John Wiley and Sons, New York, April 2002. Finished as a Finalist in the 2002 Pirelli INTERNETional Award Competition (in the top 20 of over 1200 entries worldwide). Link to Pirelli website and to downloaded pages concerning this particular competition: 1, 2, 3.
- *Solstice*, Semi-Finalist, Pirelli 2001 INTERNETional Award Competition in the Environmental Publishing category.
- *Solstice*, article about it by Ivars Peterson in *Science News*, 25 January, 1992..
- *Solstice*, article about it by Joe Palca, *Science* (AAAS), 29 November, 1991.

Exploring the relationships between land-use system and travel behaviour concepts: some first findings

Veronique Van Acker*, Frank Witlox**

Key words useful for searching:
Land-use/transportation system, Travel behaviour, Attitude measurement, Structural equation modelling.

File Navigation:
Footnotes are linked in both directions. References are linked only from inline reference to reference set and not vice-versa (because there are numerous many-to-one correspondence between inline references and entries in the reference list). Use the browser "back" button to return to the text from a reference.

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Abstract
The aim of this exploration is to try to summarise what is commonly accepted when analysing the relationships between land use and transportation. The interaction between land use and transportation composes the land-use/transportation system.
A large research body exists on the impact of land-use systems on travel behaviour (for reviews, e.g., Handy, 2002; Stead and Marshall, 2001; Crane, 2000; Wegener and Fürst, 1999). In order to obtain a clear overview, a three-fold distinction has been made based on type of variable included. Thus, three dimensions in travel behaviour research have been found: (i) a spatial dimension, (ii) a socio-economic dimension, and (iii) a behavioural dimension.

Less is known about the reverse relationship, i.e., the impact of the transportation system on location decisions of households and firms (the land-use system). The greater part of this research utilizes "accessibility" as an intermediate concept to measure the influence of the transportation system on the land-use system.
The presented literature review enabled us to detect some gaps in the knowledge on the land-use/transportation system. Understanding the interaction between land use and travel behaviour involves having (i) data on land-use patterns; on the socio-economic background of individuals; and on their attitudes, perceptions and preferences toward land use and travel; and (ii) a methodology dealing with potential multiple directions of causality. The first issue can be achieved by combining empirical, revealed, and stated-preference research. The second methodological question can be solved using structural equation modelling (SEM). This is a modelling technique which can handle a large number of independent and dependent variables, as well as multiple directions of causality. These characteristics of SEM seem useful in order to obtain an improved insight in the complex nature of travel behaviour.

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Introduction

The land-use/transportation system (often referred to as LUTS) has been subject of many research studies. The resulting large body of literature on the LUTS reports on the impact of the land-use system on travel behaviour on the one hand, and on the effects of the transportation system on land use on the other hand. Both sets of impact are rarely incorporated simultaneously in one study.

The research done by Mitchell and Rapkin (1954) is considered to be one of the first studies to deal with the exploration of the impact of the land-use system on travel behaviour. Until now, knowledge of the travel consequences of land use has certainly increased, but there is no consensus on the strength of this relationship. Some studies (e.g., Newman and

Kenworthy, 1989; Frank and Pivo, 1994; Ewing, 1994; Cervero and Kockelman, 1997; Meurs and Haaijer, 2001) indicate that various aspects of land use are linked with travel behaviour, while others (e.g., Kitamura et al., 1997; Boarnet and Sarmiento, 1996; Bagley and Mokhtarian, 2002; Schwanen, 2003) found lower effects or virtually no effect at all. A possible explanation may be that different research techniques have been applied, and that different types of explanatory variables were included in the research. Based on a literature review, a three-fold distinction may be made of this research.

1. Initially only land-use variables were taken into account.
2. Earlier results were controlled for socio-economic and socio-demographic variables.
3. However, within so-called "homogeneous groups" (i.e., respondents that are to be considered more or less identical - van Wee, 2002) there may be attitudes, lifestyles, perceptions and preferences which also have an impact on land use or travel behaviour. Currently it seems that more attention is paid to these behavioural aspects of land use and transportation.

The reverse relationship, the impact of the transportation system on land use, has less been the subject of research. Here the research mainly concentrated on accessibility and how it influences land-use patterns. Hansen's contribution (1959) on the impact of accessibility to employment, population and shopping opportunities may be considered ground-breaking.

The two approaches described above clearly demonstrate the difficulty of the problem whereby initial focus, type of model, and methodology used may differ. First, in Section 1, the problem is defined. Section 2 gives an overview of different methodological approaches applied. This overview helps to define the gaps in knowledge, presented in Section 3. Finally, suggestions for further research are made in order to attain a better understanding of the land-use/transportation system.

1. Defining the land-use/transportation system problem

The spatial distribution of activities, such as living, working, recreating or education, implies that people have to travel. Therefore, the land-use configuration is thought to be able to generate particular travel patterns. Consequently, the theoretical foundation for the impact of land use on travel behaviour can be found in the theory of utilitarian travel demand (Lancaster, 1957). This theory postulates that the demand for travel does not derive its utility from the trip itself, but originates from the need to reach the locations where activities take place (van Wee, 2002). This idea seems self-evident, but it remains important to stress the derived nature of travel demand since this offers opportunities to influence travel behaviour by designing specific land-use patterns (e.g., land-use patterns which discourage car use).[1] On the other hand, changes in the transportation system can alter location decisions of households and firms, resulting in a land-use change. For instance, an investment in transportation infrastructure changes the accessibility of a region, which has an impact on housing values, economic development, and so forth. This interaction between land use and transportation composes the land-use/transportation system (LUTS).

1.1 Definitions of the land-use/transportation system

Wegener and Fürst (1999) entitle the LUTS as the 'land-use transportation feedback cycle' (Figure 1). The set of relationships implied by this term can be summarized as follows:

(i) The distribution of land uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities, such as living, working, shopping or education.

(ii) To overcome the distance between the locations of human activities spatial interactions or trips in the transportation system are required.
(iii) The distribution of infrastructure in the transportation system allows spatial interactions and can be measured as accessibility.
(iv) The distribution of accessibility in space co-determines location decisions and so results in changes to land use.

Comparable to Wegener and Fürst (1999), Geurs and Ritsema van Eck (2001) start their study on accessibility measures with a description of the LUTS (Figure 2). They consider a similar interaction between the land-use system and transportation system and go on to define the concepts of these systems. According to them, the land-use system comprises: (i) the spatial distribution characteristics of land uses, such as density, diversity and design; (ii) the locations of human activities; and (iii) the interaction between land uses and activities. The transportation system comprises: (i) travel demand, i.e., the volume and characteristics of travel and movement of goods, (ii) infrastructure supply, i.e., the physical characteristics of infrastructure (e.g., road capacity, speed limits), the characteristics of infrastructure use (e.g., distribution of traffic levels over time, the time-table of public transportation), and the cost and price of infrastructure, vehicles and fuels; and (iii) the interaction between travel demand and infrastructure supply.

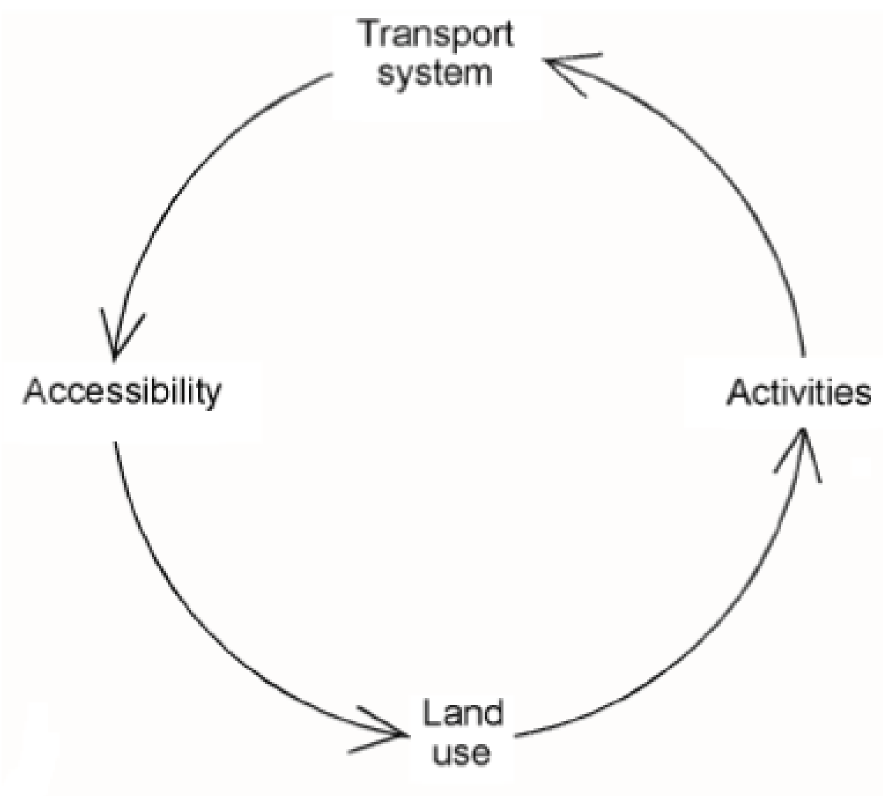

Figure 1: The 'land-use transport feedback cycle'

Source: Wegener and Fürst (1999).

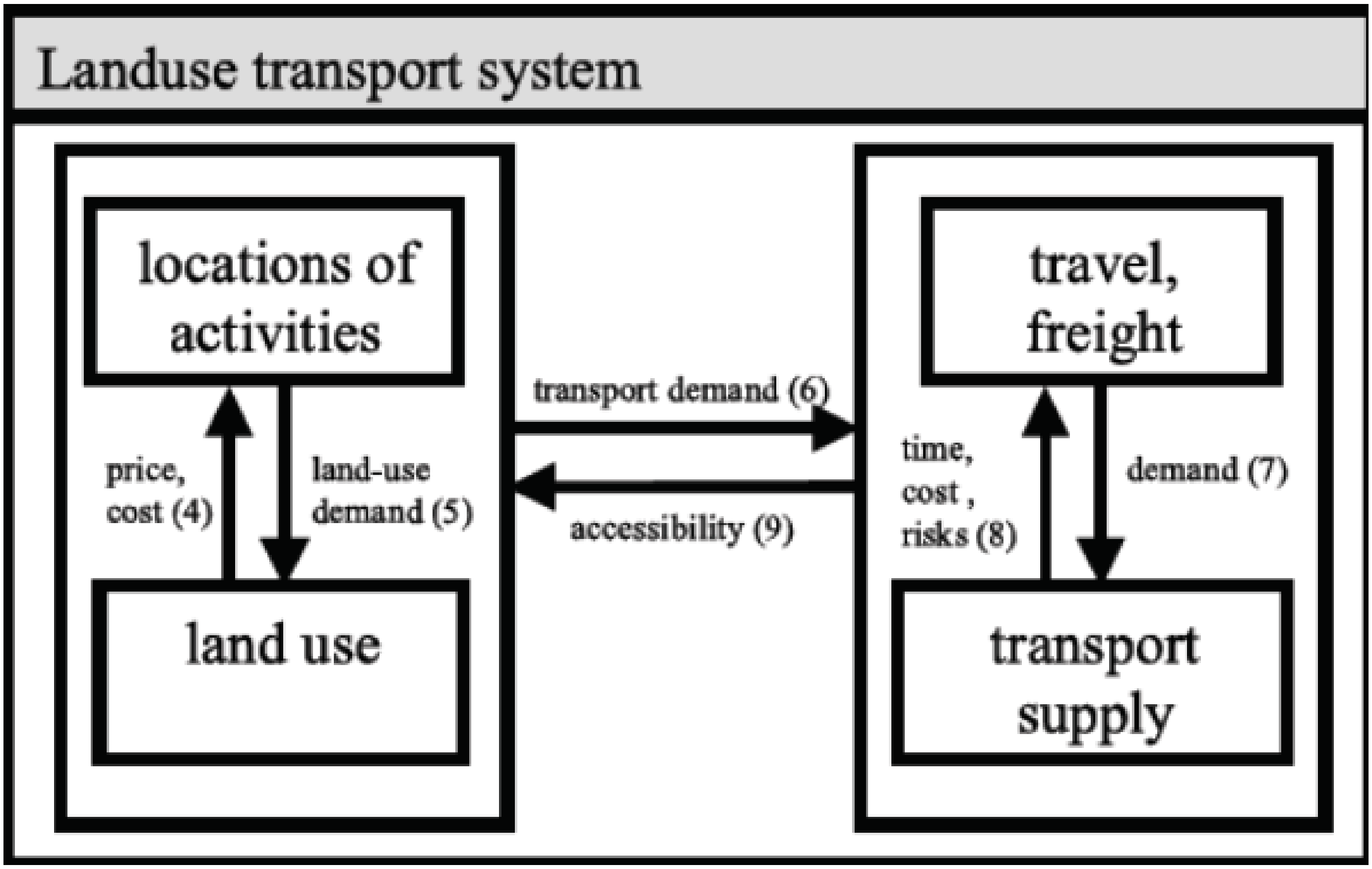

Figure 2: The 'Land-use/Transport system'

Source: Geurs and Ritsema van Eck (2001).

1.2 Definitions of the transportation system

As with Geurs and Ritsema van Eck (2001), most researchers define the transportation system as having a transportation economic background in which supply of and demand for transportation are opposed to each other (White and Senior, 1983; Cascetta, 2001; Rodrigue, 2004). However, it is not sufficient simply to travel demand and supply; the resulting travel behaviour of this interaction needs to be stressed as well. This behavioural component is found in a definition put forward by Korsmit and Houthaeve (1995). They distinguished several ways to describe the transportation system: (i) by the infrastructure network (e.g., the network of facilities for public transportation); (ii) by the use of the facilities (e.g., expressed in number and type of movements); and (iii) by the travel behaviour (e.g., modal choice).
Recently, a more technological approach to the transportation system is given by Donaghy et al. (2004). They define a transportation system as "a complex system composed of infrastructure, logistics and information systems that manage and direct the actual movement of vehicles, ships and airplanes". Note that this definition only includes the supply-side of transportation. Besides traditional infrastructure, such as roads and train lines, logistics and information systems can also be considered as infrastructure to guide travel trips.

1. 3 Definitions of the land-use system

Other definitions for the land-use system than the one given by Geurs and Ritsema van Eck (2001) are hard to find. A notable exception is made by Rodrigue (2004). He makes a distinction between urban form, urban (spatial) structure land use. Urban form refers to "the spatial imprint of an urban transportation system as well as the adjacent physical infrastructures and activities", whereas urban (spatial) structure is defined as "the set of relationships related to the urban form and its interactions of people, freight and information". In this way, urban form is the spatial and visible representation of the urban structure, which consists of functional relationships. Although these definitions make a clear distinction between urban form and urban structure, they over-emphasize transportation. Land uses other than transportation also can influence urban form and urban structure. According to Rodrigue (2004), land use is defined as follows: "While the urban form is mostly concerned by the patterns of nodes and linkages forming the spatial structure of a city, urban land use involves the nature and level of spatial accumulation of activities. The nature of land use relates to which activities are taking place, while the level of spatial accumulation indicates their intensity and concentration. Most human activities, either economic, social or cultural, imply a multitude of functions, such as production, consumption and distribution. These functions are occurring within an activity system where their locations and spatial accumulation form land uses".

2. Review of different methodological approaches

A large body of literature on several aspects of the LUTS exists, involving empirical and modelling studies. In this literature review, the focus is on only empirical studies. Although empirical studies do not easily lend themselves to establish the causality of relationships, they have some advantages (Stead, 1999). First, empirical studies are based on real examples or case studies and rely on fewer assumptions than modelling studies. Second, they are often easier to interpret and transparent in approach, whereas modelling studies are often seen as 'black box' exercises. Third, empirical studies provide data for use in the construction or testing of models.

Research studies seldom consider the LUTS in its totality. Most studies analyze the impact of the land-use system on travel behaviour, whereas a smaller part of the research is concerned about the reverse impact. This distinction is used to structure the current review. Although the review was aimed to be international, most of the reported studies originate from either the United States or Western Europe. Particular attention was paid to spatial scale, method of analysis and, most of all, variables considered.

2.1 The impact of the land-use system on the transportation system

In spite of the extended body of literature on the impact of the land-use system on travel behaviour, a three-fold distinction was found, in accordance with Naess (2003), based on the type of variables included. Doing so, three dimensions in travel behaviour research were distinguished: (i) the spatial dimension, (ii) the socio-economic dimension, and (iii) the behavioural dimension.

2.1.1 The spatial dimension in travel behaviour research

Hurst (1970) focused on trip generation of non-residential land uses in the Central Business District (CBD) in Perth, Scotland, and on some sites outside the CBD. Regression analysis was used, with city size and density as explaining variables[2] Within the CBD, higher rates of goods vehicle trip generation were found among retail and office land uses compared with storage and industrial usage. This fact, he concluded, reflects a differing relationship between intensity of land use and travel volume.

A frequently quoted study in this respect is Newman and Kenworthy (1989), who analysed 32 cities on four continents. They found a significant negative statistical correlation between residential density and transportation-related energy consumption per capita. Their work has become very influential, however, but is not spared from critism (e.g., Gordon and Richardson, 1989). During the 1990s, Kenworthy et al. (1999) updated the original data. Cities in the USA, Canada, Australia and Asia were added to the original dataset. A wide variety of data on land use and transportation in 1960, 1970, 1980 and 1990 was collected. Recently, the collected data set was supplemented with data on population, economy and urban structure in 1995.

Gordon et al. (1989) examined the LUTS for several cities in the United States. The subject of their research was the influence of metropolitan spatial structure on commuting time by car and public transit. Two regressions were run, using density, economic structure, urban size, polycentricism, and income measures as independent variables[3], plus the addition of carpooling in the regression model for automobile commuting time. Polycentric and dispersed metropolitan areas were found to facilitate shorter commuting times, and differentiation among types of densities turned out to be important. Results for public transportation and automobile were found to be similar. The addition of income in the regression analysis indicated the limited interest of researchers for socio-economic variables.

Six neighbourhoods in Palm Beach County, Florida, were used by Ewing et al. (1994) to examine the impact of density, diversity, accessibility, and percentage of multifamily dwellings on travel time for work trips and non-home based trips[4]. Because study samples were small and differences in travel behaviour could be due solely to chance, analysis of variance was performed to test for significant differences. Originally, more travel behaviour aspects were included, but only travel time seemed to differ significantly across neighbourhoods. Then, those differences were attempted to be explained by making use of the land-use variables mentioned before. Households in sprawling suburbs were found to generate almost two-thirds more vehicle hours of travel per person than comparable households in traditional neighbourhoods. Additionally, sprawl dwellers were found to compensate for poor accessibility by linking trips in multipurpose tours.

Since the 1990s, there has been a renewed interest in the effects of neighbourhood design on travel behaviour. Neo-traditional neighbourhood design developments received increasing attention as an alternative community design to standard suburban developments.

Friedman et al. (1994) used data from the San Francisco Bay Area to examine the relationship between neighbourhood type and modal choice. They distinguished two neighbourhood types: standard suburban and neo-traditional neighbourhoods. Despite the description of these types, it remains unclear which land-use variables were taken into account. Higher total household trip rates and automobile trip rates were found among residents of standard suburban neighbourhoods. This difference is explained not only by different neighbourhood design, but also by substantial income disparity between both study groups (23%). As with Gordon et al. (1989), income is the only socio-economic variable included in the research on the LUTS. Hess et al. (1999) carried out research on pedestrian volumes in 12 neighbourhoods around small commercial centres in the Puget Sound Area, United States. The neighbourhoods studied are selected to be similar in terms of population density, land-use mix and income. But they were also selected to have very different neighbourhood design as measured by block size and by the length and completeness of sidewalk systems. Urban neighbourhoods with small blocks and extensive sidewalk systems were found to have, on average, three times the pedestrian volumes of suburban sites with large blocks and short, incomplete sidewalk systems.

