ON THE RATIONALITY OF NETWORK DEVELOPMENT: THE CASE OF THE BELGIAN MOTORWAY NETWORK

Thomas Vanoutrive[1] | **Ilja Van Damme**[2] | **Greet De Block**[2]

1 *Research Foundation - Flanders (FWO), Urban Studies Institute and University of Antwerp*
2 *University of Antwerp*

The development of transport networks has been explained, predicted and planned using a variety of methodological approaches. These range from narrative historical accounts to the application of models borrowed from the natural sciences. Probably the most remarkable studies are recent attempts to align network development with organic logics – e.g. the mimicking of motorway networks by slime mould in Petri dishes. The aim of this paper is to examine and compare methods mobilized to both explain and hypothesise on the development of transport networks. More specifically, we juxtapose methods in transport planning inspired by the natural sciences with historical inquiries into transport planning. Network modelling driven by topological features (e.g. connectivity and compactness) is compared with a more historical sensitive approaches taking contextual, sociospatial factors into account. In doing so, the paper contributes to transport geography by highlighting the influence of political choice, and indeed ideas about sociospatial organization, on the network model as well as adds to planning history by including the technical rationale in the discourse on sociospatial organization and form. Belgium was chosen as case because the topology of Belgium's motorway network is considered by some researchers as one of the most 'rational' in the world, while others have often qualified its form and materiality as 'chaotic', or indeed 'irrational'. On the basis of a two-sided analysis of the Belgian motorway network, a quantitative topological approach and a planning history lens respectively, the present paper critically assesses the views and values held by actors of the past, present and future of the development of transport networks.

Keywords
transport networks, topology, rationality, metaphors

How to Cite
Vanoutrive, Thomas; Van Damme, Ilja; De Block, Greet. "On the rationality of network development: the case of the Belgian motorway network". In Carola Hein (ed.) *International Planning History Society Proceedings*, 17th IPHS Conference, History-Urbanism-Resilience, TU Delft 17-21 July 2016, V.03 p.235, TU Delft Open, 2016.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

INTRODUCTION

The development of transport networks has fascinated researchers from a variety of disciplinary backgrounds. In order to explain the growth of a system, each approach emphasises a particular rationality, logic and/or order. Besides offering an explanation for past developments, the same methods and models are also used to predict and plan the expansion of existing infrastructure networks, and gaps or 'missing links' in networks are detected based on an underlying rationality. Interestingly, many applications across disciplinary boundaries rely on models and metaphors borrowed from the natural sciences. Probably the most remarkable example is the mimicking of motorway networks by slime mould in Petri dishes.[1] Transport networks are also conceptualised and explained by using fractals,[2] Newton's law of gravitation,[3] the vascular system, Shiatsu meridians,[4] and so on. The surge of cross-disciplinary alliances in transport studies has resulted in an increasing influence of physics and complexity sciences in the analysis and planning of network development.[5]

In a recent paper, Gabriel Dupuy aims to identify the potential benefits of this disciplinary diversity, in particular of contributions from 'naïve' outsiders.[6] Such outsiders include mathematicians, biologists and physicists which apply their toolbox and concepts to transport networks without much knowledge of transport studies. Although he raises some critical remarks, Dupuy argues that hostility towards the contributions of outsiders is not warranted. In fact, there exists a continuum of studies that employ naturalising models and metaphors to transport networks, ranging from 'naïve outsiders' who hardly make reference to transport studies, to work in the core of the discipline.

This conclusion, however, urges us to re-consider why models and metaphors derived from the natural world have continued to attract scholars from different disciplines, and across different epistemic communities in time and space. Moreover, and more importantly, the continuous importance and even re-emergence of 'naturalistic' modelling in scientific discourse, should be analysed and assessed on its concrete effects and impact. Therefore, and on the basis of an analysis of the Belgian motorway network, the present paper critically questions the historical use of natural models and metaphors within transport studies. Although we recognize the merits of interdisciplinary, or even transdisciplinary research, and recognize that valuable inspiration can be found in other, seemingly unrelated, disciplines as well as outside the academic world, we are critical of using natural metaphors and models to explain, predict and plan human interventions. Not only do they seem to signal a return of overtly positivist ways of approaching the human world; they also evict the process of political-economics – and the consequential human strife related to the fundamental process of societal decision making – out of the equation. As we will demonstrate, de-naturalising the topology of transport networks precisely results in stronger historical explanations and stronger democratic policy practices.

NATURAL SCIENCE MODELS AND METAPHORS

In the past few years Andrew Adamatzky has published with a number of co-authors a series of scientific articles on the rationality of motorway networks.[7] Their research method was rather unusual: a map of the study area was 'drawn' in a Petri dish by putting oat flakes on the location of cities. Subsequently, slime mould (Physarum polycephalum) was applied to the flakes representing the capital, and after the slime mould had grown and had connected all cities with a network of protoplasmic tubes, the resulting network was compared with the actual motorway network. The topology of the motorway networks in Belgium, Canada and China was best represented by the protoplasmic networks, while the lowest values of 'bio-rationality' were found for the networks in the USA and Africa.

