



CHALMERS

**Induced urban and regional spatial development
from a “ferry-free E39”
A state of the art review and a proposal for theoretical
and methodological development**

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Induced urban and regional spatial development from a “ferry-free E39”

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Executive summary of background - problem - aim - research philosophy

The main reason for an investment in a “ferry-free E39” is regional and urban development. Today’s models and tools for cost/benefit analysis don’t account for:

- (i) Induced spatial development – i.e. longer term generation and redistribution of housing, business, commerce, industry and terminals - manifested in new buildings and facilities.
- (ii) How resulting land-use shifts in turn lead to induced travel and freight transports – i.e. VMT.

This research project proposal addresses this problem in three ways:

1. A longer - run GIS model traces how major road investments between, around and trough Norwegian cities have induced new buildings (industry, offices, homes etc.) and what kind of activities – branches - that take place in those buildings over a multi-year time horizon.
2. Comparisons with impacts from similar projects like Öresundsbron.
3. A Markov chain stochastic model that replicates the historic development process and forecast future induced spatial development in a random process usually characterized as “memory-less”: the next state depends only on the current state and not on the sequence of events that preceded it.

The aim for the research proposal is to develop:

- A cost efficient integrated GIS-based method for database handling, mapping and analysis of huge amounts of disaggregated data.
- Flow charts and standardization of data that describes the process from existing data sources to automatic analyzers and decided outcomes.

The research philosophy is to:

- See the interplay between major road investments and urban/regional development as complex, complicated and dynamic open system that changes from bottom up – not top down.

1 State of the art: Empirical findings on induced urban and regional development from new roads

1.1 History

Mankind likes to think on cities and urban regions as a planned product; and they are when it comes to design and regulations on low levels. But the urbanization process as such is not under any control. It is best characterized as an evolutionary process that started with an “innovation” some 8 000 years ago and goes on no matter political and economic systems. Today our world is littered with examples of cities that have formed at locations accessible to wider populations. In this way the rise of cities in the center of a hinterland, is maybe the most important invention in mankind. The “idea” was primary about bringing individuals together to trade the products of their labor to wider populations. The essence of the city is thus its economies of scale which increase more than proportionately as the cities grow in size (Glaeser 2011).

Following the Industrial Revolution ribbon development became prevalent along railway lines: predominantly in Russia, the United Kingdom and United States of America. A good example of this was the deliberate promotion of Metro-land¹ along London's Metropolitan Railway. Similar evidence can be found from Long Island where Frederick W Dunton bought much real estate to encourage New Yorkers to settle along the Long Island Railroad lines.² But ribbon development is known already from medieval villages and towns that emerged along roads following rivers and coastlines.

1.2 Corridor land uses and edge cities in USA 1950-1980

When the freeway system was built in USA it was the primary force that turned cities inside out because it eliminated the region wide centrality advantage of the city's Central Business District (CBD). Ironically large cities had encouraged the construction of radial expressways in the 1950s and 1960s because they appeared to enable CBD to be accessible to the swiftly dispersing suburban population. However one economic activity after another discovered its new locational foot looseness in the freeway metropolis. Now *any* location on that expressway network could easily be reached by motor vehicles; *intraurban accessibility had suddenly become an all but ubiquitous spatial good*. Much of this suburban growth has gravitated towards beltway corridors. Figure 1 displays the typical sequence of land use development along a segment of circumferential I-494 just south of Minneapolis:

¹ [MetroLand](http://MetroLand.Easyweb.easynet.co.uk). Easyweb.easynet.co.uk (1933-07-01). Retrieved on 2010-11-11

² [Long Island Railroad History Page - The Dunton Archive](http://LongIslandRailroadHistoryPage-TheDuntonArchive.Dunton.org). Dunton.org. Retrieved on 2010-11-11.

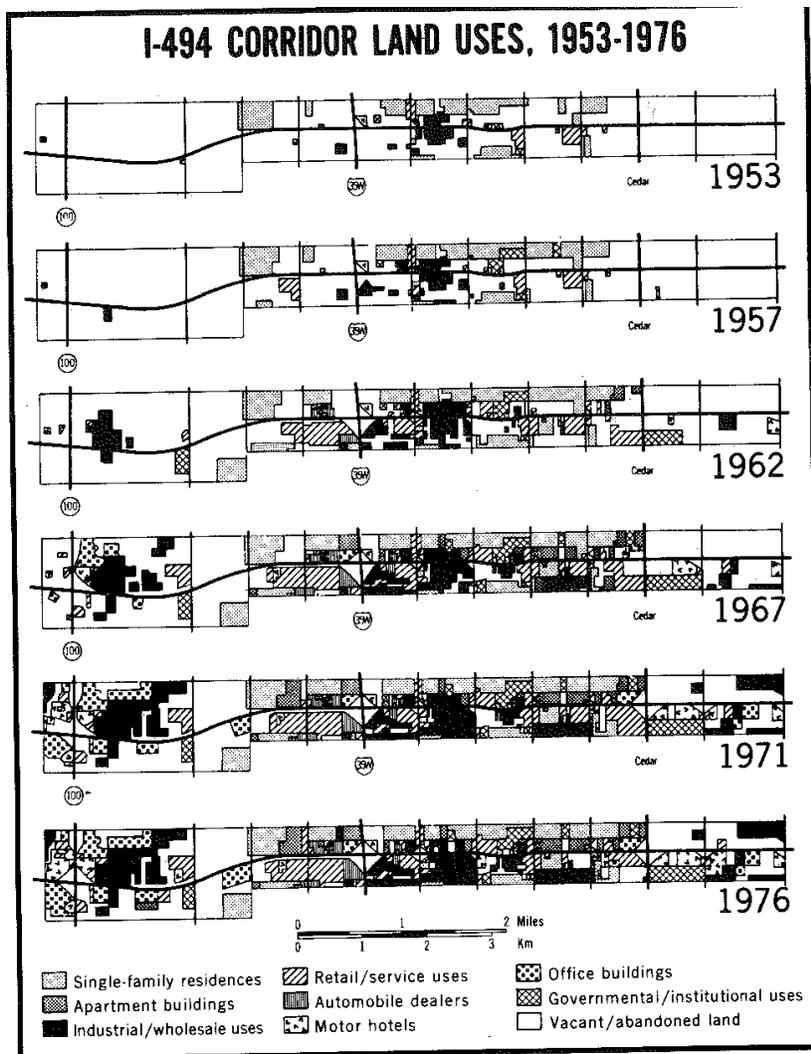


Figure 1. *The emergence of a new downtown*, T. J. Baerwald, 1978, *Geographic review*, 68, p 312.

In retrospect this massive structural transformation of the American city is one of the most dramatic tumultuous upheavals in the urban history. The next step in the transformation process was new downtown like suburban concentrations of retailing, business and lights industry popping up near major highway intersections. An early representative minicity of this genre is the array of high ordered activities around the King of Prussia plaza shopping center at the most important expressway junction in Philadelphia's northern suburbs. Garreau (1991) named these phenomena Edge Cities. Garreau argues that the edge city has become the standard form of urban growth worldwide, representing a 20th-century urban form unlike that of the 19th-century CBD. Garreau writes that edge cities' development proves that "density is back".

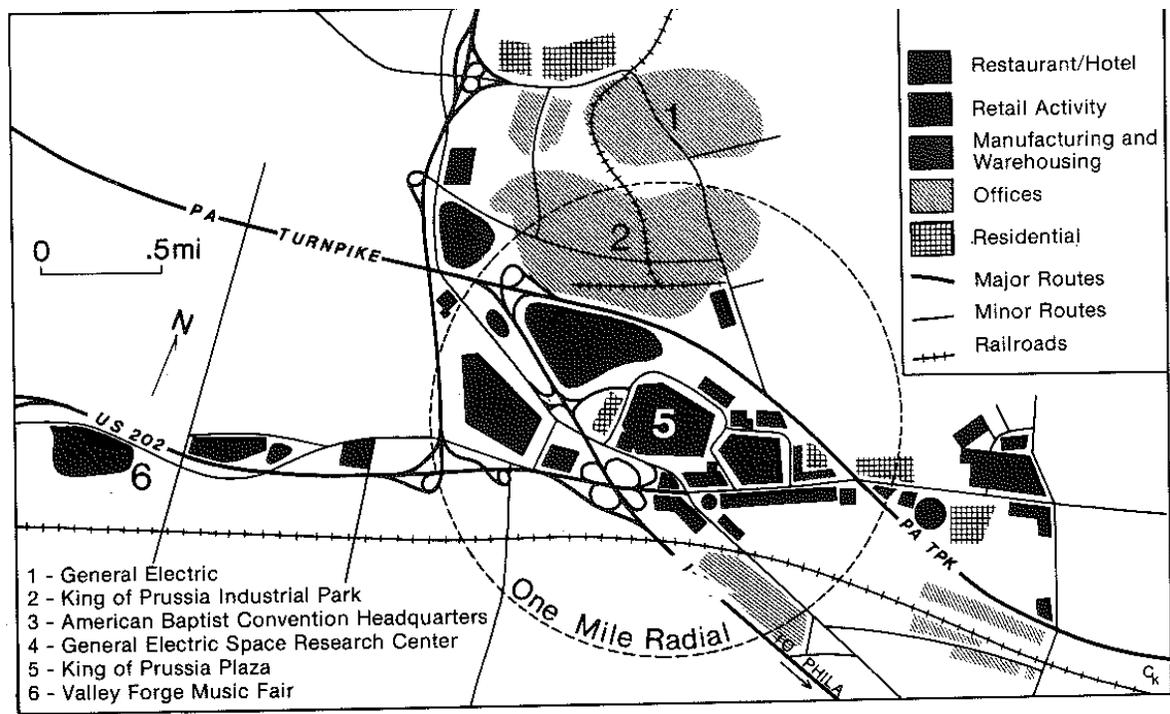


Figure 2. *The outer city: Geographical consequences of urbanization of the suburbs.* P. O. Mueller, 1976, Association of American Geographers. Resource publication no. 75-2.

The US experience is today also an experience in Europe and in fast developing economies like the Chines.

1.3 Urban growth along three motorways in Switzerland between 1985 and 1997

In both Switzerland and the European Union urban growth has mostly proceeded at the expense of agricultural land. It is not yet, however, well understood what drives this extensive land-use change. In Urban growth along motorways in Switzerland, Kalin Müller, Charlotte Steinmeier and Meinrad Küchler (2010) assesses the influence of proximity to motorway exits on urban growth and analyses urban growth along some of the main motorways in Switzerland. The analysis is based on two data collection campaigns from the Land Use Statistics with a time difference of 12 years. Proximity is measured as the distance from a motorway exit, which we related to changes in the entire urban areas and their subclasses ‘Building areas’, ‘Industrial areas’ and ‘Transportation areas’. Linear regression revealed a significant distance trend whereby the closer an area lies to a motorway exit, the higher the rate of urban growth. Industrial areas show the strongest distance trend. Further, variance partitioning revealed the exclusive explanatory power of distance from a motorway exit by partialling out two further potential predictors, the previous urban area and the local relief. We found significant effects of distance, e.g. on industrial areas in the Central Plateau and on building areas in the Central Alps. There, we can assume a causal relationship between proximity to motorway exits and urban growth. Regarding ecoregions or urban subclasses, no uniform picture emerged. We thus recommend

discussing urban sprawl separately for different areas and subcategories of urban land. This study assesses the influence of proximity to motorway exits on urban growth and analyses urban growth along some of the main motorways in Switzerland. The analysis is based on two data collection campaigns from the Land Use Statistics with a time difference of 12 years. Proximity is measured as the distance from a motorway exit, which we related to changes in the entire urban areas and their subclasses ‘Building areas’, ‘Industrial areas’ and ‘Transportation areas’. Linear regression revealed a significant distance trend whereby the closer an area lies to a motorway exit, the higher the rate of urban growth. Industrial areas show the strongest distance trend. Further, variance partitioning revealed the exclusive explanatory power of distance from a motorway exit by partialling out two further potential predictors, the previous urban area and the local relief. We found significant effects of distance, e.g. on industrial areas in the Central Plateau and on building areas in the Central Alps. There, we can assume a causal relationship between proximity to motorway exits and urban growth. Regarding ecoregions or urban subclasses, no uniform picture emerged. We thus recommend discussing urban sprawl separately for different areas and subcategories of urban land.