Previous studies also compared two distinct neighbourhood types: neo-traditional and standard suburban neighbourhoods. However, such a binary categorization oversimplifies reality. McNally and Kulkarni (1997) developed a methodology for identifying a range of neighbourhood types by a clustering technique with transportation network and land-use inputs. Land-use and socio-economic data for 20 neighbourhoods from Orange County, California, were used. Land-use variables included several aspects of the transportation network, accessibility measures and density measures.[5] The only socio-economic variable included was income, which was considered to be a proxy for the observed socio-economic differences between the neighbourhood types. The hypothesis that neighbourhood types display differences in travel behaviour was verified, but it seems that those differences are explained primarily by income.

While most studies use cross-sectional data, Krizek (2000) managed to use highly disaggregated longitudinal data for the Puget Sound Area. This permitted him to carry out a pre-test/post-test analysis of households' travel behaviour before and after they changed residential location. Density, street pattern and land-use mix were used to explain travel distance (per trip, per tour), travel time (per trip, per tour) and the percentage trips by transit, by bicycle or on foot. These dependent variables also are used to gain ~~also~~ insight into trip chaining. However, few changes in household travel behaviour after a move were observed, suggesting that attitudes toward travel are more important than land use.

Note that all of the above mentioned studies are based on US evidence (except Hurst (1970) focussing on Perth, Scotland). Note also that some studies stress the need to correct for socio-economic factors, but only a few do so. Since the mid-1990s, researchers agree on the incorporation of socio-economic and socio-demographic factors. Due to lack of data, however, some recent studies still concentrate only on land-use variables. In this respect, Schwanen (2002) carried out a cross-European comparison of 11 European cities. Three travel behaviour indicators were examined: commuting distance, commuting time and modal split for commuting. The effect of density, urban structure and city size on these three travel behaviour indicators was investigated by variance and regression analysis. Average commuting distances were found to be strongly and negatively correlated with population density, while average commuting time and modal split were associated more with the distribution of employment and population across the urban area and with urban size.

It appears from these studies that measures for density, diversity and design were analyzed frequently, mostly in relationship to modal choice, travel volume and travel time. City size, urban structure and accessibility are land use variables which were considered less often to explain travel behaviour.

2.1.2 The socio-economic dimension in travel behaviour research

Pas (1984) was one of the first to mention the effect of socio-economic characteristics of travellers on their daily travel-activity behaviour. He analyzed a much larger range of socio-demographic variables than had been done before. Land-use variables, however, were not included in his research.

2.1.2.1 Evidence from the U.S.A.

Frank and Pivo (1994) conducted research in the Puget Sound Area on the census tract level. They tested the impact of density and diversity on the modal choice for both work trips and shopping trips. Urban form measures were density and land-use mix. Control variables included a limited number of socio-economic variables and mobility constraints.[6] Statistical methods were selected on the basis of the nature of the hypothetical relationship being tested. The Pearson correlation was used to test the presence, strength and nature of the linear relationships between urban form and modal choice. The presence of a relationship between urban form and modal choice, while controlling for non-urban form factors was analyzed by regression analysis. Nonlinear relationships between urban form and modal choice were described by cross-tabulation. Findings from this research indicated that density and land-use mix are both related to modal choice, even after controlling for non-urban form factors. Nevertheless, relationships between modal choice and land-use mix remained relatively weak. Research at a smaller geographic unit of analysis is thought to be more useful.

Another study in the Puget Sound Area was carried out by Krizek (2003). Krizek (2000) already reported on the changes in travel behaviour after a household had moved to another residential location.[7] As in his earlier research, regression analysis was done with density, land-use mix and street pattern as independent land-use variables. Other travel aspects, however, were chosen as dependent variables: travel distances (per person, per vehicle), number of trips per tour and number of tours. As in his earlier research, attention was paid to trip-chaining behaviour. Most socio-demographic variables, as well as accessibility, had a statistically significant effect on the travel changes. Households which had relocated to neighbourhoods with higher accessibility reduced their vehicle miles travelled and increased the number of tours.

Because of its widely used 1990 travel survey, San Francisco Bay Area has become a well studied region. Kockelman (1997) investigated the influence of urban form on household vehicle kilometres travelled, automobile ownership and modal choice. Instead of taking only density into account, which is relative easily to compute, more complex measures of the built environment focussing on the intensity, balance and mix of land-uses were used. After controlling for socio-demographic variables[8], the results of regression analysis illustrated the significance of measures of accessibility, land-use mixing and land-use balance, computed for both trip origin and destination.

Cervero and Kockelman (1997) focused particularly on the effects of density, diversity, and design on trip rates and mode choice, mainly for non-work trips. The same socio-economic variables as used by Kockelman (1997) were accounted for. Furthermore, housing tenure and variables on transportation supply and services were added.[9] Factor analysis was used to measure the relative influence of each dimension as well as their collective impacts. Results indicated that density, diversity and pedestrian-oriented design generally reduce trip rates and encourage non-auto travel in statistically significant ways, though their influences appear to be fairly marginal. Thus, it supports the belief of New Urbanism[10] advocates that compact, diverse and pedestrian-oriented neighbourhoods can influence travel behaviour.

Other evidence from North American studies stems from research conducted by Boarnet and Sarmiento (1996) for Southern California, Rajamani et al. (2003) for Portland, and Zhang (2004) for Boston. Boarnet and Sarmiento (1996) studied the demand for non-work travel. Both travel volume and travel distance for car trips were modelled as a function of land-use and socio-economic variables near the person's place of residence[11]. Results of regression analysis showed little influence of the land-use variables. In their study, the topic of residential self-selection was dealt with to a limited degree. Residential self-selection refers to the fact that households with an affinity for a certain travel mode (e.g., walking or traveling by transit) may choose to reside in a neighbourhood which facilitates the preferred travel mode (e.g., a high density neighbourhood with walking or transit facilities). Residential location choice was modelled as function of workplace location, preferences toward commuting, non-work travel, and non-transportation location-specific amenities, land-use characteristics and location-specific amenities which are not related to transportation (e.g., school quality, municipal fiscal policy). Land-use characteristics were found to be endogenous to residential location choice. This indicates a first step into the research of preferences and attitudes toward transportation and land use.

A GIS-based method was used by Rajamani et al. (2003) to develop land-use measures at the neighbourhood level. Whereas other studies used only a handful of simple land-use measures, Rajamani's database on the local built environment included a more extensive set of variables. Land use was described based on four categories: (i) land-use type and mix; (ii) accessibility; (iii) residential density; and (iv) local street network. Besides socio-economic variables, results were also controlled for trip characteristics.[12] The results of a multinomial logit mode choice model indicated that mixed uses promote walking behaviour for non-work activities. Locations easily accessible by bicycle or on foot seemed to encourage walking and cycling for recreational purposes. The analysis confirms the principles of the New Urbanism: traditional neighbourhood street design seems to promote walking.

2.1.2.2 Evidence from the U.S.A. compared to evidence from Europe and Asia

Whereas previous studies report on only United States evidence, Gorham (2000) and Zhang (2004) compared data for North American cities with non-American cities.

Gorham (2002) examined whether similar neighbourhoods in San Francisco and Stockholm have common travel behaviour characteristics. San Francisco represents a region that has had minimal planning intervention, whereas Stockholm has had a tradition of strong urban and regional planning. Neighbourhood type was the only land-use variable taken into account, to which every respondent was assigned. Socio-economic variables controlled for were lifecycle and income. A descriptive analysis illustrated the differences between neighbourhoods according to trip generation, trip distance, modal choice, trip duration and carbon budgets[13]. This is a larger set of travel aspects examined before for the San Francisco Bay Area. Only for carbon budgets analysis of variance (ANOVA) was performed to illustrate the significance of differences among neighbourhoods. Results of the ANOVA-test suggested that there are similarities in travel behaviour between equivalent neighbourhood types in the two regions.

Zhang (2004) estimated two sets of discrete-choice models (for work and non-work trips) to analyse the influence of land use on modal choice in Boston and Hong Kong. Three classes of explanatory variables were considered: travel costs (time and monetary), traveller socio-economic characteristics, and land-use variables. Each set of models contained a base model and an extended model. The base model included variables typically considered in the analysis of mode choice (e.g. travel time, costs and traveller socio-economic variables). In the extended model, land-use variables were added into the list of independent variables. Results showed that, for both work and nonwork trip purposes, land-use explained additional variation in modal choice. Travellers in both cities responded in the same way to costs of travel, personal and family responsibilities and spatial constraints.

2.1.2.3 Evidence from Europe

Previous studies mainly show evidence from the United States. However, evidence from Western Europe, especially Great Britain and the Netherlands was found.

Stead (2001) was one of the first to introduce socio-economic characteristics in the analysis of the LUTS in Great Britain. His research concentrated on the impact on travel distances. Data from national travel surveys and two local travel surveys (Kent and Leicestershire) were analyzed by two main research methods. First, multiple regression analysis was applied, allowing identification of the main socio-economic and land-use variables associated with travel distance. Second, case studies with similar socio-economic profiles but different land-use patterns were described[14]. Results indicated that the variation in travel patterns often owes more to socio-economic reasons than to land-use characteristics.

Dargay and Hanly (2004) carried out research on the link between land-use variables, socio-economic variables and modal choice and car ownership.[15] Land use was defined in terms of the characteristics of the residential location of the individuals. Two logit models were constructed: (i) a multinomial logit model for mode choice and (ii) a binomial logit model for car ownership. Unlike Stead (2001), the estimation results strongly supported the importance of the land-use variables considered on modal choice and car ownership.

Dieleman et al. (2002) explored the determinants of modal choice and travel distance for different trip purposes by making use of the Netherlands National Travel Survey. A wider set of purposes, generally used in mobility studies, was considered: trips to work, for shopping and leisure activities. The residential environment of the respondents was described by (i) the location of the municipality within or outside the Randstad, and (ii) the urbanization level of the municipality. Socio-economic variables were gathered at the disaggregated level of individual respondents and their households.[16] Multivariate statistical analyses found an almost equal importance of personal and land-use characteristics for modal choice and distance travelled. However, these relationships changed considerably when trip purposes were taken into account. For each travel purpose, a multinomial logit model was constructed for modal choice, as well as for travel distance. The three models explaining modal choice showed the same pattern. Even after compensating for socio-economic variables, the influence of residential environment on modal choice for work trips remained high. The modal choice pattern for shopping trips and leisure activities was found to be more or less the same. A different conclusion was made for distance travelled. For work and shopping trips, the distance travelled by car depended mostly on car ownership and income level. However, the model for leisure trips showed fewer strong relationships and less clear patterns.

As in Dieleman et al. (2002), Schwanen et al. (2002a) studied the impact of metropolitan structure on commuting behaviour, especially mode choice, travel distance and travel time by car. Multilevel regression modelling was used to deal with several levels of analysis, ranging from the individual worker to the metropolitan region. Several land-use variables were collected on the level of the metropolitan region and the residential municipality, whereas more disaggregated data were found on the household and individual level.[17] The analysis revealed longer commuting distances and times by car in the majority of polycentric regions when compared to monocentric regions. Furthermore, a limited set of spatial variables seemed to be useful in the explanation of the variation in commute behaviour at the more aggregated levels, whereas the largest part of the variation at the individual level remained unaccounted for. Therefore, other additional and personal household attributes are needed which probably relate to job characteristics, housing tenure and attitudes towards commuting by car.

The greater part of previous studies concentrates on distance travelled and modal choice. Travel time has received less attention. Schwanen et al. (2002b) considers this as an unfortunate oversight as people's travel decisions are determined by time rather than by distance. The joint effects of socio-economic and land-use variables were determined in regression analyses.[18] However, results needed to be corrected for selectivity bias because the decision to travel for a trip purpose with a given mode is not unrelated to the decision regarding to travel time. Therefore, Schwanen et al. constructed two types of regression models. First, a participation model was used to estimate the probability that someone travels for a trip purpose (work, shopping, leisure) by a given mode (car driver, bicycle, walking, bus/tram/metro, train). This likelihood was then transformed and incorporated in a second model, the substantial model for travel time. Travel time was found to be influenced by socio-economic variables and, to a lesser extent, the residential context.

Meurs and Haaijer (2001) tried to contact respondents from a former study (*Tijdsbestedingsonderzoek 1990*). In this way, a pre-test/post-test analysis could be carried out in which three groups of respondents were distinguished: (i) those who did not move, but for whom the spatial situation has changed, (ii) those who did not move, but for whom the spatial situation has not changed, and (iii) those who did move. Regression analysis was used to examine the relationship between the spatial structure and mobility, in general, and modal choice, in particular.[19] The results indicated that certain aspects of land use do indeed have an impact on mobility. These effects are particularly apparent in trips made for shopping and social or recreational purposes. Commuter traffic, however, is largely or almost entirely determined by personal characteristics. Modal choice is influenced to a small degree by spatial characteristics, from about 10% for car trips to 40% for journeys on foot

Previous studies have examined the direct effects of urban form characteristics on travel behaviour. However, travel is considered to be derived from the activities in which individuals and households participate; thus, it cannot be understood independent of the activities that cause it. Consequently, Maat and Arentze (2002) carried out a survey on activity participation in 57 Dutch neighbourhoods. First, they identified activity patterns based on activity frequency and duration. Second, they retrieved the influence of the spatial context on these activity patterns. Seven activity patterns were obtained by cluster analysis. Two different approaches were used to examine how activity participation varies with land-use variables, expressed by accessibility, and socio-economic variables.[20] The concept of accessibility was thought to be useful because it takes into account both transportation costs, such as distance or time, and the attraction of an activity. First, the effects on duration and frequency per activity, as well as in total, were examined using ordinary least square regression. Then, to avoid ~~only~~ testing only separate effects, the clustered activity patterns were studied using multinomial logistic regression. Unlike the socio-demographic variables, they found little evidence that activity patterns vary across spatial characteristics.

Simma and Axhausen (2003) report one of the few studies on the LUTS in Austria. The aim of their study was to identify spatial factors which determine, or at least influence, travel behaviour, especially mode choice for different trip purposes (work, shopping). This research was carried out for only one province in Austria, but one which covers a wide range of environmental settings. Land-use and socio-economic variables were included in a Structural Equation Model (SEM).

Socio-economic variables taken into account were limited because spatial aspects were considered to be more significant.[21] Nevertheless, personal characteristics were found to be more important compared to the moderate effects of the spatial structure.

Modal choice and travel volume remained the most analyzed travel aspects in the studies cited above. However, travel distance was a new travel aspect to be explored. Density, diversity and design remained the most important land-use variables. Measures for design mainly included aspects of the local street network, or several measures were combined into a single neighbourhood type. Age, gender, household size, income and level of education were frequently used socio-economic variables. Several variables were sometimes combined into household type or lifecycle. Some studies controlled their results for mobility constraints, which included variables such as ownership of a car, a driver's licence or a bus pass; accessibility or the proximity of transportation networks or parking places.

2.1.3 The behavioural dimension in travel behaviour research

In a third dimension, lifestyles, perceptions and attitudes towards land use and travel are accounted for in addition to the widely used land-use and socio-economic variables. Since the mid-1990s, there has been some attention to this behavioural component of travel. This new approach has been undertaken in especially North American and Dutch research.

Handy (1996) was among the first to mention the importance of perceptions and attitudes towards land use. She studied the influence of urban form of five neighbourhoods in Austin, Texas, on pedestrian choices. Socio-economic variables and perceptions towards urban form characteristics were also taken into consideration.[22] Correlation analysis revealed that individual motivations and limitations are central to the decision to walk. Urban form is rather a secondary factor in pedestrian choices. The results suggested that urban form plays a greater role if the walking trip has a destination. In this case, the most obvious aspect of urban form is the distance from home to the destination.

Data from the San Francisco Bay Area remained a source of inspiration. Kitamura et al. (1997) surveyed five neighbourhoods, which were selected on the basis of density, diversity and rail transit accessibility. First, socio-economic and neighbourhood variables were regressed against travel volume by various modes. The researchers concluded that neighbourhood variables add significant explanatory power when socio-economic differences are controlled for. In particular, measures of residential density, accessibility of public transportation, land-use mix and the presence of sidewalks are significantly associated with trip generation by mode and modal split. Second, 39 attitude statements regarding urban life, leisure activities and lifestyles were analyzed into eight factors. Scores on these factors were introduced in the regression models mentioned before. Assessment of the relative contribution of neighbourhood, socio-economic and attitudinal characteristics revealed that each variable type add some explanatory power to the models. However, the attitudinal variables explained the highest proportion of the variation in the data.

Bagley and Mokhtarian (2002) examined travel demand in the same five neighbourhoods as in Kitamura et al. (1997), using a system of structural equations in which land-use, socio-economic and attitudinal variables are included. In this way, they incorporated not only a new set of variables, but they used a new research technique as well. The survey included questions about attitudes towards several transportation aspects, and lifestyle was examined using a list of more than 100 types of activities and interests. A nine-equation structural model system was used as a conceptual model of the interrelationships. The nine endogenous variables included two measures of residential location type, three measures of travel demand, three attitudinal measures and one measure of job location. They concluded that attitudes and lifestyles had much more impact on travel demand than residential location type.

Schwanen and Mokhtarian published a series of papers designed to enhance the understanding of the complex relationships among residential location, commute behaviour and attitudes towards land use and travel. They focussed on the concept of residential neighbourhood type dissonance, or mismatch between preferred and actual type of residential location. The basic question is simple: do mismatched individuals travel more like the matched residents of the neighbourhoods they actually live in, or more like the matched residents of the kind of neighbourhood they prefer to live in ? The former outcome suggests that the effects of the built environment outweigh personal characteristics, the latter outcome suggests the converse. The series of studies begins by exploring the role of attitudes toward land use and travel in residential location choice (Schwanen and Mokhtarian, 2005c Schwanen and Mokhtarian (2004) presented a model for dissonance as a function of demographic and attitudinal characteristics. The impact of dissonance on travel behaviour is then studied by three papers. Non-commute trip frequencies (Schwanen and Mokhtarian, 2003) and commute mode choice (Schwanen and Mokhtarian, 2005a) were compared between matched and mismatched urban and suburban residents and the role of dissonance in mode-specific distances for all purposes was examined (Schwanen and Mokhtarian, 2005b). All studies are based on data for three neighbourhoods in the San Francisco Bay Area and take into account land-use and socio-economic variables, mobility constraints, personality traits, lifestyle factors and attitudes towards land use and travel.

Preferences for travel modes, especially car and public transportation, were studied by van Wee et al. (2002). Their research attempts to answer four questions: (i) are there preferences for modes, (ii) is there a relationship between preferences and neighbourhood characteristics, (iii) have preferences for modes played a role in residential choices of households, and (iv) do preferences for modes add explanatory power to models for travel behaviour that include land-use, personal and household characteristics ? Results reveal positive answers to all four questions. Their research was carried out for three different neighbourhoods in the Dutch city Utrecht. Neighbourhoods differed only in terms of attractiveness for travel by car, bicycle or public transportation, whereas differences in household characteristics and types of dwellings were limited. Techniques for analysis included cross-tabulations, Chi-square test for significance and multivariate regression.

