Assessing the Sustainability of a Tramway's Impacts on the Spatial Development of Cities

-Development of a General Framework-

- Master's Thesis -

prepared by

Virginie Lannes

17, Allée la Chenai de Régailou
33140 Villenave d'Ornon
France

Lund University International Master's Programme in Environmental Science (LUMES)

Lund, November 1998
Only after the last tree has been cut down
Only after the last river has been poisoned
Only after the last fish has been caught
Only then will you find that money cannot be eaten

Cree Indian Prophecy
Acknowledgements

This thesis has been written as the final assignment of the Lund University International Master’s Programme in Environmental Science (LUMES) which I have been part of for now three semesters. In this respect, I would like to thank first the staff of LUMES who has given me a fantastic opportunity to make my university curriculum evolve towards the field of environmental science. I would also like to thank the first group of students of the newly started LUMES programme, for the great moments we spent together.

With regard to the thesis, I am grateful to Bengt Holmberg, my Swedish supervisor from the Department of Traffic Planning and Engineering at Lund’s Institute of Technology, who shared his deep knowledge of the transport issue with me. I also want to thank all the persons in Bordeaux who provided me with documents, and especially TRANS’CUB members, as well as the DIREN documentation department.

And finally, thank you to all the persons who read the diverse drafts of the thesis, and in particular Andreas Koch: I have tried to follow the red line...
Abstract

The aim of the present Master’s Thesis is to develop a framework giving the necessary background to assess the sustainability of a tramway (either a tram project or an already existing tram infrastructure) in terms of impacts on urban spatial development. In this respect, the literature review and the developed model address the issues of urban and transport (only urban passenger) sustainability.

The model, based on a system-thinking approach, examines the causal-relationships between transport and three main aspects of urban sprawling, namely the localisation of activities, the specialisation of land-uses and urban densities.

The model and its analysis make it possible to define nine specific objectives necessary for a tramway aiming at limiting the unsustainable sub-urbanisation process; they are gathered within the three following categories: reducing car traffic, reducing the need to travel, and promoting a sustainable use of energy by the tram. The model also results in proposing examples of measures to reach the nine objectives.

Key words: tramway; system thinking; urban spatial development (localisation of activities, specialisation of land-uses, urban densities); objectives and means for sustainability.
# Table of Contents

INTRODUCTION ...................................................................................................................... 6

1. THE MODEL AND METHODOLOGY USED FOR THE RESEARCH ........................................... 9
   1.1. A QUALITATIVE SYSTEMIC APPROACH ......................................................................... 9
   1.2. THE THREE ASPECTS OF URBAN SPATIAL DEVELOPMENT ......................................... 10

2. ANALYSIS OF THE MODEL AND RESULTS ..................................................................... 12
   2.1. IMPACTS OF A TRAMWAY ON THE LOCALISATION OF URBAN FUNCTIONS .................. 12
   2.2. IMPACTS OF A TRAMWAY ON THE SPECIALISATION OF LAND-USES ................................. 19
   2.3. IMPACTS OF A TRAMWAY ON URBAN DENSITIES .......................................................... 20

3. RESULTS AND OUTCOMES OF THE MODEL ................................................................... 23
   3.1. CONCLUSIONS OF THE MODEL .................................................................................... 23
   3.2. OBJECTIVES OF A SUSTAINABLE TRAMWAY AND MEANS TO REACH THEM .............. 24
   3.3. ABOUT THE MEANS ...................................................................................................... 26

4. DISCUSSION OF THE RESULTS ....................................................................................... 28
   4.1. COMMENTS ABOUT THE CAUSAL-LOOP DIAGRAMS ...................................................... 28
   4.2. UTILISATION OF THE RESULTS .................................................................................... 31
   4.3. THE LIMITATIONS OF THE MODEL ............................................................................... 32
   4.4. FUTURE IMPROVEMENTS .............................................................................................. 32

CONCLUSION .......................................................................................................................... 33

REFERENCES ................................................................................................................................... 34

BIBLIOGRAPHY .......................................................................................................................... 35

APPENDIX 1. SYSTEM-THINKING METHODOLOGY ................................................................. 37
Introduction

Background

The Aalborg Charter or "charter of European cities and towns towards sustainability", (ICLEI, 1995), states that (1) sustainable development should be one main priority of policies, (2) cities are the smallest scale at which sustainable development policies can be taken, and finally (3) urban transport is a tool to reach urban sustainability. This European Charter, signed by more than 120 cities on May 27th 1994, is in the continuation of the world-wide debate about sustainable development for which the Rio Summit is often referred to as a landmark. The World Commission on Environment and Development defined sustainable development as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987; p.43).

Sustainable development applied to cities imply the adoption of several goals, and among them the commitment to minimise the consumption of space by urban areas. Urban sprawl has dramatic impacts on the sustainability of urban areas. For example, because cities are usually built on the most productive lands, urban sprawl out of the traditional centres towards outlying areas put a strain on other activities (agriculture mainly) and other species. The ecological footprint of urban inhabitants -"a calculation of the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area" (Wackernagel & Rees, 1996; p.9) is now far beyond the carrying capacity of the Earth: each Canadian living in cities, and the results are quite similar for any developed country- has an average ecological footprint of 4.3 ha while the available ecological footprint on our planet is 1.5 ha per person. And the trend is bound to get worst since, by the year 2025, developed countries that have already reached 75% urbanisation are expected to reach 84% urbanisation by 2025 (Miller, 1998). In this context of intensive urbanisation, reshaping existing cities and in a smaller extent designing new ones with sustainability goals in mind needs to become top priorities.

And transport planning may be used as a tool in this respect. Another impact of urban sprawl refers to private cars becoming the necessary transport mode, with all the unsustainable impacts on energy consumption and air pollution it implies. Public transport is not competitive enough in de-centralised outlying areas where densities are falling. One main objective for transport policies is thus to participate in bringing new solutions so urban spatial development is getting more sustainable, mainly by limiting urban sprawl outwards.

Problem Statement

Cities are car-dominated and car-oriented, with all the impacts it implies on environmental aspects and land-use patterns. One main direction to reach sustainable transport is then to reduce car-use as well as to supply an alternative attractive to people.
Confronted with such issues problematic in terms of urban sustainability, some cities have launched a tramway project, and others are considering it because it is likely to be a real alternative to private car. However, a tramway is not the guarantee by itself of sustainability. Several conditions must be met if its potential benefits are to become real; and that is what some cities involved in a tram project tend to forget. They focus on the economic and financial aspects without even considering the long-term impacts of a tram on land-use patterns. It is also too often the case that they decide on the layout of the tram according to political fights of single municipalities eager to attract this infrastructure on their territory. But sustainability only stems from policies planning in the long-term and considering all the possible impacts of a project on the urban system. Tram by itself is not a warrant for a sustainable spatial development of cities. Aiming at urban and transport sustainability requires to launch a discussion about the objectives of a tramway and all the other conditions it should meet to pretend to sustainability in terms of urban spatial development.

**Objective and Research Questions**

The present Master's Thesis aims at developing a framework, based on a system-thinking approach, to assess the sustainability of a tramway's impacts on urban spatial development.

To reach this goal, two questions need to be answered:

1. What are the impacts of tramway on the spatial development of cities?
2. To what conditions those impacts are sustainable, i.e. to what conditions a tramway may limit urban sprawl?

This framework is designed to be used by local decision-makers involved in tramway issues and recognising that sustainability should steer their decisions. Other types of transport-related authorities or organisations can be interested in the system-thinking approach which helps to identify the crucial aspects for urban and transport sustainability.

**Scope and Limitations**

The concept of sustainable development is applied to urban systems, and in particular to their spatial patterns. Besides, this thesis focuses on sustainable transport, and in particular tramway, as a tool to reach urban sustainability.