1.4 Urban growth along 24 freeway projects in California between 1980 and 1994

In Road Expansion, Urban Growth, and Induced Travel: A Path Analysis Robert Cervero (2001) challenges past results by employing a path model to causally sort out the links between freeway investments and traffic increases, using data for 24 California freeway projects across 15 years. Traffic increases are explained in terms of both faster travel speeds and land-use shifts that occur in response to adding freeway lanes. While the path model confirms the presence of induced travel in both the short- and longer-run, estimated elasticity’s are generally lower than those of earlier studies. This research also reveals significant “induced growth” and “induced investment” effects – real-estate development has gravitated to improved freeway corridors and road investments have been shaped by traffic trends in California. The long-run model suggests that it takes around 5 to 6 years before the full brunt of traffic increases spurred by land-use shifts to be felt. Based on model outputs, it generally takes 2 to 3 years for development activity to respond to the addition of lane miles, and another 3 years for Vehicles Miles Travelled (VMT) to respond to development activity.

Based on beta weights, about 55 percent of the association between freeway expansion and VMT growth was accounted for by the path model. Thus while the postulated path model was supported by empirical analysis, more research is needed in different settings and at different resolutions of analysis to further refine our understanding of the co-dependencies between road investments, land-use shifts, and induced travel – hopefully research that is firmly rooted in behavioral and economic theories, and that adopts a casual modeling framework.

1.5 Corridor land use development after the construction of urban motorway by-passes around 7 Swedish cities

In Corridor land use development after the construction of urban motorway by-passes (Förändringar i stadens markanvändning till följd av förbifarter) Hagson et al (2001) used disaggregated national statistics from different registers processed and visualized with Geographic Information System technology (GIS) to traced the:

- Number of new buildings (annual) from the year of opening (the first 1954)
- Localization after (i) branch of trade (ii) type of housing - divided into
 - 1 minute zone from intersection
 - 1 km zone around the bypass
- Trip generation after branch of trade

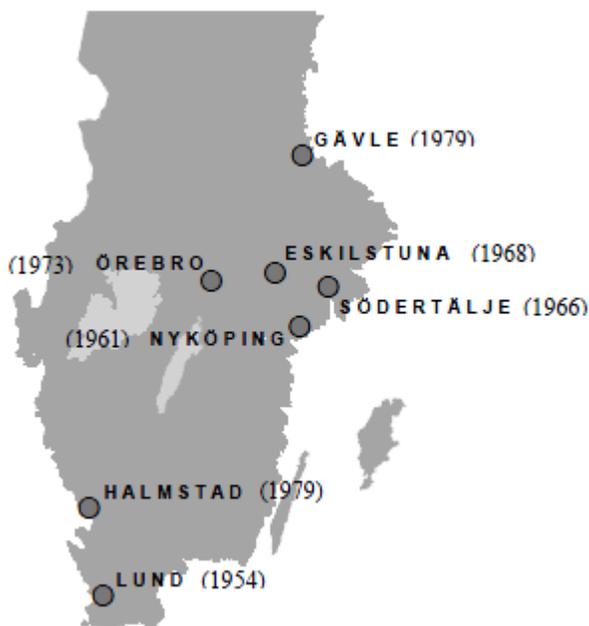


Figure 3. *Corridor land use development after the opening year of urban motorway by-passes around 7 Swedish cities.*

Corridor land use development started immediately after the opening of the first urban motorway bypass in Lund 1954. And after that new high capacity urban road reshaped every space of urban Sweden – they turned them inside out because a location along for instance a bypass is more accessible by car than the old city center. As a consequence centuries of concentric growth turned to corridor development divided into ribbon-zones depending on what bid rent firms and households willing to pay. The bid rent of firms results from the cost structure of their production function, i.e. sales price minus production and transport costs plus profit divided by size of land. A firm with higher added value per unit of land is therefore able to pay a higher price than a firm with less intensive land utilization, everything else being equal.

Results

1. Location of buildings for companies:

	New buildings within the 1 km zone (housing not incl)				Thereof within the 1 minute zone (housing not incl)			
	Industrial buildings	Other commercial buildings	Number of new buildings		Industrial buildings	Other commercial buildings	Number of new buildings	
			Total in the zone	% of the total in the city			Total in the zone	% of the total in the city
Eskilstuna	174	85	259	55,3	43	25	68	26,3
Gävle	0	1	1	0,2	0	0	0	0,0
Halmstad	249	127	376	45,0	43	42	85	22,6
Lund	199	77	276	48,6	27	17	44	15,9
Nyköping	38	33	71	30,5	17	17	34	47,9
Södertälje	196	40	236	38,7	55	12	67	28,4
Örebro	186	163	349	55,6	19	31	50	14,3
Σ	1042	526	1568	41,5	204	144	348	22,2

Table 1. *Location of buildings for companies.*

Between 55, 6 % and 30, 5 % of all new buildings for companies in all branches of trade are located to the 1 km zone; Thereof on average 22 % within the 1 minute zone.

2. Location of Housing

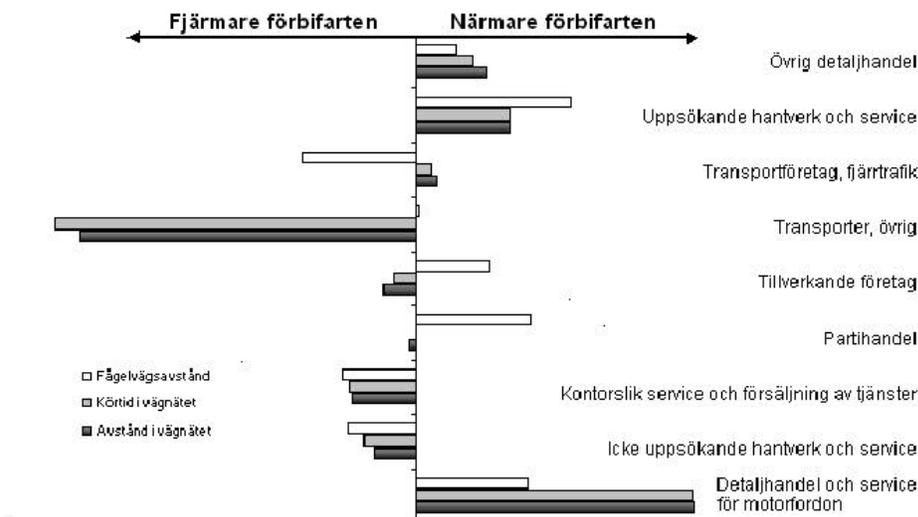
A high volume of new residential houses have been located to the 1 km zone. Surprisingly a high degree of the single-family houses:

	New residential houses within the 1 km zone – housing. Total and % of the total in the city				Thereof within the 1 minute zone			
	Tenement		Single-family		Tenement		Single-family	
	To- tal	%	Total	%	Total	%	Total	%
Eskilstuna	92	12,2	1198	40,3	20	21,7	507	42,3
Gävle	9	2,1	302	21,9	0	0	29	9,6
Halmstad	94	17,1	764	18,4	33	35,1	27	3,5
Lund	235	19,6	1908	40,1	25	10,6	308	16,1
Nyköping	132	24,5	262	16,8	52	39,4	109	41,6
Södertälje	78	16,4	236	12,5	28	35,9	136	57,6
Örebro	158	16,7	431	19,3	22	13,9	81	18,8
Summa	798	16,3	5101	26,9	180	22,6	1197	23,5
Σ excl. Gävle	789	17,7	4799	27,3	180	22,8	1168	24,3

Table 2. *Location of Housing.*

3. Location in the 1 km zone after branch of trade divided into far from/close to by-pass:

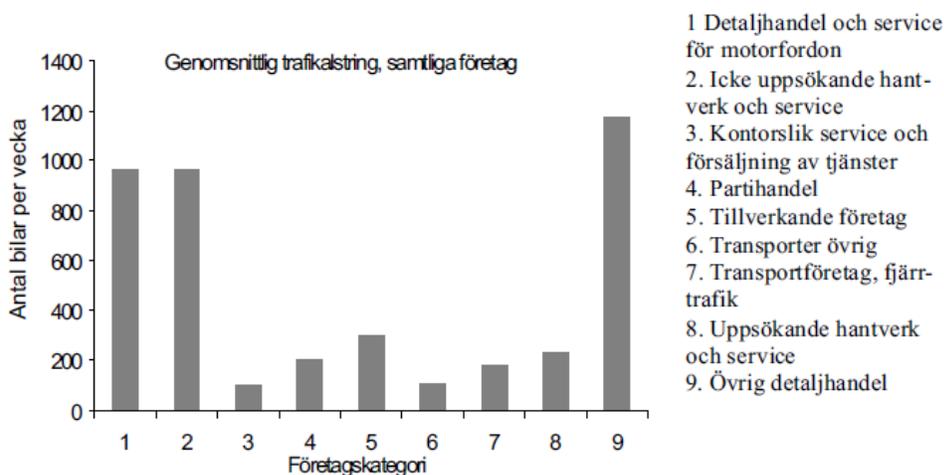
The vertical axis shows the average value for all companies in all branches of trade in all the studied cities. To the right is branches of trade with a closer location to the by-pass and vice versa to the left. Distance is divided into (i) as the crow flies (fågelvägsavståndet), (ii) driving time (körtid i vägnätet) and (iii) driving distance (avstånd i vägnätet):



Figur 4. Location in the 1 km zone after branch of trade divided into far from/close to by-pass.

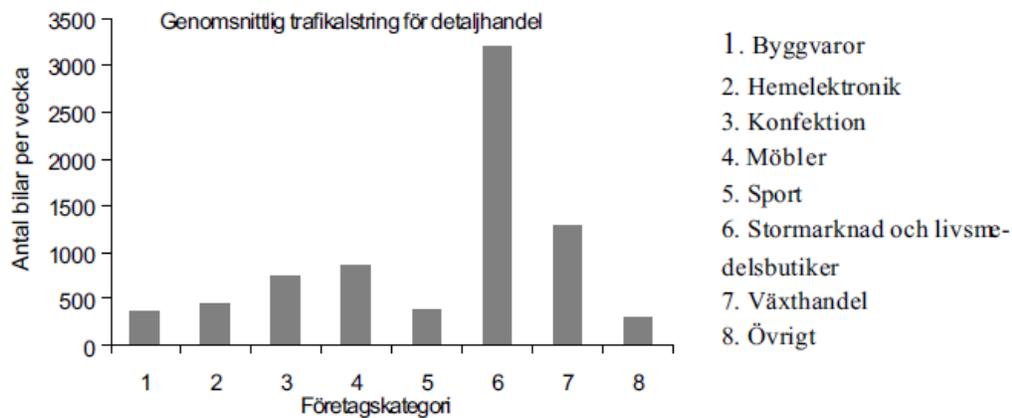
4. Trip Generation – cars per week for companies in 9 categories within the 1 km zone:

A trip generation survey was conducted for two purposes; (i) to plot actual trip ends generated by 9 categories of land use:



Figur 5. Trip Generation – cars per week for companies in 9 categories within the 1 km zone

And to (ii) sub-categories of each of those 9 broad categories (down is retail trade divided into 8 sub-categories):



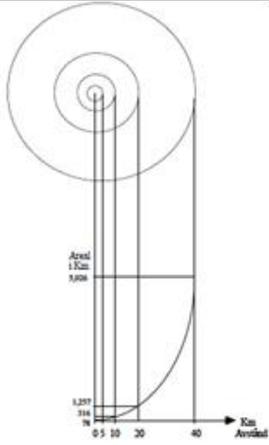
Figur 6. Trip Generation – cars per week for retail trade companies in 9 categories divided into 8 sub-categories, within the 1 km zone.

