Exploring the « tensions » in the urban mobility system

Cyrille Genre-Grandpierre, Didier Josselin

UMR ESPACE, Université d'Avignon, 74 rue Louis Pasteur 84029 Avignon

Email : cyrille.genre-grandpierre@univ-avignon.fr, didier.josselin@univ-avignon.fr

Abstract

In this paper, we present and discuss the relevance of the concept of *tension* in a system. The state of tension is comparable to an elastic becoming gradually taut and suddenly unextended. Evaluating the tension of a system amounts to measure its proximity to the failure, its ability to collapse. Our approach provides an estimate of the latent dynamics extent, which will certainly occur to release the system, further to a change of functioning.
We illustrate the concept of tension through the analysis of the urban mobility system. First, we describe the studied system by showing its rising reliance on the speed of transportation and consequently on the individual car. Then, using a simulation, we measure for a set of French municipalities around a central middle-size city (Avignon) the level of tension led by sensible change of the traffic conditions due to a speed drop. Finally, we identify the possible leverages and their interactions suited to control the tension in the mobility system, even able to make its peaceful evolution.

Key words : tension, mobility, urban systems, car dependence, accessibility, efficiency, speed

Introduction

During a process of system analysis, it is delicate to foresee the crisis corresponding to a qualitative change of the system and difficult to anticipate its effects (Walliser, 1977). Indeed, its origin generating the collapse of the system seems most of time external to the system itself and related to more or less unpredictable events working as catalyst (EPEES, 2000). So, instead of being interested in the crisis itself (when it occurs, what are the causes and the consequences), it seems more heuristic and prospective to improve the analysis of the critical precursory phases (Timmerman, 1981 ; Aschan-Leygonie, 2000). By going into the functioning of the system in depth, we can estimate if and how the conditions of a crisis are being prepared. So, here is the question: is the system on time ripe for a crisis or, on the contrary, does it have enough capacity, enough leeway in its functioning to adapt to a change of conditions?

To deal with this problem, we try to assess which level of stress or "tension" is generated by a modification of the current conditions in the operating system. The higher the level of tension, the lower the leeway in the functioning of the system. Thus, the system knows difficulties to adapt and to perform and the failure is close. In other words, we aim to see if the way the system is running "is preparing its own failure". Indeed, whereas the visible origin of a crisis seems most of the time to be an isolated event, its preparation can run for a long time. That's why, according to the state of the system (does it have a high room of manoeuvre in its functioning or not?) the same catalyst will lead to very different consequences.

So, evaluating the *tension* of a system is measuring its proximity to the failure, its ability to collapse. Moreover, assessing the state of tension of a system gives an estimate of the latent dynamics extent, which will certainly occur to release it, further to a change of the functioning parameters. The state of tension is comparable to an elastic or a tight rubber band becoming gradually taut and suddenly unextended. There exist a force pulling the band and the band exerts an opposite tension, but the system is often considered as balanced at a given scale of time, space and observation.

The more the elastic is taut, the more important the dynamics will be. When the system is "being charged" (when the elastic is tightening), the dynamics are still invisible but the conditions for their emergence are being prepared. That's why the state of tension looks like a state of equilibrium but is not. Indeed, whereas a system in balance will last for a long time, a tense system carries its own failure. Thus, the tension describes globally the state of functioning of the system, its adaptability to a change of conditions.

In this paper, we illustrate this concept of tension through the analysis of the urban mobility system. First, we describe the studied system by showing its rising reliance on the speed of transportation and consequently on the individual car. Then, using a simulation, we propose an approach to measure for a set of French municipalities around a central middle-size city (Avignon), the level of tension led by an event. We choose as an example the deterioration of the quality of the transient moves for the commuters to Avignon and ask the question: does the change of the traffic conditions compromise the way the system operates and is it