The concept of urban sustainability has been limited to the study of the spatial patterns of cities. It refers to three main aspects of urban sprawl, namely the localisation of activities and urban functions, the degree of specialisation of land-uses and urban densities. Environmental impacts of transport such as air pollution and energy consumption are only included in the analysis when relevant with regard to those spatial aspects; they are not part of the main focus of the thesis.

Transport is the only urban system considered here. The paper does not intend to deal with other aspects of urban sustainability, such as waste or water management. Only urban passenger transport is considered, and freight transport for example, or air and boat transport, are not mentioned. The focus is on the local level while regional or
international transport are out of the scope because urban sustainability is the object of
the study.

Then, alternative modes to car include not only public transport but also walking and
bicycling. Therefore, a policy aimed at sustainable transport and focusing on public
transport, may have indirect effects on pedestrians and bike-users that should not be
eluded in the analysis; but the present paper rather focuses on a comparison between
tramway and car’s impacts on sustainability access.

Finally, assessing the sustainability of a tramway is limited here to assessing the
sustainability of the operation of a tramway. It is not the point of this thesis to launch
an ecological footprint or life-cycle analysis of a tramway, which would include then
assessing the sustainability of the building of the tramway and the related
infrastructure.

Methodology

The general framework developed in this thesis is based on a qualitative approach,
based on system-thinking. The basics of this approach are further developed in
appendix 1. Several causal-loop diagrams are presented. Their explanation is
supported by an intuitive reasoning. The main assumptions behind each of them are
later discussed in chapter 4.

Outline

Chapter 1 presents the model that is the basis for developing the general framework
stated in the objectives of this thesis. A short introduction to system-thinking is
provided in order to justify its use. Then, the reader is introduced to the three main
aspects of urban spatial development, i.e. the localisation of urban functions, the
specialisation of land-uses and urban densities; their importance for urban sustainable
development is highlighted.

Chapter 2 develops a system-thinking approach to explain the causal relationships
existing between the three main aspects of urban land-use. A tramway’s impacts are
compared to private cars’ impacts on land-use, and the conditions so tramway’s
impacts are sustainable are then identified.

Chapter 3 sums up the conclusions of chapter 2 and presents the results as a table:
nine objectives are assigned to a sustainable tramway, when it comes to limiting urban
sprawl. Then, several means to reach those objectives are also deduced from the
analysis of chapter 2; and qualitative targets are suggested to measure the performance
of any tramway policy with regard to the nine objectives.

Finally, chapter 4 discussed the results as well as the main assumptions behind the
causal-loop diagrams of chapter 2.
1. The Model and Methodology Used for the Research

The present chapter aims at, first, justifying the use of system-thinking as the main methodology in the research. Further details about the method are located in appendix 1. Then, this chapter also presents the three main aspects of urban spatial development on which a tramway, or any other transport mode, may have an impact; their importance for the sustainable development of cities is also put forward.

1.1. A Qualitative Systemic Approach

System thinking is the main method used in the present research because it brings three types of crucial insights to the analysis of the urban system in relation with a tramway infrastructure.

First, system-thinking makes it possible to show the mechanisms behind a given impact. Several causal-loops are developed in the following, all put together in figure 1. They all identify the driving-forces responsible for the de-centralisation of urban functions, the specialisation of land-uses or the falling urban densities. Tramway, and car sometimes, are included in the picture, enhancing the re-enforcing and balancing impacts they may have on the urban spatial development, and how, in turn, spatial patterns may affect the transport system.

![Diagram of causal relationships between the direct and indirect impacts of a tramway on three land-use aspects: the localisation of urban functions, the degree of specialisation of land-uses and urban densities](image)

Figure 1. Causal relationships between the direct and indirect impacts of a tramway on three land-use aspects: the localisation of urban functions, the degree of specialisation of land-uses and urban densities

Virginie Lannes
LUMES Thesis
The second interest in using system-thinking is that it shows clearly the impacts of car and/or tramway on urban land-use trends, and thus makes it possible to identify the conditions so a tramway has more sustainable impacts on urban land-use than cars. As an example, figure 1 and all the resulting causal-loops put forward the key-role played by the “tolerance to distance” in promoting a tramway over cars. Then it is easier to identify objectives for policies, and this is the main outcome of the model, as presented later in chapter 3.

Finally, thinking in terms of system where each element is linked to another by a causal relationship results in making it easier to see what happens to the rest of the system when one element is modified by urban policies. Some solutions that are regarded a-priori as interesting may then turn out as being “fix-that-fails”, provoking secondary effects opposite to the initial intention. Some of those are highlighted in the analysis of the causal-loops in chapter 2.

More details about how to read causal-loop diagrams and the principles of system-thinking approach can be found in appendix 1.

1.2. The Three Aspects of Urban Spatial Development

Localisation of Activities

The de-centralisation of activities towards outlying areas has for unsustainable consequence that an increasing part of urban areas are not served by public transport anymore, and thus promote the use of car and the related unsustainable impacts on air pollution and energy consumption. Indeed, outlying areas usually develop and attract more urban functions by following car routes and motorway. The further they get from the central areas, the more complicated it is to organise public transport to serve them.

Besides, the de-centralisation of urban functions raises the issue of social equity. One main goal of urban sustainability is to “ensure equal access to resources and services, which means that access to facilities, services, goods and other people is not achieved at the expense of the environment or limited to those with cars” (EEA, 1995).

Specialisation of Land-uses

The specialisation of land-uses is not sustainable because it promotes the use of private car. Furthermore, it is nowadays less relevant than a century ago because the nature of the activities, and especially economic activities, have changed. It used to be necessary to lock highly polluting industries within remote areas, far away from living locations, on grounds of public health; but today, the progress in cleaner production as well as the fact that industry now is exceeded by tertiary activities (in general less polluting) makes specialisation less relevant.

Studies often focus on the travel patterns between poles of employment and areas specialised in housing. However, commuting trips account for only 30% of urban
travel while leisure-related trips are the dominant source of trip growth. This means that policies aiming at mixing land-uses in order to reduce the need to travel should not omit recreational areas and all those locations whose attractiveness is growing because of changing lifestyles and higher incomes: it is most probably the case with areas offering opportunities for exercise, sport, home entertainment, eating, drinking and meeting people.

**Urban Densities**

The "compact city" model aims at promoting high densities of settlements. The idea is to concentrate building activities in and around central cities. The advantages of this concept (Tjallingi, 1996) are that

1. it sustains the carrying capacity for urban services,
2. it keeps the coherence of urban functions intact,
3. it halts the disruption of environment and scenery of the agrarian landscape,
4. it stops the spatial segregation of income groups, and finally, in terms of transport management, and
5. it counteracts an increase of mobility and offers better conditions for public transport.

However, advantages at a macro-level (space for wildlife, traffic reduction) are accompanied by disadvantages at a micro-level, in the neighbourhood where residents are faced with the building of offices in their green area and more noise and pollution from cars. It is difficult to determine a threshold corresponding to the optimal density of urban areas: if the ambition fixes it too high, the quality of life of urban citizens is at stake and the risk is big that they choose to move out to the suburbs, then developing lower densities in total opposition with the initial goal of town planners.

