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Energy Signature of Urban Transportation

Techniques and knowledge to facilitate the development of sustainable urban transportation

Benoit Lefèvre

**Paper for EcoMod Conference on Energy and Environmental Modeling,
Moscow, Russia,
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Energy Signature of Urban Transportation

Techniques and knowledge to facilitate the development of sustainable urban transportation[1]

The urban explosion in Southern countries is undoubtedly one of the main environmental challenges of the century. The current tendencies of urban dynamics are alarming in terms of climate change, because they are giving an increasingly important role to cars, to the detriment of public and non-motorized transportation. Sustainable development has become widely recognized, but the challenge is now to translate the concept into action in the field, and especially in cities. Transferring a concept elaborated in a non-spatial framework, onto the local level, causes various problems: "Sustainable development is not fractal." (Godard, 1996)

In the effort to translate the sustainability requirement into urban policies, one question remains: do we have the necessary technologies to implement strategies that can significantly lower the trajectories of energy consumption and carbon dioxide emissions related to urban transportation? By technology, I mean techniques and the knowledge to organize them. Thus, first of all, the question pertains to the capacity of the existing transportation techniques that are financially accessible to poor cities, to reduce energy consumption. Secondly, it is also connected to the knowledge and decision-making instruments that allow us to elaborate long-term political strategies that can meet the challenge of the complexity of urban energetic systems.

Since every city is particular, in this article, I will address these two questions through a case study: Bangalore, India. I will demonstrate that the transportation technologies affordable to an emerging city like Bangalore can significantly lower the trajectories of energy consumption and of the ensuing carbon dioxide emissions, if they are implemented in the framework of appropriate urban planning. Furthermore, I will establish that there are tools which can be adapted to allow public decision-makers to discuss different political alternatives integrating energy issues, based on quantitative assessments. These instruments to facilitate decisions are a relevant medium for the territorialization of sustainable development.

Bangalore, India: Challenges to the sustainability of the economic boom

Over the past fifteen years, Bangalore has experienced profound urbanistic, economic and social mutations linked to the boom of information technology (IT). But these transformations, and especially their speed, jeopardize the city's urban management capacity. The sustainability of urban development, especially its environmental component, is particularly at risk. The dense and radial-concentric structure of the city is confronted to high-speed urbanization,[2] and risks becoming congested, leading to an unmanageable situation.

Though the dynamics of Bangalore's urban development underwent an abrupt change during the 1990s linked to the boom of IT activities, the realities that urban planners must work with do not exactly fit with the idyllic image of an Indian Silicon Valley. The IT sector has become an essential

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[1] I would like to thank T. de la Barra, J.P. Lestang and the entire team of SCE-CREOCEAN in Bangalore, who unreservedly supported this research.

[2] The **population** of Bangalore has tripled in thirty years. It increased from 4.13 to 5.68 million inhabitants between 1991 and 2001, growing the fastest of all Indian cities, apart from Delhi. Bangalore is now the fifth biggest city in the country. Though its growth rate has decreased slightly (from 3.52% between 1981 and 1991, down to 3.25% between 1991 and 2001), it could reach 10 million inhabitants by 2020. The **urban sprawl** of Bangalore is even more impressive: the growth rate of its urban area is 5.4% (which corresponds to 2,200 extra hectares, or nearly 8.5 square miles every year). In 2005, the city's surface area was 540 square kilometres (nearly 208.5 square miles), up from 284 square kilometres in 1990, and 202 in 1983, when the spatial growth of the city was still under control.

motor of urban prosperity,[3] but even so, it has not caused upheaval of the distribution of employment in the city,[4] or improved living conditions for the population as a whole. The IT dynamic certainly led urban society to mature, but it also contributed to the demographic explosion and the amplification of social inequalities. Alongside the glittering image of the "IT City", it would be wise to consider the risks of fragmentation incurred by urban society because of the digital revolution: the richest 20% of the city's inhabitants benefit from over half the city's income, whereas the poorest 20% only see a negligible amount – 3.8%.