Whereas most studies point to a higher significance of attitudes and preferences compared to land-use and socio-economic variables, Naess (2005) concluded the reverse. Residential location within the Copenhagen metropolitan area was found to affect travel behaviour, especially travel volume and modal choice, even after controlling for socio-economic and attitudinal variables. On average, living in a dense area close to downtown Copenhagen contributes to less travel, a lower share of car driving and more trips by bike or on foot. In particular, the length and travel mode of journeys to work are affected by the location of the dwelling relative to the city centre of Copenhagen. But also for a number of non-bounded trip purposes, a centrally located residence facilitates less travel and a higher share of non-motorized transportation. Furthermore, the respondents emphasize the possibility to choose among facilities rather than proximity. In this way, the amount of travel is influenced to a higher extent by the residential location in relation to concentrations of facilities, rather than the distance to the closest single facility within a category.

Research on this third dimension of travel behaviour seems to add significant explanatory power to previous models about the LUTS. However much counter-evidence exists, the greater part of the research concludes that attitudes, lifestyles, perceptions and preferences toward land use and transportation are important explanatory variables. Nevertheless, this type of research still is in its infancy.

2.2 The impact of the transportation system on locational decisions

The effects of the transportation system on location decisions of firms and households are primarily studied by the concept of ‘accessibility’, e.g., new transportation infrastructure influences the accessibility of a place, which, in turn, influences location decisions and land-use patterns.

The earliest of theses studies is the influential study by Hansen (1959), in which he demonstrated for Washington, D.C., that locations with good accessibility had a higher chance of being developed, at a higher density, than remote locations. A similar conclusion was drawn by Bruinsma and Rietveld (1997). They performed a correlation analysis to study the strength of the relationship between the accessibility of Dutch cities and the cities’ valuation as location sites by firms. This relationship was found to be rather strong. Furthermore, a regression analysis was carried out to explain this cities’ valuation. Among the explaining variables were ‘location’, ‘infrastructure’ and ‘accessibility’. The impact of the cities’ location in the road network on the valuation of cities as location sites turned out to be considerably important.

Willigers et al. (2002) reviewed studies of the spatial effects of high-speed rail infrastructure. They concluded that only simple measures for accessibility have been used so far. Thus, they proposed further research into different accessibility measures and accessibility as perceived by firms.

Recently, Mikelbank (2004) analyzed the relationship between smaller road investments made by municipalities and state departments of transportation and housing values in Columbus, Ohio. A first database contained information on all single-family detached houses sold in 1990. A second database included information on all accessibility-changing road investments since 1978. Results indicated that past, current and future road investments have distinct and significant impacts on house price.

However, there is also some counter-evidence. Giuliano and Small (1993) observed that in the Los Angeles metropolitan area, commuting cost has little impact on residential location choice. The computed commuting time based on the observed jobs/housing balance in the region does not compare to the observed commuting time.

Linneker and Spence (1996) explored the regional development effects of the M25 London orbital motorway. The M25 has affected levels of accessibility in Britain, which are thought to influence regional development. They constructed a series of measures of both regional development (e.g. differential employment shift, index for demand for labour) and accessibility. Regression analysis also included a number of other potential explanatory factors, such as industrial structure, congestion, employment density and labour availability. However, a negative relationship was found between accessibility and employment change. Areas which are highly accessible are losing employment and vice versa, thus illustrating two types of potential effects of improved accessibility. It may facilitate local firms to expand their market areas by penetrating more distant markets, potentially increasing employment in the area with improved accessibility. On the other hand, it may facilitate expansion in the reverse direction as stronger firms external to the area penetrate the area whose accessibility has been relatively improved. Thus, any expansionary developmental effects such as employment growth may occur in areas other than those in which accessibility has largely been improved.

Remarks on the impact of the transportation system on land use are made by Miller et al. (1998). Their review of North American studies included studies mainly on the impact of light rail, subway and commuter rail lines and stations on residential density, employment density and property values, among others. Four main observations could be made: (i) fixed, permanent transit systems have the most significant effect, (ii) transit's effects are measurable only in the long term, (iii) transit's effects on land and development markets, not land values, must be considered, and (iv) transportation facilitates development but does not cause development. Besides the small number of studies, most of them suffer from methodological problems. In virtually no case did the study design provide an adequately controlled 'experiment' to properly isolate the impacts of transportation investments from other evolutionary factors at work in the urban region.

3. Some gaps in our knowledge and how to fill them?

3.1 Gaps in the research of the land-use/transportation system as a whole

Research studies seldom consider the LUTS in its totality. A large number of empirical studies on the impact of the land-use system on travel behaviour exists. However, the reverse direction of impacts, the impact of the transportation system on land use, has attracted much less attention from researchers. One reason may be a difference in time scale: travel behaviour can change easily, while land-use changes occur much more slowly. Thus, research which wants to capture the impact of transportation changes on land-use patterns must be carried out on the appropriate moment of time and not within a too short period after the transportation changes (Miller et al., 1998). Furthermore, land-use is subject to many other influences other than transportation, such as population growth, economic development, changes in lifestyles, household information, consumption patterns and production technology, and are therefore difficult to isolate (Wegener and Fürst, 1999; Handy, 2002; Martínez, 2002).

3.2 Gaps in the research of the impact of the land-use system on travel behaviour

Studies of the influence of the land-use system on travel behaviour mainly focus on travel amount, travel distances and modal choice, and recently, travel time. More complex aspects of travel behaviour, such as trip-chaining and point-in-time, scarcely have been investigated. Trips for different purposes have been examined, although commuting trips have been the primary focus. Since they take up a large part of our travel behaviour, recreational, shopping, visiting trips should be looked at more closely. Previous studies offer a wide range of explanations of land-use and socio-economic variables, on several scales of analysis. At present, researchers agree on the inclusion of socio-economic variables. Furthermore, information about perceptions, attitudes and lifestyles seems to add some explanatory power. Since this kind of information is hard to find in empirical surveys, stated preference is thought to be useful. Studies which include information about attitudes and perceptions, do this either towards land use or either towards transportation. Almost no studies were found that include this kind of information for both land use and transportation at the same time.

Furthermore, land-use and socio-economic variables mainly are observed only at the place of origin. Generally, studies do not take into account these variables at the place of destination or in the course of the trip. This fact could be interesting for further research, e.g., the provision of public transportation at the place of destination can influence the decision whether to travel by public transportation.

Principal component analysis, factor analysis, cluster analysis and especially regression models are commonly used statistical techniques in the research on the LUTS. As more types of variables are to be considered, techniques must deal with several directions of interrelationships. As Bagley and Mokhtarian (2002) and van Wee et al. (2002) pointed out, structural equation models (SEM) can deal with these multiple relationships, where the same variable that is the outcome (dependent variable) in one set of relationships may be a predictor of outcomes (independent variable) in other relationships. Therefore, it seems a useful research technique to investigate the LUTS in its totality.

3.3 Structural Equation Modelling

SEM is a research technique dating from the 1970s. Most applications have been in psychology, sociology, the biological sciences, educational research, political science and market research. Applications in travel behaviour stems from 1980. Golob (2003) gives a review of the latter, although applications involving travel behaviour from the perspective of land use (like Bagley and Mokhtarian, 2002; Simma and Axhausen, 2003) were not included.

SEM is a confirmatory method guided by prior theories about the structures to be modeled. As in traditional used regression analysis, SEM captures the causal influences of the independent (explaining) variables on the dependent variables. Furthermore, SEM can also be used to measure the causal influences of independent variables upon one another, which is not possible with regression analysis. This fact is considered very useful in order to obtain better insights into the complex nature of travel behaviour. A SEM can be composed of up to three sets of simultaneous equations (Golob, 2003): (i) a measurement (sub)model for the endogenous (dependent) variables, (ii) a measurement (sub)model for the exogenous (independent) variables, and (iii) a structural (sub)model, all of which are estimated simultaneously. This full model is seldom applied. Generally, one or both measurement models are dropped. SEM with a measurement and a structural model is known as 'SEM with latent variables', whereas 'SEM with observed variables' consists only of a structural model without any measurement models. Many standard statistical procedures can be viewed as special cases of SEM. A measurement model alone equals confirmatory factor analysis. Ordinary regression is the special case of SEM with one observed endogenous variable and multiple observed exogenous variables. In general, a SEM can have any number of endogenous and exogenous variables.

A main reason why SEM is widely used is that it explicitly takes into account measurement error in the observed variables (both dependent and independent). In contrast, traditional regression analysis ignores potential measurement error in all the explanatory variables included in a model. As a result, regression estimates can be misleading. SEM makes also the distinction between direct, indirect and total effects. Direct effects are the effects that go directly from one variable to the target variable. Each direct effect corresponds to an arrow in a path (flow) diagram. Indirect effects occur between two variables that are mediated by one or more intervening variables. The combination of direct and indirect effects determines the total effect of the explanatory variable on a dependent variable. Advantages of SEM compared to most other linear-in-parameter statistical methods can be summarized as follows: (i) treatment of both endogenous and exogenous variables as random variables with errors of measurement, (ii) latent variables with multiple indicators, (iii) separation of measurement errors form specification errors, (iv) test of a model overall rather than coefficients individually, (v) modeling of mediating variables, (vi) modeling of error-term relationships, (vii) testing of coefficients across multiple groups in a sample, (viii) modeling of dynamic phenomena such as habit and inertia, (ix) accounting for missing data, and (x) handling of non-normal data (Kline, 2005; Golob, 2003; Raykov and Marcoulides, 2000). But, besides the benefits of SEM, a greater knowledge about the conditions and assumptions for appropriate usage is required in order to obtain valid outcomes and conclusions (Chin, 1998).

4. Conclusions

Theories on the reciprocal relationship between land use and transportation address changes in locational decisions and travel behaviour of private actors (households and firms) due to alternations in the transportion and land-use system. This two-fold relationship is called the land-use/transportation system (LUTS).

Research studies seldom consider the LUTS in its totality. A large body of literature exists on the impact of land-use on travel behaviour. Our literature review revealed three dimensions in travel behaviour research: (i) a spatial dimension, (ii) a socio-economic dimension, and (iii) a behavioural dimension. As more types of variables need to be included in research on the LUTS, research techniques must be able to deal with more potential relationships among those variables. Because SEM can model the influences of independent variables upon dependent variables and influences between independent variables, this research technique is considered to be helpful in travel behaviour research. In this way, a distinction can be made between direct effects and indirect effects of the independent variables upon the dependent variable. Traditionally used techniques, such as regression analysis, can measure only the direct effects. It can be useful to compare the results of those traditionally used techniques (e.g., regression analsyis) and more sophisticated techniques (e.g., SEM).

Evidence is based primarily on U.S. data. Only from the late 1990s forward, were European studies undertaken, especially in Great-Britain and the Netherlands. Research indicates that Europeans travel half as many kilometres, consume half as much energy for transportation, and emit half as much greenhouse gases as North Americans (Wegener, 2002). The difference in travel behaviour may be the result of, among other factors, the existence of a culture of historical cities (most of them dating from the Middle Ages) and the tradition of spatial planning in Europe. However, between European countries substantial differences in travel behaviour may appear. For instance, Belgium's spatial context differs from its surrounding countries (e.g., the Netherlands) due to its lack of an established spatial planning system. From 1998 forward, this lack appeared to diminish with the approval of the Ruimtelijk Structuurplan Vlaanderen (1998). This plan contains spatial principles which have been applied previously in other countries. For instance, in the Netherlands the politics of deconcentrated centralization (1970s and 1980s), the compact city (1980s and 1990s), and urban renewal (1970s until 1990s) were already known. Although comparable data sets exist (national and regional travel surveys, time use survey, and so forth), limited studies with a Belgian setting could be found. Given its different spatial context, this limitation is rather surprising.. Thus, an exploration of Belgian data seems appropriate. Because research on the behavioural dimension of travel behaviour has only been conducted in the United States, it is important also to obtain information about attitudes and preferences towards land use and transportation in other cultures.

5. **References**

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[1] Only recently, the derived nature of travel has been questioned. Mokhtarian and Salomon (2001) discuss the phenomenon of “undirected travel”. They hypothesize that, under some circumstances, travel is desired for its own sake (e.g., touring, letting the dog out, balloon flight).

[2] City size was expressed in number of inhabitants, employees and jobs, whereas industrial and commercial floor space are density measures.

[3] Density was measured by residential and (commercial and industrial) employment density; urban size by number of inhabitants and surface; and economic structure included industrial and commercial economic structure.

[4] Density was measured by residential density and employment density; diversity included job-housing ratio.

[5] Transport network was described by number of cul-de-sacs, T- and X-crossroads and access points; accessibility was measured by access to residential, commercial and other land uses; and density was measured by density of single and multiple families, residential density, shopping density, general and office-commercial density, density of services, transportation density, population density and uncommitted density.

[6] Density was measured by residential and employment density. Socio-economic variables included household type, age and

employment outside the home; mobility constraints included possession of a driver's licence or bus pass, number of cars per household and number of cars at destination.

[7] Socio-economic variables included household income, number of vehicles, and number of adults, children and employees per household.

[8] Age, gender, ethnicity, household size, income, full- or part-time employment, professional occupation, car ownership and driver's licence

[9] Transit service intensity, proximity of public transport and parking places described transportation supply and services.

[10] Supporters of the New Urbanism believe that the right neighbourhood design will encourage walking, thereby encouraging interaction and a greater sense of community, and discouraging automobile dependence (Handy, 1996).

[11] Socio-economic variables included: age, gender, ethnicity, level of education, income and the number of children under age 16 in the household. Population density, percentage of the street grid within a square mile radius of a person's residence, density of total employment, retail and service employment were used to describe land use.

[12] Socio-economic variables comprised: age, gender, ethnicity, student status, employment status and presence of a physical handicap. Trip characteristics comprised level-of-service variables: travel time and travel cost.

[13] Carbon budgets were defined as "the product of the number of trips an individual makes per day, the distance per trip, the proportion of trips made by different modes, and a carbon emission factor for each of those modes … It represents the amount of carbon released into the atmosphere as the sum of transportation decisions that an individual has taken." (Gorham, 2002)

[14] Land-use variables included: development density, diversity, distance from the urban centre, settlement size, provision of local facilities, proximity to the main transport network (main road network, railway station) and availability of residential parking. Socio-economic variables included: age, gender, household size and composition, working status, socio-economic status, possession of a driver's licence.

[15] Land-use variables included: population density, urban size, accessibility to public transport and local amenities (e.g., shops and services). Socio-economic variables included: age, gender, income, household structure and employment status.

[16] Socio-economic variables included: income, household type, education and car ownership.

[17] Polycentrism, job density and development in number of jobs were used as land-use variables. Age, gender, household type, income, education, car availability are considered as socio-economic variables.

[18] City size, residential density, land-use mix and the structure of the urban system are used to identify the residential environment. Age, gender, education, car ownership and income are considered as socio-economic variables.

[19] Land-use included characteristics of the dwelling, the street, the neighbourhood and its position in the total urban area. Results were controlled for socio-economic variables, but, from their report, it remains unclear which variables specifically were accounted for.

[20] Socio-economic variables included age, gender, income, possession of a driver's licence, availability of a car, number of cars per household (one or two), children < 6 years, children 6-12 years, household size and number of workers per household.

[21] Socio-economic variables included gender, employment status and number of children per household. Land-use was expressed by several accessibility measures, both at the municipality and household level, distance to the district capital, share of farms, working women and commuters, size of shop base and number of work places, supply of public transport and car.

[22] Urban form was described by the neighbourhood transportation system, the level of public transport service, the characteristics of residential streets, housing, neighbourhood commercial areas and types of commercial establishments. Socio-economic variables included: age, gender, number of inhabitants, average years residing in the neighbourhood, number of vehicles per household, household size, children under 12 years, income.

Solstice: An Electronic Journal of Geography and Mathematics.
Volume XVI, Number 2, 2005.
Institute of Mathematical Geography (IMaGe).

SUNBELT XXV

International Social Network Conference

Redondo Beach, CA 2-17-05

Using Asymmetry to Estimate Potential

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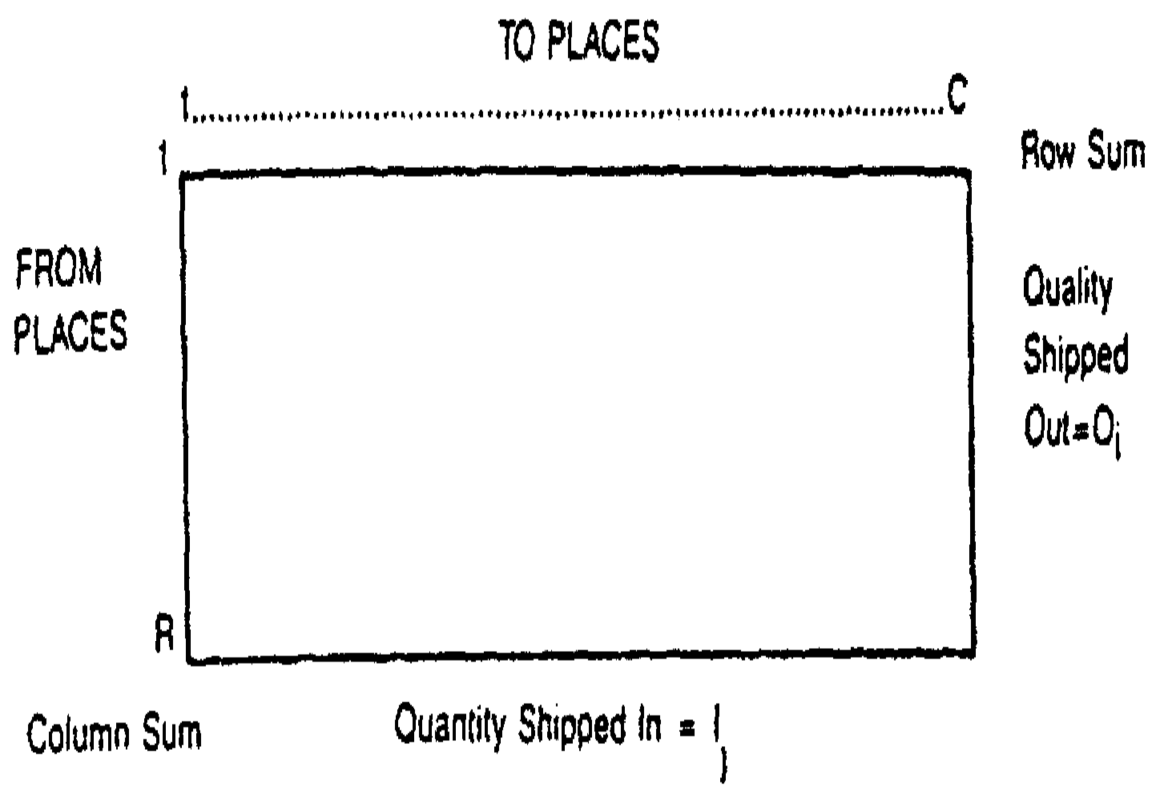
The concern is with complete, square, asymmetric, valued tables, though the procedure may also work with two mode tables.

For this demonstration I have used only small examples.

One example is based on geographic data, the other on journal-to-journal citations.

The form of a movement table M_{ij}

In a non-geographic, network, environment the 'places' are sometimes called 'actors'.



Let M_{ij} represent the movement table, with i rows and j columns. It can be separated into two parts, as follows.

$$M_{ij} = M^{+} + M^{-}$$

where

$$M^{+} = (M_{ij} + M_{ji})/2 \qquad \text{symmetric}$$

$$M^{-} = (M_{ij} - M_{ji})/2 \quad \text{skew symmetric}$$

The variance can also be computed for each component,

and the degree of asymmetry can be computed.

How the two parts are used

I consider the symmetric component as a type of background.
The real interest is in the asymmetric part.

In the geographic case the position of the places is known.

But if locations are not given then the symmetric part may be used to make an estimate of these positions.