By contrast to the "compact city" model, Gunther (1998) proposes the "integrated low-density city" model, which couples integrated areas (by opposition to specialised) with low-density settlements. Its principal motivation is to satisfy local needs by a local production in order to promote local recycling of nutrients; and such a principle is only possible in a small scale, justifying low densities. The consequence in terms of transport is that the need for food transport is significantly reduced because local agricultural lands are sufficient to cover the needs in food of the local population. Another basic assumption behind this model is that the energy use in urban areas is mostly based on food transport rather than on personal transport. But, the "integrated low-density" model reaches several limits. First, it only addresses the design of new urban areas more than it gives solutions to re-fashion existing cities, which is of limited interest in the perspective of urban sustainability. Second, it lies on one basic assumption, which is that the main reason behind urban transport is the transport of food rather than passenger transport (Gunther, 1998); but this assumption is highly arguable since some studies (Expert Group on Urban Environment, 1996) shows that each person in the EU consumes 5,000km per year while and only 670km of truck and other heavy vehicles.
2. Analysis of the Model and Results

A tramway has both indirect and direct impacts on urban spatial development because it shapes urban mobility. The point of the three following sections is to identify to what extent the impacts of tramway on the three main aspects of urban spatial trends, i.e. the localisation of urban functions, the specialisation of land-uses and urban densities, are sustainable and what are the conditions necessary to meet so they are sustainable.

2.1. Impacts of a Tramway on the Localisation of Urban Functions

Tramway Promotes the Re-Centralisation of Urban Functions Because It Reduces Car-Related Air Pollution (Indirect Impact)

The air pollution due to car-traffic supports the deterioration of the quality of urban environment and especially in city centres where road congestion is the worst. This is one reason that pushes city inhabitants to move out towards suburbs, where car’s negative effects is less striking because dispersed over a larger surface (figure 2). This sub-urbanisation process then encourages the use of car, and thus generates even more atmospheric pollution.

![Diagram](image)

Figure 2. Technological innovations to improve the fuel efficiency of private cars are a "fix-that-fails" type of solution because, though it improves the quality of air downtown, it promotes the decentralisation of urban functions and the related car traffic (re-enforcing loop)
The common solution brought to the air pollution problem refers to technological innovations. By improving the energy-efficiency of cars' engines, or by reducing the polluting emissions from cars thanks to catalytic converters, the air pollution problem is expected to decrease. But this technological solution is actually a “fix-that-fail” type of solution for mainly two reasons. First, the better efficiency of single vehicles is soon cancelled out by an ever increasing car-traffic.

Second, it cannot be a solution because the problem is not well identified: innovative policies owe first to aim at reducing the need to travel by car, rather than focusing on technological fixes. Of course, the first requires more political commitment to the idea that cities should be human-oriented rather than car-dominated; but this is the necessary condition so we can hope that cities are more sustainable one day.

And by focusing on technological fixes, transport policies usually elude this central land-use issue, and make conditions even worst, as illustrated by the re-enforcing loop of figure 2. Because an improved energy-efficiency of private cars reduces the costs attached to travelling by car (mainly fuel consumption in this case), car-users are not given any incentive to reduce the distance they travel with their cars. Distance is not an issue for them, which generates, or at least promotes, the de-centralisation trend.

A tramway, by curbing down car traffic, limits the air pollution generated by vehicle engines, as shown in figure 3. A discussion of the air pollution generated in turn by tramway can be found in chapter 4.

![Diagram](image)

Figure 3. Because it curbs down car traffic and the related air pollution, tramway supports the re-centralisation of urban functions (re-enforcing loop)

*Tramway promotes the re-centralisation of urban functions when it improves the accessibility of central areas without supporting car-use (indirect impact)*

Road supply is one key-element behind the de-centralisation of urban functions. By providing new roads to regulate traffic congestion downtown and in order to improve the accessibility of town-centres, local authorities actually also promote the attractiveness of outlying areas, enhancing the de-centralisation of activities. Figure 5 describes the re-enforcing effect of road supply on the decentralisation of urban functions and on car traffic, and implies that, by reducing car traffic, a tramway
decreases the car-provoked decentralisation. But before, figure 4 describes the re-enforcing mechanism that makes road supply be a “fix-that-fail” solution.

![Diagram showing the re-enforcing mechanism of road congestion and road supply](image)

Figure 4. Road supply does not solve the problem of road congestion in the medium and long-term (re-enforcing loop)

Congestion in Europe is relatively low in that it only affects a small proportion of the total infrastructure. The network of Germany and the Netherlands for example is congested only up to 2%. However, the perception by road-users of the time they waste in traffic jams is three times higher than the actual waiting time (ECMT/OECD, 1995). This temporal dissatisfaction drives the demand for more road infrastructure. The most common response turns out to be the supply of new roads. This is a typical example of decision-making that replies to demand by supply, the so-called Facilitating Infrastructure Supply (FIS). In current policies, no thought is given to the source of the problem, i.e. city’s own generation of car-traffic due to land-use policies that consume space in an extensive way, or even to a lack of attractiveness of alternative transport modes, and among them public transport. And new available roads generate more traffic by offering car-users an improved comfort, speed and shorter waiting-times.

This kind of re-enforcing loop is also referred to as a “fix-that-fails”: the measure (supply of new roads) introduced to fix the problem (road congestion) ends up re-enforcing the initial problem (the level of congestion on roads is still the same, if not worst, after a certain period of time because new roads attracted new traffic) instead of fixing it.

The above endless road supply has a paradoxical effect in a long term perspective. Conceived at the beginning to improve the accessibility of town centres (as argued in the discussion in chapter 4), it actually makes conditions also favourable to outlying areas, as illustrated in figure 5.
Figure 5. Road building promotes the decentralisation of urban functions by improving the accessibility of outlying areas (re-enforcing loop)

Indeed, the expansion of the road network towards town-centres, along radial routes serving city centres, increases the accessibility of suburbs, the other end of the radial routes. Investments in road infrastructure make car’s use even more attractive, because it usually curbs down the time spent to travel and therefore decreases the sensitivity of commuters to distance. Urban travellers then are not reluctant anymore to move out to the periphery for some or all their activities, and longer distances require the use of private car.

One way of countering this re-enforcing loop, and its resulting decentralisation and increasing car traffic, is to make it more difficult for cars to access town-centres. This “negative” approach (“negative” because it sanctions car-users instead of giving incentives to use public transport) refer for example to increasing the cost of using a car by internalising external effects such as the costs related to air pollution, accidents on persons, road congestion and the value attached to the time spent in traffic jams (Hansson, 1997). But it also means for example removing parking-lots or limiting their availability for certain uses (for residents of central areas for example).

But, the policy aiming at making it more difficult for cars to access town-centres, by limiting the availability of parking-lots for example, may be two-sided: the positive effect expected on the attractiveness of public transport may be countered by a spontaneous reaction favouring the decentralisation of activities to outlying areas where conditions (space for parking mainly) are favourable to car-users.

Furthermore, it is not proved by facts that the traditional “negative” approach (through sanctioning car users) can succeed in operating a modal shift in favour of public
transport. On the contrary, some studies (Walmsley and Pickett, 1992 in: ECMT/OECD, 1995) give evidence that most users of a new metro or tram system were previously bus-users rather than car-users. Then the modal split evolves from a public transport to another, without affecting the number of cars circulating. One main reason behind such a failure is that policies usually adopt a "negative" approach without giving incentives ("positive" approach) to car-users to shift to public transport. It seems then more effective to design an attractive public transport system and, when relevant compared to the conditions proper to each city, to implement a tramway.

**Tramway promotes the re-centralisation of urban functions along radial routes and central areas because it improves the accessibility and attractiveness of town-centres (direct impact)**

Like in the case of car (see figure 5), building a tramway infrastructure entails that both ends of a tram route are made more accessible, leaving the door open for more decentralisation of urban functions and then turning cars as a necessary and more convenient mode of transport. But this balancing effect does not have to happen. Town-planning authorities have the choice to actively counter a spontaneous decentralisation phenomenon by improving conditions of tramway operation and circulation, as described in figure 6.

![Diagram](image)

**Figure 6.** Active policies enhancing tram’s attractiveness balance a possible spontaneous decentralisation of urban functions (re-enforcing loop)

By “active policies”, figure 6 mainly refers to three types of intervention by local authorities.