The question of the development of IT activities is often misapprehended. A review of the factors that allowed their expansion would be valuable. Indeed, the different sectors of Bangalore's economy are well aggregated. Some sectors are more visible than others and earned the city its national and international reputation, but they are all part of a network of strong mutual relations. The fulfillment of Bangalore's aspirations to megacity status will probably depend on seeking an additional range of superior economic services, with strong investment capacities and that are less volatile than IT, and less dependant on external factors. However, it would be wise to counterbalance this headlong rush toward tertiary sector growth with an assessment of local development, and to base economic analysis primarily on the components of supply, rather than just on external demand. This would mean considering a series of local elements, such as the quality of factors of production, cross-sector synergies, agglomeration and urbanization economies,[5] and innovation capacity, as the real parameters of long-term development of the metropolitan area.

The demographic and economic boom of the 1990s led to a dislocation of the dynamics that structure urban space, causing a significant change in the distribution of geographic variables. In the absence of geographical constraints, Bangalore is now spreading in all directions, especially along major roads. These main roads attract industries and commercial activities, and the residential function is developing in the background. The passage from urban growth in concentric circles, which produced the dense fabric of the earlier city, to this linear and divergent expansion, leads to distortions. The intensity of urban development is not identical in all directions. It continues to sprawl massively to the North-East and to the South, whereas along Whitefield Road to the East and along Hosur Road to the South-East, it is resolutely linear.

Between 1991 and 2005, the number of vehicles registered in Bangalore has increased by over 200% (from 680,000 to 2,200,000), which corresponds to an annual growth three times greater than that of the population (10.8% compared to 3.25%). Today, Bangalore and Delhi share the highest motorization ratio in India (32 vehicles for every 100 persons). Though there is more and more congestion at rush hour, traffic nonetheless remains relatively fluid. But this privileged situation is not likely to last, in view of the correlation between motorization ratios and the rising standard of living of half the population. We can expect extensive gridlock to appear within the next five years, accelerated by the dispersion of housing schemes in peripheral areas, which leads people to use private cars. Now traffic congestion, the increasing duration of transportation, the restriction of mobility, as well as the deterioration of the quality of life, can all have a direct impact on the economic dynamism of the city. The improvement of mobility is linked to different conceptions of the city: it can be obtained through a car-centered approach, by the exponential development of bypass roads, or on the contrary, through a denser conception of urban fabric, adapted to public transportation. The demand for space in a city in the process of growing from 6 to 10 million inhabitants requires a global vision of its future. Considering Bangalore's present morphology, it is not inevitably reduced to the car-centered

[3] From 1997 to 2001, overall job growth amounted to approximately 500,000 jobs; 94,000 companies were also created, of which 93,845 were small businesses, mostly non-organized. This growth partially corresponds to the many cases of production offshoring that Bangalore benefited from in recent years. They also led to significant increases in induced employment in more traditional sectors of activity, especially services. However, though the turnover of IT companies increased rapidly, the rate of this exceptional growth slowed significantly year by year, from 70% (2000-2001) to 33% (2001-2002), then to 25% (2002-2003).

[4] Out of a total working population of 2.4 million, only 360.000 are employed by IT companies. It is estimated that the non-organized sector employs about 1 million persons in Bangalore, which is over 40% of all jobs! Some experts even claim that the correct proportion is around 75%.

[5] Economists identify three factors to explain the accumulation of productive activities in cities: economies of scale, which are internal to companies; localization economies, which are external to companies but internal to the relevant industrial sector; and urbanization economies, which are external to companies and to the industrial sector, and which proceed from the presence of public infrastructures and strong interaction between multiple activities.

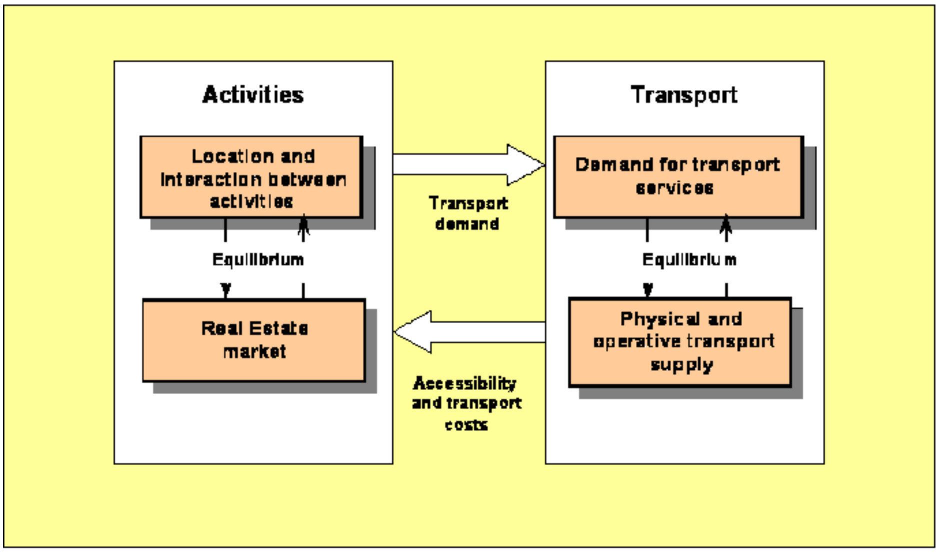
approach, even though the latter is already affecting the city and causing congestion. The dispersion of built-up areas is limited, and the structure of the city is still essentially suitable to classical urban transportation systems. The potential for development of a rapid mass transport system, along heavy traffic corridors, is intact.