The main author of these slime mould studies, Andrew Adamatzky, is '*Director of the Unconventional Computing Centre*' at the University of the West of England in Bristol.[8] It seems indeed rather 'unconventional' to examine

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

transport networks using slime mould. However, as Mirowski reminds us, in the 1970s, 1980s and 1990s, leading economic journals published the results of experiments with laboratory rats and pigeons in which animals were seen as consumers with demand curves, as workers, and as players in different kinds of markets.[9] When plunging even further into history, the very idea of transport networks can be traced back to organic metaphors in the 19th century, on carefully constructed concepts reconciling the natural and artificial, as studied by scholars like Antoine Picon.[10] In fact the term 'réseau' (network) appears in engineering literature at the same time it is used in the medical sciences to refer to artery and nerve systems or tissue structures.[11] In the course of the 19th century, these organic notions moved from medicine, biology and engineering studies to the social sciences and philosophy, in which principles of the natural sciences were transposed to society as a whole.[12] These examples illustrate that the use of biological experiments is not unique, but taps into a long-running, and re-emerging positivist tradition of approaching and speaking about the human world as a 'natural environment'.

Indeed, a considerable number of studies have employed analogies and metaphors from biology, physics and other natural sciences, and what such studies share is the search for (an) order.[13] While the slime mould approach is situated at the margin of the discipline of transport studies, the application of gravity models is a significant element of transport economics and geography. Since the gravity model is used in transport models to estimate future demand to direct investments, its application is not an innocent act. The emphasis on rationality in the model suggests that society should strive for optimal transport networks. In a similar vein, newspaper articles reported that according to slime mould some motorways in the UK should be re-routed.[14] The question we raise is 'what kind of planning is mimicked by slime mould?'. The word 'polycephalum' in the Latin name of the organism means 'multi-headed' and indicates that the mould is a single cell with multiple nuclei. In other words, the development of a transport network is an organic process carried out by a decentral organism resulting in a rational, orderly outcome. From here it is a small step to Friedrich Hayek's war against central planning and his preference for spontaneous order.[15] In Hayek's view, no central planner can gather and process all available information to plan the most optimal outcome, instead, he proposes decentralised planning based on market mechanisms since the market can process information better.[16] The market is thus the ultimate information processor, on top of being an efficient allocator of resources.[17] Paradoxically, an opponent of the Chicago School of economics, William Vickrey, is credited for introducing this idea in transport economics, i.e. the idea that markets should guide investments in transport infrastructure on the basis of the willingness-to-pay of road users, which is 'decentrally' revealed in their willingness to pay tolls.[18] Also planning concepts like polycentricism in relation to 'bottom-up' policymaking, which are currently in vogue (see Davoudi)[19], tie in with the notion of decentral development as well as with the splintered spatial reality.[20] In general, these concepts were used to describe and analyse the existing reality, but are increasingly deployed to plan and thus determine this reality.[21] The critical distance between analysis and project seems to be loosing ground when applying these 'natural' models.[22]

As indicated above, natural metaphors play a double role. On the one hand, biomimicry and gravity models are employed to explain the past growth of transport networks, on the other hand, the same models are used to plan extensions of existing networks. The former raises questions about the role of agency and contingency in the development of networks, while the latter reduces the role of government to building the optimal network that 'nature' reveals. To examine these issues, this paper focuses on the Belgian motorway network, a network characterised by a high level of 'bio-rationality' according to Adamatzky et al..[23] In what follows, however, we will argue that this supposed 'bio-rationality' of the Belgian motorway network is not a natural process at all, neither is it the outcome of 'naturalised' (read: 'neutral') market forces at work. Thus, natural explanations or models or only indicative on a descriptive level, but fail to analyse and explain what is driving historical change. To illustrate this central aim, we start with an analysis of the development of the Belgian motorway network using a classic gravity type of method. Subsequently, we complement and assess this analysis with a historical geographical view to indicate the shortcomings of naturalised models and metaphors.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

THE GROWTH OF TRANSPORT NETWORKS

Numerous studies have been published which simulate and explain the growth of transport networks.[24] It is generally acknowledged that networks start growing from and in between large centres while more peripheral parts of the network are built later. Once congestion becomes an issue, investments are again concentrated in core areas.[25]

Here, as is common in the literature, we focus on the topology of networks and on the question why a segment is added to the network (or not). Usually, the nodes in the network represent cities, although networks within cities are analysed as well.[26] Whether a segment connecting two cities is added to a network depends on construction costs, budgetary constraints, the structure of the existing network, and transport demand.[27] The latter factor is commonly estimated as in a standard transport model, i.e. demand is a function of both the size of and the distance between the cities: the larger the distance and the smaller the size of the cities, the lower the demand for transport between these cities. Rietveld and Van Nierop reformulate this in terms of the *rate of return on capital*: whether an investment in an additional segment is made depends on transport demand, which determines the receipts, which are in turn a function of passenger kilometres travelled (or in the case of freight, ton-kilometres). The number of kilometres travelled also determines the variable costs, while the length of the network is a proxy for the investment costs.[28]

Most studies use population data to estimate demand, although it is recognised that employment and economic development matter as well, but data on this are much more difficult to obtain. Regarding costs, expenses per kilometre are much higher in case of river crossings, steep slopes and marshes. Furthermore, the shape of cities is relevant since in more compact cities, a larger share of the population can reach a station or highway entry within a given time frame, and land acquisition costs might be lower.[29] Finally, investments in infrastructure can be motivated by political-military, mining, agricultural and exogenous reasons.[30]

TRANSPORT PLANNING: TOPOLOGICAL MODELLING OF THE BELGIAN MOTORWAY NETWORK

Figure 1 depicts the (topological) growth of the Belgian motorway network. The unit of analysis is the segment, a finished motorway link between 2 of the 19 selected cities. The period under consideration is subdivided into three intervals: 1954-1965, 1966-1975 and 1976-2000.[31] For each of the three periods a regression model estimates the probability that a new link is added to the network.[32] The variables chosen were (1) demand, which is a function of the size of and the distance between two cities, (2) investment costs, which is a function of the length of a segment, and (3) overlap with the existing network, i.e. it is not very likely that a road is built close to an existing one. The results can be found in Table 1 in Appendix.