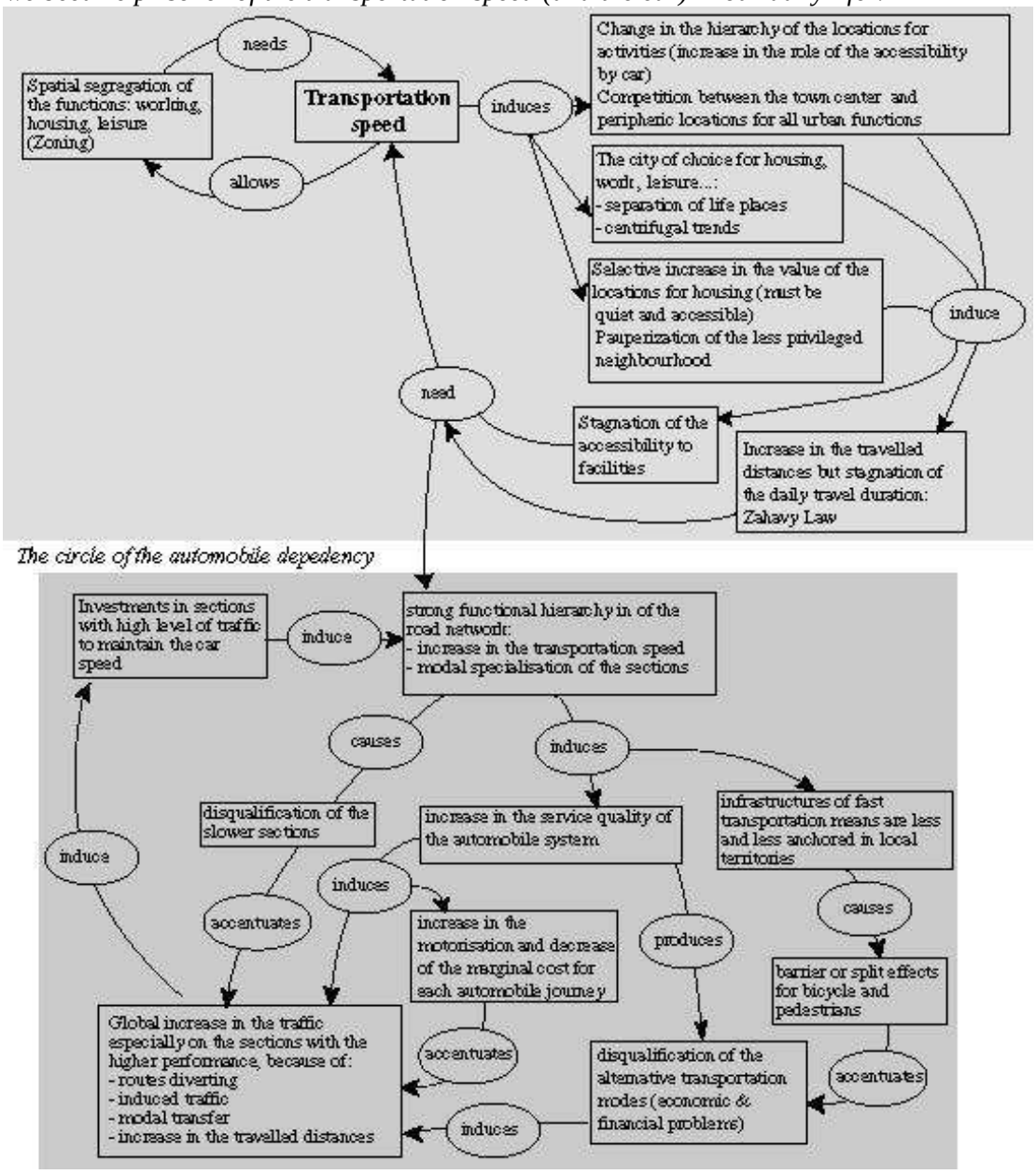
everywhere the same situation? Finally, we identify the possible leverages and their interactions suited to control the tension in the mobility system, even able to make its peaceful evolution.

1. The rising reliance of the urban mobility system on the speed of transportation makes it fragile

A/ Zoning and speed of transportation lead the cities to sprawl

The figure 1 aims to explain how people become prisoner of the automobile speed and therefore why people have an even more limited latitude in their daily life. A high transportation speed appears necessary to allow and to justify the spatial segregation of the urban functions ("Zoning") that recommends the charter of Athens, and which is materialized in the current urban planning in France (land use plan, local urbanism plan etc.). Indeed, without speed it is very difficult even impossible for people to perform their daily program of activities (Sesame, 1999), that is to say to articulate the different places they visit or they live in, those beeing more and more distant from each others. The speed of transportation becomes mandatory to make the urban system work.

Figure 1.*City transformation in its shape and in the resulting way of life:*
how we became prisoner of the transportation speed (and the car) in our daily life ?



Unfortunately, these interactions between zoning and speed of transportation weaken the urban mobility system integrated into a vicious circle. The speed of transportation allows the separation of the places of life. For example, in France, the distances between places of housing and working have doubled the last 15 years. Moreover, speed allows and encourages people to choose not only their accommodation or their work locations, but also their consumption or leisure places. All the elements of the urban supply are now in competition and widely available, that leads to an increase in the travelled distances. For individuals choosing their places of life, there is no more constraint due to physical proximity (distance in kilometers or miles), but rather a rationality to optimize temporal proximity (distance in minutes). Nevertheless, while the travelled distances increase, the daily travel duration remains stable for about 30 years, thanks to the increase in the speed of transportation (Zahavi Law). Thus, we can notice that people use the growing speed to conquer new spaces instead of saving time by reducing the travel duration.

Another point is that the speed is supposed to offer a greater choice in the urban and opportunities for households. But, in fact the speed gives only an illusion of an "hyperchoice". Indeed, we travel more faster through space, but as the facilities are more and more distant, the ratio between their variety and number and the required time of transportation remains almost the same. This leads to consider that the only real place of hyperchoice provided by the speed of automobile is definitely the supermarket... This process and this evolution in behaviour result in a paradox: people travel faster, but they save less time and have at their disposal a tighter latitude in their daily life.

Globally, these evolutions lead to a dramatic increase in traffic (3 to 7% a year), specially on the sections with the higher performances. This increase brings out a necessary consequence: the improvement of the road network in order to avoid traffic jam (in France, half of the capital expenditure of the cities concern the road network). These evolutions tend, most of the time, to increase the allowed speed for cars by an appreciable improvement of the road surfaces and types, and the modal specialization of the concerned sections. So, alternative transportation modes are disqualified, because their speed don't benefit of an equal increase, that causes an unfavourable modal transfer (from public transport to individual car). This is one of the reasons why in France, public transports know rather serious difficulties to keep their services financially viable and durable. Moreover, the environment-friendly modes (bicycles, pedestrians) are subjected to the occurrence of "splits and barriers" in their trails due to large road crosses such as highways and rings (US department of transportation, 1993). This modal transfer, added to the increase in the car speed which accelerates the distanciation of the places of life, induces a growing in the traffic, and the system comes full circle (Kenworthy, 1991; Newman, 1996; Dupuy, 1999).

Thus, the structure of the road network, the accessibility by car it provides and the investments planning tend to stretch the people and the activities over the urban regions, by favouring the speed. That's why, due to the current functioning of the urban mobility system, people are more and more dependant on speed and on car. To buy a car seems often the more rational answer to a life more and more speedy, stressful and awkward.
However, as far as the speed is increasing enough to compensate the distanciation of the places of life, the system works. The "only" remaining difficulties are the following ones:

-for people without any personal motorized transport, who can not access to a lot of urban facilities not accessible by car,

-the environmental pollutions due to the massive use of car,
-the “decay” of the town centers for housing and for activities, due to a kind of unfair competition with peripheric urban poles.