We did not weight average trip generation against independent variables like number of employees or gross floor area due to lack of data.

1.6 Induced growth in housing-job market from major road investments in Gothenburg metropolitan area 1970-2004

A problem mentioned earlier is the operation with a pre-defined influence zone (in our case 1 km around the new road). Based on the simple fact that new roads with a high operating speed opens large areas with extensive cheap land use (often farm and forest land) for development Hagson and Mossfeldt (2008) (i) calculated the growth in areas within 15, 30, 45 and 60 minutes commuting time with car from the CBD in Gothenburg and (ii) plotted the number of new residential houses as well as buildings for all kinds of workplaces from 1970 - within those zones. From that we could calculate the effects on VMT, commuting time with different transport modes, mode share etc. What we could not estimate was to what degree homes and workplaces was generated and redistributed. The results are summed up in brief below:

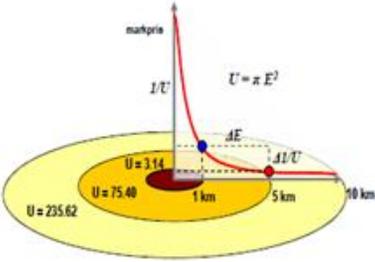
The accessible area for urban development within the same travel time grows with the square of the radius



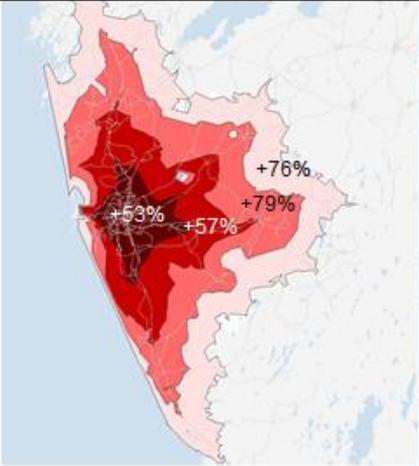
So, major road investments in the Gothenburg metropolitan area 1970-



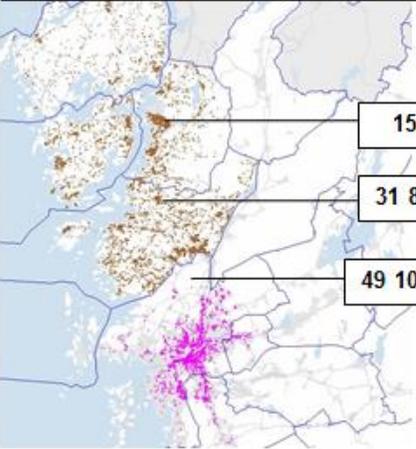
.... will give rise to huge amounts of cheap land in the periphery i.e. a strong stimulus for building single family homes



Growth in areas within 15, 30, 45 and 60 min car trip from CBD 1970 -



Commuting from single family home in the North West sector to work place in the city of Gothenburg

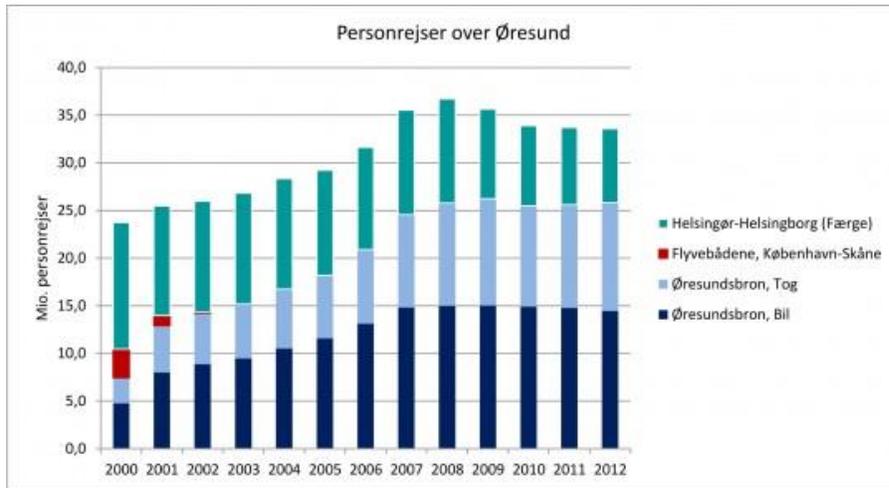


Figur 7. Induced growth in housing-job market from major road investments in Gothenburg metropolitan area 1970-2004.

1.7 Induced regional enlargement from The Öresund bridge

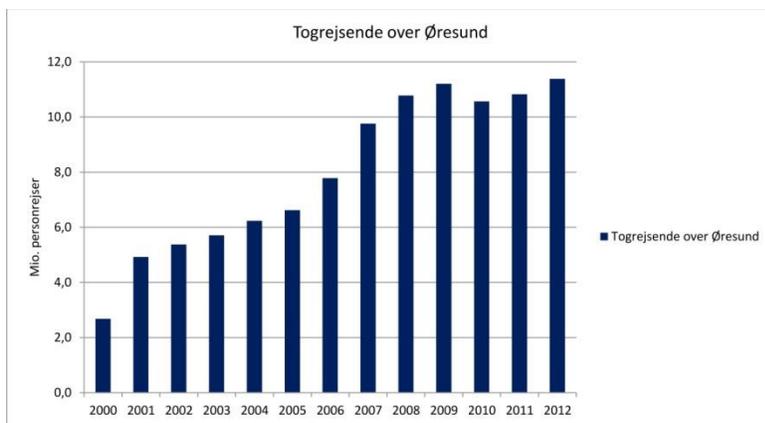
In 1999, the year before the Öresund Bridge was opened; it was 2600 daily Öresund commuters. During the first years of the Öresund Bridge lifetime, the number of commuters increased steadily, but the increase during the period 2005-2007 was exceptionally high due to both the Danish labor shortages and huge price differences for homes on the two sides of the Öresund. In

2008 the number of commuters peaked at 19,800 and has since then decreased due to the financial crisis and the recession. The development of commuting across the Öresund after the bridge was opened in July 2000 has mainly taken place between Southwest Skåne and the Danish part of the Öresund region.



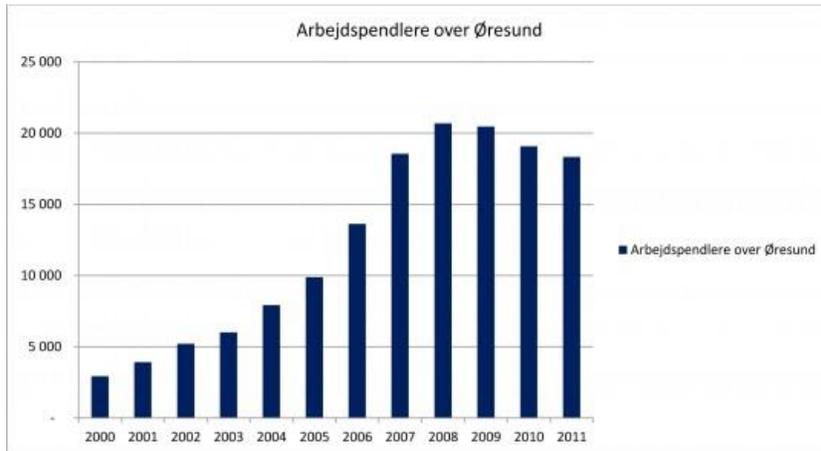
Figur 8. *Commuting across Öresund. Annual million passenger trips by Ferry (green), Speedboats (red), Train over the Öresund Bridge (light blue) and Car over the Öresund Bridge (dark blue), 2000 – 2012.* Source: The Öresund Bridge and Shippax, www.tendensoresund.org

Rail travel has doubled since the Öresund bridge opening. In the year 2012, the number of train passengers across the Öresund Bridge was 11.4 million trips. After a dip in 2009 increase in rail passengers after 2010 is mostly explained by the opening of the City Tunnel in Malmö, which resulted in reduced travel time.



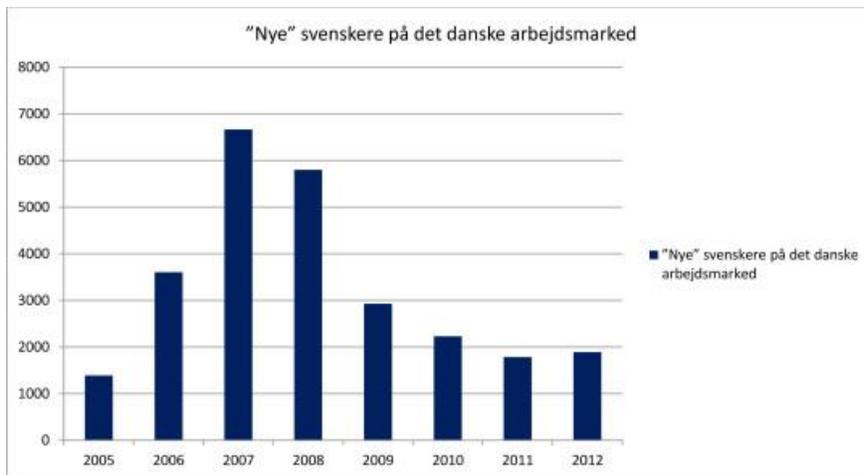
Figur 9. *Annual million passenger trips by train 2000 – 2012.* Source: Trafikstyrelsen, www.tendensoresund.org

Recent years the commuting across the Öresund has decreased, after a strong growth between 2000 and 2008. In 2011, approximately 18,000 people commuted to the other side of Öresund. The decline is partly due to the fact that both Sweden and Denmark are hit by recession. The consequence of the recession is increased unemployment in Sjaelland, which resulted difficulty to find work on the Danish side of the Öresund.



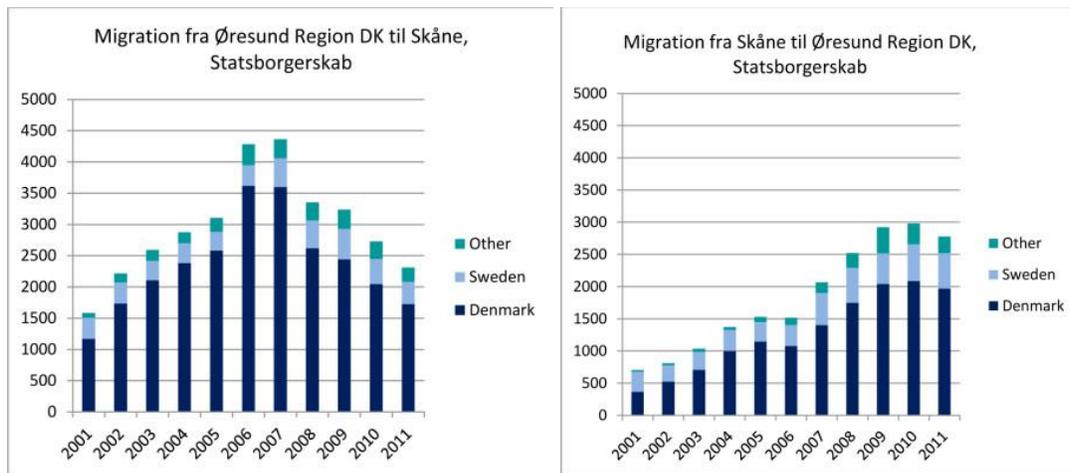
Figur 10. Annual commuting to work over the Öresund Bridge, 2000 – 2012. Source: Örestat, www.tendensoresund.org.

New Swedes in the Danish labor market means persons who gets their first job on the Danish labor market. The table indicates the rise of a very competitive Danish labor market, resulting in a decline in the number of newly registered Swedes since 2007.