Model 1: 1954-1965

On the eve of the Second World War, the Belgian government had started building a section of the motorway between Ghent and Bruges. However, it was not until the first half of the 1950s that the first segment connecting two cities was completed. From a topological perspective, Belgium was an edgeless graph at the start of this period, and taking into account the assumptions stated in Appendix, 79 segments could have been added to the network. In reality, only seven segments were completed in the period 1954-1965. Simple statistical analysis was used to explain why certain motorway segments were added, but none of the parameters were statistically significant at the 5% level, which might be partly due to the small sample size. Nevertheless, the estimates for the variables *segment length* and the *angle* between a segment and one of the other segments built have the expected negative sign. In contrast to what was expected on the basis of the literature, the demand variable has a negative sign, indicating that investments were mainly directed towards peripheral parts of the network. Note that no account is taken of the existing non-motorway network.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

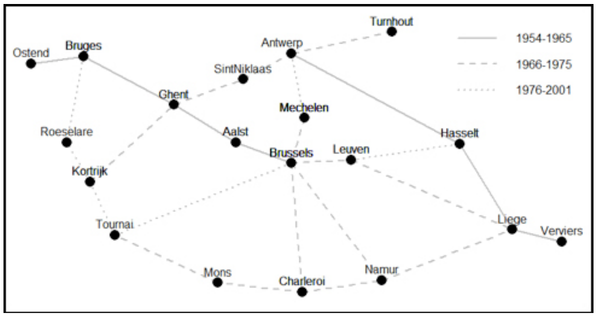

FIGURE 1 The Belgian motorway network

FIGURE 2 Plan with missing links (Source: Devallée 1938)

Model 2: 1965-1975

After the completion of seven segments in the previous period, there were still 72 segments that could have been built. In the second period, thirteen segments were actually added to the motorway network and the regression model indicates that the larger the demand, the greater the probability of construction. Furthermore, a larger angle between the segment and other motorways increases the probability that a segment was built.

Model 3: 1975-2001

The third period witnessed the completion of six additional motorway segments. The only variable that was significantly correlated with construction probability was the angle. Hence, the structure of the existing network seemed to be the main determining factor for new investments.

PLANNING HISTORY: SOCIOSPATIAL DEVELOPMENT OF THE MOTORWAY NETWORK

This contribution reflects on the search for rationality in transport networks, and rationality plays at least two roles in this context. First, scholars attempt to reveal the rationality underlying network growth to explain the historical formation of infrastructures. Second, it is regularly argued that infrastructure systems, and investments therein, should follow a certain rationality. The latter is especially clear in cost–benefit analysis, but we start here with a discussion of the explanatory power of models of network growth.

The case of the Belgian highway network illustrates that, despite a ‘rational’ outcome, investments were not made according to a ‘rational’ plan that can be summarised in one or two variables. The quantitative analysis of the development of this network reported in the present paper indicates that this supposed rationality is seldom followed and seemingly ‘irrational’ parameters literally deviate its growth. More specifically, for the early period, an explanation needs to be given why the segments connecting Ostend-Bruges-Ghent-Aalst(-Brussels) were built first (1954, (1956)), while the motorway between Brussels and Antwerp (via Mechelen) was not completed until 1981. Therefore, the quantitative part is complemented by a historical analysis which focuses more on the role, and indeed rationality, of historical actors and the wider institutional context.

In contrast to the early enthusiasm for motorways in countries like Germany, Italy and the United States, in Belgium this new type of limited access road for cars was perceived as ‘snobbish’ and indeed anti-democratic by many engineers and politicians. In addition to the loss of public street life, these roads would act as barrier, or ‘Chinese Wall’, in the densely urbanized landscape of Belgium. Instead of being a means to rebuilt the nation

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

after World War I, the motorway would fragment the 'typically' Belgian landscape.[33] Even influential automobile clubs, often with a strong focus on recreational driving, preferred more exciting sceneries and capricious routes over functional and standardized infrastructure. Although the idea of special purpose roads was known in 1900, it took decades to make the concept acceptable in Belgium.[34] Consequently, the Road Fund, set up in 1928 by Prime Minister Henri Jaspar to reconstruct the damaged network as well as to respond to the growing popularity of the car, was not used for the conception of modern motorways. In this first wave of public works during the interwar period, engineers focused on adapting the surface and profiles to multimodal roads. For example, considerable investments were made in the Brussels-Antwerp connection, with some financial input from the legacy of King Leopold II. Accessible for cars, trams, bicycles and pedestrians in separate lanes, it was more than an ordinary road, but definitely not a motorway.[35] The availability of an, albeit somewhat less efficient, alternative might have reduced the need for an entirely new motorway between Brussels and Antwerp. Although the new type of multimodal road did not allow for high speed car traffic, it did incorporate the sociospatial motives of the Road Fund aspiring reconstruction and modernization. Infrastructure was designed as a collector of traffic and consequently attractor of urbanization and industrialization.[36] Translated to the slime mould method: not only the cities, also the connections between cities were designed to become attractors. Or, the mould had to transform into oat flakes: a fairly improbable evolution in natural science, a logic causal, and indeed intentional, development in history.