B/ The imminent decrease in the speed of transportation will put the urban mobility system under tension

Althoug they appear serious, the problems previously checked don’t seem to be suitable to reappraise the system. In fact, the fragility of the system doesn’t lie on its several side effects, but rather on its reliance on the speed, that appears as the key factor. If the speed stagnates or decreases, then the way the urban system works becomes jeopardized, because the daily life is turned out to be unbearable, even for people owning cars. Two issues are then available: this generates a new equilibrium (*e.g.* new household strategies) or locks definetely the system (trafic jams, strikes). This stage of evolution can give the opportunity to invert the process and make the circle vertuous.

Now in France, for the last five years, it is the first time that the travel duration increases because the speed of transportation decreases for a lot of people, in particular for those who are in urban outskirts (the Zahavi law seems to be over). Indeed, the traffic has reached such a level that the improvement of the network is no more sufficient to preserve the speed, all the more as the main constructions and developments have already be done. Moreover, the increasing part of people who must adapt their working hours in order to avoid the traffic jams and to keep the same travel duration sets as another indicator of the growing stress in the urban mobility system. So the system comes under tension, its functioning seems to have led to a critical point. However, people are not involved in the same way, depending on their mobility and housing behaviour, more generally, on the location of their places of life.

2. A simulation to assess the proximity to a collapse for a mobility system put under tension: the example of the commuters between Avignon and its vicinity

A/ Two components of the tension: static and dynamic

We propose to simulate on a large territory a drop in the speed on a few main road sections around the city of Avignon (200000 inhabitants), France. This simulation reproduces an current occasional event (peak hours, road accidents) becoming recurrent because of the increase in the traffic.

We aim to evaluate and spatialize the level of tension generated by the speed fall, that is to say to locate where the system may be first compromise and so its proximity to the collapse. To try to make it as clear as possible, we shall focus on a simple application, concerning only a part of the urban mobility system and a selection of two criteria enhancing the concept of tension. Indeed, the simulation concerns the relations in terms of commuting between Avignon and the surrounding polarized municipalities. For these municipalities, Avignon is the most important city for employment among the few big cities of the region. Even if the part of the journeys to work decrease in the whole mobility, they remain very important in the daily organisation of individuals. Thus, the aim of the simulation is to analyse spatially the sensitivity of the mobility system for the commuters to Avignon to a decrease in the speed of transportation in their urban region.

As we explained in the first section, the concept of tension transcribes the state of a geographical object, a commune for instance, that a collapse threaten. The tension shows two related aspects. The first one lies in the static dimension of the tension. The commune is considered under tension in its relation with Avignon if a set of current constraints makes this relation difficult (*e.g.* a high distance, a low quality of the network). The second one lies in a dynamic view of the tension. Here we aim to assess for each municipality the level of impact in its relation with Avignon further to the local drop of the speed (*i.e.* the elasticity of the tension to a change of mobility conditions). Thus, a given level of tension may result from different combinations of static and dynamic dimensions of the tension.

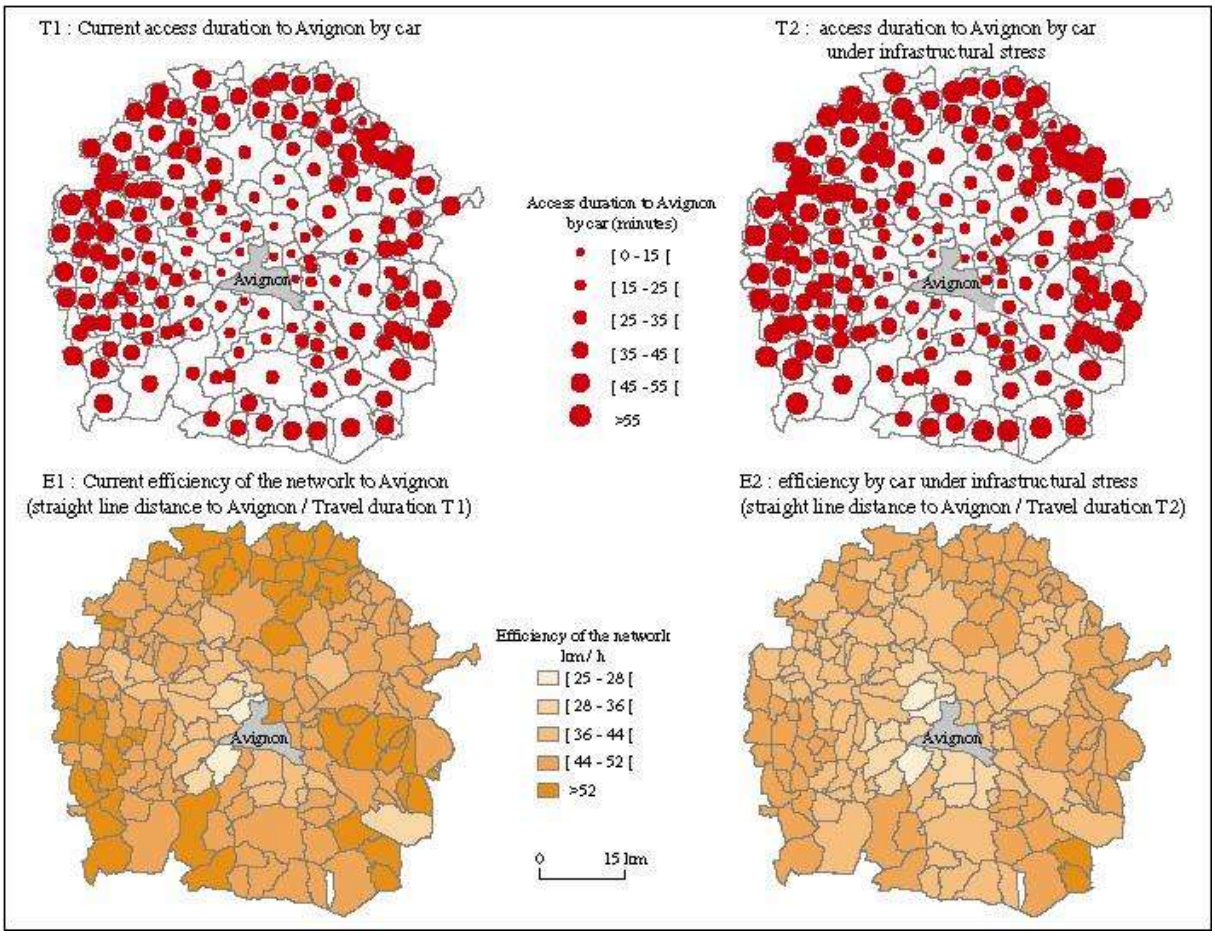
Therefore, the assessment of the tension mixes two complementary aspects, requiring to know or to estimate the breakpoint to which corresponds the failure for each of the system variables.