These observations underline some alarming tendencies: the spread, fragmentation and congestion of the urban machine, which endanger the sustainability of Bangalore's development. The economic pillar is affected through the fragmentation of traditional economic cohesion, the social pillar is affected through increasing social inequalities, and the environmental pillar is affected through the dramatic rise in energy consumption and, hence, of local and global pollution. In view of these economic, demographic and spatial dynamics, is there a sustainability window in the dynamics of growth of an emerging city like Bangalore? If so, how can it be reached? In this article, I will concentrate on environmental issues. In order to answer this question, we need a model, a representation of urban dynamics that is accurate enough to allow us to evaluate the differences between several alternatives in transportation policies and town-planning. We must be able to measure the consequences of each policy in terms of energy consumption and carbon dioxide emissions, associated to urban transportation.
Therefore, I have studied the existing operational models for the simulation of urban dynamics. I selected TRANUS as the most appropriate model to answer this question. I also completed TRANUS with a module called "Energy Signature of Urban Transportation", or in French "Signature Energétique des Transports Urbains," (SETU), which allows me to translate urban policies in terms of energy consumption and the resulting carbon dioxide emissions. Finally, I applied TRANUS-SETU to Bangalore.

TRANUS, an integrated "Transport-Land Use" model

TRANUS is an integrated "Transport-Land Use" model, which de la Barra and Perez have been developing[6] since 1982. TRANUS models the interactions between the transportation system and the land use system. It is a forecasting model, meaning that it simulates the evolution of the urban system in different scenarios of action on these two subsystems.
TRANUS is based on the principles of spatial interaction, and of the dichotomy between localization decisions and the demand for transportation. The interaction between activities in space generates the demand for transportation; in turn, accessibility, determined by the balance of supply and demand for transportation, conditions the localization of residents and activities. TRANUS comprises three modules: 1) An "urban development" module, which calculates levels of production in the different sectors (activities and population) from exogenous data on exporting activities. 2) A "land use" module; it balances the localization of activities and residency in different zones, according to the properties of the real-estate market. The interactions between the different socio-economic sectors generate a matrix of functional flows. 3) A "transport" module, which transforms the matrices of functional flows into trip matrices (origin-destination matrix) and calculates the generalized costs of transportation, which are components of the utility function of the activity localization module. Thus, transportation costs are reintroduced into the localization model, but it is assumed that this feedback is not carried out immediately. It is completed at the next period (t+1). This represents the inertia of the localization system in adapting to change in the transportation system.

[6] The software and the source code are freely accessible.



Source: de la Barra, www.modelistica.com

Next, TRANUS enables us to evaluate the effects of these policies on different levels of the organization of traffic (by mode, operator, origin-destination, etc.), as well as on spatial (localization of activities and homes, urban sprawl, etc.), economic (real-estate prices, well-being of different populations, etc.), and financial organization (ratio of recovery of operation costs, etc.).

There are around twenty different integrated models, but TRANUS is the most widely applied, and the most valid: it has been implemented both in Northern cities (Baltimore, Sacramento, Osaka, Brussels, etc.) and in Southern cities (Sao Paulo, Mexico, Caracas, Bogota, etc.). The World Bank and the U.S. Environmental Protection Agency have endorsed it, and consulting agencies such as SYSTRA are already using it.