Virginie Lannes

LUMES Thesis
First, transport policies have to favour tram over car; this means adopting a “positive” approach (giving incentives to use tramway) instead of focusing on a “negative” approach (sanctioning car-users). The best argument to convince car-users to shift to public transport seems to be to provide a real attractive alternative. If tramway is to attract new users, it is necessary to meet users’ expectations in terms of service, i.e. regularity, comfort, reliability, safety and higher speed than by using the car. In this respect, tramway must have a broad coverage in terms of time and space, should have priority at cross-roads, and be affordable as well as easy to use.

Second, it is important to re-place the focus on central areas by re-vitalising the attractiveness of commercial and other activities in town CENTRES, as well as by supporting the implementation downtown of the most appropriate activities. According to a study by ECMT/OECD (ECMT/OECD, 1995), the specialisation of central areas in services such as banking, corporate management, marketing, communications, high quality retailing and higher education may help re-vitalising central areas. The same study shows also that land-use policies should develop those activities that fit and require central locations or proximity to similar complementary institutions (high-tech offices, hotels, shopping malls and museums, tourist attractions, banking, corporate management, marketing, communications, high quality retailing and higher education, etc.).

Third, land-use policies have to grant building license only to the poles of activities (shopping malls, sport centres, etc.) which are planned into areas already served by public transport. Holland for instance is exploring the idea of “ABC Zoning” which integrates town planning and transport strategies (Sund Bytraffic, 1998). There are three kinds of zones, from A to C. Zone A means that there is a railway station close by, while zone B implies that access is just as easy with either public transportation or car, and finally zone C means that the place can practically only be reached by car. Certain activities are not permitted in certain zones. For instance, large shopping centres may not be built in C zones, because it would mean encouraging the use of a private car instead of public transportation. This type of policy aims at favouring the use of public transport at the expense of car, not by means of sanctions but rather by planning the city from the beginning so as to reduce the need for travelling by car. The central instrument in this type of policy is a policy integrating town planning and transport strategies.

**Tramway promotes the re-centralisation of urban functions because it increases the sensitivity of urban travellers to the length of trips (direct impact)**

One of the main differences between car and tramway is that a tram supports and needs travellers to use alternative modes (walking and biking mainly) in between the tram stop and the final destination of the trip. If the distance is too important, travellers may look for a more convenient solution, and mostly car; providing enough tram stops so distances are not too long is an important implication when deciding about the layout of a tramway infrastructure. Another implication is that tram-users are more sensitive to trip distances than people travelling by car. This implies that, in ideal conditions, tram-users change their travel behaviour and the activities they implement so as they are located close to a tram stop (limitations to this hypothesis are
discussed in chapter 4). In this way, a tram infrastructure acts as a limiting factor to trip distances and to the decentralisation of activities: those activities that are not served by a tram are not attractive to urban travellers. Figure 7 displays the causal relationships between the above elements, putting forward the re-enforcing effect of tramway.

![Diagram of causal relationships](image)

Figure 7. Tramway promotes the re-centralisation of urban functions because it reduces the tolerance of urban travellers to long distances (re-enforcing loop)

Figure 7 does not mean that all activity or urban functions situated in the suburbs are to disappear or be re-located in central areas; the explanation of figure 6 stated that only selected activities should be centralised. Instead, figure 7 implies that public transport has to be also directed at suburbs rather than only within central areas. Indeed, it is more efficient in a sustainable perspective to design solutions for existing suburbs than ignoring them; the risk would be then that they gain importance, following spontaneous developments not regulated by public policies. In this respect, tramway should be used in outlying areas not with the aim of re-centralising urban functions around central areas but instead with the aim of structuring suburbs along radial routes. Tram would then, here again, act as a limiting factor to trip distances and to the sprawling out of activities, on the same model as above in central areas.

Suburb-to-suburb traffic now accounts for the majority of the traffic in urban areas; in France for example, 75% of all trips made in urban areas are between peripheries, increasing by 6% over the last decade (Pusher, 1996). As a consequence, they should be the main target of public transport policy: if tramway is not economic-efficient enough in those outer areas, then bus lines should be developed instead.

Developing urban sub-centres is also one possible solution with regard to tramway in suburbs. Polycentric urban structure, in which facilities are decentralised in order to be closer to the residents which they serve have a great potential for sustainable land-uses if reducing car travel is clearly stated as an objective: journey lengths are shorter,
motorised vehicles are not necessary, accessibility of any kind of facilities and services is good. If town-planning also promotes mixed land-uses within those sub-centres, then they widen opportunities for multi-purpose trips; and if public transport is well developed, sub-centres may ensure a decreasing car-dependence.

2.2. Impacts of a Tramway on the Specialisation of Land-Uses

Tramway favours mixed land-uses because it increases the sensitivity of urban travellers to distances

Car-dominated cities support specialised land-uses because it makes travellers less sensitive to the long distances usually separating specialised areas: distances are no longer regarded as an obstacle. And travelled distances are bound to be higher in a specialised city because, in order to implement all the activities he/she needs, an urban dweller needs to travel in several different directions instead of having diverse activity at proximity.

Tramway, because it is also a motorised mode of transport making it possible to travel long distances, may also favour a specialisation trend, more than in a walking-oriented city for example. However, figure 8 shows that a tram does not favour as long distances as cars; so, if urban travellers use tramway and other alternative modes, distances are expected to be shorter than in a car-oriented transport system, limiting the specialisation of land-uses.

![Figure 8. A city using tramway as a backbone favours shorter distances than in a car-dominated transport system: the diameter of a tram-city may be up to 30 km while a car-centred city extends this diameter dramatically (Source: Adams, 1970 in: Book & Eskilsson, 1998).](image)

One main reason why tramway supports shorter distances than private cars is that tramway relies on the use of alternative modes, as mentioned before; as a consequence, tramway shapes a lower tolerance to distance in tramway-users minds, which oppose a trend of specialisation of land-uses. The key-role played by the tolerance of urban travellers to distance is illustrated in figure 9.

Virginie Lannes  
LUMES Thesis
Figure 9. Tramway promotes mixed land-uses because it increases the sensitivity of urban travellers to long distances (re-enforcing loop)

If tramway has a better comparative speed than car, and if it provides passengers with the quality and service they expect, then urban dwellers are prone to use it. This induces they travel only where the tram goes: in this respect, tramway shapes and constricts travel patterns (the conditions for such an ability to actually occur are discussed in chapter 4). Rather than going on with activities that are located outside their “area of influence” (i.e. this perimeter where mainly housing and working are located), they are pushed to modify their behaviours so as to choose activities that are located in their close surroundings. By doing so, they decrease the distances they travel and favour the use of tramway and alternative modes.

2.3. Impacts of a Tramway on Urban Densities

A Tramway Fosters High Urban Densities Because It Promotes the Re-Centralisation of Urban Functions (Indirect Impact Via the Localisation of Urban Functions)

Thanks to car in particular (other reasons behind de-centralisation of urban functions are discussed above), people and activities have moved away from town centres to areas where land prices are cheaper, which opens the possibility to settle on a bigger piece of land; the result is, besides specialisation and longer distances, falling urban densities, as highlighted in figure 10.
Figure 10. By promoting the re-centralisation of urban functions, a tramway helps increasing urban densities (re-enforcing loop)

Then, higher densities provide more potential passengers for tram, improving its financial feasibility. More investments can be launched to improve the quality of the operation and the service, or the spatial coverage.

The intermediary steps between tramway and de-centralisation are not mentioned here, but they refer to the use of alternative modes and the tolerance to distance, as explained around figure 7. Then distances are longer within the large urban area which means that alternative modes are no longer attractive or competitive as compared with private car.