B/ the accessibility and the efficiency of the network to assess the tension:

At this stage of our research, we choose two variables to represent the two components of the tension (static and dynamic), relating to the accessibility and to the efficiency of the network, key elements of the mobility. Concretely, our objective is to evaluate for a municipalities the level of tension generated by a decrease in transportation speed.

The time access T is computed by finding the shortest time path between the centroid of each municipalities and the central post-office of Avignon (which sets as a mean time distance for all people living in the commune). The higher the time of travel to Avignon, the smaller the room for manoeuvre, so the higher the tension. For instance, somebody who spends 40 minutes to reach Avignon for work has less margin if the duration of his(her) travel increases than somebody who spends 20 minutes.

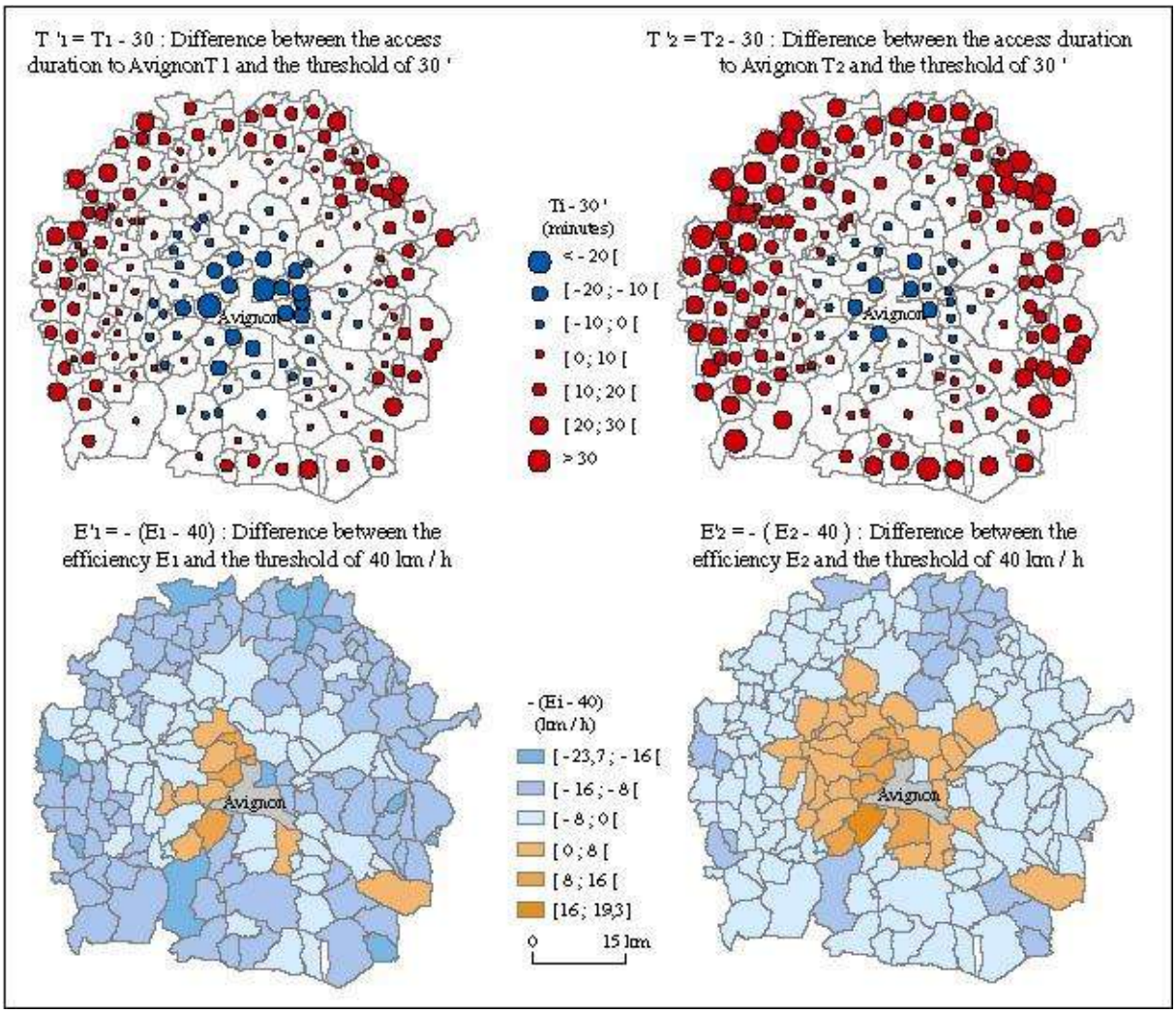
Figure 2.*Access duration to Avignon and efficiency of the network*



According to common surveys carried out in France (Banos & Josselin, 1999), we fix the time value at 30' for the threshold over which the travellers feel a real constraint to reach Avignon. The distance (T'=T–30) is then computed to measure the global state of tension, from a static point of view, for each periurban commune. Negative values inform that there still exists a room for manoeuvre before the theoretical collapse (*i.e*. the possible relocation of individuals who do not endure more than 40 minutes in their travel duration), this room reducing in case of values close from 0. Positive values signify that the threshold has been overcome and therefore that individuals are already under tension (they have no leeway, a little disruption can compromise their mobility to Avignon).