On the level of the network, engineers chose not to start from a clean slate, but to select existing roads requiring modernization, like the Brussels-Antwerp connection, as well as to graft new components on the existing network. Based on both contemporary flux diagrams and the aspiration to connect productive cities and regions for industry, leisure and agriculture, a plan of missing links was published by engineer-in-chief Armand Devallée in 1938 (Figure 2). Connecting Brussels to the coast as well as being part of the international London-Istanbul connection, the road between Brussels, Ghent and Ostend was defined as one of the four sections to be built first (Figure 3). Besides the logic of missing links, also regional preferences within the department of Public Works might have played a role in the geographical pattern, and speed of realization of the motorway network. In particular *Ponts et Chaussées* engineers in Bruges (Claeys and De Wulf), did believe in the potential of motorways.[37]

Although Devallée was critical for the road 'as an obstacle', he conceived a compromise between the contemporary mobility requirements and the road as 'creating factor … backbone of the agglomeration'.[38] When crossing thinly populated areas the road could be designed as limited access motorway. In or near urban areas the road had to transform to a multimodal road with level crossings and open to adjacent lots.

Although in the course of the 1930s and 1940s, several proposals were made, there did not exist a comprehensive motorway policy in pre-war Belgium. It is not until the 1950s that the integration of the variety of proposals lead to a national plan worthy of the name.[39] At the sixth Belgian road conference in 1950, engineer Henri Hondermarcq presented his program for 930kms of motorway defined by the twin goal of facilitating national socio-economic processes and surfing the wave of imminent European Integration. Hondermarcq presented Belgium, and more specifically Brussels and Antwerp, as the strategic crossroad of the new European politico-economic configuration, resulting in numerous connections linking Brussels and the port of Antwerp with its national and international hinterland. The following Road Fund positioned the Antwerp-Brussels region, and indeed connection, as an economic and urban core in both Belgium and Europe.[40]

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

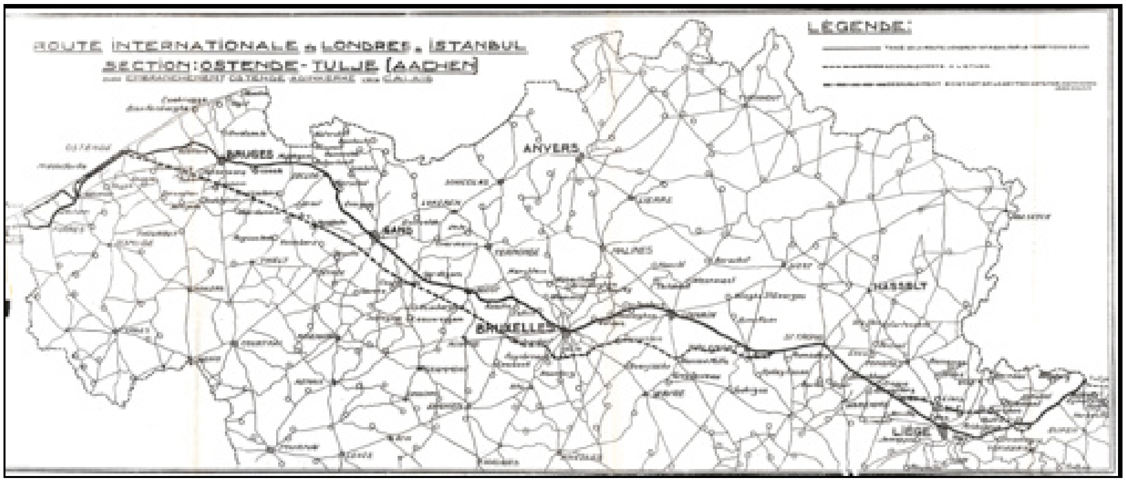

FIGURE 3 The Belgian trace presented at the Budapest conference on the London-Istanbul connection (Source: Claeys 1936)

THE NORMATIVE FORCE OF SLIME MOULD AND OTHER FORMS OF TOPOLOGICAL RATIONALITY

As mentioned in the introduction, natural metaphors and models are not only used to explain the growth of transport networks, they are also employed to indicate which new segments would make the network more rational. Today, rationality is often defined in terms of productivity and demand, disguised in sweeping concepts on 'natural' development. Perhaps the most sustained critique comes from Karel Martens who points to the fact that demand-based cost-benefit analysis places a disproportionally large weight on transport projects beneficial for highly mobile groups. Accordingly, he proposes to replace the concept of demand by the concept of need.[41] Gabriel Dupuy, to whom we referred earlier, is aware that some logics, in particular the preferential attachment principle, might result in networks providing unequal access to destinations.[42]

Note that basing investments on 'rational' economic principles such as demand, productivity and efficiency, is distinctly different from an economic development rationale. Models based on principles such as demand and productivity identify projects that make the best use of resources, and this economic 'rationality' tends to favour the core regions, as is often argued in the regional policy literature.[43] In contrast, the economic development rationale of the post-war planning consensus aimed to develop the entire territory, and special attention was devoted to the growth of underdeveloped regions. Motorway construction in Belgium was mainly based on an economic development agenda,[44] fitting with a Keynesian state which emphasised planning and large public works.[45]