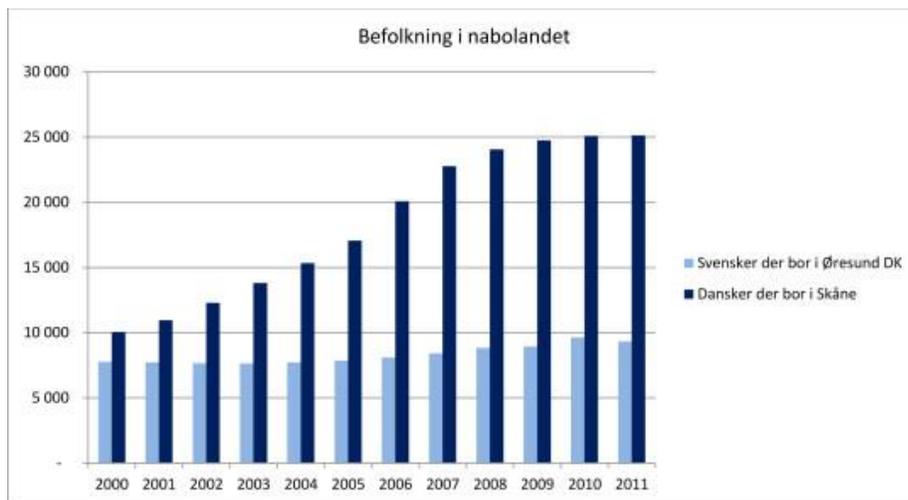
Figur 11. New "Swedes" on the Danish labor market, 2000 – 2012. Source: Örestat, www.tendensoresund.org

The majority of people who move across the Öresund have Danish citizenship. In recent years there has been a shift in migration flows. Now more people moves from Skåne to Denmark because of falling prices on the Danish housing market.



Figur 12. Left: Migration from the Öresundsregion in Denmark to the Skåne region in Sweden. Right: Vise versa. Citizenship: Dark blue Danish, Light blue Swedish, green Other), 2000 – 2012. Source: Örestat, www.tendensoresund.org.

Since the bridge opened in 2000, there has been a high influx of Danes to the Skåne region, which is explained by the lower square meter prices on the Swedish housing market. After the bubble burst in the Danish housing market in 2007, the stream of Danes to Skåne slowed down.



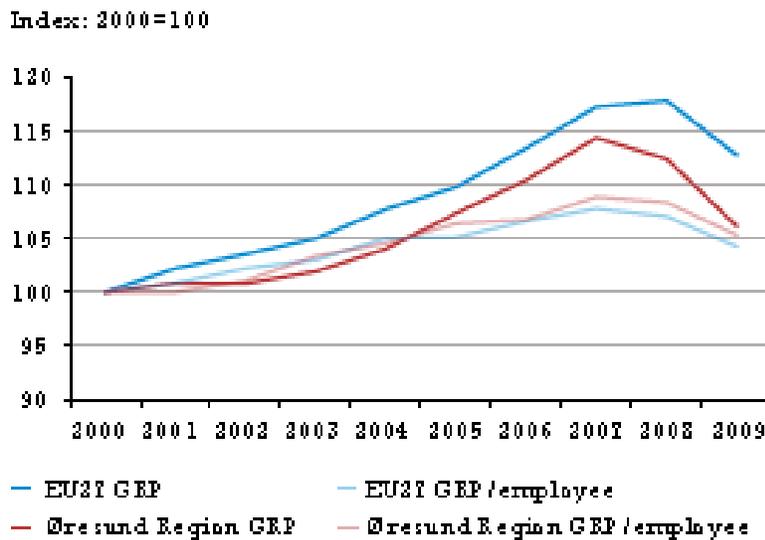
Figur 13. Swedes living in the Öresundregion in Denmark (light green). Danes living in the Skåne region in Sweden (dark blue), 2000 – 2012. Source: Örestat, www.tendensoresund.org.

Benefits

The integration across Øresund is important for both Denmark and Sweden. In 2010, Øresund commuters contributed 740 million EUR in added value to the Danish economy. Since the Øresund Bridge opened in 2000, the Danish economy has received a substantial financial injection totaling 4.4 billion EUR through Øresund commuters. For that money, it would be possible to build one and one-third Øresund Bridges. At the same time, the Swedish economy saves expenditure on unemployment benefits. In 2010, this saving was nearly 175 million EUR.

Businesses traffic across the Øresund Bridge consists of B2B traffic in passenger cars and vans, as well as by freight traffic in goods and trucks. Businesses traffic is stable: about 20 percent of the traffic over Øresund Bridge. To an increasing extent, the road freight operators find the Øresund Bridge to be an effective and convenient connection between Denmark and Sweden. In more than half, 51.5 percent to be exact, of all truck passes over Øresund used the Øresund Bridge.

The Øresund Region is important to both the Danish and the Swedish economy: the region accounts for 27 percent of the total GDP (gross domestic product) of the two countries. In 2009, the average of GRP per employee was 69,000 EUR in the Øresund Region and 48,000 EUR per employee in the EU27 countries.



Figur 14. *Development in GRP and GRP per employee in EU27 and the Øresund Region (2000–2009)*. Source: Øresund Bridge and Shippax, www.tendensoresund.org.

1.8 Conclusion: Transportation technologies have always determined urban form

The evolving form and structure of Cities over the globe may be traced back to to four transportation eras. Each growth stage is dominated by a particular movement technology and network expansion process that shaped a distinct pattern of intra-urban spatial organization:

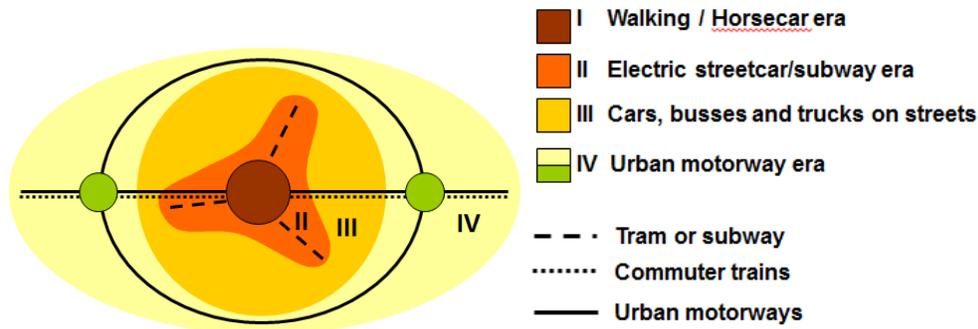


Figure 15. Adoption from: *Intra urban transport eras and metropolitan growth patterns*, J. S. Adams, 1970, *Annals of the Association of American Geographers*, 60, p 56.

The process diagrammed above reveals two sharply different morphological properties over time. During eras 1 and 3 uniform transport surface conditions prevailed, permitting directional freedom of movement and decidedly compact overall development pattern. During eras 2 and 4 pronounced network biases dominates, producing irregularly shaped cities in which radial transport routes, corridor and edge city developments overshadowed growth in relatively inaccessible interstices.

It then becomes obvious that transport eras have near and longer term impacts. Exemplified with era 4, increased capacity prompts behavioral shifts – some formerly suppressed trips are now made (i.e., latent demand), and some motorists switch modes, routes, and times of travel to exploit available capacity, what Downs (1962, 1992) calls “triple convergence”. For example, those who previously patronized transit to work might decide to drive once they see traffic flowing more smoothly. Some who previously commuted on the shoulders of the peak might start filling freeway slots that are vacant in the heart of the peak.

Some of the traffic gains spawn by a new or improved road is redistributive: Route and schedule changes do not increase total miles traveled. Other investments are generative in nature. They induce new travel that did not previously exist in any form. Thomson (1969) included here: formerly suppressed trips, longer trips as motorists opt to travel farther because of freer flowing traffic, enhanced advantage of having a car will accelerate the growth of car ownership that in turn stimulate more modal shifts from public transport. That gives us this short-term effect model:



Figure 16. *Near-term effect model.*

Improved accessibility to employment and other personal activities influence individual's choice of home, working place, where to shop etcetera. For business and industry access to markets and labor influence their location. In this way supply of land miles and roadway speed leads gradually to greater dispersal of associated activities, involving longer journeys and hence more traffic for a given volume of activities (i.e. the most important example of this is the journey to work). To quote Thomson (1969 p. 34) "*New roads induce people to live farther from their work or to work farther from their home.*" In this way, over a longer period of time, *induced urban structural changes can be expected.* Today's urban landscape are dotted with: fast-food restaurants, gas stations, and other auto-oriented uses cluster around interchanges, warehouses align themselves along frontage roads, and new residential subdivisions spring up along connecting arterials. "Sprawl" ad inducement towards higher car-ownership and shift away from public transport. This leads to demand for more road capacity. These processes give us this medium- to long-term effect model:

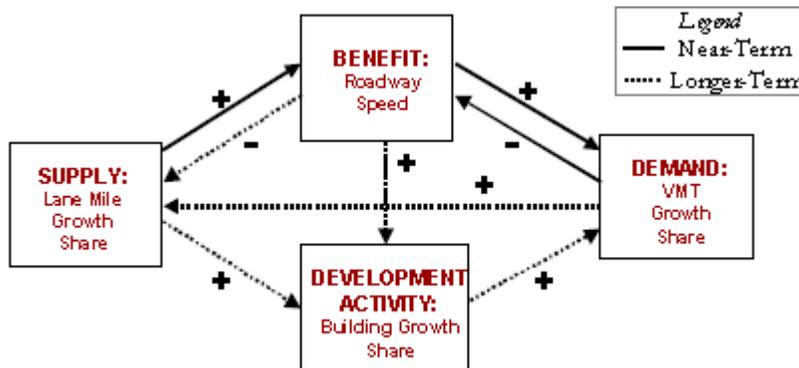


Figure 17. *Near and Longer term effect model.*

2 Induced traffic in today's traffic forecasting models in Sweden

Today there are two main models for estimating the effects of road investments in Sweden:

- Sampers/Samkalk. Samkalk cost model is coupled to the forecasting system Sampers - used for systems analysis, analyzes of major road, rail and flight investment and for policy analysis.
- EVA. Used for analysis of smaller road investments.

There are also models for even more detailed analysis, but in this review we stick to Sampers / Samkalk and EVA.

Samkalk calculates:

- Producer surplus (ticket sales, vehicle costs, ticket tax and track access charges)
- Budgetary impacts (fuel tax for road, tolls / road tax, ticket tax etc.)
- Consumer surplus (travel costs, travel times, toll / road tax and freight time savings for road)
- Externalities (pollution, traffic accidents)
- Operation, maintenance and reinvestment

Sampers/Samkalk are used for estimations of most of the cost/benefit calculus. Effects not include are:

- intrusion (either noise or barrier effects)
- road safety at intersections between road and rail
- delays
- freight time savings for rail (only freight time savings for road calculated).

The consumer surplus calculated in Samkalk are on the O/D level using the so-called "rule of the half":

- Additional and transferred traffic is assumed to utilize half the travel time gains and
- Lowering the generalized cost of travel leads to increases in travel.

Sampers thus calculate the difference between traveling before and after the investment - in other words, the induced traffic (this is the purpose of the model). However, there are effects not taken into account:

- Land use is not affected by accessibility changes. It is possible to add different land uses in comparative and investigative option, but it is never done (mainly because it is labor-intensive).
- Car ownership is not affected by change in accessibility changes.

The major difference between EVA and Samkalk is:

- EVA is not based on a forecasting model, while Samkalk is based on the output of Sampers.
- EVA is based on the assumption that no traffic is transferred and no new trips are generated.

2.1 Case studies and conclusion

The question we asked ourselves before the case studies (Hagson et al, Trafikverket, report 2011:052) was: Does Sampers and/or EVA capture the shorter-term induced traffic? Theoretically, we know that Sampers should capture the short term induced traffic.