TRANUS is a complex model; it is difficult to master and requires large amount of exogenous data, but nonetheless, it is a transparent model: a user may follow the causal link from political decisions to energy consumption and associated carbon dioxide emissions.

The application of TRANUS-SETU to Bangalore

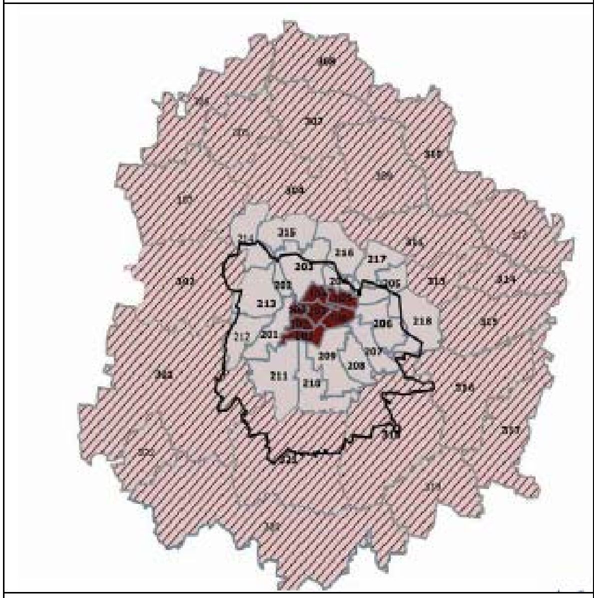
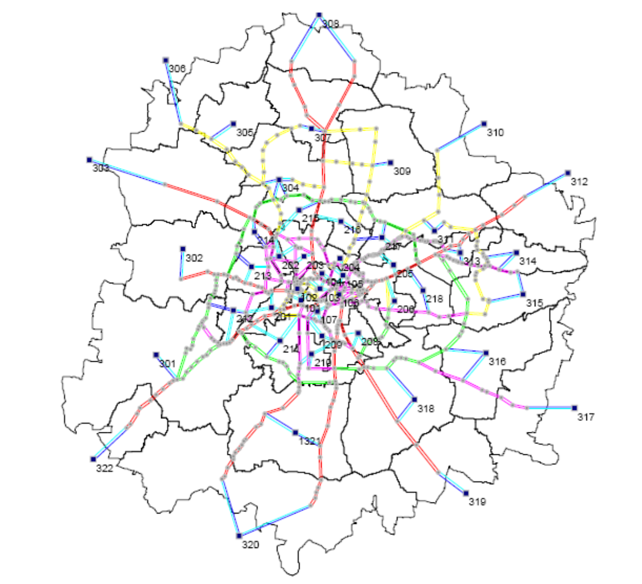
Based on a Geographic Information System (GIS), I divided the urban area of Bangalore into forty-eight zones. To determine their limits, I had to arbitrate between administrative divisions, the data presentation format, and the homogeneity of territories. Thus, the representation of the city comprises seven central zones, which constitute the historic center of Bangalore, and concentrate most jobs and commercial and administrative services, and therefore, commuter destinations. The whole network converges toward this center, which provokes congestion in the areas just beyond it. It also comprises nineteen peri-central zones, which have different profiles: some are being developed through the spontaneous concentration of activities linked to IT, while others are declining, especially former traditional craftsmanship centers. Finally, the representation of Bangalore also comprises twenty-two peripheral zones with a highway bypass crossing through them (the Outer Ring Road). These are socially diverse areas, including both under-developed zones and wealthy neighborhoods.

Finally, for each zone, I entered a series of data for the base year (2003) used to calibrate my simulation. Activities were separated into "exporting activities" (traditional heavy industries, IT and administrative services), and "induced activities" (retail, educational services). Land was divided into four categories: mixed-use land (for homes, IT activities and retail), residential land, and industrial land (for traditional industries and IT activities). The population was divided up into five groups that correspond to quintiles.[7] For each quintile of the population, I defined two categories[8] of trips, according to whether they are journeys from home to work, or from home to school. Then I defined

[7] The division of the households of a population into fifths, according to income.

[8] These two categories of trips respectively represent 60% and 20% of all trips in the urban area. Given that trips that do not start from, or finish at, homes constitute 1.3% of the total, and that Bangalore has a high level of functional diversity, it seems the trips that are not comprised in these two categories are negligible in terms of the distance covered.

two modes of transportation (public and private) and five operators (bus, rickshaw, car, motorcycle, walking). Finally, I represented the road network: 1,547 segments were classified into five categories determined by their characteristics (carrying capacity, free-flow speed, etc.).