The distinction between economic development and market-based rationality can be seen in light of changing views about markets, the economy and economics. The modern view of the market popular in the first decades after World War II is built on the distinction between, on the one hand, a government sphere, and on the other hand, a market sphere, the economy.[46] Both spheres are supposed to follow their own logic. Applying this to the case of motorway planning, we have an engineering/planning logic aiming at national or regional economic development in the government sphere, and a market logic of firms which are supposed to locate themselves in new industrial estates near motorways. However, the modern government/market dichotomy has been blurred and has often been replaced by a neoliberal political rationality which boils down to the application of market norms, metaphors and logics to all social phenomena. Motorway construction is then no longer a tool of the Keynesian state, but the outcome of market-like processes. In the latter case, the consumption behaviour of motorists, preferably measured by their willingness to pay road user charges, indicates where new road capacity is needed.[47] This is nothing more than applying the principles of consumer democracy to motorway development, rendering public debate about road construction obsolete.[48]

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

Although metaphors can be interpreted in many different ways, the slime mould approach seems to correspond to the type of decentral market-like planning described above. Likewise, the demand-based gravity-style model can be used to replace democratic debate by a specific kind of technocratic decision-making.

THE POTENTIAL ADDED VALUE OF MODELS

This paper offers a critical account of natural models that explain and plan transport network development. Nevertheless, these models have the potential to generate useful descriptive information for network planning. Dupuy refers to the use of graph theory in Geographical Information Systems (GIS) as an example of a fruitful collaboration between geographers and other scientists.49 He also refers to the work of Laporte et al. who employ operation research methods to measure network characteristics and to suggest new designs for transport networks.50 Laporte et al. stress the flexibility of the heuristics which can be adapted to meet a variety of objectives, in other words, the metaphors (which are abundant in the field of operations research51) and conceptualisations are less binding and constraining. This openness is a requirement for the use of models in network design if democratic dialogue is to be taken seriously, and if external actors are able to bring their own rationalities.

Despite its potential advantages, the topological approach has its limitations. The role and function of nodes may change over time and it is not certain whether a topological analysis will fully grasp changes such as the development of the Paris metro system from a relatively autonomous network serving the local population to one of the building blocks of a much larger integrated transport system.[52] Returning to the case of the Belgian motorway network, the topological analysis presented here ignores the lively debate that ensued over the integration of motorways in the urban fabric, democratic access, and the number and position of motorway entries and exits.[53] While it is possible to see each entry as a node in the motorway graph, this would add much noise to the analysis, and the approach would lose its appeal of rationality.

DISCUSSION AND CONCLUSION: WHO HAS THE HIGHER EXPLANATORY POWER: SLIME MOULD VERSUS HISTORIANS

The question is how meaningful a distinction between ‘rational’ and ‘irrational’ factors and outcomes is, or between ‘predicted by the model’ and noise – or indeed between ‘objective’ or ‘neutral’ transport parameters like efficiency and connectivity, and, on the other hand, ‘subjective’ socio-political and cultural-economic factors. Earlier in this paper we referred to Gabriel Dupuy’s claim that studies of transport networks might benefit from interdisciplinarity, in particular from the application of natural science metaphors and analogies.[54] In a paper on transdisciplinarity in urban studies, Thierry Ramadier[55] recognises that ‘interdisciplinary bridges have been built’, but he also points to the existence of ‘contradictory theoretical schools’. The first school is mainly influenced by the natural sciences, with the gravity model as the most well-known example, while the second school is based on a cultural (critical, anti-positivist) vision. Regarding these schools, Ramadier states that ‘few attempts have been made to confront their points of view’. This paper takes up this challenge and confronted the ‘natural science’ approach to transport network development with a ‘historical’ view, and we particularly focused on the supposed and desired ‘rationality’ of transport networks.

We might conclude that while an *a priori* rejection of input from the natural sciences is not warranted, historical social science needs to uncover the underlying principles and rationalities of the models and concepts used. For example, the slime mould model used to mimic transport networks lends itself easily to describe it in terms of decentral market-like planning, and the economic concept of demand is regularly present in gravity-inspired models. The same metaphor can be used in many different ways, but what these examples illustrate is that it also evicts the process of political-economics – and the consequential human strife related to the fundamental process of societal decision making – out

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

of the equation. By 'naturalising' human sciences and historical explanations, the importance of political ideology and economic power within history is downplayed in favour of a positivist, technocratic reading of the human world. Material provided by this case study supplies fuel for discussion about broader issues, in particular the underlying ideological and political-economic claims associated with a particular methodological approach. This is especially relevant given the fact that models used to predict past transport investments are also employed to evaluate future investments in infrastructure. Quantitative approaches generally attribute a central role to the concept of demand, and thus degrees of 'rationality' are in fact linked to ideas of consumer democracy where individual demand guides investment decisions. In contrast, interpretations of a less deterministic nature emphasise the degrees of freedom of political actors/choice. We conclude that the views held by actors of the past, present and future of transport networks are relevant for democratic debates on transport policy since the metaphors and models used are not value-neutral.