The case studies for the Southern Link (Södra länken) in Stockholm and E4 bypass Örkeljunga do not indicate that the induced traffic is underestimated in the short term. Traffic from Samper forecasts are for some measure points even over the measured levels. It is not possible to categorically draw conclusions about the Sampers system based on only two case studies, but it is likely that the model:

- accounts for the interaction between benefit and demand as in the near-term path model above (Figure 16) and
- don't have any possibility to account for longer-term impacts from induced land use and car ownership changes from additional road capacity.

3 State of the art: Integrated land use – transportation models

Are there models that can capture longer-term impacts on urban form and land use from road investments?

It all started with Mitchell & Rapkins paradigm breaking book *Urban Traffic A function of Land Use* (1954, p 3) that starts up with this statement: “It is commonly observed that various kinds of activity based on the land – called land uses – ‘generate’ different amounts and kinds of traffic. It is also observed that a change in the amount of daily traffic movement or in the facilities for it, or an expected change in the traffic in a particular site, has a considerable on the location pattern of the land uses.” From then and on a vast flora of approaches and models has been developed. We will not review or discuss all models and approaches. We focus on models can be considered as “road maps” of a specific approach. This means we will exclude models that have not gained momentum such as CARPE, TOPAZ, POLIS and STASA.

3.1 The first era: aggregate spatial interaction-based models

The Lowry-Garin model

One of the first models that gained substantial interest was developed for the Pittsburgh metropolitan region by Lowry (1963, 1964). He related population, service, manufacturing and primary employment to residential, service and industrial land use activities. The division of employment into service and basic sectors reflects the use of the economic base method to generate service employment and population from basic employment.

Then those activities are translated into land-use/activity ratios. Population is allocated in proportion to the population potential of each zone and service employment in proportion to the employment potential of each zone with respect to the amount of land “free for use” in each zone (so that a fixed maximum density constraint for every zone is not exceeded). In the service sector, a minimum size constraint is placed on each category of service employment, and the model does not allow building up service (-employment) which are below these thresholds.

In next step the model locates the various activities in a consistent way by feeding back the predicted population- and employment development over time; and then reiterating the whole allocation procedure until the distributions input to the model are coincident with the outputs.

In 1966, Garin (1966) published an important paper where he suggested to replace the potential models by production-constrained gravity models. Thereby the coupling between allocation and generation was much improved.

The model started the the quantitative revolution in urban planning and gave rise to many similar models.

TOMM

The first offspring from Lowry’s model - called the Time Oriented Metropolitan Model (TOMM) - was developed as part of the Pittsburgh Community Renewal Program (Crecine, 1964). This

model, called the Time Oriented Metropolitan Model (TOMM) introduced a disaggregation of population into different socio-economic groups to increase the explanatory power of the model. In addition, time was treated in a different ways. In a later version, Crecine (1968) replaced population and employment potentials by linear equations including rent, transport cost and site amenities such as the availability of schools.

PLUM

The Projective Land Use Model (PLUM) was designed by Goldner (1971) for the Bay Area Transportation Study Commission. In this model potentials are replaced by gravity models to allocate land uses. More specifically, the model allocates services and population using intervening-opportunity models. In addition, Goldner disaggregated the parameters for each of the nine counties in the Bay Area and used zone-specific activity rates and population-serving ratios to account for differences in population and employment structure. It reflects a more general tendency to use disaggregation and a wider set of parameters in an attempt to make the models more realistic, which made them also more of a black box and a data-fitting exercise.

ITLUP/DRAM/EMPAL/METROPILUS

ITLUP represents the first fully operational integrated transportation and land use model (Putman, 1983). The land use model was a modification of Goldner's version of the Garin-Lowry model of land use. The network model was a conventional capacity-constrained incremental assignment model. A preliminary allocation of land use activities was used to produce Origin-Destination (O/D) matrices. The resulting travel times were used to calculate new activity distributions.

Later, the land use model was revised by modifying the spatial allocation equation. This became known as DRAM and EMPAL, which in the early 1990s were the most widely applied land-use models in USA. DRAM locates households, while EMPAL locates employers/employees. These models were simple and did not have up to date theoretically comprehensive structures. But the simpler the better - apparently they matched the demand in the practice. After the models were installed on agency hardware, calibrated to regional data, and applied in forecasting by the agencies, about fifty percent of them continued to use the models as a component of their in-house ongoing land-use and transportation and forecasting analyses as a part of the urban and urban transport planning process.

In the 1990's modified versions were developed and distributed as METROPILUS. It is embedded in a GIS environment.

LILT

The Leeds Integrated Land-Use model (Mackett, 1983, 1990, 1991b) combines a Lowry type of location model with a traditional four-step transport model. Forecasts of total change in population, new housing and jobs are allocated to zones according to accessibility functions and the attractiveness of the zone, using entropy-maximizing principles. Employment is divided into twelve branches, while population is divided into three socio-economic groups.

The model handles demolition, changing occupancy rates and vacancies. Car ownership is estimated as a function of time and travel costs. Trips for work, shopping and other purposes are allocated to car, public transport and walking. Capacity-constrained road assignment is used, implying that speeds are a function of traffic flow.

IRPUD

The IRPUD model was developed for the city of Dortmund Michael by Wegener and his partners (Wegener, 1982a,b; Wegener, 1983). A macro analytic model of economic and demographic change is used to simulate employment change in different branches of industry, commerce, public sector etc. and demographic changes by age, gender, and nationality within a set of labor market regions. Given this model, a meso-scopic spatial model is used to simulate intra-regional location decisions of industry, residential developers and households. Finally, a micro-analytic model of land use development within statistical tracts is used to allocate the demand generated by the meso-scopic model. The transportation and land use subsystems are operated separately:

The spatial distribution of land use is allowed to change through aging; exogenous events and accessibility based spatial choices generated explicitly within the model. The simulation of the land use involves interlinked sub models for aging of people, households, dwellings, and workplaces; relocation of firms, and new jobs; nonresidential construction and demolition; residential construction, rehabilitation, and demolition; change of job; change of residence, and car ownership.

Mode choice is nested within destination choice and takes into consideration car availability and generalized travel costs. A distinction is made between discretionary and non-discretionary travel, using respectively doubly constrained and production-constrained entropy-maximizing models. T

The use of gravity models makes the model very similar to the oldest type of models; while the use of micro simulation is more typical of the later generations of land use-transport models.

3.2 The second era: utility-maximizing multinomial logit-based models

The MEPLAN model

This model was developed by Echenique and Partners through a series of aspect-studies over time in different countries/cities (Echenique, et al, 1969; de la Barra, et al, 1975; Flowerdew, 1977; Hirton and Echenique, 1979; Williams and Echenique, 1978; and Geraldes, et al, 1978).

The model system is based on an input-output model that predicts the change in demand for space (Echenique, 1994). The model is used for allocation of the demand to spatial zones, using random utility concepts. Spatial choices link production to consumption, generating the demand for transport. An equilibrium model is derived by solving all the equations, subject to constraints.

Given transport demand by type and flow, the transport model predicts modal split and route choice with adjustment for capacity constraints that affect travel time. Again, random utility

concepts are used in the transport model. Information about costs, travel times due to congestion, etc. are fed back into the land use-economic model to provide time-lagged measures of accessibility. Echenique, et al (1995) used the model to simulate the effects of urban policies’.

TRANUS

The Tranus integrated land-use and transport modeling system was developed to simulate the probable effects of applying particular land-use and transport policies and projects, and to evaluate their social, economic, financial, and environmental impacts. A detailed explanation can be found in de la Barra (1989). Tranus has a land use or activities model and a transport model. It is assumed that activities compete for real estate, resulting in equilibrium prices. The location of activities is influenced by such prices, but also by accessibility, generated by the transport system. The location of activities is modeled in the land use system. The transport model uses travel demand as input and assigns it.

In this process, potential travel demand calculated by the land-use model is transformed into actual trips at a particular time of the day (peak hour, twenty-four hours, etc.) by transport mode as an elastic function of cost. Next, modal split is estimated using a logit model (a combined trip generation – model split also exists). Trips for each category are assigned to the different multi-modal paths connecting origins to destinations. Since each path implies a particular sequence of modes and transfers, trips are simultaneously assigned to modes as well as to links of the network, using another logit model, where the utility functions are determined by the overlapped generalized cost of each path. By applying vehicle occupancy rates, trips are transformed into vehicles by mode in each link of the network. Public transport is assigned directly to the network. In turn, the number of vehicles by operator is transformed into standard vehicles by applying appropriate rates. The final stage of the iterative process is a capacity restriction procedure, in which travel speeds are reduced and waiting times are increased in every link for each route as a function of demand/capacity ratios. Waiting times take into consideration the frequency of transit services and the demand/capacity ratio of the vehicles themselves. This iterative process continues until convergence is achieved.

BASS/CUF

As indicated by Landis (1994), the California Urban Futures Model (CUF), earlier known as the Bay Simulation System (BASS), was developed to simulate how growth and development policies might alter location, pattern and intensity of urban development. The model differs from the typical integrated transport-land use model in a number of ways. First, regional forecasts are not allocated, but a bottom-up approach is followed. Secondly, development is not only a function of spatial accessibility but of a wider set of variables. Central to the model is the notion of the profit potential of each developable land unit as a function of sales price, raw land price, hard construction costs, site improvement costs, service extension costs, development, impact, service hookup and planning fees, delay and holding costs and extraordinary infrastructure capacity costs, extractions and impact mitigation costs. CUF-2 (Landis and Zhang, 1998a, b) consists of two multinomial logit models of land use change. The first sub model explores the determinants of land use change among undeveloped sites, while the second model examines the determinants of land use change among previous developed sites.

The probability of land use change is a function of initial site use, site characteristics, site accessibility, community characteristics, policy factors and relationships with neighboring sites.

MUSSA and RURBAN

This model, developed by Martinez (1992, 1997) received some interest because the spatial allocation of land uses is handled using a bid function. The model is not a fully integrated model, but can accept as input the total demand (growth) from households and firms and a transport model. Central to the model then is to predict the location of households and firms and the resulting rents. To that effect, following Ellickson (1981), a bid function is used, which is specified as a function of property attributes, zone attributes, transport attributes and consumer clustering variables. He showed that the spatial probability distribution obtained from the bidding function is identical to the probability distribution obtained by the maximization of individuals' (consumer) surplus, emphasizing the equivalence of the bid and choice approaches, given the traditional set of assumptions. Operationally, a multinomial logit model is assumed. The reliance on bid rent is similar to the earlier developed RURBAN model (Miyamoto, et al, 1989; Miyamo and Udomsri, 1996)

CATLAS and METROSIM

The Chicago Area Transportation – Land Use Analysis System (Catlas) was developed by Anas (1982, 1983a,b) for studying the relationship between land use and transportation. It differs from previous attempts in that it was better rooted in economic theory. The system consists of four sub models that are all derived from discrete choice theory and utility-maximizing behavior: 1. a demand sub model, 2. an occupancy sub model, 3. a new construction sub model and 4. a demolition sub model. The model predicts the probability that a worker employed at a workplace will live in some residential zone and the conditional probability that he will commute by some transport mode. The demand and supply sub models are estimated only for two workplaces: the CBD and the rest of the Chicago SMSA. A multinomial logit model is used to predict four modes (car, commuter rail, rapid transit and bus) for the CBD and only car and bus for the remainder of the study area.

Building on the CATLAS model of combined residential location, housing and mode choice, the modelling of non-work travel choices and commercial real estate markets in the New York region (the NYSIM model), and the modelling of metropolitan housing market dynamics in a number of US cities (the CHPMM model), Anas and his colleagues have developed a highly integrated economic model of transportation and land use called METROSIM (Anas, 1994). This model consists of 7 sub-models, providing analysis of a region's basic industry, non-basic industry, residential and commercial real estate, vacant land, households, commuting and non-commuting travel and traffic assignment, within a single structure.