**High Densities Develop Along Tramway Corridors (Direct Impact)**

Three forces may favour high or medium-density areas to develop around the tramway infrastructure: the structuring impact of tramway, a shift in travel behaviour and increasing land values along tram corridors.

First, activities settle along tramway corridors and not in-between, contrary to car system, because a tram user must be as close as possible from a tramway stop without needing to use one’s car. This promotes the use of alternative modes instead, and particularly walking. But of course, if the distances between an activity site and a tram stop are too long for walking or cycling, people will use their cars. In this case, park-and-ride facilities are necessary. P&R are parking-lots located close to tram stops, or to the bus routes feeding the tram, and encouraging car passenger to shift to public transport outside the inner city-areas, thus decreasing the volume of car traffic in town centres. But the impact of park-and-ride facilities on urban sustainability is not clear,
and thus they ought to be used with caution. Indeed, they make it still convenient for city-users to use their cars from their home (for example) to a tram stop. This means that the access to park-and-ride facilities to cars should be limited (by selective fares for instance) so as to discourage those people who could easily walk or bike to rather use their cars.

The second driving-force behind the density process refers to habits and individual travel behaviour. It is expected that people get used not to using car and then become less tolerant to distance, which in the end favours alternative modes and tramway traffic. Of course, this shift in mentalities takes some time and must be considered in a medium, if not long-term perspective.

Finally, land-value theories explain that, because a tram brings higher accessibility to urban areas, the value of the land located around tramway corridors usually increases (Hagget, Etchenique, Peiser in: Books & Eskilsson, 1998). This means that less people will be able to afford big urban land per capita in those areas; as a consequence the urban densities of population and activities may be expected to increase along tram corridors.

Densities increase along tram corridors, but get lower outside. However, the average higher densities compared to car-dominated cities make it easier to walk or bike, and improves the attractiveness of public transport. Besides, a second level of public transport, namely buses, can contribute to increase densities even outside tram corridors. Buses should not be competing with tramway, but rather the opportunities for complementing each other ought to be developed harder. Mainly because of different capacities in terms of passengers, buses can be used in those suburban areas where the volume of potential customers is not sufficient to guarantee an efficient tramway service: bus routes feed tram lines with passengers mainly coming from low-density areas while tram operates along radial routes serving central areas.
3. Results and Outcomes of the Model

The sustainability potential of a tramway comes true only under certain conditions, as put forward in chapter 2. Those conditions are intermediary steps necessary to meet the goals of a sustainable tramway, i.e. urban and transport sustainability, and are referred to as “objectives”. The objectives of a sustainable tramway, as well as the means designed to reach them, are deduced from the system analysis of chapter 2 whose conclusions are summed up first in the following. Then, ways to calculate the compliance of policies with the means to reach the objectives are suggested.

3.1. Conclusions of the Model

Conclusion of Figures 5 and 6

The two figures have identified several conditions so tramway really improves the accessibility of town centres and does not make outlying areas too attractive:

- active transport policy to favour good conditions for the operation (comfort, reliability, reasonable prices, etc.) and the circulation (speed) of tramway;
- promoting the attractiveness of town-centres through active commercial policy and land-use policies;
- limited parking-lots for car downtown: they should only address the needs of central residents so as to encourage the use of tram for other travel purposes (leisure, shopping, commuting...);
- a land-use policy that is compatible with the goal of sustainable transport to reducing the need for travel and to favouring the use of public transport.

Conclusions of Figure 7

A tramway infrastructure gives good results in terms of re-centralisation of land-uses only if:

- the time spent in tramway is perceived as shorter than with a private car. That is one of the key-conditions so that car-users shift to tram, while distances in terms of length are not a main argument in the choice of transport mode;
- public transport, which means tram completed by buses when relevant, addresses town-centres but also outlying areas.

And the goal could also be to develop and maintain sub-centres around a tramway infrastructure only if:

- the sub-area is not too close from the main centre: otherwise, the risk of competition between them is too large which could result in the transformation of the sub-centre into a “dormitory” area, dependent on the main centre for any other
function and activity: this would amount to a new trend of decentralisation with its 
related transportation issues;

- different land-uses are mixed and integrated in each sub-centre;
- public transport is actually promoted; and finally
- the reduction of car use is a clear objective in the transport and town-planning 
policies.

Conclusions of Figure 9

The specialisation generated by tramway is weaker than the mixing-force, and less 
serious than in a car-dominated city only if:

- alternative modes are fully promoted and integrated into tramway’s policy as a 
  complement to tramway;
- distances between activities and other urban functions are shorten.

Conclusions of Figure 10

High densities are achieved thanks to tramway, only:

- if land-uses are mixed;
- along tram corridors: outside, densities are usually lower. But some measures may 
  be implemented to increase urban densities even outside tram corridors. For 
  instance, tram should be completed with buses lines in areas where low densities 
  do not offer satisfying conditions for the exploitation of a tramway infrastructure;
- if the access to outlying park-and-ride facilities granted to cars is limited to low-
  density areas, and to those people who really do not have the opportunity to walk or 
  bike there. On the contrary, large capacities to fit bikes are to be built in those park-
  and-ride places.

3.2. Objectives of a Sustainable Tramway and Means to Reach Them

According to the discussion throughout chapter 2, the objectives of a sustainable 
tramway are:

(1) reducing the volume of car traffic,
(2) improving the quality of the service supplied by a tramway,
(3) making it possible and attractive to use the tramway by implementing specific 
  land-use policies,
(4) supplying tram (and/or buses) not only to central areas, but also to outlying areas,
(5) supporting the alternative modes of transport (walk and bike) because they are the necessary complement to tram,

(6) re-centralising urban functions,

(7) mixing land-uses,

(8) increasing urban densities, and finally

(9) using a sustainable source of energy, which pollutes the least the atmosphere.

Objectives 1 to 5 refer to the more general category of promoting tramway (and bus, walk and bike) at the expense of private cars; objectives 6 to 8 aim at reducing the need to travel, while objective 9 concerns the operation of tramway. They are all listed in table 1, together with the means to reach them. Both objectives and means are directly deduced from the above conclusions of chapter 2.

Table 1. Nine objectives for a sustainable tramway

<table>
<thead>
<tr>
<th>Objectives of a sustainable tramway</th>
<th>Means to reach the objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives and means to promote tramway (and/or buses, walk and bikes) at the expense of private cars</strong></td>
<td></td>
</tr>
<tr>
<td>1. Reducing the volume of car traffic</td>
<td>• the reduction of car use is a clear objective in transport and town-planning policies,</td>
</tr>
<tr>
<td></td>
<td>• decreasing number of cars downtown,</td>
</tr>
<tr>
<td></td>
<td>• decreasing number of cars from suburbs to central areas,</td>
</tr>
<tr>
<td></td>
<td>• decreasing number of cars transiting by central areas without stopping,</td>
</tr>
<tr>
<td></td>
<td>• decreasing number of parking-lots for cars downtown,</td>
</tr>
<tr>
<td></td>
<td>• increasing number of parking-lots downtown with a restricted access to residents,</td>
</tr>
<tr>
<td>2. Providing a tramway with a high-quality service</td>
<td>• good regularity, high frequency, low waiting time at tram stops,</td>
</tr>
<tr>
<td></td>
<td>• high comfort: at least 1/3 of sitting places, air conditioned, seats for disabled, elderly and pregnant women,</td>
</tr>
<tr>
<td></td>
<td>• reliability,</td>
</tr>
<tr>
<td></td>
<td>• good space coverage (length of tram and bus lines),</td>
</tr>
<tr>
<td></td>
<td>• distance between stations &lt; 600metres,</td>
</tr>
<tr>
<td></td>
<td>• time coverage: adapted to activities both during week-days and week-ends,</td>
</tr>
<tr>
<td></td>
<td>• safety,</td>
</tr>
<tr>
<td></td>
<td>• a comparative speed favourable to tram (and buses), thanks to priority at cross-roads, right-of-ways, etc.,</td>
</tr>
<tr>
<td></td>
<td>• affordable prices and special fares for different categories of tram/bus users,</td>
</tr>
</tbody>
</table>
Assessing the Sustainability of a Tramway’s Impacts on the Spatial Development of Cities