The other key variable involves the speed, more precisely the balance between the euclidean distance (that supposes an ideal isomorph space) and the access duration T. In other words, this corresponds to the ratio between the range of the travel from the center of a municipality to Avignon, and its related duration. It is called the network efficiency E, given in kilometers per hour (Gutiérrez et al., 1998). The more efficient the network, the higher the tension. Indeed, if the efficiency is already good, it will be very difficult for planners to improve it. On the contrary, if the efficiency is weak, small investments may improve it giving more room for manoeuvre to individuals. Once again, we fixed a threshold (at 40 km/h), which corresponds to the current mean speed of the local public transportation on a large territory, including urban and less dense areas. Beyond this threshold, automobile appears unefficient and lead to a change of housing location and/or transportation means.

Figure 3. *Difference between the access duration and the efficiency and their threshold of collapse*


T '1 = T1 - 30 : Difference between the access duration to Avignon T1 and the threshold of 30 '
T '2 = T2 - 30 : Difference between the access duration to Avignon T2 and the threshold of 30 '
Avignon
Avignon
T1 - 30 '
(minutes)
< - 20 [
[- 20 ; - 10 [
[- 10 ; 0 [
[0 ; 10 [
[10 ; 20 [
[20 ; 30 [
≥ 30
E'1 = - (E1 - 40) : Difference between the efficiency E1 and the threshold of 40 km / h
E'2 = - (E2 - 40) : Difference between the efficiency E2 and the threshold of 40 km / h
Avignon
Avignon
- (Ei - 40)
(km / h)
[- 23,7 ; - 16 [
[- 16 ; - 8 [
[- 8 ; 0 [
[0 ; 8 [
[8 ; 16 [
[16 ; 19,3]
0
15 km

The interpretation of this variable criterion (E'=E-40) is similar to the previous one, except for the sign. When the speed efficiency E exceeds 0, this means that the efficiency is quite high giving to the local policy a low margin to make an evident evolution of the network to improve the speed. However, this also means that the travellers are currently moving in a state of low tension, because of the high efficiency of the network (the network completely fulfils their requirements). Let us notice this variable enhances two opposite interpretations of the tension regarding the urban planning *versus* the commuters. Choosing the travellers as the entity we refer to, we have to invert the sign of the variable E' to make it consistent with the variable T', so that their positive values signify a relative state of tension.

In the following step, we propose to catch the dynamic aspect of the tension, to measure in which extent the local speed drop changes the current level of tension for each municipality (that's is to say the elasticity of the tension to a change of mobility conditions). We assume, in our example, that the urban context changes in such a way that a part of the flows on the main sections of the network becomes perceptibly less fluent, due to unfavourable traffic conditions (increase in the "impedance"). In the simulation, those sections are chosen because they are already often or probably soon congested. This infers new access duration T'_2 ($>T'_1$) and new efficiency E'_2 ($< E'_1$) for a given municipality. As we said before this new context may induce new household behaviour, such as long term modification of transportation used modes and housing locations.

Then, for both variables T' and E', we compute a relative indice of tension, *i.e.* an increase rate based on the initial state of tension and its evolution. This leads to this simple formula:

$$A_T = (T'_2 - T'_1) / T'_1$$

$$E_T = (E'_2 - E'_1) / E'_1$$

Finally, the combination of these two "tensional variables" provides an evaluation of the global tension of the system, according to the several assumptions we made. Thus, the higher A_T and E_T, the stronger the tension. Knowing the quantity of commuters per municipality, it becomes easy to foresee and assess the impact of the tension on the commuters vulnerability and the following mobility strategies. The levels of tension and the number of commuters give an idea of the probability and the extent of a coming dynamics able to release the system. The figures 2, 3 & 4 present the method and the results of such an approach of simulation, that we performed thanks to a Geographical Information System.

C/ Results: a mixed set of municipalities and commuters more or less tense following a drop of speed