DELTA

This model was developed by David Simmonds Consultancy, MVA Consultancy and the Institute of Transport Studies, Leeds during the period 1995-1996 (Simmons 1999). It is not an integrated package, but a link of separate models. Input to the land use model is the accessibility and area quality output of the transport model. New to the model is that accessibility is based on

accessibility from each zone to alternative destinations for each variety of purposes. Log-sum type of accessibilities is used.

Land use change is modelled for demographic change and employment change. Demographic change is primarily modelled in terms of household formation, dissolution and transformation. The economic growth model applies sector growth or decline rates to each sector in each zone and specifies which proportion is mobile during the current period. These rates are exogenous to the model. The location model predicts the location of those activities that are mobile as a function of accessibility, transport-related change in the local environment, area quality and rent of space.

UrbanSim

The initial design of the UrbanSim model was funded by the Oahu Metropolitan Land-Use Model as part of a larger effort to undertake the development of new travel models. The project involved the development of a travel model system based on modelling tours rather than trips. The model was further elaborated in 1996 when the Oregon Department of Transportation launched the Transportation and Land Use Model Integration Project (TLUMIP) to develop analytical tools to support land-use and transportation planning. The model was extended and a prototype was implemented. The model was calibrated for a case study in Eugene-Springfield. Later, the dynamic aspects of the model were calibrated, and the model was applied in Utah and Washington (Alberti and Waddell, 2000; Waddell, 2002) questionable for the choice of destination for leisure/recreation, where variety-seeking behavior may be quite important. Some of these effects may be picked up by replacing the trip or tour-based models with activity-based models.

However, it should be realized that at the present state of the art, this would only partly solve the above problem. Virtually all existing activity-based models depend on one or two-day diaries and hence will not fully capture the notion of time-variant utility functions. In addition, the dominant utility-based models of activity-travel patterns, relying on the nested logit model, represent observed activity-travel patterns. They do not attempt to derive the principles that generate such patterns. Computational process models of activity scheduling behavior do, but fully operational computational process models are still scarce.

Most integrated land use – transport models predict employment directly rather than focusing on locational choice behavior of firms. To the extent that such behavior is modelled, again the multinomial logit framework does not seem appropriate. Location choice of firms is often sequential, based on imperfect information, no compensatory decision-making, a group decision rather than an individual decision, and often involves soft, non-spatial factors. Again, a different modelling approach would be required to incorporate such aspects.

3.3 The third era: Developing truly integrated models

Many so-called integrated land-use – transport models involve some ad hoc combination of different modelling approaches. Often, the demand for different types of land use is determined by separate models, another set of models is used to allocate the demand across space.

Next, this spatial distribution is used to predict traffic flows, using a trip, tour or activity-based model, and a transportation model are finally used to calculate travel times. The notion of integration is often reduced to the principle that the calculated accessibility measures or travel times serve as one of the explanatory variables of the residential choice module.

However, the literature on residential choice behavior (e.g. Molin and Timmermans, 2003) has systematically shown that accessibility at best plays a marginal role in the residential choice decision. The attributes of the house and the physical and social characteristics of the neighborhood are far more important. Although there is some literature in the field of transportation (e.g., Gayda, 1998; Kaysi and Abed, 1999; Cooper et al, 2001; Walker, et al, 2002) arguing the importance of accessibility, these studies have typically left out many critical housing attributes. Hence, it is not a surprise that they found significant transportation attributes. These effects are however likely statistical artefacts rather than evidence of behaviorally important constructs.

Other aspects of integration seem to receive far less attention, but might be more important to model today's cities. Examples are task allocation within households, the residential choice, job choice and vehicle holding decision for double-earner households, the scheduling of activities in time and space, competition and agglomeration of land uses/actors in the urban development process, the co-evolutionary development of demographics, employment sectors, land use and activity profiles, and a fuller treatment of varying time horizons, including both anticipatory and reactive behavior, to name a few.

3.4 Conclusion

From this review of developments in complex, integrated models of land use – transport we can conclude that the landscape of basic techniques has not changed all that much over the past decade (e.g. Clarke 2014; de Montis et al. 2013, Bettencourt et al. 2007), apart from a shift toward more micro level simulation, Big Data³ and an integration with innovation studies and other types of interaction networks.

We can also conclude that although progress has been made in terms of more detailed classifications and finer scales of spatial resolution, *not much theoretical progress has been made*. Especially the operational models are still largely based on traditional location theories and models that may have been adequate to describe traditional cities and traditional centralized planning methods, but that *seem inadequate to describe the evolution of modern cities*, dominated by service industries and information technology. The field has consistently been *criticized for its complexity and black box character*. The criticism and our standpoint - contrary to the plea for behaviorally better models that implies further complexity - is: ***Cities and urban regions are complex, complicated and dynamic systems and therefore a “wicked” problem***, as described in Figur 11. We will develop on this theme in the next chapter.

³ The data set that we used in Andersson *et al.* (2003, 2005, 2006) was considerably larger and more complete than similar studies at the same time.

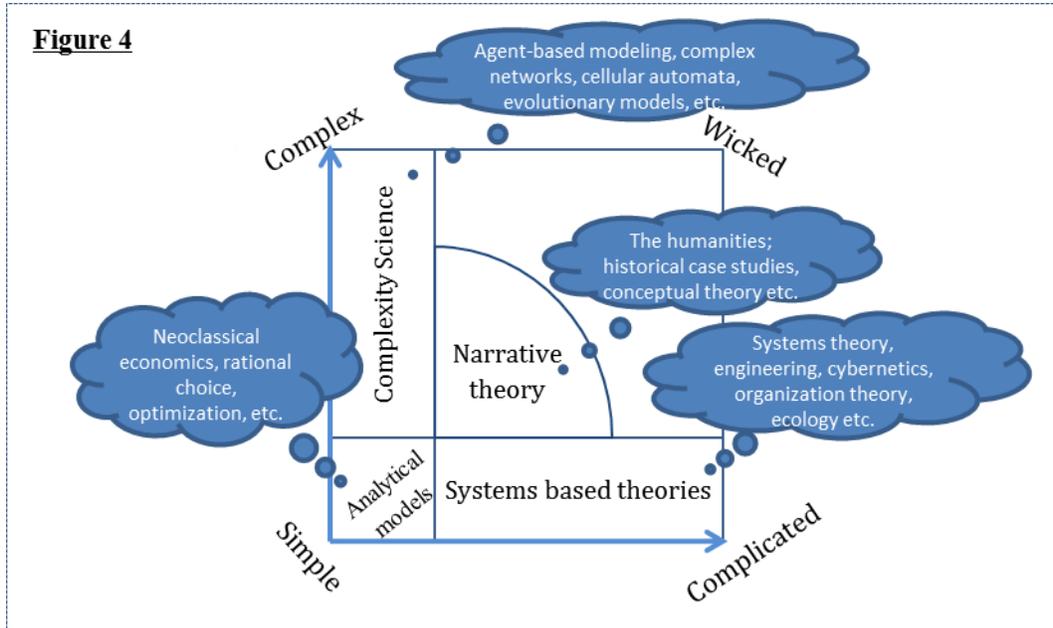


Figure 11. The landscape of basic modelling techniques are still simple while cities and urban regions are complex, complicated and dynamic systems and therefor a “wicked” problem.

4 Urban dynamics

Over time it is commonly observed that cities and urban regions continually changes. Some grows slow and continuously (they are normally highly diversified). Other grows big and suddenly decline and disappear (most often “company towns”). In the latter case huge investments in infrastructure (like the monorail in Detroit) will not help – they already have good access. In the first case transport investments are crucial – and they canalize growth (planned or unplanned).

So, at any given time the existing (fixed) land use causes a demand for transportation (a dependency on transport means to get to to work, school ...; and to undertake movements of goods). From day to day it is therefore correct to say “Urban Traffic – A Function of Land Use”. Over time the direction goes the opposite way: land use changes as a result of a large number of individual decisions that interact in a highly complex and subtle way; but investments in new transport infrastructure capacity are almost always a necessary factor. From this fact Manuel Castells (1989) has defined the modern city as being a “space of flows”. The dynamics of urban land use and urban transport system can be described in this way:

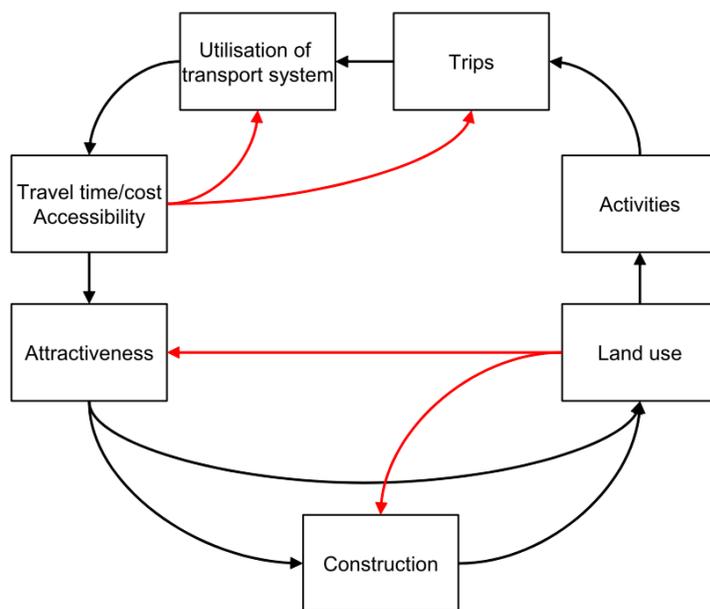


Figure 12: A general representation of the interaction effect between transport systems and location (land - use).

Politicians and planner may want to use highway or transit planning to help create a desired land use development. Experienced planners know that a change in urban and regional traffic channels will affect the pattern of land use, but they cannot tell exact where, when and to what degree. They need, therefore, to be provided with a better understanding of and better tools for handling the functional relationship between traffic system investments and land use changes within and between cities.

To understand place we must understand flow and to understand flows we must understand networks. This gives us the first principle that we will use: *relations* (networks) between space and place – not intrinsic attributes of place and space – makes understanding of urban dynamics possible. The second principle we will use is about properties of networks (roads) and flows (traffic) and in turn of spaces and places that depend on them (i.e. a bypassing urban motorway with intersections – and the localization of shopping malls).

4.1 A “Science” of Cities

For decades the “science of cities” was based on normative applications of geometry and form in order to achieve best possible fortification standards and social conditions. Patric Geddes (1915, p. 269) switched the argument away from notions of mechanisms to the flows and fluxes that had begun to dominate the life sciences. Half a century ago we started to consider cities as “systems”. These were in the main defined as collections of interacting entities in equilibrium, but with functions that could enable their control; often with analogy to existing top-down institutions for urban planning and political management.

The rise of the sciences of complexity has changed the direction of systems theory from a top down to a bottom up perspective. At the same time the image of a city as a machine or an organism has been replaced by that of an ecosystem, more like an arena for evolution than the adapted and functional outcome of evolution or design.

This replacement allows us to draw some conclusions about earlier approaches:

- Plans based on arranging activities and their land uses into ideal configurations, or imposing constraints on what activities can locate where, rarely grapple with the essence of how cities evolve.
- Location and land use encapsulates the working of urban activities but does not reveal the relations and interactions - networking - between them, which represents the rationale for living and working in cities.

But although the complexity perspective is crucially important, and constitutes essentially our approach for developing tools, it too has its inherent limitations. In particular, like tools based on systems theories, complexity-based tools must be placed in a larger context. They are not that final and privileged perspective that finally allows us to understand everything that we need to understand. Today we have approaches that allow us to understand both complex and complicated systems, but, as we shall argue, societal systems – such as urban systems – are both complex and complicated *at the same time*. They change in an involved process of innovation (e.g. Andersson *et al.* 2014a) that characterizes, precisely, both ecosystems and societal/cultural evolution. We will refer to such systems as “wicked systems” and argue that the big issue is how we can do policy for such systems at all.