This estimate is made using an ordination, trilateration, or multidimensional scaling algorithm.

The first example uses a 33 by 33 matrix of commuting in the vicinity of Munich, Germany.

The matrix is shown next.

A map of the regions is given in:

D. Fliedner, 1962, “Zyklonale Tendenzen bei Bevölkerungs und Verkehrsbewegungen in Städtischen Bereichen untersucht am Beispiel der Städte Göttingen, München, und Osnabrück”, *Neues Archiv für Niedersachsen*, 10:15 (April 4): 277-294, (following p. 285).

A geographic example

Munich Commuting 1939

Between 33 districts of known location

Nach Arbeitsstätte im Stadtbezirk ...... / Von Wohnsitz im Stadtbezirk	NO-Altstadt 1	SO-Altstadt 2	SW-Altstadt 3	NW-Altstadt 4	Universitätsviertel 5	Techn.-Hochschulviertel 6	SW-Schwabing 7	Viertel nw. Hauptbahnhof 8	Viertel südl. Hauptbahnhof 9	Viertel nö. Südbahnhof 10	Viertel sw. Isar u. Südfriedhof 11	Viertel sw. Museumsinsel u. Altstadt 12	Viertel südl. Engl. Garten 13	N-Haidhausen 14	Mittel-Haidhausen 15	SW-Haidhausen 16	Giesing 17	Harlaching u. Menterschwaige 18	Unter- u. Mitter-Sendling 19	Viertel westl. Theresienwiese 20	O-Neuhausen 21	O-Schwabing u. Freimann 22	Gern u. W-Neuhausen 23	Ober-Sendling, Solln u. Thalkirchen 24	Laim 25	W-Schwabing 26	N-Schwabing u. Milbertshofen 27	Moosach 28	Bogenhausen, Daglfing etc. 29	Ramersdorf u. Perlach 30	Berg am Laim u. Trudering 31	Allach u. Feldmoching 32	Pasing u. Menzing 33	Insgesamt	
1 NO-Altstadt		174	151	435	212	157	48	119	247	74	86	100	192	52	52	47	79	26	70	30	76	91	22	112	23	27	86	24	42	12	29	8	7	2910	1
2 SO-Altstadt	428		335	482	215	153	51	176	414	164	176	170	170	59	48	68	123	57	102	76	87	124	34	232	49	46	128	40	58	16	31	18	15	4345	2
3 SW-Altstadt	209	149		435	114	133	43	143	350	107	85	60	73	35	30	42	58	24	85	39	59	75	29	128	26	38	100	31	48	22	15	10	8	2821	3
4 NW-Altstadt	104	32	55		77	76	13	46	92	25	21	23	41	5	6	7	21	6	20	14	11	22	5	32	12	8	48	6	15	7	1	6	3	860	4
5 Universitätsviertel	549	165	242	998		669	139	284	587	121	110	74	367	61	38	60	99	26	90	72	172	393	59	187	61	207	333	39	95	20	39	22	9	6387	5
6 Techn.-Hochschul-Viertel	508	182	252	765	516		180	697	784	140	124	77	220	66	44	53	86	36	116	89	326	230	111	235	72	160	373	70	51	13	26	41	18	6401	6
7 SW-Schwabing	441	180	348	935	1063	982		625	878	197	121	94	365	106	66	70	133	53	141	112	497	438	95	274	94	386	709	95	110	37	39	53	28	9762	7
8 Viertel nw. Hauptbahnhof	245	123	207	643	405	504	159		880	158	116	66	155	81	57	66	103	40	124	171	469	191	204	262	100	107	356	76	58	26	29	36	72	6233	8
9 Viertel südl. Hauptbahnhof	338	190	429	843	368	426	88	439		350	162	91	194	62	77	77	109	36	188	197	179	145	69	302	141	78	270	33	67	26	21	61	39	6095	9
10 Viertel nö. Südbahnhof	426	366	483	874	394	362	87	447	1312		405	149	241	115	95	186	258	117	432	193	190	196	87	746	125	80	341	46	73	41	45	58	37	9005	10
11 Viertel sw. Isar u. Südfriedhof	353	510	546	1049	465	472	97	456	984	726		347	392	168	131	272	360	151	362	144	228	231	65	740	125	86	422	56	94	91	62	59	34	10478	11
12 Viertel sw. Museumsinsel u. Altstadt	548	415	354	847	370	308	88	256	653	203	332		348	134	123	225	145	82	193	110	132	181	64	289	65	59	258	32	63	69	61	40	22	7049	12
13 Viertel südl. Engl. Garten	836	221	270	1137	526	379	65	266	493	146	153	193		150	107	129	108	44	63	77	115	244	40	149	29	52	220	21	110	37	35	51	19	6485	13
14 N-Haidhausen	508	318	286	793	448	373	108	360	637	204	192	140	741		463	304	295	92	172	85	152	247	62	349	75	81	332	47	348	184	313	38	20	8787	14
15 Mittel-Haidhausen	509	344	331	747	448	401	69	443	726	248	283	199	476	658		461	436	121	203	77	184	226	55	442	110	79	368	61	212	213	397	43	32	9602	15
16 SW-Haidhausen	625	531	478	946	442	431	84	456	843	377	469	322	441	304	399		562	244	257	109	211	272	77	511	128	95	391	58	135	190	188	49	21	10654	16
17 Giesing	380	374	284	582	319	337	111	306	678	353	381	198	257	276	209	375		285	233	111	120	200	44	506	73	55	294	46	77	212	90	33	17	7816	17
18 Harlaching u. Menterschwaige	647	567	522	1013	568	639	99	430	1028	570	642	266	472	303	214	525	1230		407	123	216	286	47	766	120	99	415	86	148	176	38	42	28	12792	18
19 Unter- u. Mitter-Sendling	592	447	571	1178	591	692	65	690	1556	908	422	162	419	234	99	184	340	114		280	254	259	98	2165	310	111	477	82	82	135	52	50	77	13694	19
20 Viertel westl. Theresienwiese	278	216	296	606	281	403	86	722	1756	284	235	81	208	107	73	94	185	59	484		228	172	136	609	415	54	402	64	54	42	40	68	51	8789	20
21 O-Neuhausen	305	166	234	664	390	510	73	987	805	171	185	53	233	114	39	81	109	40	117	150		263	281	266	164	123	427	192	42	32	27	105	37	7325	21
22 O-Schwabing u. Freimann	575	239	327	1042	1053	725	121	428	713	204	166	66	537	189	60	104	102	57	143	71	265		85	284	92	444	1221	187	168	32	55	173	29	9902	22
23 Gern u. W-Neuhausen	559	282	340	1147	616	893	105	1186	1824	226	148	103	397	126	54	81	119	30	169	217	635	561		379	614	156	453	243	86	44	39	181	54	12007	23
24 Ober-Sendling, Solln u. Thalkirchen	290	212	201	447	373	418	69	291	372	396	237	88	178	150	62	100	183	112	717	151	113	182	46		107	39	161	47	71	51	31	16	58	6089	24
25 Laim	518	342	457	1115	567	799	84	946	2312	371	303	147	347	206	84	120	201	74	598	799	424	440	269	897		118	508	153	81	90	52	139	199	13760	25
26 W-Schwabing	494	228	361	1230	1188	1039	278	550	871	211	155	95	519	117	71	67	118	54	124	112	414	1140	100	295	107		1220	79	125	53	41	81	114	11556	26
27 N-Schwabing u. Milbertshofen	212	142	160	403	419	346	93	229	382	133	80	38	235	83	29	63	70	34	99	65	247	802	47	162	65	280		91	90	36	22	51	30	5228	27
28 Moosach	378	272	895	743	499	788	117	839	950	204	129	88	309	129	56	71	134	44	188	135	1074	439	470	401	240	157	1054		81	40	29	175	52	10516	28
29 Bogenhausen, Daglfing etc.	366	169	165	680	452	379	41	190	437	124	101	87	753	321	199	143	101	51	105	52	116	297	24	147	43	79	224	48		76	234	28	14	6246	29
30 Ramersdorf u. Perlach	329	240	248	518	319	317	49	210	480	155	187	130	316	252	419	222	347	78	144	49	123	215	26	273	58	46	214	43	165		262	27	21	6482	30
31 Berg am Laim u. Trudering	300	268	236	457	347	330	55	245	537	221	206	144	337	396	859	238	301	110	197	53	149	286	54	328	92	77	261	63	259	339		28	20	7793	31
32 Allach u. Feldmoching	103	65	95	201	149	178	74	204	389	56	44	34	78	10	17	36	26	33	58	45	200	230	100	123	93	59	1169	320	36	44	12		220	4501	32
33 Pasing u. Menzing	307	195	243	380	356	602	67	521	1255	172	107	69	251	50	54	58	75	67	342	238	225	265	151	564	529	66	184	90	38	35	41	284		8081	33
Insgesamt	13260	8264	9882	24563	14450	15160	2901	14167	26445	7999	6501	3934	10258	5119	4334	4629	6616	2397	6743	4246	7881	9343	3054	13139	4355	3550	13419	2509	3182	2461	2436	2014	1274	260440	

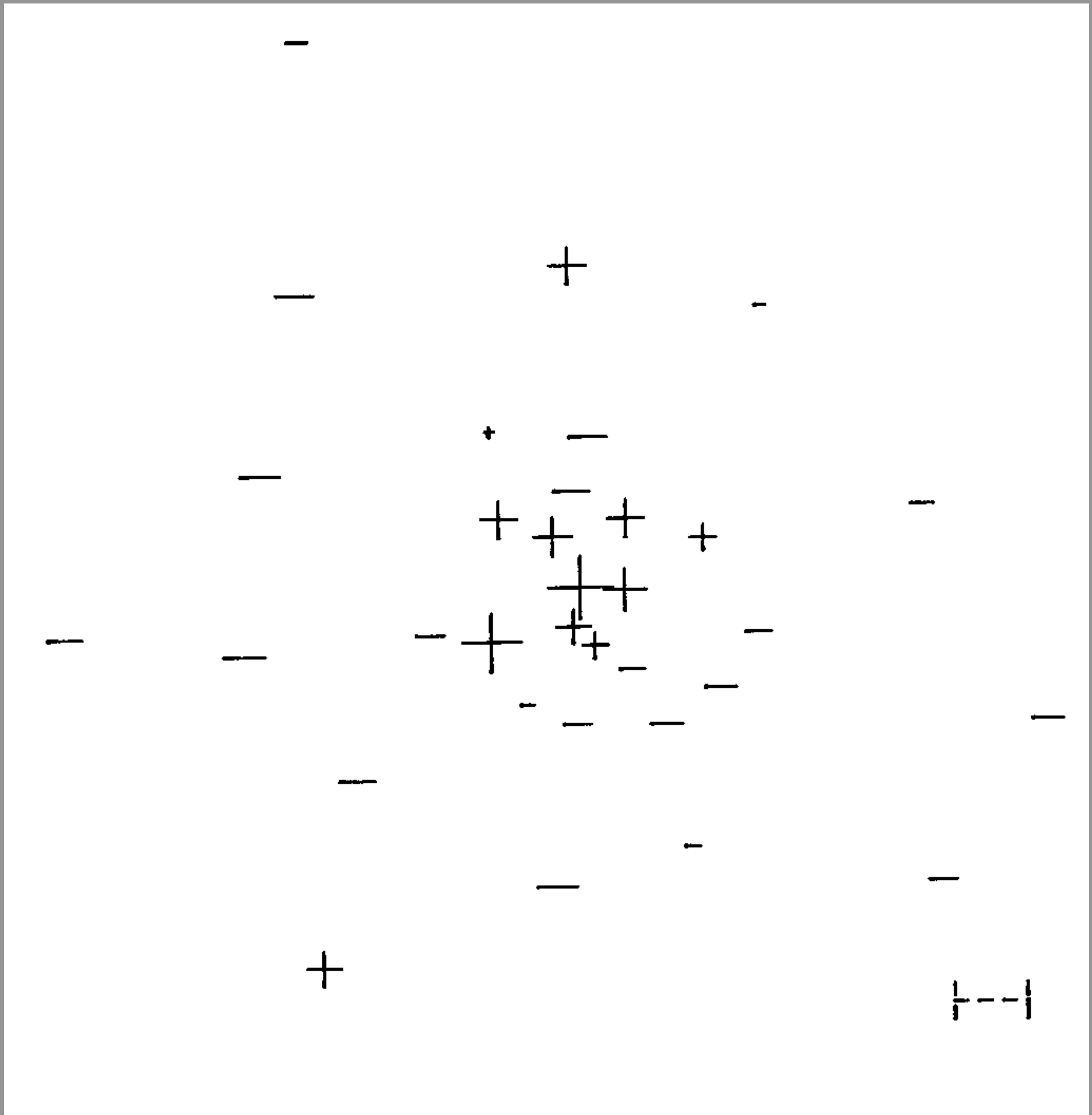
Adding across the table, the column marginals give the outsums (a.k.a. outdegree). Summing down the rows gives the insums (a.k.a indegree).

The ‘sending’ places (rows) are known as ‘sources’, and are shown on the map as negative signs.

The ‘receiving’ places (columns) are the ‘sinks’ and are shown as plus signs.

The size of the symbol represents the magnitude of the movement volume.

Munich Commuting (1939)



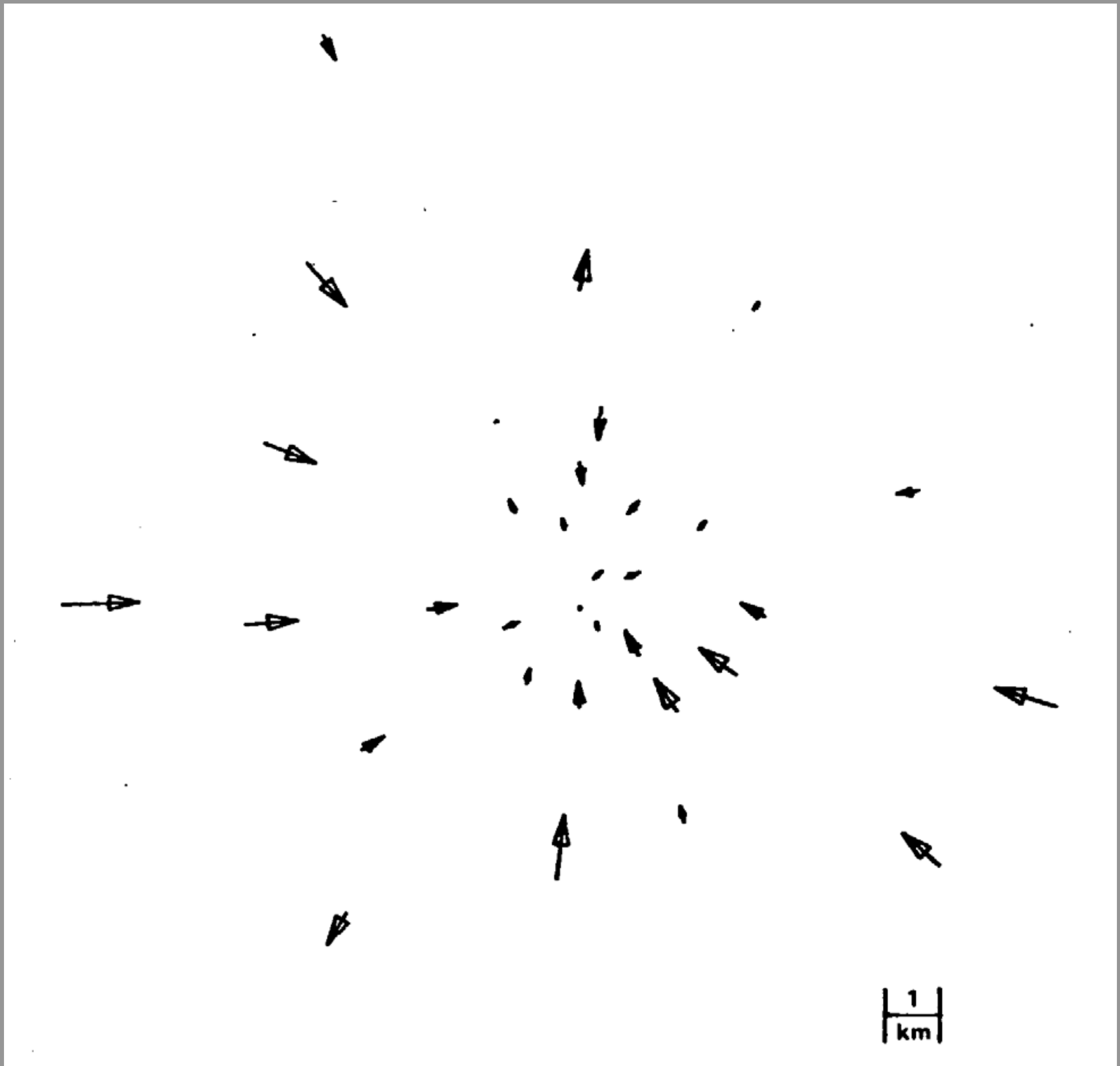
The movement from source to sink can be computed to show the direction and magnitude of the movement.

The computation is based on the asymmetry of the movement table.

Small directed vectors represent this movement on the next map.

Munich Commuting

Displacement vectors

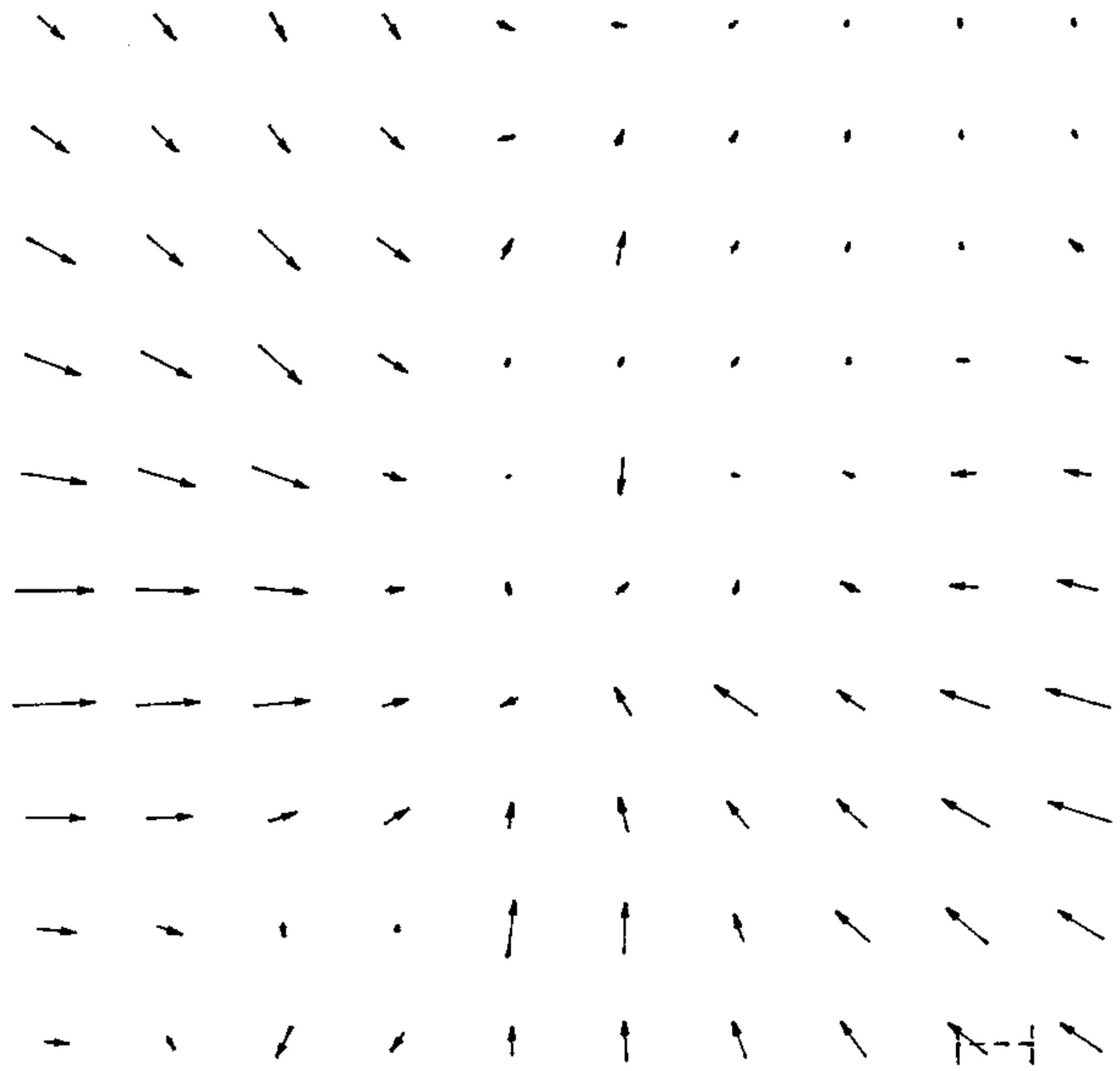


An interpolation is then performed to obtain a vector field from the isolated individual vectors.