Division of Bangalore into 48 zones	**Graphic Representation of Bangalore in TRANUS**
	
Source : SCE-CREOCEAN	Source : elaborated by the author

<u>Testing two distinct scenarios</u>

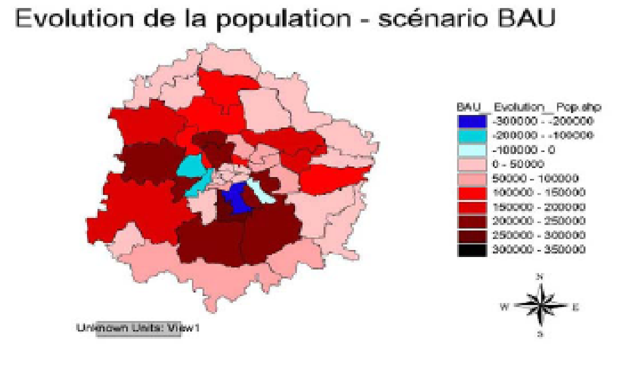
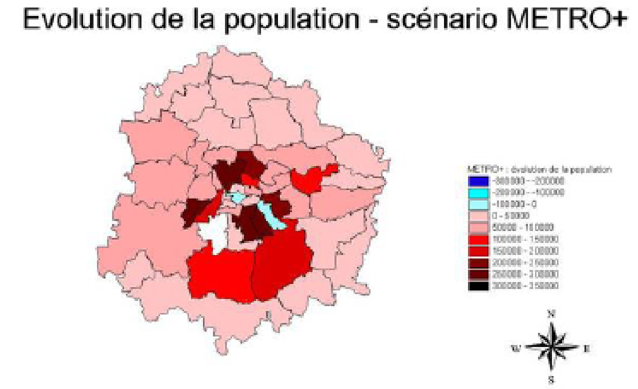
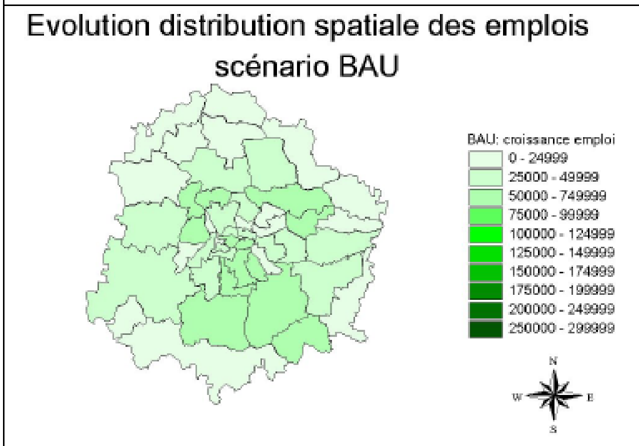
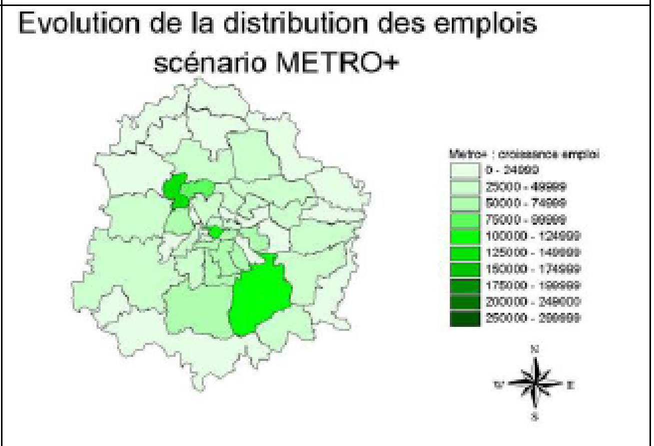
Next, I compared a business-as-usual scenario with a "metro +" scenario articulated to the metro project which is under construction in Bangalore. This is not fictional urban planning: the policies involved here are being implemented or planned in Bangalore or in other developing cities. The business-as-usual scenario is based on continuation of the tendencies observed in Bangalore over the past fifteen years. Among its main characteristics there is the construction of two highway bypasses that have already been voted on: a central one, 3-5 kilometers[9] from the center and one further out (18-20 kilometers[10] away). It also includes the construction of bridges or underpasses at highly congested intersections, broadening roads, and converting two-way to one-way roads – temporarily for the rush hour, or permanently. Finally, it also involves no control of urbanization, the extension of bus lines, particularly all the way to the outer highway bypass, and a rising motorization ratio. The "metro+" scenario implies the construction of two metro lines intersecting in the city center, as well as a determined policy for densification, containment of urban sprawl, and functional diversification of the center and its immediate periphery. It also includes a pricing policy to deter people from using their cars: fuel taxes, parking charges in the center and its immediate periphery.
In both cases, financial constraints were determined by the budget that is currently devoted to the construction of the two metro lines today (US$ 1,089 billion over 20 years). Moreover, I was working *ceteris paribus.*[11]