APPENDIX

To model the growth of the Belgian motorway network,[56] this study uses population data provided by the LOKSTAT project.[57] Data were aggregated at the municipality level (merged municipalities, since 1983, n=589) and distances were measured as the crow flies between the centroids of these municipalities (making use of Lambert 1972 coordinates). A threshold value of 50 000 residents was used to select cities. To this end, the population of all municipalities within a range of 5km was taken into account. Two cities which are located at a distance of less than 10km are considered as one urban area (this was the case for Mons-La Louvière and Hasselt-Genk). The centroid of the central municipality (whose name is used for the entire city region) is used for further calculations. On the basis of this method, there were 16 cities in 1931 and 19 in 1971.
The maximum number of edges in a network of 19 cities is 171 (note that cities in neighbouring countries are ignored, like in the work of Adamatzky[58]). In reality, only 26 segments were built (Figure 1). Only segments with a distance of less than 75km were used in the analysis (n = 79; note that the longest road built is Antwerp-Hasselt with a distance of 74km). Given the limited number of observations, the number of variables was kept small. Three binary logistic regression models estimated the probability that a segment was added to the network in the period under consideration (software: R). Figure 4 illustrates the situation.

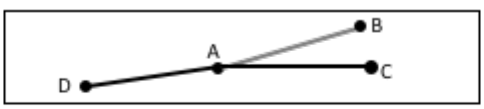

FIGURE 4 Graph representing four cities (A, B, C and D), one existing motorway (AB) and two possible connections (AC and AD) (Source: the authors).

The cos α variable is incorporated in the model to test the hypothesis that it is less likely that a more redundant segment was added to the network. [59] Given that AB has already been built, it is more probable that AD is added to the network than that AC is built. Since we might expect that it is known at the beginning of a period which segments will be built, the angle α is measured between the segment under consideration and all other segments finished at the end of the period. When a motorway connects two cities without any other motorway connection, cos α = 0.The following independent variables were included in the analysis:

d: the distance between two cities, which is a proxy for construction costs
Demand (log(D)); $D = Pop_A\beta^1\ Pop_C\beta^2 / d\beta^3$ [60]
with Pop_A, Pop_C: population of cities A and C respectively (in 1000s)
d: the distance between A and C
β_1, β_2 and β_3: parameters, set at 1
cos α; $\cos\alpha = (d_{AB}^2 + d_{AC}^2 - d_{BC}^2)/(2\ d_{AB}\ d_{AC})$

Thomas Vanoutrive | Ilja Van Damme | Greet De Block

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

PERIOD 1954-1965

Est.	Std. Err.	z value	Pr(>|z|)		
Intercept	28.96	23.22		1.25	0.21
log(Demand$_{1951}$)	-4.29	3.14	-1.37	0.17	
distance	-0.15		0.12	-1.28	0.20
cos1965	-16.94	11.81	-1.43	0.15	
n = 79					
Y: new motorways 1954-1965					
Adjusted rho-squared = 0.86	*AIC: 15.913*				

PERIOD 1966-1975

Estimate	Std. Error	z value	Pr(>|z|)		
Intercept	-9.68	4.77	-2.03	0.043 *	
log(Demand$_{1961}$)	1.14		0.50	2.28	0.022 *
distance	0.0096	0.032		0.30	0.76
cos1975	-2.25	0.99	-2.27	0.023 *	
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					
n = 72					
Y: new motorways 1966-1975					
Adjusted rho-squared = 0.40	*AIC: 59.531*				

PERIOD 1976-2001

Estimate	Std. Error	z value	Pr(>|z|)	
Intercept	-0.94	7.08	-0.13	0.90
log(Demand$_{1971}$)	0.47	0.76	0.62	0.54
distance	-0.0076	0.048	-0.16	0.87
cos2001	-6.36	2.64	-2.41	0.016 *
n = 59				
Y: new motorways 1976-2001				
Adjusted rho-squared = 0.62	AIC: 30.926			

TABLE 1 Results of three binary logistic regression models

Acknowledgements

Population data were obtained from 'Historische Databank van Lokale Statistieken – LOKSTAT, Universiteit Gent, Vakgroep Geschiedenis o.l.v. E. Vanhaute en S. Vrielinck'.

Disclosure Statement

No potential conflict of interest was reported by the author.

Bibliography

Adamatzky, A., S. Akl, R. Alonso-Sanz, W. van Dessel, Z. Ibrahim, A. Ilachinski, J. Jones, *et al*. "Are Motorways Rational from Slime Mould's Point of View?". *International Journal of Parallel, Emergent and Distributed Systems* 28, no. 3 (2013): 230-48.

Armstrong, H., and J. Taylor. *Regional Economics and Policy*. Oxford: Blackwell Publishers, 2000.

Benguigui, L., and M. Daoud. "Is the Suburban Railway System a Fractal." *Geographical Analysis* 23, no. 4 (1991): 362-68.

Black, W. R. "Iterative Model for Generating Transportation Networks." *Geographical Analysis* 3, no. 3 (1971): 283-88.

Burger, M. and E. Meijers. "Form follows function? Linking morphological and functional polycentricity." *Urban studies* 49 (2012): 1127-1149.

Claeys, "La route international de Londres à Istanbul et les routes en Hongarie. Rapport de mission", *Annales des travaux publics de Belgique* (1936).

Dardot, P., and Ch. Laval. *The New Way of the World : On Neoliberal Society*. London: Verso, 2013.

Davoudi, S. "Polycentricity in European spatial planning: from an analytical tool to a normative agenda?" *European planning studies* 11 (2003): 979-999.

De Block, G., and B. De Meulder. "Iterative Modernism: The Design Mode of Interwar Engineering in Belgium." *Transfers* 1, no. 1 (2011): 97-126.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

De Block, G., *Engineering the territory. Technology, space and society in 19th and 20th century Belgium*. Leuven: PhD thesis KULeuven,, 2011.

De Block, G. "Ecological infrastructure in a critical-historical perspective: From engineering 'social' territory to encoding 'natural' topography." Environment annd Planning A 48, no. 2 (2016): 367-390.