3. A land-use policy favouring the use of tramway
   - limited authorisations granted to shopping malls, leisure centres, etc. in suburbs that are not served by public transport,
   - a “proximity concept” so as to reduce distances between the main centre and suburbs,

4. Providing tram (and/or bus) to outlying areas and sub-centres
   - tram, bus and train complementary rather than competing: the bus feeds train and/or tram radial routes in those areas where densities are not enough to sustain tram,
   - convenient modal shift between train, tram and bus: limited number of changes between lines and modes, limited waiting-time during a modal shift, fair price for a trip including several shifts,

5. Supporting alternative modes (bike and walk)
   - investing in bike lanes and public space for pedestrians,
   - priority to bikes and walking over cars,
   - safe conditions for cyclists or pedestrians,

Objectives and means for a land-use policy to reduce the need to travel

6. Supporting the re-centralisation of urban functions
   - limiting the authorisations granted to the development of activity poles in outer areas,
   - launching an active commercial policy to increase the attractiveness of central areas,
   - supporting the development of selected activities in central areas (those that fit and require central locations),

7. Developing mixed land-uses
   - using the land-use plan to select the new activities setting up in sensitive areas,

8. Increasing urban densities
   - defining an more or less broad margin around tram/bus corridors where to increase density,
   - launching investments operation in real-estate along tram corridors and in margins around,
   - restricting outlying park-and-ride facilities to low-density areas and where distances between urban functions are very long, and restricting the access for cars to those people who really cannot bike or walk to the tram stops, as well as providing large capacities to fit bikes,

Objectives and means for the sustainable operation of a tram

9. A sustainable source of energy
   - using a sustainable energy source for the tram
   - reducing the polluting emissions at the site of energy production

3.3. About the Means

No quantitative target can be fixed in the absolute for each means. Instead, sustainability should be seen as a process, rather than an end by itself, and the aim is to promote an ever-improving environment. This is why the means in the above table are not completed by a quantified target, but are rather qualitative and compare the situation with a tramway to the situation before the tram; the direction of the evolution that supports sustainability is indicated by an arrow besides each indicator.

Virginie Lannes

LUMES Thesis
Assessing the Sustainability of a Tramway's Impacts on the Spatial Development of Cities

- indicators to measure objective 1: number of cars downtown (N); number of cars coming from the suburbs to central areas (N); number of cars transiting by central areas without stopping (N);

- indicators to measure objective 2: number of travels by public transport (S); length of tram and buses lines (S); number of tram and bus stations (S);

- indicators to measure objective 3: distance between the main centre and sub-centres (N);

- indicators to measure objective 4: measuring the density of settlements and activities to assess whether a tram is relevant or a bus is more efficient; length of tram and bus lines from suburbs to suburbs (S); length of tram and bus lines from suburbs to central areas (S); quality of the service to link suburbs to central area (S) (see objective 2 and the related means);

- indicators to measure objective 5: average distance of urban trips (N); percentage of urban trips below 5 km (S); % of trips by bike and walk (S). This objective fits the concept of "proximity" also mentioned under objective 3;

- indicators to measure objectives 6 to 8: % (S) and length (N) of urban trips in central areas; % (N) and length (N) of urban trips suburb-to-suburb (N); % (S) and length (N) of urban trips suburb-central area.

- indicators to measure objective 6: number of jobs in central areas (S) and in suburban areas (N); number of customers for leisure activities in central areas (S) and in suburban areas (N); number of customers for shops in central areas (S) and in suburban areas (N);

- indicators to measure objective 7: distance between daily activities (N);

- indicators to measure objective 8: density of population downtown and in suburbs (S); density of settlements and employment along tram and bus corridors (S); density of settlements and employment outside tram and bus corridors (S);

- indicators to measure objective 9: energy consumption and polluting emissions in urban areas and around energy-site production (N).

The advantage when using those indicators is that the information necessary to measure the results is often already available in any city or, if not, easy to calculate or measure.
4. Discussion of the Results

The first section discusses the main assumptions behind some of the causal-loops presented in chapter 2. Then, the relevance of the results as well as the limitations and the possible improvements are discussed.

4.1. Comments about the Causal-Loop Diagrams

Comments about the impact of tramway on air pollution (figure 3)

Figure 3 states that tramway indirectly reduces atmospheric pollution in urban areas because it curbs down car traffic and the related polluting air-emissions. But the final impact of tram on air pollution depends on the result of the comparison between this indirect reduction and the direct pollution tramway also generates.

Table 2 shows the very clear difference between different modes of passenger transport in terms of air pollution. Of course, bus is the least polluting motorised mode, but tramway is still much less harmful for the atmosphere than private cars. The fact that an electricity-powered tramway emits more CO₂ than diesel buses, according to this table and contrary to what is usually expected, is due to the fact that those data come from Germany, where the main source of energy for electricity production is the burning of fossil fuel, like coal. That means that in another national context, as in Sweden or in France where electricity is for the most nuclear, tram would pollute even less, in terms of CO₂ in particular. The second comment relates to the quite old data (from 1987) of the table: as a consequence, car’s emissions of NOₓ are much larger than diesel buses’ because cars where not, at the time of the table, equipped with catalytic converters. Today, results are less unfavourable to cars in terms of NOₓ emissions in most cases.

Table 2. Specific air-polluting emissions of different passenger transport modes in Germany, 1987.

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Bus</th>
<th>Urban tram, Tram, metro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billion passenger-km/yr</td>
<td>525</td>
<td>68</td>
<td>11</td>
</tr>
<tr>
<td><strong>Emissions (g/passenger-km)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>180</td>
<td>48</td>
<td>61</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.3</td>
<td>0.07</td>
<td>0.2</td>
</tr>
<tr>
<td>VOC</td>
<td>2.2</td>
<td>0.29</td>
<td>0.15</td>
</tr>
<tr>
<td>NOₓ</td>
<td>2.1</td>
<td>0.79</td>
<td>0.15</td>
</tr>
<tr>
<td>CO</td>
<td>11</td>
<td>0.28</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Source: Whitelegg, 1994 (p.57)*
Air pollution by a tramway is bound to be less than by cars, though depending on:
- the fuel-efficiency of the tramway;
- the rate of occupancy of the vehicle;
- the distances travelled;
- the source of energy.

More should be said about the source of energy used to operate the tramway. However, it is not the focus of the present paper to discuss what is a sustainable source of energy. It is enough to point at the fact that tramway running on electricity is not an absolute "clean" vehicle. The sustainability perspective requires a life-cycle approach of the environmental impacts of not only using, but also producing, the electricity. It is important to compare for example the impact of nuclear electricity (in case of countries like France whose main source of energy is nuclear) to the impact of cars using fossil fuel. In brief, switching from car to tramway may be a transfer of pollution to the site of electricity generation and the final balance sheet when it comes to air pollution is not as clear as it is generally thought. Transferring air pollution from a local scale- i.e. the city where cars circulate- to another- the site where the power plant is operated- cannot be a solution in a sustainable development perspective!

*Comments about the impact of tramway on road congestion and its secondary effect on car traffic (figure 5)*

Congestion can be expected to steer car users to shift from car to public transport or other alternative modes (walking or biking); this would have a balancing effect on car traffic then reducing congestion on roads. Thus, tramway may have this secondary effect, opposite to its first intention, that it fosters car traffic because it makes car traffic less heavy.