This is done to simplify the mathematical integration needed to obtain the forcing function.

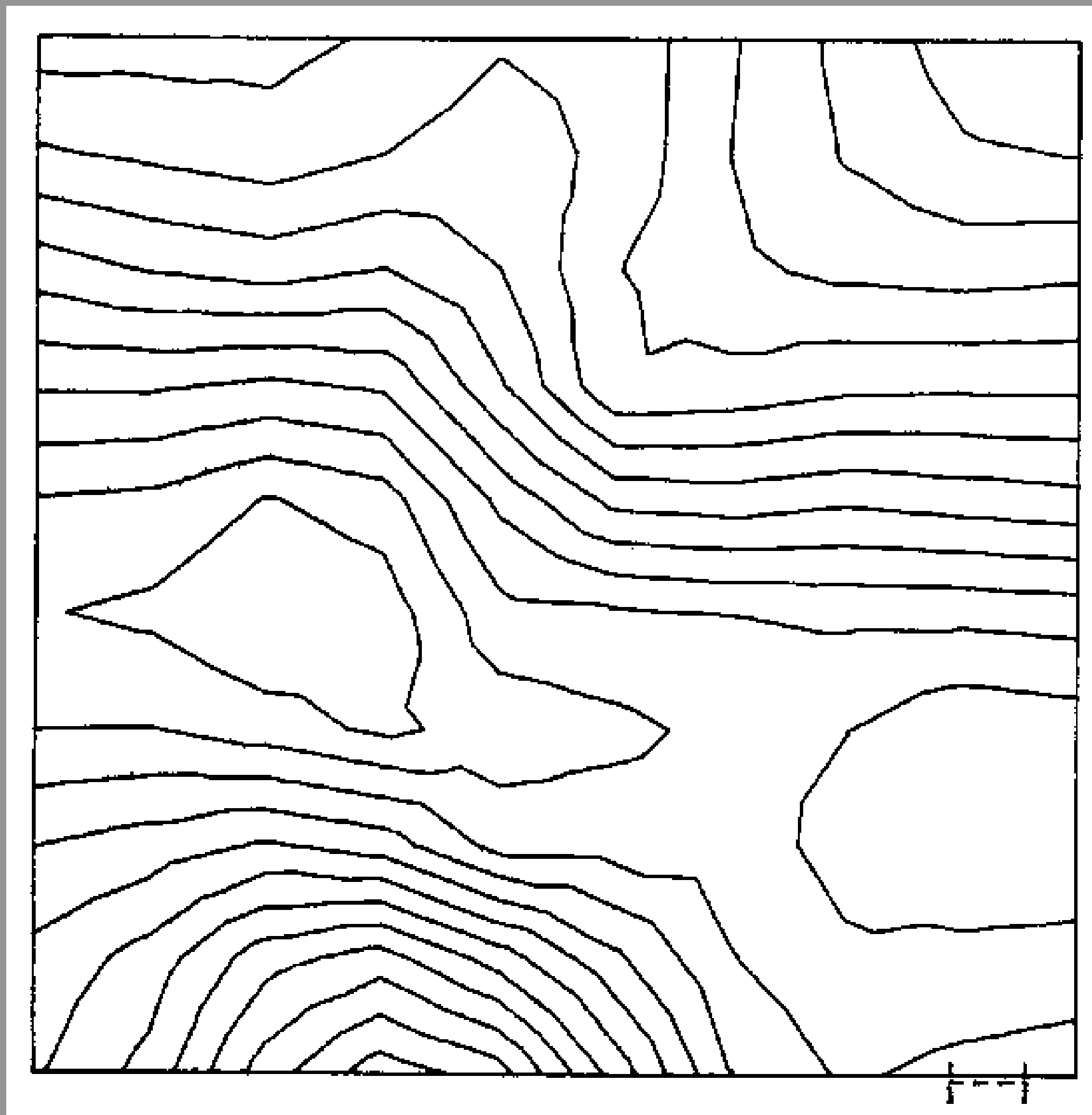
Interpolated Field

of displacement vectors



Computed Potential

based on the displacement vectors



The computed potential should have the vector field as its gradient.

This is a hypothesis that can be tested.

The base level of the potential is determined only up to a constant of integration.

The vector field, to be a gradient field, must be curl free. This can also be tested.

The attempt is now made to apply these ideas in a social space.

This can be considered a development of Lewin's *Topological Psychology* or his *Field Theory in the Social Sciences*.

The data represent citations between a small set of psychological journals. Larger citation tables are now also available.

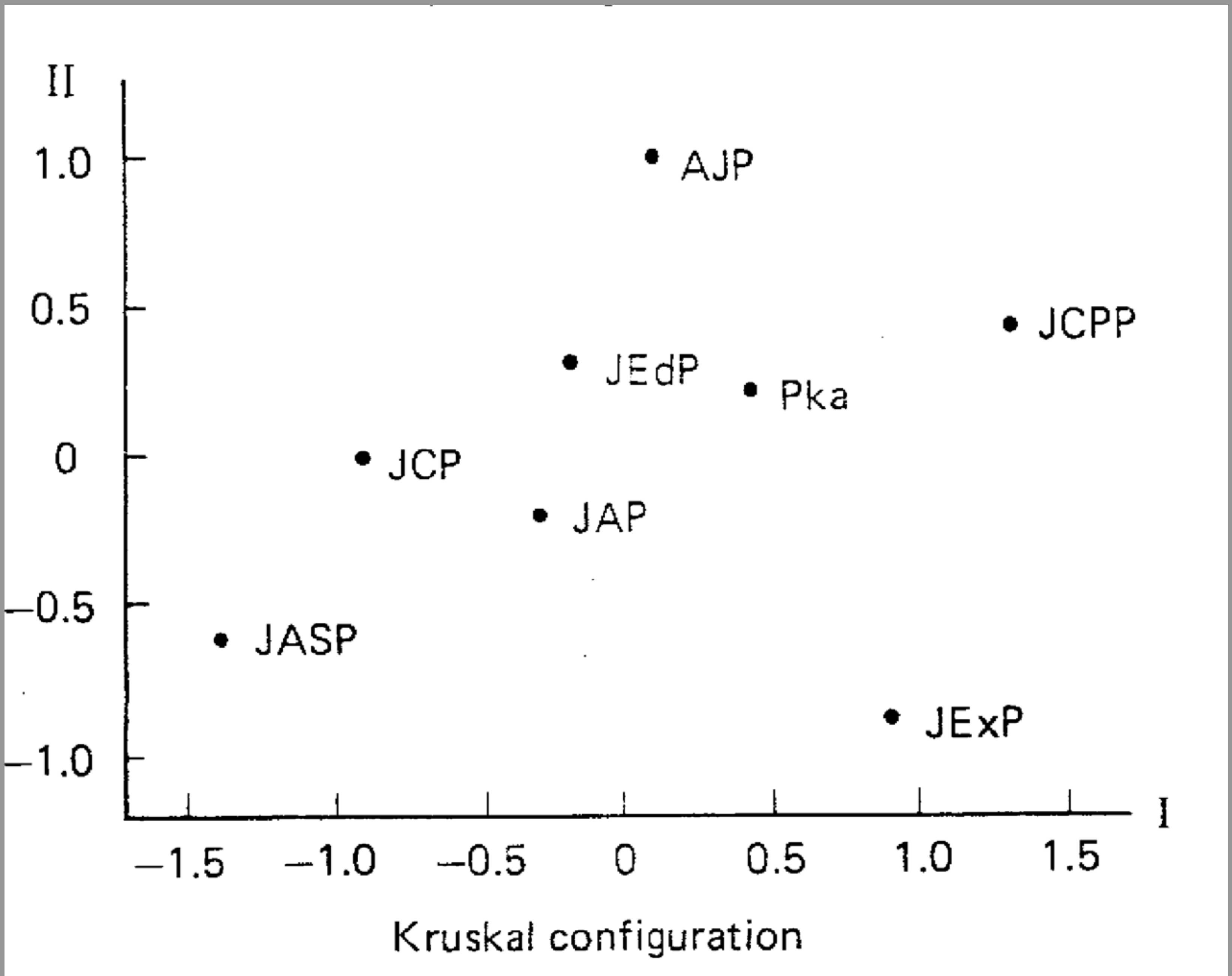
Citations among psychology journals

Coombs et al 1970

Data from 1964

	AJP	*JASP*	*JAP*	*JCPP*	*JCP*	*JEdP*	*JExP*	*Pka*	*Total*
American Journal of Psychology	119	8	4	21	0	1	85	2	240
Journal of Abnormal and Social Psychology	32	510	16	11	73	9	119	4	774
Journal of Applied Psychology	2	8	84	1	7	8	16	10	136
Journal of Comparative and Physiological Psychology	35	8	0	533	0	1	126	1	704
Journal of Consulting Psychology	6	116	11	1	225	7	12	7	385
Journal of Educational Psychology	4	9	7	0	3	52	27	5	107
Journal of Experimental Psychology	125	19	6	70	0	0	586	15	821
Psychometrika	2	5	5	0	13	2	13	58	98
Total	325	683	133	637	321	80	984	102	3,265

In Journal Space



Journal to Journal Citations

To From									X	Y	Net Flow
AJP	119	8	4	21	0	1	85	2	125	910	-85
JASP	32	510	16	11	73	9	19	4	-1382	-644	91
JAP	2	8	84	1	7	8	16	10	-261	-237	3
JCPP	35	8	0	533	0	1	126	1	1302	366	67
JCP	6	116	11	1	225	7	12	7	-924	-2	64
JEdP	4	9	7	0	3	52	27	5	-180	324	27
JExP	125	19	6	70	0	0	586	15	904	-924	-163
Pka	2	5	5	0	13	2	13	58	416	207	-4

AJP Am J of Psychology

JASP J of Abnormal & Social Psychology

JAP J of Applied Psychology

JCPP J of Comparative & Physiological Psychology

JCP J of Consulting Psychology

JEdP J of Educational Psychology

JexP J of Experimental Psychology

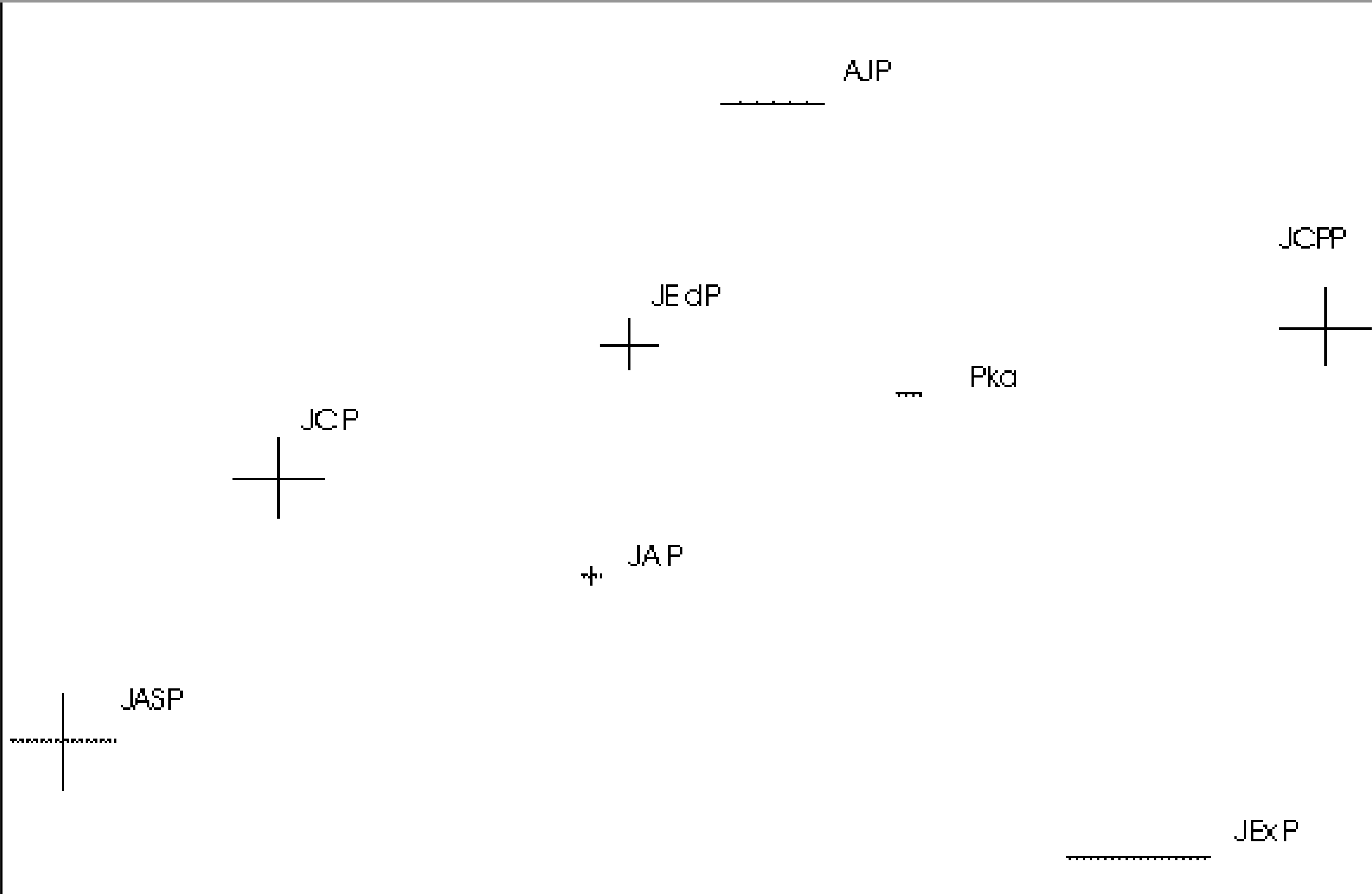
Pka Pyschometrika

C. Coombs, J. Dawes, A Twersky, 1970, *Mathematical Psychology*, Prentice Hall, Engelwood Cliffs, NY, Pages 73-75

The table gives the being-cited journal across the columns. But the information can be considered to move from that journal to the citing journal.

Therefore the transpose is used to produce the source to sink map.

Journal Sources and Sinks



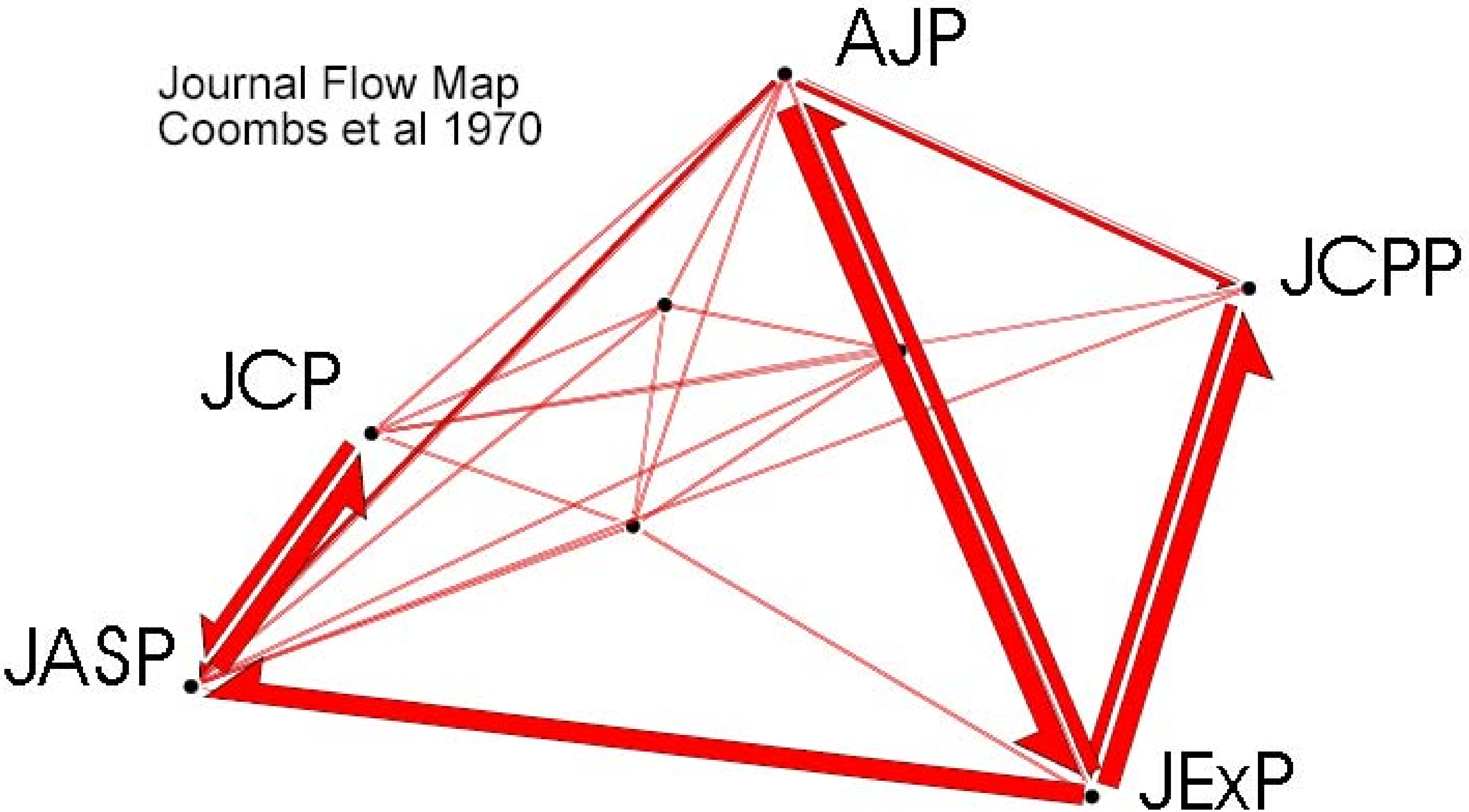
We now have an assignment problem. How to get 163 citations from JExP, 85 from AJP, & 4 from Pka to the 5 receiving journals. There are obviously many possibilities

One solution is to use the "Transportation Problem" (Koopmans, Kantorovich, ~1949): Minimize M..d.., subject to $M_{.J} = O_I$, $M_{I.} = I_J$, $M_{IJ} >= 0$, given the distances computed from the coordinates and using the simplex method for the solution.