Devallée, A. "Les routes de l'Etat en Belgique. Autoroutes", *Annales des travaux publics de Belgique*, (1938), 289.

Dupuy, G. "Les Stations Nodales Du Métro De Paris: Le Réseau Métropolitain Et La Revanche De L'histoire." *Annales de Géographie* 102, no. 569 (1993): 17-31.

—. "Network Geometry and the Urban Railway System: The Potential Benefits to Geographers of Harnessing Inputs from "Naive" Outsiders." *Journal of Transport Geography* 33 (2013): 85-94.

Foucault, M. *Naissance De La Biopolitique: Cours Au Collège De France (1978-1979)*. Paris: Gallimard/Seuil, 2004.

Gandy, M. "Above the treetops: nature, history and the limits to philosophical naturalism." *Geoforum* 39 (2008): 561–569.

Graham, S. and Marvin, S. Splintering Urbanism. Networked Infrastructures, Technological Mobilities and the Urban Condition. London: Routledge. 2001.

Hayek, F.A. "The Use of Knowledge in Society." *The American Economic Review* XXXV, no. 4 (1945): 519-30.

Hodgson, G.M. "Hayek, Evolution, and Spontaneous Order." Chap. 16 In *Natural Images in Economic Thought "Markets Read in Tooth and Claw"*, edited by Ph. Mirowski, 408-47. Cambridge: Cambridge University Press, 1994.

Hondermarcq, H. "La modernisation du réseau routier belge" *Annales* (1950)

Hondermarcq, H. *Le réseau des routes E*. Liège: CERES, 1964.

Kim, K. S., L. Benguigui, and M. Marinov. "The Fractal Structure of Seoul's Public Transportation System." *Cities* 20, no. 1 (2003): 31-39.

Kolars, J., and H. J. Malin. "Population and Accessibility - Analysis of Turkish Railroads." *Geographical Review* 60, no. 2 (1970): 229-46.

Koopmans, C., P. Rietveld, and A. Huijg. "An Accessibility Approach to Railways and Municipal Population Growth, 1840-1930." *Journal of Transport Geography* 25 (2012): 98-104.

Laporte, G., J. A. Mesa, F. A. Ortega, and F. Perea. "Planning Rapid Transit Networks." *Socio-Economic Planning Sciences* 45, no. 3 (9// 2011): 95-104.

Levinson, D. "Density and Dispersion: The Co-Development of Land Use and Rail in London." *Journal of Economic Geography* 8, no. 1 (2008): 55-77.

Levinson, D., and R. Karamalaputi. "Induced Supply - a Model of Highway Network Expansion at the Microscopic Level." *Journal of Transport Economics and Policy* 37 (2003a): 297-318.

—. "Predicting the Construction of New Highway Links." *Journal of Transportation and Statistics* 6, no. 2/3 (2003b): 1-9.

Martens, K. "Basing Transport Planning on Principles of Social Justice." *Berkeley Planning Journal* 19, no. 1 (2006): 1-17.

Mirowski, Ph. "Postface: Defining Neoliberalism." In *The Road from Mont Pèlerin: The Making of the Neoliberal Thought Collective*, edited by Ph. Mirowski and D. Plehwe, 417-55. Cambridge, Massachusetts: Harvard University Press, 2009.

—. "The Realms of the Natural." Chap. 17 In *Natural Images in Economic Thought "Markets Read in Tooth and Claw"*, edited by Ph. Mirowski, 451-83. Cambridge: Cambridge University Press, 1994.

Ozeki, T. "Topological Analysis of Tokyo Metropolitan Railway System." Chap. 2 In *Infrastructure Design, Signalling and Security in Railway*, edited by X. Perpinya, 25-50. Available from: http://www.intechopen.com/books/infrastructure-design-signalling-and-security-in-railway/topological-analysis-of-tokyo-metropolitan-railway-system: InTech, 2012.

Picon, A. *French Architects and Engineers in the Age of Enlightenment*. Cambridge: Cambridge University press. 1992.

Picon, A. *Les Saint-Simoniens. Raison, imaginaire et utopie*. Belin, 2002.

Ramadier, T. "Transdisciplinarity and Its Challenges: The Case of Urban Studies." *Futures* 36, no. 4 (2004): 423-39.

Rietveld, P., and J. Van Nierop. "Urban Growth and the Development of Transport Networks; the Case of the Dutch Railways in the Nineteenth Century." *Flux* 19 (1995): 31-43.

Roth, G.J. *A Self-Financing Road System*. London,: Institute of Economic Affairs, 1966.

Ryckewaert, M. "Building the Highway System. Planning & Mass Motorization in Belgium since 1945." In *Dutch mobility in a European context. Two centuries of mobility policy in seven countries edition:2*. Utrecht, 2009.

Saey, P. "En Toen Was Er Akkermans, Minister Van De Mensen - Een Introductie in De Pioniersperiode Van Vlaamse Planning." In... *Ter Wille Van De Samenleving - Liber Amicorum Georges Allaert*, edited by L. Boelens, H. Leinfelder and A. Pisman, 19-39. Ghent: Academia Press, 2013.

Schwanen, T, "Geographies of transport II. Reconciling the general and the particular", *Progress in Human Geography* (online Januari 31, 2016).

Sorensen, K. "Metaheuristics-the Metaphor Exposed." *International Transactions in Operational Research* 22, no. 1 (2015): 3-18.