---

Virginie Lannes

LUMES Thesis
But two other forces oppose and minimise this balancing effect, namely (1) the lack of attractiveness of alternative modes to car as well as (2) the fact that the re-enforcing loop described in figure 5 is stronger than this balancing loop.

First, public transport in most developed countries is usually not considered as an attractive alternative to car because it does not offer better traffic conditions: buses for example do not circulate on their own lanes and are not given priority at cross-roads, resulting in being trapped in traffic jams provoked by cars affluence. As for walking or biking, safety and convenience are most of the time lacking to operate a modal shift.

The second force opposing the first balancing loop relates to the secondary impact of road building, i.e. enhancing the accessibility of outlying areas and then the decentralisation of urban functions described in figure 5. Though, in a first place, new roads improve traffic flows downtown, it also increases the convenience to reach the other end of the road, i.e. suburbs. Road supply improves the accessibility of town centres and then make them more attractive pumping economic activity into central areas. It makes decentralisation of land-uses less relevant, and slows down the increase of car traffic. But this balancing loop is valid only for a short period of time; after a while, the new traffic generated by the new roads comes eloger to a new saturation leve!, and congestion is worsening before new roads are built.

Comments about the positive relationship between decentralisation and specialisation on one side and distances on the other side (figures 7 an 9)

Figures 7 and 9 assume that tram-users modify their travel behaviour and their activities so they are situated close to a tram stop. They state a positive relationship between specialisation and distances. Both figures explain that, when a tramway is implemented, urban travellers are less tolerant to long distances, and then change their activity patterns: by choosing activities that are located in their eloger surroundings, they favour a mixed and more centralised land-use.

But it can be argued that this positive relationship is not observed in reality. Preferences for certain activities may be stronger than the perception of the distance to reach them; this favours the use of car because it is a more convenient mode of transport, usually faster. Households, for example, may prefer travelling 20 km to reach a shopping mall located at the periphery of a city because it offers cheaper prices for goods than a small retail shop downtown; and, as those outlying areas are seldom served by public transport, people use their car instead. It implies that, even if a tramway promotes a higher mix of land-uses, people do not stop having preferences for activities located outside their close areas; this may in the end question the efficiency of tramway to shape travel behaviours in the direction of shorter distances.

Two main arguments can support the positive relationship put forward by figures 7 and 9, namely a time delay and the necessity of active transport and land-use policies. The fact that urban dwellers change their activity localisation is, first, merely a question of time-scale. They need time to realise how much more convenient it is to
take the tramway than their private cars; and then they will consider changing their activity patterns. Urban travellers are sensitive to the distances they travel disregarding their transportation mode, though they are less sensitive when they use a car. They are especially sensitive to the time they spend travelling, rather than to the distances in terms of kilometres. This means that, whenever traffic congestion is too heavy, provoking time-consuming traffic jams, car-users are willing to shift to another mode more efficient in terms of time. This represents an obvious opportunity for tramway: it has to strike car-users’ minds that it is faster than private cars.

Such a change is also dependent on land-use policies. If they limit the authorisation granted to activity poles to settle in outlying areas, where car is the most convenient and feasible mode of transport, then urban citizens do not have any reason to travel long distances towards the edge of cities; it is an example of supply-driven modification of travel behaviours.

Another opportunity for authorities to curb down specialisation and the resulting travelled distances is by supplying the maximum of areas with tram, or bus when it is more financially feasible and efficient. Indeed, a sustainability approach is as much concerned with the re-shaping of existing areas as with the design of totally new areas. Those specialised areas currently situated outside city centres are not to disappear; rather, they need to be included in land-use policies aiming at sustainable spatial development. And if they are served by public transport (tram and/or bus), and if public transport is attractive enough to operate a major modal shift at the expense of private cars, then those outlying areas are not a big problem for sustainability any longer.

4.2. Utilisation of the Results

Applying system analysis to the relation between tramway and urban sustainability makes it possible to identify nine objectives and the related means that a tramway must meet in order to be a sustainable mode of transport.

The results are likely to be used when deciding about the design of a new tramway infrastructure (in this case, one talks about an “a-priori” evaluation of the sustainability of a tramway project) or also when trying to find out how to improve the sustainability of an already existing tramway infrastructure (and in that case, it is an “a-posteriori” evaluation).

But, if the aim is not only to develop a theoretical discussion about sustainable tramway but also to propose a guideline that decision-makers can use in practice (and this is the case of the present paper), the results should be easy to disseminate to the field; section 3.3 shows that it is easy to evaluate the performance of any tramway (infrastructure, or only project) in terms of objectives and means. The results have of course a limited reach but are still relevant and helpful to assess the sustainability of a tramway.
4.3. The Limitations of the Model

Tramway is not self-sufficient to ensure all the changes in urban patterns and transport behaviours: it is only one tool, even if the present thesis is focusing on it. Of course, it has to be considered in the much broader context of transport policy that encompasses public transport in general, restrictions on car-use (such as the principle of polluter-payer that charges private cars the full cost of their use), parking-lots issues, incentives given to walking and cycling, etc.

Besides, the expected consequences of a tramway project, and especially those dealing with changes in urban form, depend not only on the tramway itself but also on town-planning policies. The limitation of the sub-urbanisation process for instance does not succeed unless a more general policy of containment of the built-up area is implemented, favouring a mix of different urban land-uses, maintaining and developing central areas and in some cases sub-centres, and striving for high and medium urban densities. It is thus clear that the present study does not have the ambition of covering the whole spectrum of urban policies. It is rather focusing on only one part of public transport policies, i.e. tramway, though encouraging the reader to link it with more general transport policies as well as with town planning as a whole.

4.4. Future Improvements

The objectives and means presented in table 1 are considered as the most important elements to be taken into consideration when assessing the sustainability of the impacts of tramway on urban spatial development. This implies of course that others have been eluded mainly because they did not fit the “close your loop principle” or because they would have made the picture of the urban system too complex to grasp.

Of course, the number of means can be increased significantly: the aim here was not to be exhaustive but rather to use the system analysis of chapter 2. It is possible, for example, to go further in the literature review in order to complete the list of means on a theoretical basis, but it could be also interesting to look at case-studies in order to identify the most relevant and most successful measures taken in practical situations.

When it comes to the objectives yet, it is better not to add any to the above list, though it could be possible. Indeed, each of the nine objectives stems from the system analysis of chapter 2. Adding an objective would then imply to add new causal-loops, which is likely to make the understanding of the whole system difficult to grasp.
Conclusion

The present research has supported the idea that tramway has the potential to be a sustainable mode of transport, at least when it comes to its impacts, direct and indirect, on urban spatial development. However, no “black-and-white” picture is provided, because urban policies have to meet several conditions before they turn the sustainability potential of a tramway into actual sustainable impacts on spatial development.

Those conditions are:

- reducing car traffic; this can be achieved by (1) reducing the volume of car traffic, (2) providing a tramway with a high quality service, (3) a land use policy favouring the use of tramway, (4) providing tramway (or buses) to outlying areas and sub-centres, and finally (5) supporting alternative modes;
- reducing the need to travel thanks to an appropriate land-use policy requires (1) supporting the re-centralisation of urban functions, (2) developing mixed land-uses and (3) increasing urban densities by appropriate means, such as those suggested in chapter 3; and finally
- reducing the energy consumption and air-polluting emissions by adopting a sustainable source of energy.
References


Gunther (1998) Lecture at LUMES, Lund University, Sweden


Roberts, Nancy; Andersen, David F.; Deal, Ralph; Garet, Michael S.; Shaffer, William (1996) Introduction to computer simulation: a system dynamics modelling approach. Productivity Press, Portland, Oregon, USA.


Tjallingi, Sybrand P. (1996), Ecological Conditions, Strategies and Structures in Environmental Planning. DLO Institute for Forestry and nature Research, Wageningen, the Netherlands.