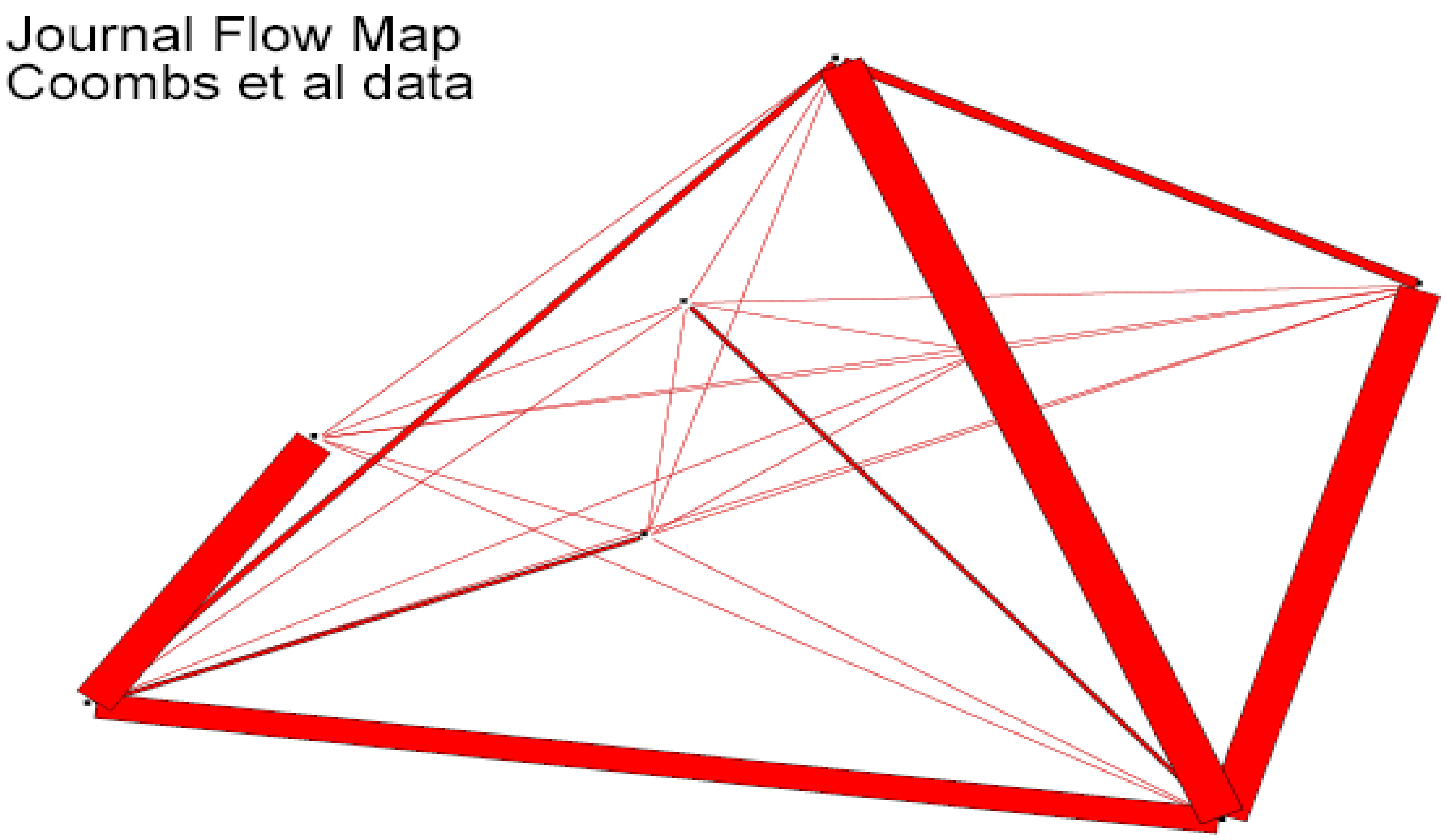
A more realistic solution is given by the quadratic transportation problem: Minimize M^2..d.., subject to the same constraints.

Both of these solutions result in discrete answers, and 'shadow prices'. We are looking for a spatially continuous solution that allows vectors and streamlines, in order to determine spatial flow fields and a continuous potential.

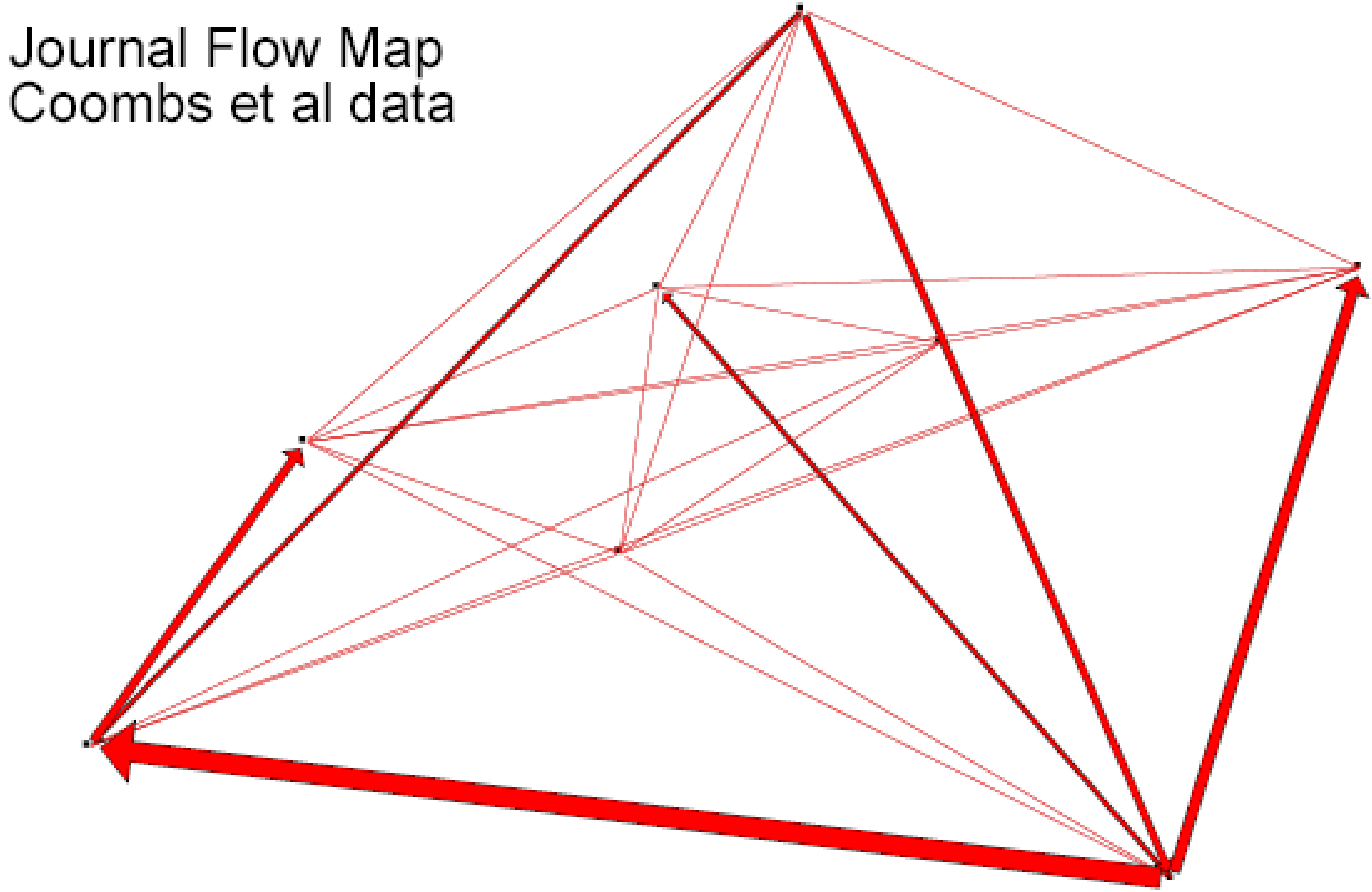
The observed <u>two-way</u> flow between the journals



The total flow between the journals



The net flow between the journals



The next step is to compute the displacements between the cited journals.

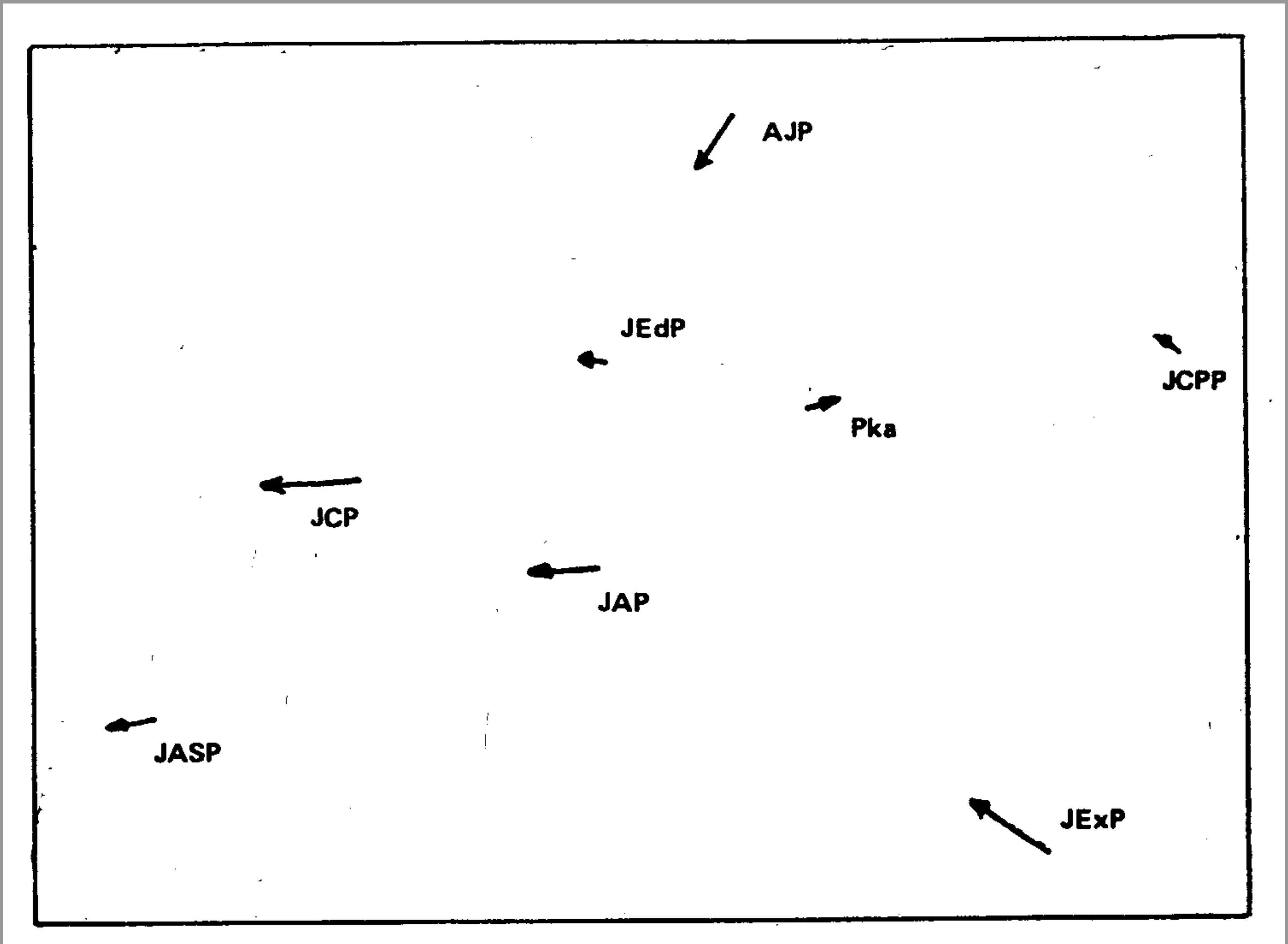
This is based on the asymmetry of the citations table.

The fundamental idea being that there exists a ‘wind’ making movement easier in some directions.

The mathematical details are given in a published paper.

W. Tobler, 1976,“Spatial Interaction Patterns”, *J. of Environmental Systems*, VI(4):271-301

Displacement between Journal Citations

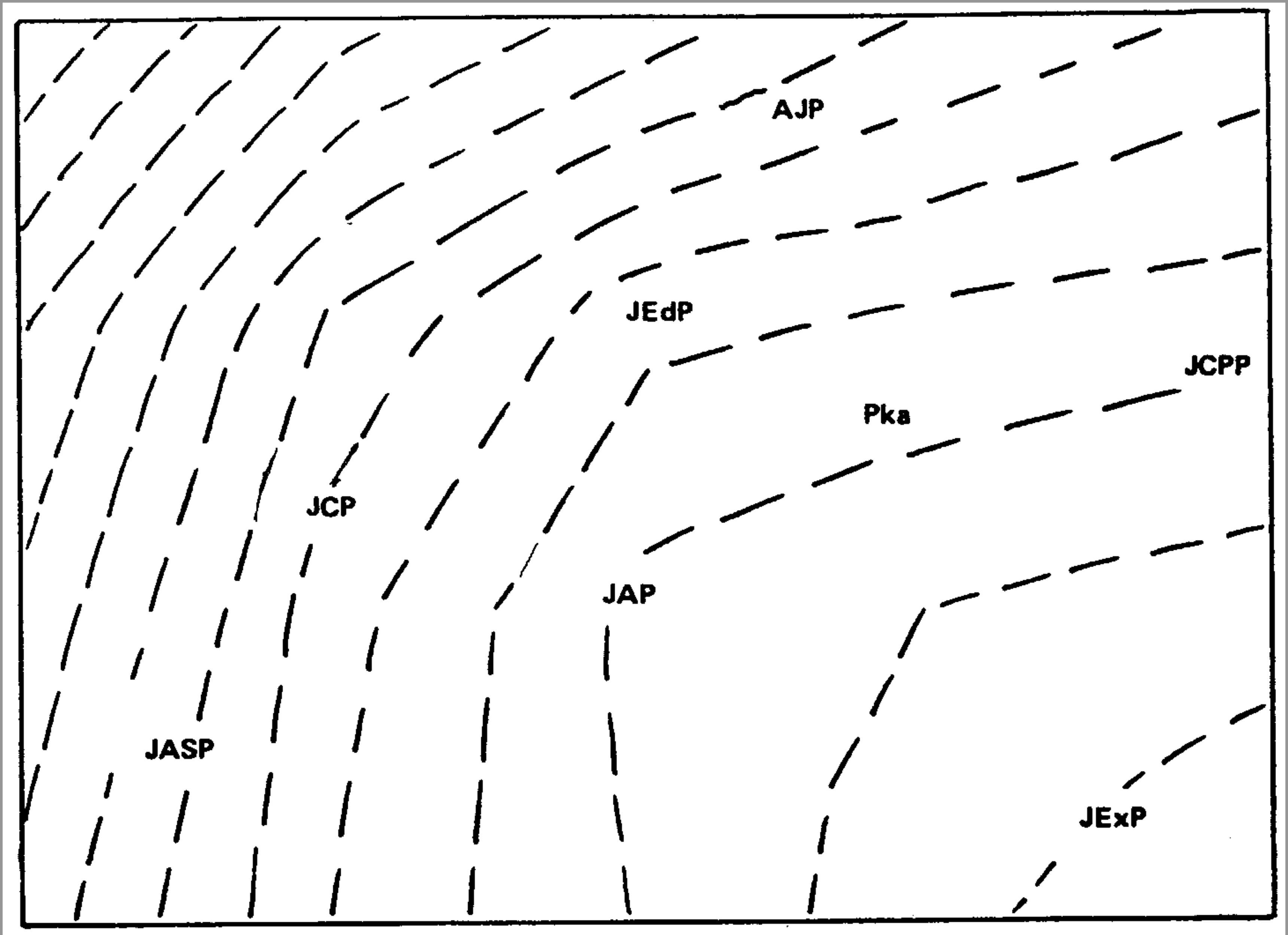


Then the potential is computed by integration.

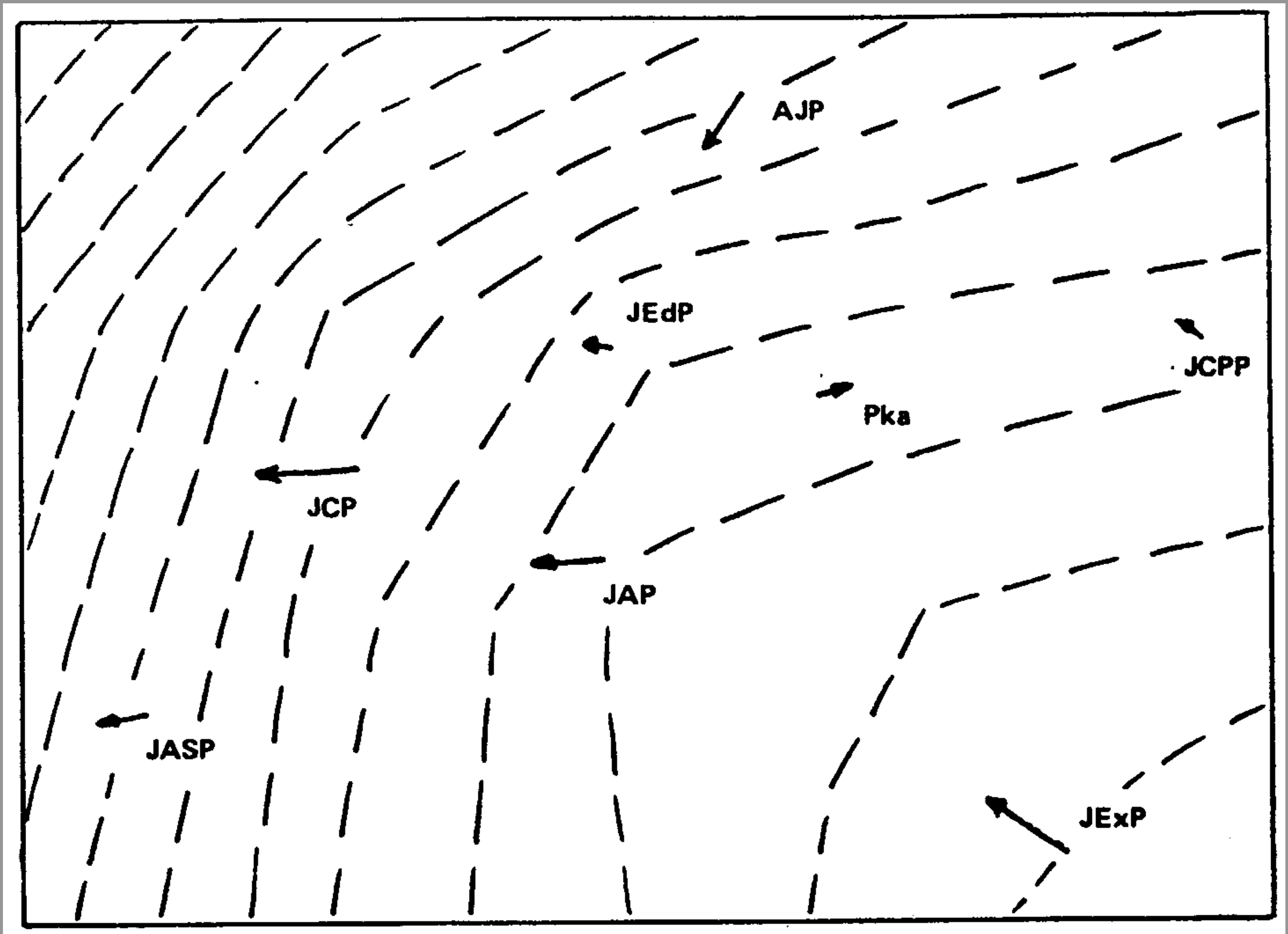
This potential should be such that its gradient coincides with the displacement vectors.