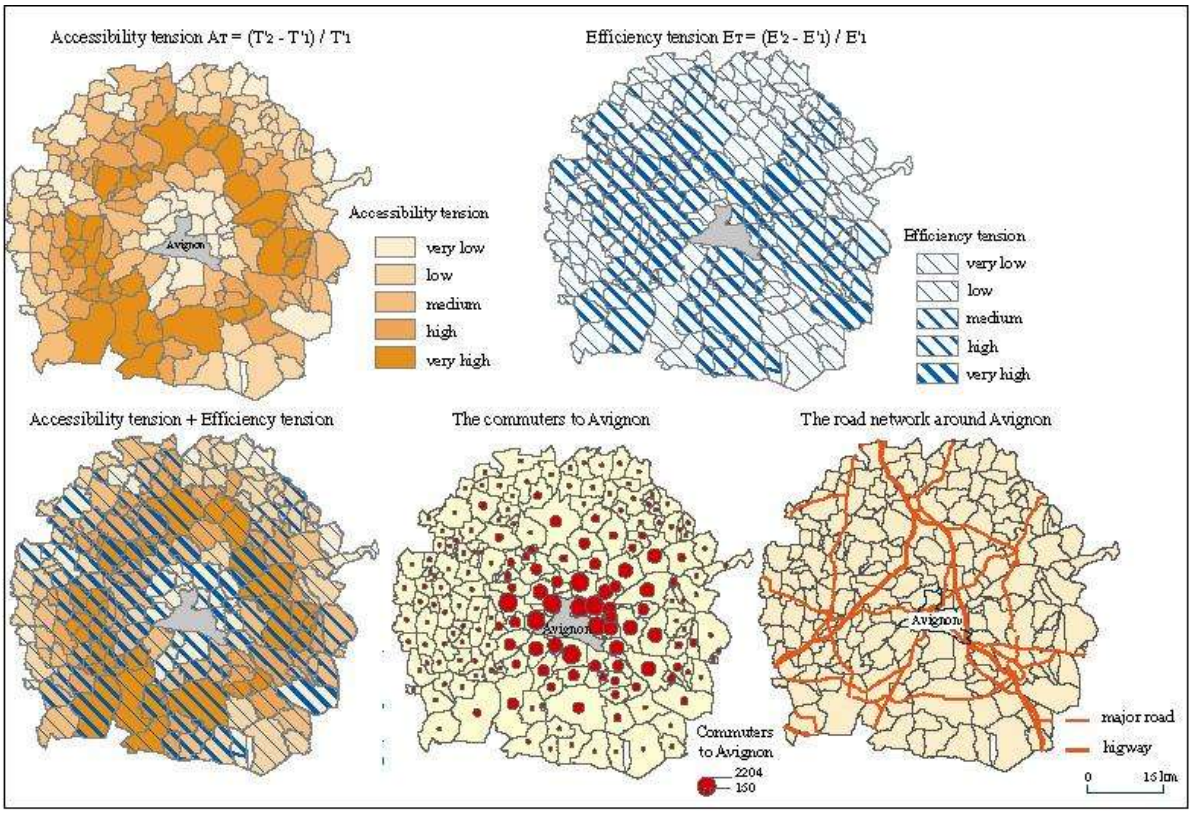
The figures 2, 3 and 4 provide heuristic informations about the tension in the mobility system of the commuters to Avignon.
Logically, the introduction of a speed loss on a few major large sections of the network changed both the access duration from the surrounding communes to Avignon and the efficiency of the network. For instance, beyond a similar spatial structure (center-periphery), we can notice that many communes moved on a higher category of access duration (T_1 and T_2 on figure 2). The same process is visible on the bottom of this figure, where, for instance, a large group of communes in North-West aggregated in the same class of efficiency E_2, while numerous others upgraded their class on the whole map.

Moreover, the spatial structures of T and E seem quite the same. Indeed, the farther from Avignon the higher the value of travel duration and the higher the efficiency of the network too. Indeed, a person located far from Avignon can drive on high performance sections for a greater part of his(her) travel than an individual close to Avignon, who is constrained to use the urban roads with lower performances.

If we analyse on the figure 3, the difference of the access duration and of the efficiency to their relative expected threshold of collapse (30' for T and 40km/h for E), we can deduce two main elements:
- the spatial distributions of T' and E' are not symmetric (non isomorph), especially for E'. This is due, on one hand to the main roads' location, on the other hand to the presence of the two rivers Rhone and Durance following respectively the North-West and the south of Avignon. These barriers are weakening the accessibility to Avignon for the communes located over these rivers, because their crossing requires to drive on very few (and so often congested) bridges, leading to important deviation.
- the spatial differentiation for T' (access duration – 30') is more important than for E' (efficiency – 40). So T' appears to be the main criterion to differentiate locally the level of tension.

The 4th figure shows the part of increase in accessibility and efficiency tensions (A_T and E_T) and provides a crossed analysis referring to the commuters location. For accessibility tension, there emerges a neat ring, whose radius is about 20 kilometers far from the center of Avignon. In this band, the increase in tension due to the simulated decrease in the speed appears very important related to the initial state. The highest changes of efficiency tension occur almost in the same areas, but doesn't draw a circle (there exist some aggregates). Thus, all other things being equal, the municipalities neither too close nor too far from Avignon are those for which the simulation leads to major changes from the initial state.

Figure 4.*The tension in the commuters mobility system*



By a combination of the three maps (accessibility and efficiency tensions + commuters to Avignon), it becomes possible to identify the most vulnerable communes. Those are the ones which cumulate a high accessibility tension A_T, a strong efficiency tension E_T and generate numerous commuters. They are located for most of them in the ring designed by the accessibility tension, and preferentially near the major roads.

Therefore, the analysis of the evolution of the level of tension in the mobility system describes a kind of sensitivity of the places for a particular type of travels (journeys to work) to the change of the mobility conditions. It aims to know where the system might to collapse first, and where the change of these conditions will have the deeper impacts. This simulation, done for a particular type of journey and for a particular destination, could be applied for any type of journeys and for any destinations.

3. A peaceful evolution for the urban mobility systems: which leverages are available to control the tension in the mobility system?

In this paragraph, first we describe briefly some of the probable consequences of the drop of the transportation speed. Then, we identify the possible leverages and their interactions suited to control the tension in the mobility system in order to improve its resilience (figure 5).