[9] or 2-3 miles
[10] or 12-14 miles
[11] In other words, we assumed that the social and economic structure of the city was not going to be modified, meaning that demographic growth would be identical (leading to 10 million inhabitants in 2020), that the ratio of the working population to the total population would remain constant, that economic growth would be identical. This also entails the input/output ratios of different activities remain constant, that income inequalities remain stable compared to the present situation, and that the distribution of workers between the different job categories linked to export remain the same, in terms of percentages of all jobs.

Findings: A policy integrating transportation and urban planning can significantly lower the trajectories of energy consumption associated to urban transportation.

Over the next twenty years, a business-as-usual scenario would mean that energy consumption and carbon dioxide emissions would increase by 70% compared to 2003 levels. Conversely, if the political option selected is that of investment in a mass transportation system – two subway lines – along with appropriate land use regulations, then energy consumption and emissions of greenhouse-effect gases would only increase by 9% compared to 2003. Therefore, the answer to the initial question is “yes”: with pragmatic policies (building a subway network, encouraging urban planning for higher density, and implementing a few economic instruments), a significant decrease in energy consumption and carbon dioxide emissions is conceivable.

TRANUS-SETU is a transparent model: a user may follow the causal link from political decisions to energy consumption and the ensuing greenhouse-effect gas emissions. To illustrate this, I analyzed the evolution of urban structure characterized by the spatial localization of homes and jobs, as well as by the growth in land consumption. Then, I examined the impact of this urban structuring process on inter-zone mobility, characterized by distance, and the average duration and modal distribution of trips.

<table>
<tr><td>Evolution of the population – BAU scenario</td><td>Evolution of the population – metro + scenario</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Evolution of the spatial distribution of jobs – BAU scenario / metro + scenario</td><td>Evolution of the spatial distribution of jobs – metro + scenario</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Evolution of real-estate consumption – BAU scenario</td><td>Evolution of real-estate consumption – metro + scenario</td></tr>
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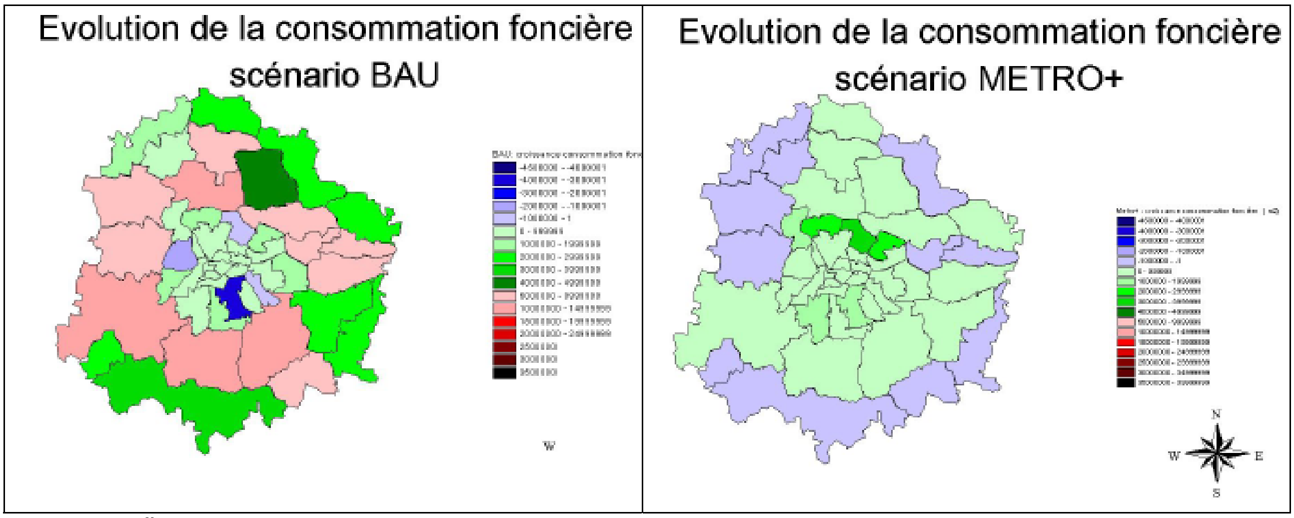