It may be necessary to use an iteration to obtain this result.

Journal Potential Function



Flow and Potential between Psychological Journals



Some questions

Suppose a new psychological journal were started. Where should it be inserted into in this space?

Does it make sense to treat journal citations as being located in a continuous two-dimensional social space?

Can other social data be treated in a similar fashion, for example social mobility tables?

And more general network data?

CONCLUSION

I have given some speculative thoughts on how one might represent network relations with vectors fields and scalar potentials in a continuous social space.

Still needed are error estimates.

Your comments are desired.

Thank you for your attention.

http://www.geog.ucsb.edu/~tobler

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C. Coombs, J. Dawes, A. Twersky, 1970, *Mathematical Psychology*, Prentice Hall, Englewood Cliffs, NY.

D. Fliedner, 1962, "Zyklonale Tendenzen bei Bevölkerungs und Verkehrsbewegungen in Städtischen Bereichen untersucht am Beispiel der Städte Göttingen, München, und Osnabrück", *Neues Archiv für Niedersachsen*, 10:15 (April 4): 277-294 (Table 2, p. 281, map following p. 285).

K. Lewin, 1936, *Principles of Topological Psychology*, McGraw Hill, New York

K. Lewin, 1951, *Field Theory in the Social Sciences*, Harper, New York.

W. Tobler, 1976, "Spatial Interaction Patterns", *J. of Environmental Systems*, VI (4) 1976/77, pp. 271-301.

W. Tobler, 1981, "A Model of Geographic Movement", *Geographical Analysis*, 13 (1): 1-20.

W. Tobler, 1996, "A Graphical Introduction to Surveying Adjustment", *Cartographica*, 33-42.

S. Wasserman, Faust, K., 1994, *Social Network Analysis: Methods and Application*, Cambridge University Press, Cambridge.

PHOTO ESSAY: THE EMERALD ASH BORER

John D. Nystuen

Professor Emeritus of Geography and Urban Planning
The University of Michigan
Ann Arbor

The Emerald Ash Borer is an exotic Asian beetle that is killing most of the ash trees in Southeast Michigan. First identified in 2002 by David Roberts, Ph.D. Michigan State University (http://web1.msue.msu.edu/reg_se/roberts/ash/) the infestation is spreading to other parts of Michigan and adjacent states despite mitigation efforts and quarantines by state and federal environmental agencies (http://www.emeraldashborer.info/files/TriState_EABpos.pdf) . The beetle was probably introduced to North America by infested solid wood packing material for cargo imported from Asia through the Port of Detroit. There are millions of ash trees in Michigan alone and many more millions across North America. As of 2005 eight to ten million ash trees in Southeast Michigan have died.

The Emerald Ash Borer is an environmental disaster, especially in urban areas where the ash tree was widely planted on city streets as replacement for the elm trees lost to the Dutch elm disease four decades ago. Cities are struggling to remove dead trees from city right-of-ways and parks. To give a sense of the magnitude of the problem officials of the City of Ann Arbor proposed a two year millage to raise four million dollars to pay for removal of over 10,000 city ash trees. The voters turned the tax proposal down in a recent election. The City will have to find other funds to pay for the removal and more time will be needed to complete the job.

Dead ash trees on private property are problems for the individual homeowner. This photo essay is a record of one homeowner's approach to the problem. His seventy foot tall white ash tree with a three foot diameter trunk seemed perfectly healthy in 2004 but was clearly dead by spring of 2005 and had to be removed. Estimates for the cost of removal were $2500 and $2000. Instead he took the matter into his own hands. He rented a cherry picker for one day ($500) and a wood chipper for a few hours ($150). He and his brother-in-law cut the tree down. He hauled the felled wood and chips to the Ann Arbor Recycling Center for disposal. This site was an official disposal site for Washtenaw County in which Ann Arbor is located. Washtenaw is one of the quarantined counties in southeast Michigan where ash tree wood and waste can be left free of charge. Unfortunately despite being an excellent hardwood (baseball bats are made of ash wood) the infested wood cannot be salvaged for any purpose. The quarantine particularly prohibits shipping fire wood out of the quarantined counties.

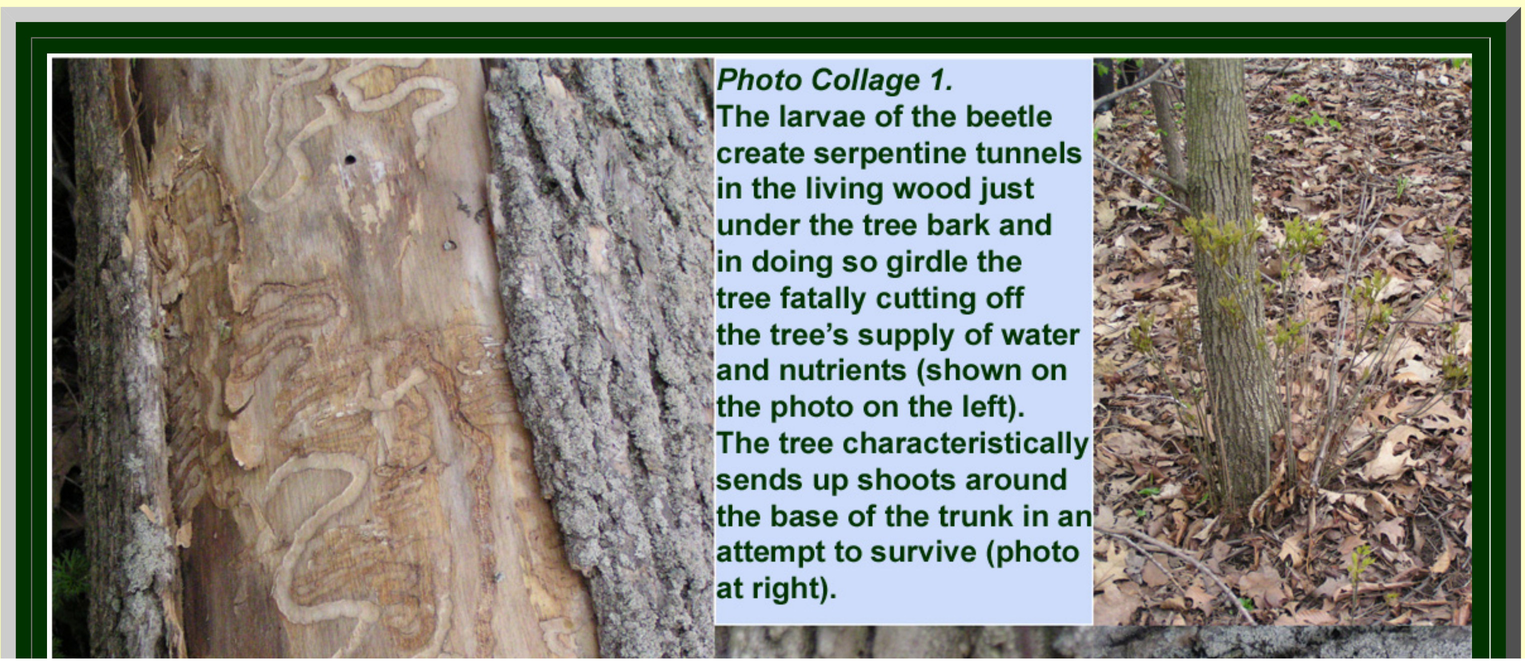
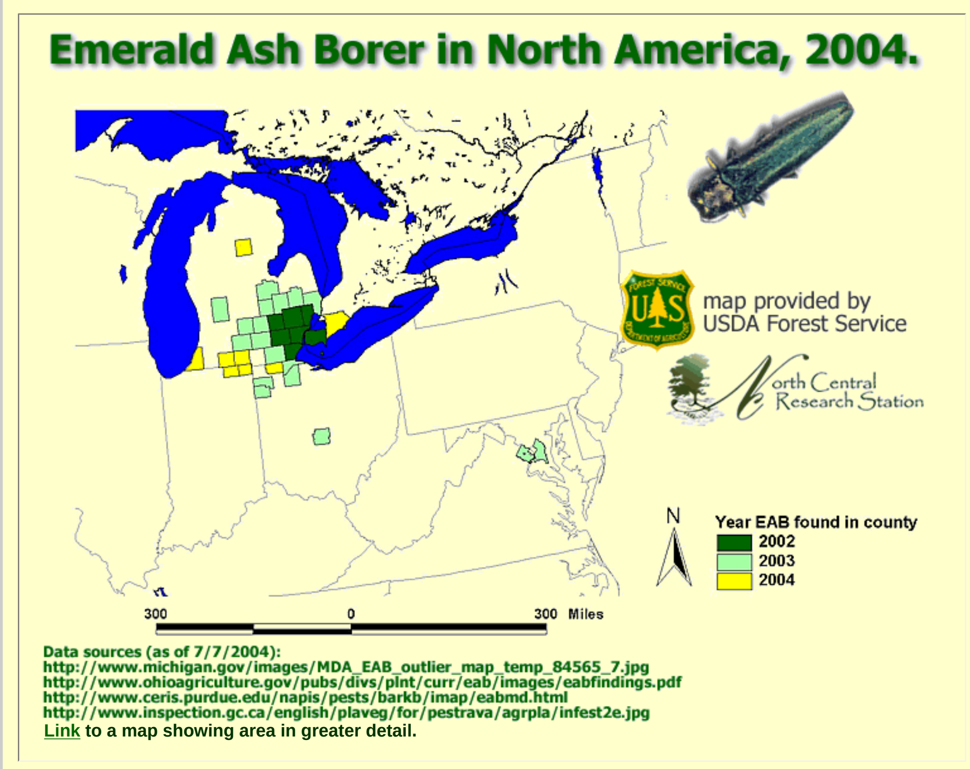


Photo Collage 1. **The larvae of the beetle create serpentine tunnels in the living wood just under the tree bark and in doing so girdle the tree fatally cutting off the tree's supply of water and nutrients (shown on the photo on the left). The tree characteristically sends up shoots around the base of the trunk in an attempt to survive (photo at right).**

On the left, Ann Arbor parks now have many dead ash trees which have opened the canopy of the forest with possible detrimental effects on the ponds and pond life.


Emerald Ash Borer in North America, 2004.
map provided by
USDA Forest Service
North Central
Research Station
N
Year EAB found in county
2002
2003
2004
300
0
300 Miles
Data sources (as of 7/7/2004):
http://www.michigan.gov/images/MDA_EAB_outlier_map_temp_84565_7.jpg
http://www.ohioagriculture.gov/pubs/divs/plnt/curr/eab/images/eabfindings.pdf
http://www.ceris.purdue.edu/napis/pests/barkb/imap/eabmd.html
http://www.inspection.gc.ca/english/plaveg/for/pestrava/agrpla/infest2e.jpg
Link to a map showing area in greater detail.


1


1

Emerald Ash Borer

Dorsal View

The adult beetle is slender and from 5/8 to 1 inch long.

Rent a cherry picker for the day

The homeowner gets checked out on how to operate the machine.

.


JLG

Photo Collage 2.

**Start at the top, work your way down.
This approach is not recommended for the average homeowner!**

Experience and initiative pay off. The homeowner was experienced in running a cherry picker and his brother-in-law had experience cutting trees. The two man crew felled the tree in one day. Sawing of big limbs and the trunk took several days and cost extra to rent big chain saws.

Base cut.

Animation of working down from the top. Timber-r-r-r !

Chipper makes quick work of felled ash tree.

Animation of the cleanup.

It was a splendid effort but at the same time a tragedy. A beautiful ash tree is gone, one of many thousands in the city and millions across the region, victims of our global society.

Ewen Nicol (left) is the homeowner who had to remove his big ash tree due to the emerald ash borer infestation. Ewen's brother-in-law, Chai Montgomery, is on the right.   Ewen lives with his family in the Burns Park Neighborhood of Ann Arbor, Michigan. The tree was downed June 21, 2005 (summer solstice, 2005, in Ann Arbor). Photographs by J. Nystuen

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Institute of Mathematical Geography (IMaGe).

Beyond the Shadow

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To see a World in a grain of sand
And a heaven in a wildflower,
Hold infinity in the palm of your hand
And eternity in an hour.
William Blake, *Auguries of Innocence*

Far more than mere dark recesses, shadows have long served as toolsl to aid scientific communication, explanation, and calculation. Herodotus noted that Thales of Miletus systematically forecast an eclipse in 585 B. C. Kepler used the shadows of protruberances on the moon to calculate their elevation above base level (http://www.depauw.edu/sfs/backissues/8/christianson8art.htm). Eratosthenes of Alexandria used the shadow of an obelisk to apply a theorem of Euclid to measure, with remarkable accuracy, the circumference of the Earth (http://www.imagenet.org/, Ebook on Spatial Synthesis).

More generally, a shadow is a projection of a 3-dimensional object into a 2-dimensional space (and even more generally, of an n dimensional space into and n-1 dimensional space). Sometimes one focuses only on the shadows, as in the case of the eclipse. Sometimes one focuses only on the object itself. When the system is taken together, however, both shadow and what casts the shadow, it is then that understanding arises. As Minkowski noted: "Henceforth Space by itself, and Time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (http://math.ucr.edu/home/baez/physics/Relativity/SR/TwinParadox/twin_spacetime.html).

Consider the following example. On the campus of The University of Michigan there is an interesting sculpture of a large cube standing on one of its vertices (Figure 1). Even a gentle push of the cube will cause it to rotate smoothly on its vertical axis.

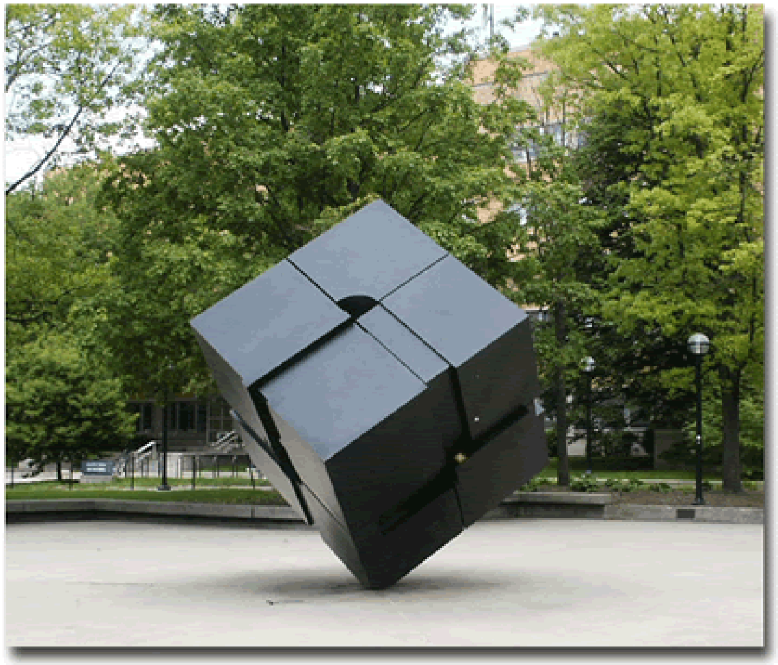

Figure 1. Cube sculpture, "Endover," The University of Michigan Regents' Plaza, created by Bernard Rosenthal and installed in 1968. There are similar sculptures elsewhere in the world, including one in New York City, by I. M. Pei, outside the Marine Midland Bank building. The length of a side of this cube is 8 feet (approximately 2.438 meters). Original source of link to this image of the sculpture is: http://www.plantext.bf.umich.edu/planner/sculpture/central/cube.htm.

On cloudy days, the shadow cast by the cube is diffuse, as it is in Figure 1. Here the focus is on the cube, itself. On a clear day, in mid-afternoon, the shadow of the cube becomes unobstructed by surrounding buildings and is sharply traced on the surrounding sidewalk (Figure 2).

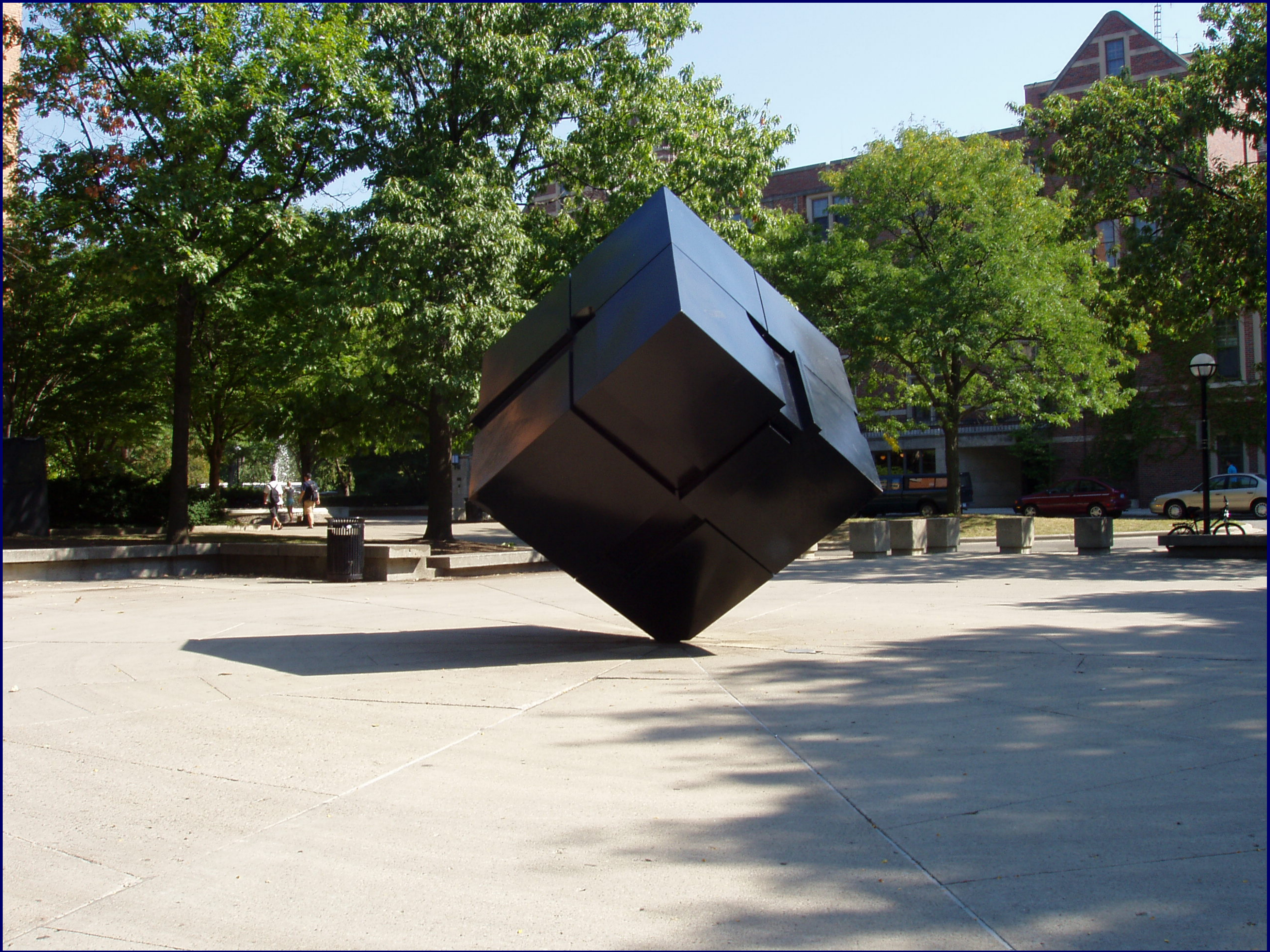

Figure 2. Cube and shadow. Photograph taken 2:00 p.m. September 12, 2005, S. Arlinghaus using an Olympus C-50 Digital camera mounted on a tripod (latitude approximately 42.27 North). Click here to see a virtual

reality version of the cube spinning (without shadows).