A/ Consequences and benefits of a drop in the transportation speed

The consequences of an increase in the duration of transient moves can be economic,

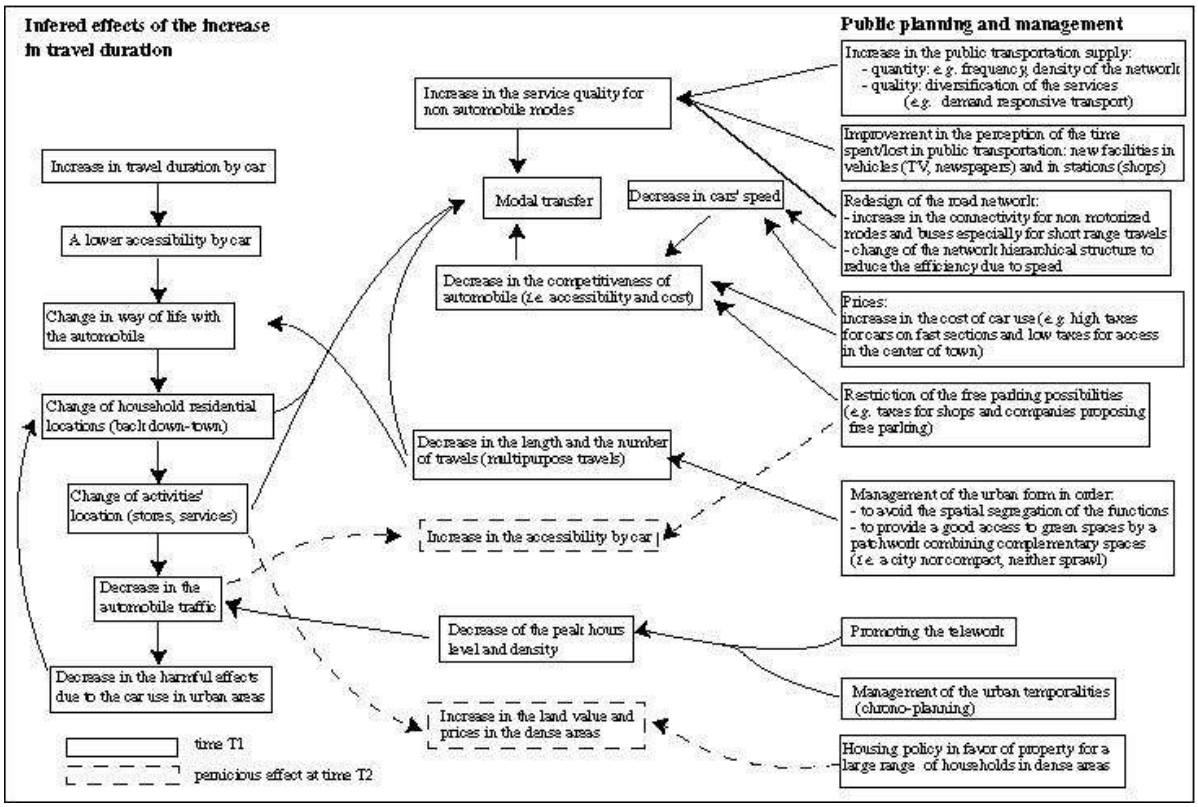
environmental and can affect the personal quality of way of life. From an economical point of view, an increase in the duration of transient moves means at first a loss of money for the society and for the individuals. Indeed, the time lost for transportation is unproductive and can't be used for profitable activities. Moreover, this augmentation leads to a decrease in the value of some places, that depends first of all on the accessibility by car (*i.e.* locations in periphery). Indeed, the higher the travel time, the less accessible these places become. Furthermore, most of the time, a unique kind of amenity is available in these specialized areas. Whereas the marginal cost of a journey increases, these locations become less and less attractive. Moreover, an increase in the duration of transient moves has also many environmental consequences: the consumption of petrol increases and so do the related pollutions and noise.

The rise in the transportation duration increases also the cost of the mobility and the unproductive times. This implies some effects on individual quality of life. As people lost a substantial part for their free time, they have less latitude in their daily life. The accessibility by car to the urban facilities is modified, in such a way it can lead to a change of the suitability for the way of life related to automobile. This evolution may be materialized by a modification of residential location strategies.

B/ Public planning and management leverages and their interactions suited to control the tension

Several leverages are available to prevent the worst effects, but also to keep the desirable ones of such an increase in the duration of transient moves, and to avoid a collapse of the urban mobility system. On top of these leverages related to the public management and urban planning, phenomena of feed-back control of the system arise to set back its failure (figure 5).

Figure 5.*A peaceful evolution for the urban mobility system*



Globally, the aim of the public management and the urban planning should be to try to balance the quality of accessibility provided by the public transportation system *versus* the individual car in order to allow a modal transfer. This goes through an increase in the public transportation supply concomitant with a decrease in the service quality of the car system. Indeed, as car is most of the time faster than the other modes, it doesn't seem sufficient to increase the public transportation supply to obtain a modal transfer. Indeed, the choice of a transportation mode is done by comparing the level of accessibility provide by the different modes (Kaufmann, 2000 ; Foltête et al., 2002).

Moreover, a raise in the cost of car use (petrol) and a decrease of its ubiquity (*i.e.* restriction of the free parking availability) might be two very efficient leverage to achieve the balance of the accessibility by car *versus* by public transportation. It also seems fruitful to promote the change of residential locations in favour of the city centers at time T_1 and T_2 (figure 5). This goes through an appropriate housing policy in order to facilitate the access to property for anybody in dense areas.