4.2 Scientific Philosophy – our view of urban systems

Commonly an urban system – as a part of an economic system – is characterized as a hierarchic structure, like in Christaller's (1933, 1966) central place theory and Beckman's (1970) model. We argue:

- That urban and regional development is – like many natural systems – a self-organized process that changes the system through a bottom-up dynamics.
- That this tends to give rise to hierarchical organization.
- That more persistent emergent structure all the time scaffolds faster and less persistent bottom-up dynamics (e.g. roads scaffold traffic while the needs of traffic calls for changes in the road network), giving rise to a concurrent action of top-down and bottom-up causation in this hierarchy.
- That this mix between bottom-up and top-down interaction gives rise to a specific type of systems that is both complex and complicated at the same time.
- That, because of this, urban systems become something like Rorschach figures: arguments for and against any major approach can be made convincingly, whereas the bitter truth is that neither provides a full picture.
- This calls for new approaches in science and policy for dealing with urban and regional development (a lesson that extends to societal systems more generally).

Hierarchical organization is characteristic of these systems, but unfortunately the same is the case also for systems that are organized by entirely different processes. We organize technology hierarchically to better be able to re-organize them to realize new artifacts with new functionality. Organisms are organized in a similar way to be amenable to evolutionary variation and selection. Both of these are examples of top-down (in the sense of centralized) control where the parts essentially collaborate perfectly in order to realize some overall functionality. In this sense, urban systems are more like ecosystems undergoing evolution over long time scales. They develop a rich hierarchical structure, but not one with a nice separation between scales (such as between cells, tissues and organs), but an organization where the vertical levels keep mixing up and where the components sometimes work together, other times are in competition with one another.

Characteristic for any evolutionary theory is that it explains a current state of affairs from history⁴. Time and space are intrinsically linked in an evolutionary framework. Our current urban system is the result of an unbroken chain of development that extends far back into time – at least to the origins of sedentism, which began to develop already in the Pleistocene in certain parts of the world, and that, in turn, organized with regard to earlier more mobile patterns of land use (e.g. Goring-Morris and Belfer-Cohen 2011). Certain aspects of this system is more persistent than others, and there are actually structures and patterns that basically remain with us from the dawn of sedentism: the echoes of what happened even 10,000 years ago can still be heard in the global urban system. But at the same time, dramatic transitions can take place over relatively short time scales; the balance of power shifts, areas fall into decline and new technologies enter the picture and transform the urban system.

⁴ 'The explanation to why something exists intimately rests on how it became what it is' (Dosi, 1997, 1531).

By this we have painted a picture of how we view urban and societal systems. The question that this leads to is that of how we deal with such systems. The answer, basically, is that we need development on three interlinked levels: theory, policy and methodology. We will pursue these three aspects by (i) developing models and (ii) a new theoretical and methodological perspective. In both cases we begin from solid starting points.

We begin by explaining our modeling approach, moving then to the development of a new perspective on methodology and policy.

4.3 A new perspective

We see the challenges that we face understanding and steering urban systems as manifestations of a much broader challenge. What lies at the bottom of the unpredictability and intractability of urban systems is, we contend, not just that they are non-linear and path-dependent (although that is certainly a big part of it), but also that it is part of a much larger tangle of societal challenges like for example climate change. Classic disciplinary-based and modeling frameworks are inadequate not only to capture the dynamics of such problems, but also to propose workable solutions to them. As such, they have long been argued to require novel and innovative approaches (e.g. Brown, V. A., Harris, J. A., & Russell, J. Y. (Eds.). (2010); Scoones, I., Leach, M., Smith, A., & Stagl, S. (2007); Rittel, H., & Webber, M. (1973); Funtowicz, S., & Ravetz, J. (1993); Funtowicz, S. O., & Ravetz, J. R. (1991).

Wicked problems is a term that was first coined in management research by West Churchman in 1967 to characterize a class of problems that failed to fit into the molds of the formal systems theoretical models that were being applied with considerable enthusiasm at the time. Just about any large-scale societal problem can in fact be confidently put into the category of wicked problems: problems that escape definition, and where there is a constant feeling that the efficacy of proposed solutions is called into question not only with regard to feasibility and adequacy, but also with regard to the risk of creating cascades of other problems that are impossible to foresee and that may be even worse than the initial problem (e.g. Leach, M., Scoones, I., & Stirling, A. (2007); Funtowicz, S., & Ravetz, J. (1993)). Explicating the concept, Rittel and Webber (1973) conclude that the domain of wicked problems is vast – it includes just about any problem short of trivialities. In West Churchman's words (1967), what we tend to do with wicked problems is to either tame them by creating “an aura of good feeling and consensus” or by “carving off a piece of the problem and finding a rational and feasible solution to this piece”.

The work that we propose, and the ideas behind it, spring out of a growing realization that a shift in perspectives on a fundamental level is needed, and that is what we aim for. Wicked systems, as we shall see, are “worse than complex”, and we think this category stakes out a crucial future challenge for science. So part of our “complex systems” perspective is in fact the development of a “wicked systems” perspective.

There are many concrete reasons for why this is a necessary step to take, but the main reason is that all basic approaches to understanding and forming policy for societal systems seem to come

up against some intangible barrier. Our idea of using infrastructure as a policy tool is in direct response to these ideas: we use the system to scaffold their own dynamics. That is, we intervene in their innovation process and nudge it with multiple objectives, viewing interventions as forward- and backward looking at the same time. While we serve the needs that have been detected we “take the opportunity” to also factor in change that we wish to achieve into the solutions. This leads to a more active policy process of continual monitoring of the dynamics, dealing with novelty and needs as they turn up since we see the goal of predicting and controlling as essentially misguided.

We will now explain our theoretical starting point, which stems out of our past decade working with societal systems and innovation from a complexity perspective.

Our door into the concept of wickedness goes via the concept of complexity, which is an even more common description of these vexing problems. Complexity, however, is a very broad descriptor, and we think that it harbors a conflation that has far-reaching consequences. What we did (Andersson et. al. 2014b) was to break “complexity” up into two ontologically and epistemologically distinct components: “complexity” and “complicatedness”.

“Complexity” here corresponds to the types of systems with which complexity science has dealt highly successfully – systems with many simple interacting agents; e.g. fish shoals, crowds, traffic, and many physical and chemical systems. “Complicatedness” in contrast, characterizes systems with a highly organized structure, typically modular and hierarchical, such as organizations, organisms and engineered artifacts. This distinction in itself is far from new – a simple Google search will reveal that it is frequently made, most often to delimit the scope of complexity science. What is new is the realization that it harbors substantial analytical power and can be explored at greater depth. The key to its power is that complexity and complicatedness corresponds to the two major ways in which problems and systems are hard for us to understand, and that vast bodies of theory and methodology are directed explicitly at helping us deal with these qualities. It is not hard to see the development of these different major approaches also in the history of how policy tools for urban planning have been designed, what has been seen as hot and new, what has been seen as belonging to yesterday.

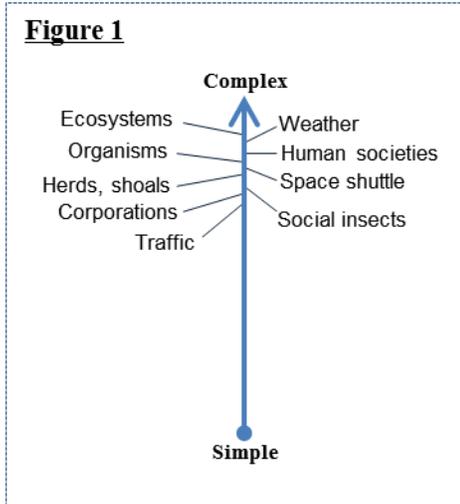
Central to the starting point is the development of a diagram that visualizes the logic behind this and that serves as an analytical and pedagogical tool.

We begin by noting the futility and pointlessness of trying to arrange “complex matters” along an axis between simple and complex (**Fig 1**). The feeling of mixing apples and oranges is overbearing. If we split complexity into complexity and complicatedness (**Fig. 2**), however, this yields a plane in which these “complex matters” become more productively separated (**Fig. 3**). We will refer to this as the Complex-Complicated-Wicked (CCW) diagram.

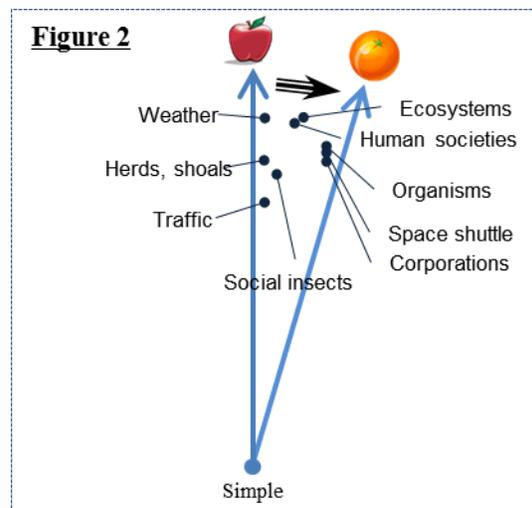
We now also get four corners that each correspond to idealized qualities of systems. First we have the simple, complex and complicated – but then we also have a new corner. Noting that this is where our wicked problems seem to cluster, we call this quality wickedness. “Wickedness” is emergent: although it combines complexity and complicatedness it is qualitatively distinct from both, and we argue that it defines a viable class of systems on its own – a class for which we need

to develop theory, method and policy tools to substantially improve how we deal with large-scale societal problems; see Andersson et.al. (2014b).

The CCW diagram yields a surprising range of lessons and possibilities. We may map not only systems, but also problems, approaches, theories and models into the diagram (**Fig. 4**). By doing so we may explore their interrelations, their historical development, their ambitions and we also get some idea about why developing new approaches is so challenging. When we try to combine the two major approaches that extend along the axes – an approach that almost suggests itself – we run into fundamental trouble: both rely critically on the assumption of simplicity along the OTHER axis. So when we combine them we tend to combine their weaknesses, creating models that are as wicked and impenetrable as the systems that they aim to help us understanding.



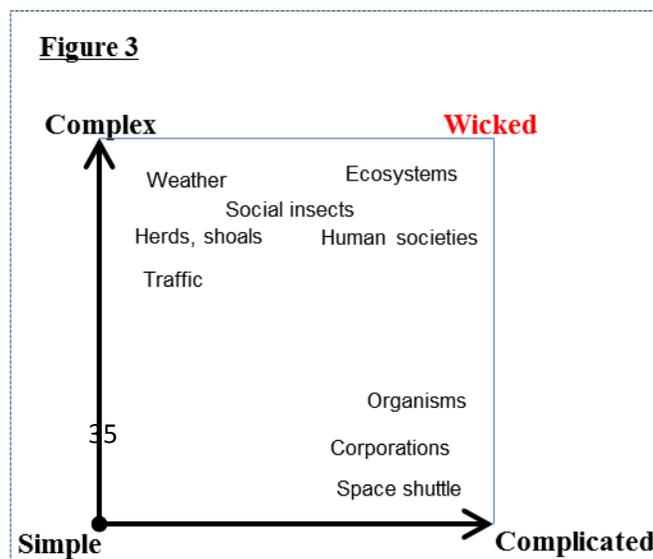
But what really opens up new prospects is this: We may map also process and organization into this plane. This means that our epistemological elucidation become directly linked to the ontology of systems, and thereby also at foundational theory and applicable policy. How does complexity and complicatedness come to become entangled into wickedness? How are systems organized across this diagram? What does this tell us about how to understand and change them?