Source : B. Lefèvre

In the business-as-usual scenario, phenomena of peri-urbanization and de-densification can be observed in the city center, whereas the localization of jobs remains stable. The localization of new jobs is homogenous throughout the territory of Bangalore. On the contrary, in the “metro+” scenario, the spatial distribution of new homes and jobs is concentrated in the inner-ring suburbs and in the South of the second-ring suburbs. The city center, at the intersection of the two subway lines, is still losing residents but this time, it is clearly because the population is being driven out by jobs. The trend of job concentration in the city center increases real-estate prices, and the population that cannot pay leaves the center to find housing in peripheral areas that are accessible by metro.
Likewise, the evolution of real-estate consumption[12] is very dissimilar in these two scenarios. In the “metro+” scenario, real-estate consumption is concentrated in central zones and in the first-ring and second-ring suburbs accessible by metro. I observed that this real-estate consumption is relatively low, which indicates densification of these zones. Real-estate consumption decreases in the other zones, especially the more peripheral ones; this suggests a phenomenon of urban condensation. Thus, the subway, integrated into appropriate urban planning, channels urban development toward certain areas. In contrast, in the business-as-usual scenario, the peripherization (shifting toward the periphery) of homes and jobs, and the de-densification of the city center induce high real-estate consumption in the periphery and abandonment of land in certain central urban areas.

Scénario	Mobility* (tot trips)	Average Distance (Km)*	Average Time (H décimale)*	Share of private mode	consoE (L)
Base year	664.553	12,66	1,13	45%	853.151
BAU	+65%	13,66	1,27	43%	+70%
METRO+	+59%	12,19	1,23	23%	+9%

*Only inter-zone trips are taken into account here. Intra-zone trips are not counted in mobility calculations, average duration and average distance.

How is this evolution of urban structure translated in terms of mobility? In the “metro+” scenario, these new tendencies in the urban structuring of Bangalore imply lower inter-zone mobility (+59%), a decrease in the average distance traveled (12.19 kilometers[13]), slow growth of the average duration of

[12] This was the parameter chosen to represent the phenomena of urban sprawl or condensation.
[13] or 7.57 miles

trips (1.23 hours), and the share of private transportation is small in the modal distribution of trips (23%). Conversely, in the BAU scenario, the number of trips between zones increases by +65% over 20 years, the average distance traveled rises from 12.66 to 13.66 kilometers[14] and the average duration of trips increases from 1.13 to 1.27 decimal hours. This evolution of inter-zone mobility is explained by the tendencies of peripherization and de-densification of the city center, described previously.

Beyond the case of Bangalore, these significant results demonstrate the capacity of accessible technologies (techniques and knowledge) to offer sustainable development to poor cities on the one hand, and the relevance of tools constructed along the lines of the TRANUS-SETU model, on the other. Indeed, TRANUS-SETU allows one to test different combinations of the three main policies available to urban planners: regulation of urban and peri-urban land use, investment in transport infrastructure, and pricing policies. Users can easily understand how the energy signature of the policy decisions being simulated, is formed. In this sense, TRANUS-SETU is an instrument to facilitate decision-making: it allows the stakeholders to discuss political alternatives based on quantitative evaluations. It makes the concept of sustainable development operational, by identifying the appropriate priorities and strategies for action adapted to the territorial dynamics of a specific city, and organizing them into a hierarchy.

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[14] or 7.87 to 8.49 miles

Urban Sprawl of Bangalore 1970 – 2003 :

Source : SCE-CREOCEAN