At last, the major leverage suitable to put the urban mobility system in a virtuous circle, that is to say to release the tensions, might be the reshape of the road network to make it less dedicate to car as currently (Newman, 1995). This redesign should lead :
- to avoid the “cut effect” (barriers which cause detours) by increasing its connectivity to promote the use of non motorized modes, especially for short range travels (Vernez Moudon *et al*., 1997, Heran, 2002 ; Foltête , Genre-Grandpierre, 2003)
- to decrease the weight of its hierarchy based on the network speed. This would be helpful to avoid the circle of the automobile depedency due to the concentration of traffic on particular sections (figure 1). Indeed, it has been shown that the flows' patterns depend not

only on the location of traffic generators, but rather on the global network configuration (Genre-Grandpierre, 2000). So the goal is to promote a morpho-functional structure of a network able to provide a good accessibility and to distribute the flows in a homogeneous way. This is only possible with a non hierarchical network with a high connectivity enabling direct paths between origin and destination. Such a network allows slower travels but as they are shorter too, the accessibility remains good. Moreover, this redesign of the network offers the advantage to be nearly imperceptible for the users, so it doesn't run into opposition (this is not the case for the other leverages such as the increase in cost of the car use).

These multiple actions will have two main consequences: first a modal transfer and secondly a decrease of the reliance on speed and car because they lead to re-densify the urban areas and to mix the functions.

Conclusion

The concept of tension brings several questions and outcomes.

Our simple simulation illustrates how delicate and heavy it is to develop such an empirical and instrumental method. We have indeed to make lots of assumptions, about the key variables (Which ones? What are their relative importance?), about the thresholds (Are they stable in time and space and shared by all the individuals? Aren't they fuzzy or receding so that the system gets a strong resilience?), about the measurement of the tension (Which mathematical index is pertinent? How to combine the variables to compute a global tension? Is the tension significant and corresponds to a real sensitivity or vulnerability?). And, « to crown it all », we are supposed to use topological data handled in a Geographical Information System for simulating! But the end justifies the means and the assumptions that we required to experiment the theoretical concept of tension through an application with real data.

As we illustrated by the example of an urban mobility system, assessing the tension provides to experts a fruitful conceptual level of discussion, in the sense it exceeds a static description of the studied system characteristics and constraints, by considering the system in its dynamics and in its relation with a possible, not to say a probable, collapse or failure. Whereas the resilience suggests the system has *a priori* a given level of resistance and adaptation to the occurrence of new constraints, the « tensional approach » assumes that this level of resilience depends on the level of tension existing in the functioning system.

Moreover, the fine distinction between the static and the dynamic tensions highlights advantageously the complex and complementary dimensions of the concept of tension. To draw an analogy with the modelling process, this approach allows to study the system features or variables (the constraints, such as accessibility and efficiency), their residuals or deviation (the static tension related to the leeway) to a reference (the collapse), the process (the dynamic tension, or « tensioning ») during which the individuals (the geographical objects or the persons) are subjected to a change of their state (they come under tension), due to a change of some parameters (contextual conditions, such as a drop speed). Our position comes within a decision support process, where the proposed scenarios can be helpful to describe a system more or less tense, to avoid or to prevent from a possible collapse, to

identify the key leverages able to release the system and above all to question the system through a heuristic and prospective approach in order to explore new ways for environment and planning.

Bibliography

Aschan-Leygonie C., 2000: Vers une analyse de la résilience des systèmes spatiaux, *L'Espace Géographique*, 1, pp. 64 – 77

Banos A., Josselin D., 1999, Les services de transport à la demande dans leur marché et leur cadre institutionnel – étude de faisabilité d'un repositionnement socio-économique de ces marchés, Rapport d'étape PREDIT d'octobre 1999, THEMA et VIA-GTI, pp. 58.

Dupuy G., 1999 : *La dépendance automobile*, Anthropos, économica.

EPEES, 2000: Evènement spatial, *L'Espace Géographique*, 3, pp. 193 – 199

Foltête J.C, Genre-Grandpierre C, Houot H., Flitti M., 2002: *Structures urbaines, offre de transport et comportements de mobilité*, Rapport de recherche pour le Ministère de l'Education, de la Recherche et de la Technologie, ACI Ville 99 V358, 200 p

Foltête J.C, Genre-Grandpierre C., 2003 : Morphologie urbaine et mobilité en marche à pied, in Cybergeo, n° 248. http://www.cybergeo.presse.fr/

Genre-Grandpierre C., 2000 : *et fonctionnement des réseaux de transport : approche fractale et réflexions sur l'aménagement des villes*, Thèse de doctorat, Université de Besançon.

Gutiérrez J., Monzòn A., Pinero J.M., 1998 : Accessibility, network efficiency and transport infrastructure planning, *Environment and Planning A*, 30, pp. 1337-1350.

Heran F., 2002: Indicateurs pour des aménagements favorables aux piétons et aux cyclistes, rapport Prédit 2002 – 2006 http://www.predit.prd.fr/02-Predit/01/publications/fiches/pub0057.htm

Kaufmann V., 2000: *Mobilité quotidienne et dynamiques urbaines: la question du report modal*, Lausanne, Science, Technique, Société.

Newman P., Kenworthy J. : 1991 : *Cities and Automobile Dependance*, Gower Technical, Brookfield, 1991.

Newman P., et al., 1995 : Can we overcome automobile dependence ?, *Cities*, vol 12, n° 1, 1995.

Newman P., 1996 : Reducing automobile dependence, *Environment and Urbanization*, vol 8, n°1.

SESAME consortium, 1999, SESAME final report, CERTU, pp. 143.

Timmerman P., 1981 : *Vulnerability, resilience and the collapse of society.* Toronto : Univresity of Toronto, Institute for environmal Studies.

US department of transportation, Federal Higway Administration, 1993: Reasons why bicycling and walking are and are not being used more extensively as travel modes, National bicycling and walking study, #case 1, 95 p.

Vernez Moudon A., Hess P., Snyder M.C., Stanilov K. : 1997 : *Effects of site design on pedestrian travel in mixed-use, medium-density environments*, report for the Washington State Transportation Center, Federal Higway Administration, 19 p.

Walliser B., 1977 : *System et modèles, introduction critique à l'analyse des systèmes. Paris, seuil.*