These foundational issues will be tackled from a solid starting point in a body of theory for change in societal systems developed over the course of three major EU projects (ISCOM, INSITE⁵, MD⁶), the latter two of which I have played a major role in. We have here conceptualized change in wicked systems generally as a process of innovation. Key publications include Lane, D. (2014); Anzoise V., Sardo S. (forthcoming

⁵ <http://www.insiteproject.org/>

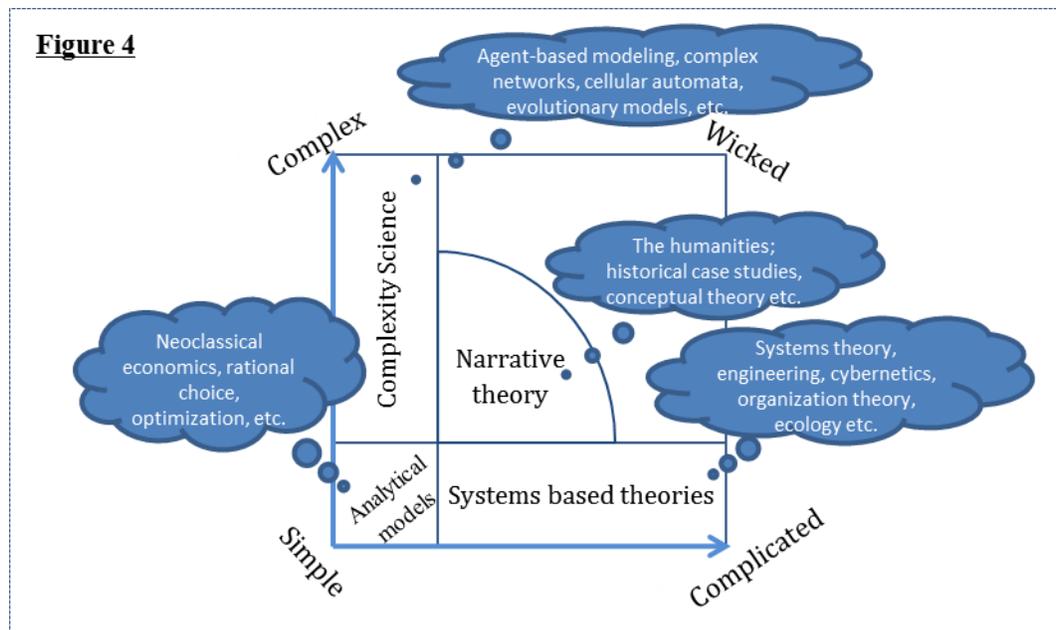
⁶ <http://emergencebydesign.org/>



Spring 2015); Anzoise V. and Sardo S. (forthcoming Winter 2015); Lane, D. (2002); Lane, D., & Maxfield, R. (2005); Lane, D. A. (2011); Lane, D., van der Leeuw, S. E., Pumain, D., & West, G. B. (Eds.). (2009); Andersson, C., Törnberg, A., & Törnberg, P. (2014a); Andersson, C. (2014); Lane, D. A. (2006); Wimsatt, W. (1986); Wimsatt, W. C. (2001).

Our theoretical work here aims to develop the very notion of what policy is, can be and should be for this class of systems. Work will proceed alongside our work on the Markovian based modeling tools, which clearly belong on the left-hand-side in Figure 4. It now becomes more clear why we choose not to simply throw “more realism” into the model, and why we choose to develop it in a hierarchical fashion where we can detect when the cost of making the model “more wicked” (which is that it becomes harder to understand what the model does in the first place) is no longer compensated by increased performance.

What happens at that point is that we must figure out how the tool is to be used, or, more generally, how modeling tools in general are to be used, in a larger policy context. Clearly, we do not see models as black boxes, but as a support to policy processes. This is a view that is quite widespread today, and our proposed work aims, in part, to understand the questions of why this is so and how different elements of policy should be used together.



So this is also an inquiry into the crucial question of what the powers and limitations of different approaches are. Without the ability to answer this question, we are missing half the problem and we are left with new policy tools in an old policy paradigm. Our aim is to contribute to the development of both.

4.4 Modeling

To understand the uneven distribution of human activity across space as the outcome of historical processes, stochastic growth models are of particular use as these models account for *path*

dependence in which each event changes the probability of a next event to occur (Simon, 1955; Krugman, 1996; Batty and Xi 1994; Putman, 2006; Glaeser 2011; Batty 2013): *History is, in this simplest way of looking at the dynamics, represented only through the pattern.*

Our philosophy is to begin from very simple principles, in this case a Markovian model of land use change which captures the basic principle that land use change is a dynamical process where change is local in time. A Markov model, in its simplest form, consists of a set of discrete states that change according to a table of transition probabilities. This basic model is extremely configurable and may be deepened in virtually all its aspects, and applied to just about any thinkable empirical context; the most obvious one in this context being that of linking transitions between land-use states in a buffer zone around urban and regional motorways.

Markov models may, via their transition tables, be subject to both supervised and un-supervised learning via data. That is, one may tune the transition model such that the model reproduces empirically known histories, with the aim of using such a trained model to predict future states. This is how Hagson (2011) mimicked land use changes in buffer zones around motorway by-passes in Swedish cities.

The short version is that we prefer simple models, we know that we need to combine models, we know that models provide limited perspectives on a system that in reality is impossible to grasp in its entirety, and we know that models therefore must be used in conjunction with “softer” methods where it can be contextualized, such as experimentation, the building of intuition, narratives and case studies.

When we build the models we will therefore proceed by capturing the dynamics in increasing levels of specificity in a hierarchical fashion. This is different from the traditional notion of building a system of models where each sub-model covers a specific aspect; rather than painting different parts of the picture and bringing them together we begin with the broadest brushes and move to using finer brushes. This allows us to somewhat avoid the need to de-compose a system that is poorly decomposable (Simon 1996), and to detect at which level we actually stop gaining anything by moving into more details. The importance of this is that higher detail – “more realism” as it were – makes models opaque and severely limits the amount of understanding that they contribute. Wicked systems (see following section) are highly challenging to understand, so if our model of a wicked system is also wicked, we have not gained very much.

The simple Markov model, with highly simple representations of spatiality, states and transitions represents the broadest brush, and we are encouraged by the fact that we get quite far already at that stage. But we have a number of other model components to begin from that allows us to move to a higher level of detail in a way that we think will be fruitful.

One such aspect is that of relaxing simplistic assumption of spatial interaction. One consequence of this is to move from local state-interactions to global state interactions. We have worked extensively on this and have developed methods for implementation that are in wide use today

(Andersson et al. 2002a,b). Another aspect is to move from regular land use interaction to a network representation where the heterogeneity of the system can be represented, also here we have developed methods that is seeing wide usage today (Andersson et al. 2003, Andersson et al. 2005, Andersson 2005, Andersson et al. 2006). Moving to a network representation also naturally moves us from simple qualitative states to combined quantitative and qualitative states; i.e. not just what is in an area, but the intensity of the activity. We know that we thereby can generate states that are in superior agreement with statistical features of large-scale urban systems in terms of the distribution of sizes of agglomerations, the shape of agglomeration and intensities/land values. The challenge that lies before us is to combine these elements.

4.5 Challenges

Beyond these components we have a number of new challenges that we have not formerly dealt with and that we will need to develop new models and methods for.

The first is to move from a Euclidean model of distances to a travel-time distance. This is challenging in several ways.

One is the high computational complexity of finding distances between arbitrary locations, in particular since one needs to dynamically update the distances in a model where the states change dynamically.

Another is the storage complexity of the distance matrix. The distance matrix in a Euclidean space reduces to a simple equation while in a general distance matrix the memory demanded to store it grows as the square of the size of the system. For example with a system of $1000 \times 1000 = 10^6$ locations, the distance matrix has a size of 10^{12} . It is challenging to store and access such a structure in a timely manner, so the approach is to “close the gap” from two directions: (i) high performance computing to increase the amount of data and computations that can be handled; (ii) effective algorithms to reduce the amount of data and computations that are needed. The latter point is particularly important for the wider usefulness of the models that we develop – if they demand very expensive equipment, fewer will be able to use it.

This is the modeling component that we anticipate will be the most “messy” in the sense of employing various tricks for figuring out where and when updates are needed, how distances can be stored in a way that combines memory economy with speed of access and compatibility with the models of the dynamics that are used.

The second is to introduce various aspects of land suitability; i.e. factors that determine what is likely and unlikely to develop in different areas, what is allowed to develop, and so on. This component is not overly challenging as it can be applied as a series of filters.

The third is to incorporate the growth and change of roads into the model of land use change. This is necessary in order to cover time ranges across which the urban innovation cascades that we wish to develop the capability of dealing with take place. The main challenge here is that the topology of roads is different from that of local state changes, and so is the interaction between roads. We have developed such models, although not to the stage of publication.

4.6 Description of work

The research plan has three interacting main prongs: development of Policy, Methodology and Foundations, to be integrated in empirical cases and dissemination activities.

By Policy we mean, quite broadly, the ability to act purposefully in wicked systems. This includes the ability to form visions, to organize, to achieve functionality, to detect and deal with problems that arise. It involves both bottom-up and top-down elements, and not least how to combine such approaches to achieve diversification, integration, alignment and robustness. We will here consider modeling tools in the wider context of policy – from the decisions of individual agents in the system up to institutions tasked with overarching policy decisions and their implementation.

The aim of the Methodological work is to understand the powers and limitations of analytical and interpretational approaches relative to systems and problems. We think – and many have testified – that one of the most immediate effects of the preliminary methodological results (expressed largely around the CCW diagram) is that they organize and unlock thinking and reflection about what is otherwise a bewildering tangle of problems, approaches and models. We will develop this potential to address questions about how models and theories can be combined and extended, to detect where new theory and policy tools are needed, and to be able to better specify what such methods would need to accomplish. Another way of describing what we aim for is to say that the aim is to chart out the rules under which anything like a post-normal science [4-5, 22] must play.

The Foundations underpin and integrate the whole endeavor, and the aim is to produce a general understanding of how a “Ferry – free” E39 will induce urban and regional development i.e. how this kind of wicked systems works. We will also deal with fundamental questions about data needs and how it might be obtained and analyzed.

4.7 Goal

We use models for two main purposes: for policy and for building a general theoretical understanding, that then feeds back into the modeling effort again.

The immediate goal with respect to policy is to develop a set of models that allows us to forecast changes in land use and transportation induced by the addition of major novelty to the system, such as the construction of a major road like the E39. Although such additions tend to be made in order to cater for a need in the system (e.g. better road capacity), it is easy to see that they also

trigger large cascades of downstream change, not only in land use but in society generally. Such cascades are historical and contingent processes that are highly non-linear and emergent (i.e. they bring not just more, but also different).

Future states are not primarily useful as detailed predictions, telling us in detail what will happen in the future. In fact, it is more as a basis for more qualitative instruction that models are really useful. Does it seem like development persistently tends to be predicted in a particular area? What type of development? Is that desirable? If not, what makes the model respond in a different way?

We also anticipate developing several computational algorithms that will be widely useful in the community.

The opportunity that opens up here is that of using infrastructure development as a policy tool for shaping urban regional systems. That is, to shift the view of infrastructure as serving urban systems to the view that it plays an active part in the urban dynamics and – since it is under more political control than land use, which is to a large extent decided by much more distributed decisions – that it can be used for scaffolding the city as it grows. This is what planning becomes in what we have called a “wicked system”⁷ (Andersson et al. 2014) and it reflects both the work of Hagson in the context of infrastructure and urban systems and the more general theoretical work of Andersson on his group on innovation in complex adaptive systems⁸.

⁷ “Wicked systems” is a generalization of the widely used concept of “wicked problems” that we have made from recent insights about innovation and change in evolutionary systems. Systems such as societies and ecosystems are not just complex or complicated (which is the starting point of complexity science and systems approaches respectively). Complex “fluid” dynamics builds and maintains complicated structure, so that complexity and complicatedness become intertwined in a characteristic way that is emergent, i.e. different from either, and it is this quality that we refer to as “wickedness”.

⁸ Which we have worked on in a series of three EU FET projects; ISCOM, MD and INSITE. Please see www.emergencebydesign.org and www.insiteproject.org.

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