Clearly, one reconizes the shadow on the ground to the left of the cube, in Figure 2, as the shadow of the cube and not as the shadow of a tree or of something else. However, the cube itself is clearly present in the picture when one looks at the shadow. If one were to look first at only shadows, would one know that the cube produced them? Consider the following set of two images (Figure 3.a and Figure 3.b). In the top frame of Figure 3 (Figure 3.a) one sees a four-sided shadow on the ground; in the bottom frame of Figure 3 (Figure 3.b) one sees a six-sided shadow on the ground. These two shadows occupy approximately the same space (referenced to cracks and spots on the sidewalk). That seems contrary to intuition when one sees only part of the picture.

Figure 3a. Four-sided shadow.

Figure 3b. Six-sided shadow.

Figure 4 (composed of an animated sequence of static frames as a Quicktime Movie) explains, of course, how this is possible: the cube spins, it is a moving body. Thus, different shadows emerge in approximately the same location and and at approximately the same time depending only on the position of the cube. The cube is a constant body that controls what one sees in different static frames: the cube is the constant body in this simple, easy to visualize, system. As does Blake's poetic art, this sculptor's physical art communicates the essence of a larger system.

For us, this simple system offered added insight into the basic postulates of Special Relativity Theory; thus, we wish to share it with others. For us, the "cube" represents the constant body of knowledge embodied by the Laws of Physics. The table below shows two statements of these Postulates. Both were found using the Internet: the first is from a single authoritative source and the second set is from an compilation of user views with interaction coming from web forms.

Stanford University Linear Accelerator Laboratory. http://www2.slac.stanford.edu/vvc/theory/relativity.html Einstein's theory of special relativity results from two statements -- the two basic postulates of special relativity: • The speed of light is the same for all observers, no matter what their relative speeds. • The laws of physics are the same in any inertial (that is, non-accelerated) frame of reference. This means that the laws of physics observed by a hypothetical observer traveling with a relativistic particle must be the same as those observed by an observer who is stationary in the laboratory. Given these two statements, Einstein showed how definitions of momentum and energy must be refined and how quantities such as length and time must change from one observer to another in order to get consistent results for physical quantities such as particle half-life. To decide whether his postulates are a correct theory of nature, physicists test whether the predictions of Einstein's theory match observations. Indeed many such tests have been made -- and the answers Einstein gave are right every time!	*Wikipedia :* *http://en.wikipedia.org/wiki/Special_relativity* *(external links in text have been removed below)* *Main article: Postulates of special relativity* 1. First postulate (principle of relativity) The laws of electrodynamics and optics will be valid for all frames in which the laws of mechanics hold good. Every physical theory should look the same mathematically to every inertial observer. The laws of physics are independent of location space or time. 2. Second postulate (invariance of *c*) The speed of light in vacuum, commonly denoted *c*, is the same to all inertial observers, is the same in all directions, and does not depend on the velocity of the object emitting the light. When combined with the First Postulate, this Second Postulate is equivalent to stating that light does not require any medium (such as "aether") in which to propagate.

***NOTE:** A previous version of this paper was submitted to the Pirelli Relativity Challenge of 2005. That competition causes the authors, neither one a physicist but both with strong orientations toward pure mathematics, to reflect on the endurance of high-level interest in scientific communication throughout their academic lives. As pre-collegiate students, both participated in the experimental stages of the Physical Science Study Committee's "PSSC Physics" (Jerrold Zacharias, Massachusetts Institute of Technology, Director): the first author at The University of

Chicago Laboratory Schools, 1958-59 (Mr. Bryan Swan, teacher), and the second author at The University of Detroit (Jesuit) High School, 1959-61 (Mr. Herbert Stepaniak, teacher). The mission of the PSSC, in developing these courses, is summarized in the quotation below.

> "On Labor Day 1956, Jerrold Zacharias, an MIT physics professor, gathered together a group of prominent American scientists to change the mediocrity of physical science education. The group, called the Physical Sciences Study Committee (PSSC), consisted of Nobel Laureate physicists, MIT professors, prominent high school teachers, and industry leaders. The purpose of the committee was to evaluate the 'content of courses in physical science, hoping to find a way to make more understandable to students the world in which we live' ". (A. J. Howes, Chemical Engineering, University of Virginia, "Sputnik: Fellow Traveler Takes America for a Ride. How a Russian Satellite Placed American Education Reform in the Spotlight," Journal of Young Investigators (http://www.jyi.org/), Featured Article, Issue 4, January 2002.)

Almost 50 years later, as adult academic "students," we continue to seek systematic and interesting ways to look at the world around us. The material above offers others outside the college town of Ann Arbor, Michigan (USA), a chance to see how a piece of sculpture, created by Bernard Rosenthal in 1968 and prominently displayed on the campus of the University of Michigan, continues to inspire us in that quest for imaginative views of science, technology, and the communication of associated ideas

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Related Classical References

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Coxeter, H. S. M. *Introduction to Geometry*. New York: John Wiley and Sons, 1965 (fourth printing).
Loeb, Arthur L. *Space Structures: Their Harmony and Counterpoint*. Reading MA: Addison-Wesley Advanced Book Program, 1976.
Weyl, Hermann. Symmetry. Princeton: Princeton University Press, 1952.

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Please contact an appropriate party concerning citation of this article: sarhaus@umich.edu
http://www.imagenet.org

NEWS: UPDATE ON THE 3D ATLAS OF ANN ARBOR

Sandra Lach Arlinghaus

The 3D Atlas of Ann Arbor is an ongoing project begun five years ago. The early development centered on the creation of base maps/surfaces formed from buildings, terrain, streets, photographic textures, and so forth. There is abundant reference to this development in *Solstice* (link to an article in Volume XVI, Number 1; link to Volume XV, Number 1 to two articles on this topic, one by Beier and one by Arlinghaus, Beal and Kelbaugh--the latter contains links to all previous references on this topic). As the base surfaces emerged, so too did applications. Most of these centered on one form of planning or another. Now, thanks to direct efforts, and indirect input, from*

- **The principal investigator:** Sandra Lach Arlinghaus;
- **Students, teaching staff, and faculty in Engineering 477, Virtual Reality, College of Engineering, The University of Michigan**
  - **Students:**
    - 2003: Taejung Kwon, Adrien Lazzaro, Paul Oppenheim, Aaron Rosenblum
    - 2004: Nikolai Nolan, Rasika Ramesh, Itzhak Shani
    - 2005: Alyssa J. Domzal, Ui Sang Hwang, Kris J. Walters
  - **Teaching Staff, Graduate Student Instructors:**
    - 2003: Thana Chirapiwat, Jamie Cope
    - 2004: Thana Chirapiwat, Jamie Cope, Bonnie Bao
    - 2005: Jamie Cope, Brian Walsh
  - **Faculty:** Professor Klaus-Peter Beier.
- **Other faculty and external advisors:**
  - 2003: Matthew Naud, Environmental Coordinator, City of Ann Arbor; John D. Nystuen, Prof. Emeritus, University of Michigan
  - 2004: Matthew Naud, Environmental Coordinator, City of Ann Arbor;
  - 2005: Matthew Naud, Environmental Coordinator, City of Ann Arbor; Paul Lippens, Intern, City of Ann Arbor; Braxton Blake, Composer and Conductor of Music, Edmond Nadler, Adjunct Prof. of Mathematics.
- **Staff in the 3D Laboratory, Duderstadt Center, The University of Michigan:** Professor Klaus-Peter Beier, Director of the 3D Laboratory; Scott Hamm; Steffen Heise; Brett Lyons; Eric Maslowski; Lars Schumann
- **City of Ann Arbor staff:** Matthew Naud, Paul Lippens, Wendy Rampson, Chandra Hurd Gochanour, Merle Johnson, Jim Clare
- **Members of the Downtown Residential Taskforce, Downtown Development Authority, City of Ann Arbor:** Susan Pollay, Executive Director DDA; Fred J. Beal, Jean Carlberg, Robert Gillett, Karen Hart, Douglas Kelbaugh, William D. Kinley, Steve Thorp, Frances Todoro, Wendy Woods. Substantial citizen input also from Brian Barrick, Ray Detter, and Peter Pollack.
- **The University of Michigan:** Donald T. Uchman, Coordinator of Space Graphics, Space Information and Planning, Plant Extension--AEC

there are thousands of files present to create a variety of images for use in application. Specifically,

- **there are extruded buildings, textures, streets, terrain, hydro, for the entire Downtown Development Authority**
- **there are extruded buildings representing residences and businesses throughout the entire city (about 35,000 in all)**
- **there are extruded buildings for the entire University of Michigan**
- **there are modeled buildings for selected locations in the Downtown Development Authority.**

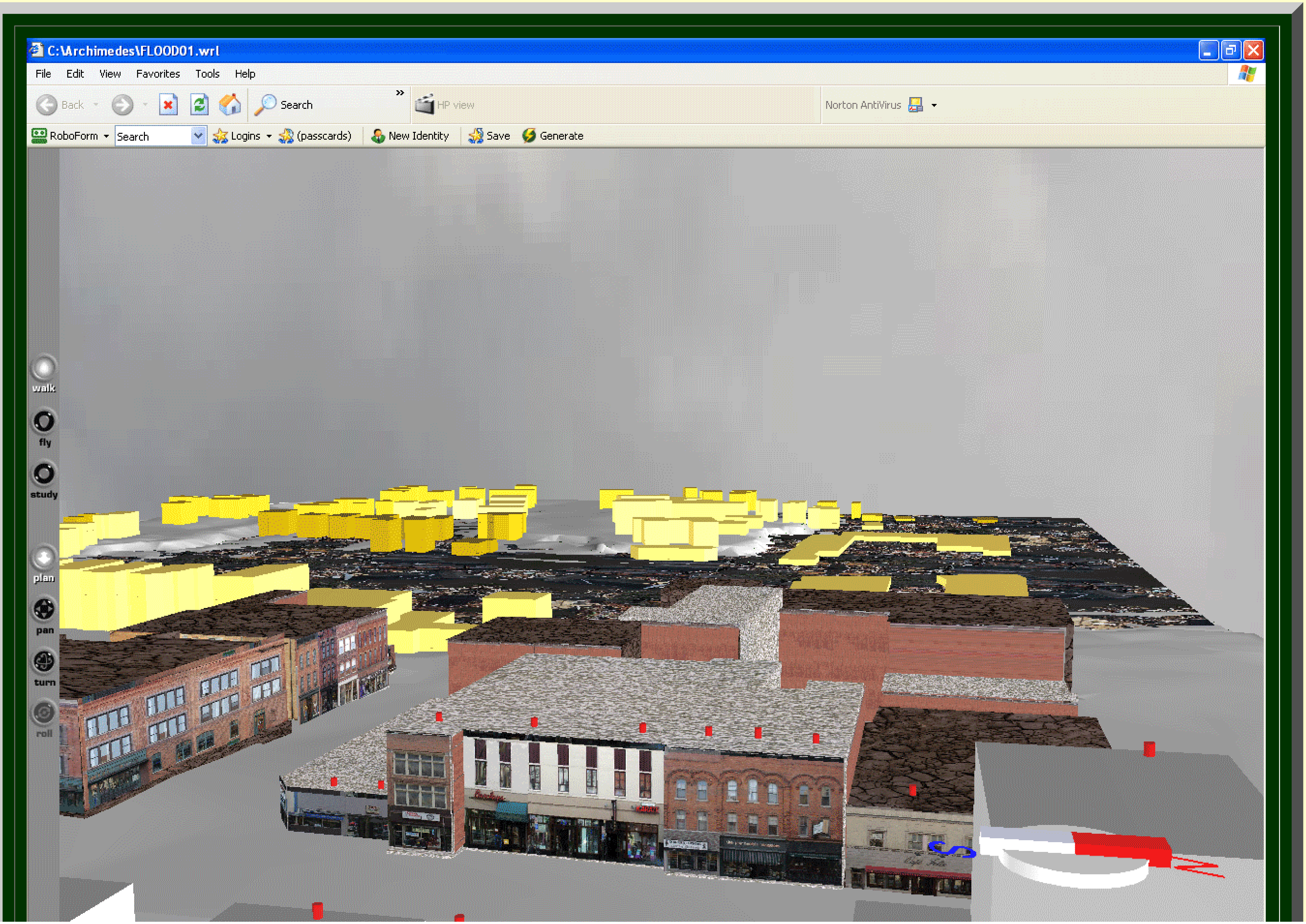
New files from the City this past fall, for extruded structures for the entire city and for contours at a 1 foot contour interval, opened the door to consider preliminary environmental management applications involving floods. The two links below show views of such ideas; the first was developed to be implemented in a public policy context and the second as an analysis linked to that context developed by students in the university setting.

Sandra Lach Arlinghaus

Archimedes in Ann Arbor?

An illustration of an application in the public policy arena using 3d mapping and virtual reality files. Fire

hydrants, lamp posts, and street signs of Domzal were also incorporated into this work, as were streets, blocks, lamp posts, and benches from Kwon, et al. Link to newspaper article (November 27, 2005) related to the files linked to this work.

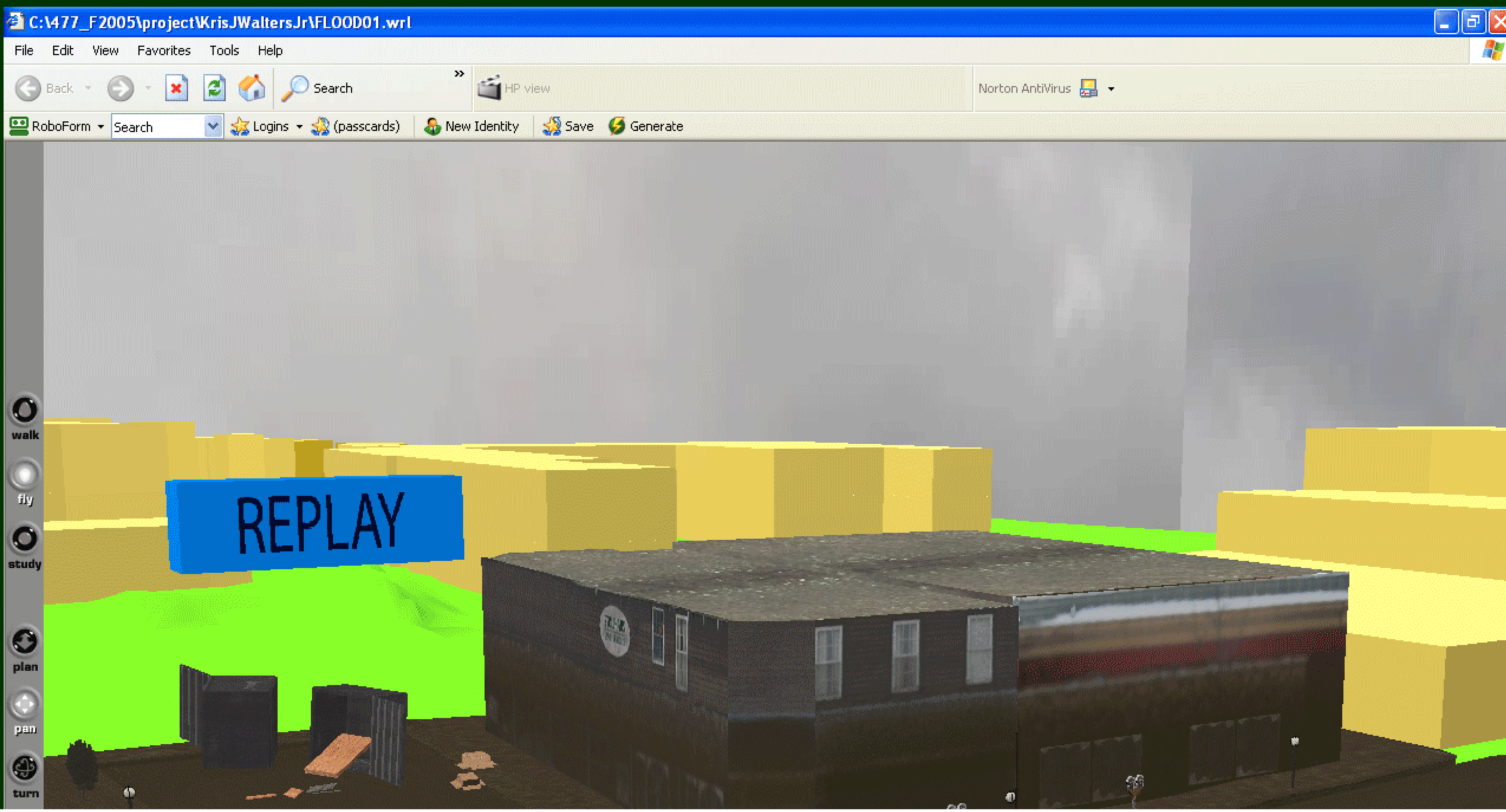


Animated sequence of screen shots taken from three linked virtual reality models, above. To get the full experience, enter the scene and drive around!

Alyssa J. Domzal, Ui Sang Hwang, and Kris J. Walters, Jr.

Virtual Flood in the Allen Creek Floodplain and Floodway

The virtual reality model above, December 13, 2005, requires the use of Cosmo Player or Cortona plug-in for your browser. The demonstration of that day also included a presentation of the files in the CAVE and a discussion involving strategy for file development for use in the immersion CAVE.



Animated sequence of screen shots taken from three linked virtual reality models, above. To get the full experience, enter the scene and drive around!

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*All of the individuals mentioned here are known to the P.I.; there may be other secondary contact not noted here.
Apologies for any omissions.

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Please contact an appropriate party concerning citation of this article: sarhaus@umich.edu
http://www.imagenet.org

Mail

(in reference to material from *Solstice*, Volume XVI, Number 1, Summer 2005)

Mail from (other than about submitted manuscripts):

Lynn Scott, President, Vassar College Class of 1964--"Wow, Sandy...why don't you post a short blurb to the class web site [http://www.aavc.vassar.edu/classes/sixt/1964/index.html], under "Latest News" saying that this is what you have been working on and putting that link in. Quite an undertaking--nice to see that it seems to be a family event."

Estelle Cashman--"And Happy Solstice to you too!"

Carolyn Westbrooks--
"Nice to hear from you Sandy, please keep me on your mailing list."

Richard Wallace--"The eBook is very nice Sandy."

Nathan Caplan--"Terrific!!!"

Harold Moellering--"Thanks Sandy...Sometime when we have more time, I would like to discuss this with you. Also, I don't see the equations for this [dot clustering] work."

Robert Holmberg--"Many thanks for retaining me on your mailing list. And Spatial Synthesis even at first glance is beautiful, inspiring."

Diana Sammataro--checking on updates for animated honeybee map...

Carlo Werlen--"we thank you for your amazing message... unfortunately it's not in german..."

Chuck Drake--"Thanks for the Solstice reading!"

Waldo Tobler--"I think that you would enjoy some of the items at: http://watermanpolyhedron.com/index.html "

Anna-Lena Johansson
"We have received a suggestion to include Solistice. An electronic journal of geography and mathematics in DOAJ (Directory of Open Access Journals, <http://www.doaj.org>). We will review the journal on the basis of our definitions and selection criteria (please refer to <http://www.doaj.org/articles/about#definitions>). To increase the speed of the reviewing process it

would be very helpful if you provided us with the following information." ...