Bibliography


Holmberg, Bengt (1998) Own calculations for access to car in Sweden.


Internet References


EURONET/ICLEI (1996) Local Sustainability- European Good Practice Information Service
Local Government Management Board- Local Agenda 21, Case Study Project <http://www.iclei.org/egpis/lgmbinfo.html>


Appendix 1. System-Thinking Methodology

The Purpose of System Thinking

The EarthWatch programme of the United Nations Environmental Programme (UNEP, 1998) points to the fact that “it is a characteristic of complex systems that they may show higher order interactions or forms of behaviour that are not evident from a knowledge of the parts. System models will be required to understand and identify those large scale system parameters for which indicators should be developed”. Similarly, the policy report European sustainable cities, prepared by the Directorate General XI of the European Commission, strongly recommends a systems approach to grasp the complexity of implementing sustainability goals at the local and urban level, as well as to achieve integration across the multiple policy areas concerned with sustainable development of urban areas (Expert Group on the Urban Environment, 1996).

System thinking, as developed in chapter 5, is a first step in this process of identifying the cause-effect relationships existing within the transport and city systems. It is based on a series of causal-loop diagrams, presented in appendices, which present the different elements necessary to take into account, and which are then put into relation with one another (in figure 7) in order to illustrate the complex dynamics of urban and transport systems together.

System-thinking may be helpful whenever the goal is to implement policies to break a vicious circle: causal-loops identify the cause that endlessly feeds the circle. In the case of the present thesis, system thinking supports the search for the unsustainable impacts of cars on the urban system and shows what issues a tramway policy should prioritise.

Building Causal-Loop Diagrams

System thinking is based on the analysis of systems, as indicated by its very name. Roberts et al (1996; p.5) define a system and give the basic purpose of systems approach: “a system may be defined as a collection of interacting elements that function together for some purpose”. For example, “the human heart, lungs, and bloodstream are a physiological system whose purpose is to provide oxygen for the body. Of course, the circulatory system, like any system, may at times fail to achieve its purpose. One motive for studying issues from a systems perspective is to gain an understanding of some of the reasons for poor system performance”.

Interacting elements are the main object of systems approach. Each element vary over time, steering the system to the completion of its purpose or on the contrary making it fail. The forces responsible for the variability of the system can be described causally in a closed system of feedback loops. Three steps are necessary before producing such causal-loop diagrams (Roberts et al, 1996).

Step 1 identifies the elements to be included in the system. That is when the basic principle “KISS” is to be applied throughout the process. KISS stands for Keep It
Simple Stupid and stresses the fact that all the possible elements encompassed in the system in reality are not to be automatically included in the causal-loop diagram; on the contrary, important elements have to be differentiated from unimportant ones in order to keep a system possible to understand. The point of systems approach is to organise and structure the knowledge gained about a system rather than reproducing the reality piece by piece.

Another principle when identifying the elements of the system is to adopt a cross-disciplinary approach. For example, an analysis of a city system might require considering aspects related to politics, geography, economics, sociology, technology, etc.

Step 2 integrates all the elements in a network of causal relationships. This implies to understand what a causal relation is. Two elements are bound by a causal relationship when one causes, affects or influences the variation of the other. For instance, money may affect happiness, and setting a fire causes smoke.

However, it may happen that one element does not produce the anticipated effect; for the sake of example, the fact that a country has a positive birth rate does not necessarily imply that its population is growing. A causal relationship implies the provision “other things being equal”, and when a causal relation fails it is because all other things are not held equal: other elements may exert counter-forces that compensate the causal link; in the previous example, a positive birth rate may be cancelled out by a superior death rate, causing the population to decline.

One crucial principle behind step 2 is the “close your loop principle”. It is explained in Roberts et al (1996, p.16) as: “within a causal loop, an initial cause ripples through the entire chain of causes and effects until the initial cause eventually becomes an indirect effect of itself. This process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself is called feedback”. The “close your loop principle” implies that only those elements that can generate a feedback loop are to be included in the system. The other elements are simply eluded; otherwise, causal chains could include an endless number of elements without any feed-back relation, but that would not help grasping the “big picture”, nor would it help to organise and structure the knowledge about a system. A striking example is given by Roberts et al and illustrated by figure 1:

“Consider an initial disturbance in the temperature of a room caused by a sudden cold spell. This drop in temperature might in turn cause various types of activities. For example, persons in the room might put on sweaters or move to a warmer spot in the house. Also, the thermostat might turn on the furnace. The activity of the furnace might in turn cause a number of things to happen. Furnace activity might cause the future purchase of more fuel oil. Furnace activity might also cause wear and tear on the burner unit, which might cause future repairs to be made. However, none of those causal chains feeds back to influence room temperature. The important effect of furnace activity, for our purposes of analysing the control of room temperature, is the heating up of radiators in the room, which eventually causes the room temperature to rise” (Roberts et al, 1996; p.16).
The elements that are not included in a closed loop are not considered in the systems approach. The reason to only consider closed-loop feedback effects relates to control issues. If a policy aims at breaking a vicious circle, it is necessary to identify first the cause that endlessly feeds the circle; that is what a closed feedback loop is made for.

Finally, step 3 defines the boundaries of the system. A system boundary is "the line of demarcation that determines what is included in the system and what is not. Identifying a system's boundary is the complex process of defining the size, scope, and character of the problem being studied" (Roberts et al, 1996; p.25). Steps 1 and 2 may help to identify a system's boundaries: only important elements are part of the system, and causal loops that do not generate a feed-back are not to be included in the system.

**Reading Causal-Loop Diagrams**

Here are the main principles to keep in mind when reading the causal-loop diagrams presented in chapter 5:

- a *positive link* between two elements (indicated by the sign: +) means that both elements evolve in the same direction.
Example 1: car \( \rightarrow \) air pollution

should be read as “the more car, the more air pollution” but also “the less car, the less air pollution”.

- a negative link between two elements (indicated by the sign: \(-\)) means that both elements evolve in an opposite direction.

Example 2: road congestion \( \rightarrow \) accessibility

should be read as “the more road congestion, the less accessibility” but also “the less road congestion, the more accessibility”.

- a re-enforcing loop is a loop that contains an even number of negative links or only positive links. It means that the element that starts the loop is in the end of the loop re-enforced in its initial direction.

Example 3:

\[
\begin{array}{c}
\text{Car traffic} \\
\downarrow \\
\text{Road congestion} \\
\downarrow \\
\text{Road supply}
\end{array}
\]

should be read as follows: “the more car traffic, the more road congestion; the more road congestion, the more road supply; the more road supply, the less road congestion; the less road congestion, the more car traffic”. It is a re-enforcing element because “car traffic”, that has been chosen as the starting element, is re-enforced when the loop is closed: “the more car traffic... the more car traffic”.

- a balancing loop is a loop that contains an odd number of negative links. It means that the element that starts the loop ends the loop in the opposite direction compared to the start.

Example 4:

\[
\begin{array}{c}
\text{Energy consumption} \\
\downarrow \\
\text{Technological innovation}
\end{array}
\]

should be read as “the more energy consumption, the more technological
innovation; the more technological innovation, the less energy consumption”. This is a balancing loop because “energy consumption” that was the starting element is compensated when the loop is closed: “the more energy consumption... the less energy consumption”.

To have more details about the principles and possible applications of the system thinking approach (including computer simulation that the present Thesis does not address), see Roberts et al (1996) from which most of this introduction to system thinking is taken. It also includes a foreword by Jay W. Forrester: pioneer in digital computers, he has been considered as the “father” of system dynamics since he developed studies of “limits to growth” in the 1950’s and concluded that “the structure of the system is the cause of its behaviour” (LUMES, 1998).