Tero, A., S. Takagi, T. Saigusa, K. Ito, D. P. Bebber, M. D. Fricker, K. Yumiki, R. Kobayashi, and T. Nakagaki. "Rules for Biologically Inspired Adaptive Network Design." *Science* 327, no. 5964 (2010): 439-42.

van Nederkassel, M. *Waarom België Één Van De Meest Rationele Autosnelwegennetwerken Ter Wereld Heeft*. Antwerp: Master Thesis, University of Antwerp, 2015.

Vickrey, W.S. "Congestion Theory and Transport Investment." *American Economic Review* 59, no. 2 (1969): 251-60.

Weber, D. *De Blijde Intrede Van De Automobiel in België 1895-1940*. Ghent: Academia Press, 2010.

Wils, K. *De omweg van de wetenschap; Het positivisme en de Belgische en Nederlandse intellectuele cultuur*, 1845-1914. Amsterdam: Amsterdam University Press. 2005.

Witte, E., J. Craeybeckx, and A. Meynen. *Politieke Geschiedenis Van België Van 1830 Tot Heden*. Antwerpen: Standaard Uitgeverij, 2005.

Xie, F., and D. Levinson. "Modeling the Growth of Transportation Networks: A Comprehensive Review." *Networks & Spatial Economics* 9, no. 3 (2009): 291-307.

Zuidhof, P-W. "Imagining Markets: The Discursive Politics of Neoliberalism." Rotterdam: Ph.D. thesis Erasmus Universiteit Rotterdam, 2012.

—. "Thinking Like an Economist: The Neoliberal Politics of the Economics Textbook." *Review of Social Economy* 72, no. 2 (2014): 157-85.

Endnotes

1 Adamatzky et al. 2013; Tero et al. 2010.
2 Kim et al. 2003; Benguigui and Daoud 1991.
3 Koopmans et al. 2012.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264

4 Ozeki 2012.
5 Schwanen 2016
6 Dupuy 2013.
7 For an overview, see Adamatzky et al. 2013
8 http://uncomp.uwe.ac.uk/adamatzky/ access date 7/6/2015
9 Mirowski 1994.
10 Picon 1992.
11 Picon 2002
12 Wils 2005; Gandy 2008
13 Ibid.
14 http://www.theguardian.com/cities/2014/feb/18/slime-mould-rail-road-transport-routes access date 10/03/2016
15 Hodgson 1994.
16 Hayek 1945.
17 Mirowski 2009.
18 Vickrey 1969.
19 Davoudi 2003.
20 Graham and Marvin 2001.
21 Burger and Meijers 2012.
22 De Block 2016.
23 Adamatzky et al. 2013
24 For an overview, see: Xie and Levinson 2009.
25 Levinson and Karamalaputi 2003a, b.
26 Levinson 2008; Levinson and Karamalaputi 2003a.
27 Levinson and Karamalaputi 2003b.
28 Rietveld and Van Nierop, 1995.; see also Koopmans et al. 2012.
29 Rietveld and Van Nierop 1995.
30 Kolars and Malin 1970.
31 Data regarding the growth of the Belgian motorway network stem from http://wegen-routes.be (access date 09/03/2016). This website takes 1965 and 1973 as cut-off points, here we take the year 1975 instead of 1973 to include the Tournai-Mons segment, which was finished in 1974, in the second period. No segments were added to the topological network in the periods 1965-1969 and 1975-1976, which makes these periods suitable candidates to act as breaks.
32 See appendix.
33 De Block and De Meulder 2011.
34 Weber 2010.
35 Weber 2010.
36 De Block and De Meulder 2011.
37 Ibid.
38 Ibid.
39 Ryckewaert 2009.
40 Hondermarcq 1950, 1964; De Block, 2011.
41 Martens 2006.
42 Dupuy 2013.
43 See e.g. Armstrong and Taylor 2000.
44 Ryckewaert 2009.
45 Witte et al. 2005; Saey 2013.
46 Zuidhof 2012, 2014; Foucault 2004; Note that civil society might be considered as a separate sphere, besides the state and the market.
47 For some early works see e.g. Roth 1966; Vickrey 1969.
48 For more about the concept of consumer democracy, see e.g. Dardot and Laval 2013.
49 Dupuy 2013.
50 Laporte et al. 2011.
51 Sörensen remarks that ‘the behavior of bats, birds, ants, bees, flies, and virtually every other species of insects – it seems that there is not a single natural or man-made process that cannot be used as a metaphor for yet another “novel” optimization method’, p.4; Sorensen 2015.
52 Dupuy 1993.
53 Ryckewaert 2009; Weber 2010.
54 Dupuy 2013.
55 p.435; Ramadier 2004.
56 For a descriptive analysis based on different data, see van Nederkassel 2015.
57 Population data were obtained from ‘Historische Databank van Lokale Statistieken – LOKSTAT’, Universiteit Gent, Vakgroep Geschiedenis o.l.v. Eric Vanhaute en S. Vrielinck.
58 Cities outside Belgium, however, were relevant as well, e.g. Lille, Luxemburg, Bergen-op-Zoom, Roosendaal, Aachen, Valenciennes, Dunkirk, Maastricht, Eindhoven, Breda, Paris, Rotterdam and Amsterdam.
59 Black 1971.
60 This corresponds to a gravity model, as used in most transport models. Following Black (1971), Demand is incorporated in the model as one variable to keep the model parsimonious.

DOI: http://dx.doi.org/10.7480/iphs.2016.3.1264