A SUSTAINABLE URBAN TRANSPORTATION SYSTEM: THE "SURFACE METRO" IN CURITIBA, BRAZIL

By

Jonas Rabinovitch
and
John Hoehn

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For more information, contact:

Jonas Rabinovitch
United Nations Development Programme (UNDP)
One United Nations Plaza, Room FF1044
New York, NY 10017 USA

Tel: (212) 906-5780
Fax: (212) 906-6973

or

John Hoehn
Department of Agricultural Economics
Michigan State University
East Lansing, MI 48824-1039 USA

Tel: (517) 353-6735
Fax: (517) 336-1800

For copies of this publication, contact:

Ellen A. Maurer
Communications Director
EPAT/MUCIA Research & Training
University of Wisconsin-Madison
1003 WARF Office Building
610 Walnut Street
Madison, WI 53705-2397 USA

Tel: (608) 263-4781
Fax: (608) 265-2993
Email: eamaurer@facstaff.wisc.edu

Edited by Ellen A. Maurer
Layout by Sharon Graham and Lesa Langan

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FOREWORD

This Working Paper is a product of the Environmental and Natural Resources Policy and Training (EPAT) Project funded by the United States Agency for International Development (USAID). EPAT is part of USAID's effort to provide environmental policy information to policymakers and practitioners in developing countries. The objective is to encourage the adoption of economic policies for promoting sustainable use of natural resources and enhancing environmental quality.

EPAT Working Papers are written for development professionals and policymakers in developing countries who are responsible for establishing and implementing policies on the sustainable use of natural resources and for civil servants, project officers, and researchers who are directly involved in the implementation of development activities.

This Working Paper deals with a successful, innovative approach to mass transportation policy in a large Brazilian city (pop. 1.6 million). By taking a systematic, yet pragmatic approach that recognized both financial and social constraints, Curitiba was able to develop a system that reduced travel times, increased convenience, contained automobile congestion, saved fuel costs, and reduced air pollution. Urban planners in developing countries may find elements of the approach outlined in this study to be applicable to their own situations as they try to solve urban transportation problems.

The contribution of USAID toward writing, printing, and distributing this document is estimated to be $13,500. The document is being distributed to more than 2,000 policymakers and professionals in developing countries. We will assess its effectiveness by soliciting the views of recipients. An evaluation sheet is enclosed with each mailing of EPAT publications for that purpose.

David Hales
Deputy Assistant Administrator
Center for the Environment
USAID/G/ENV
Washington, D.C. 20523

Twig Johnson
Director
Office of Environment &
Natural Resources
USAID/G/ENV/ENR
Washington, D.C. 20523

ABSTRACT

This analysis examines an innovative approach to transportation policy in Curitiba, Brazil. Curitiba is a city of 1.6 million residents that has grown fourfold in the last 30 years. Unlike many cities, quality of life and transportation has not been a casualty of growth. Curitiba's transportation system actively helps residents obtain the benefits of growth, including access to jobs, homes, recreation, and other elements of the urban community.

Curitiba's transportation planning process is practical. It recognizes financial and social constraints. Curitiba began with buses because it had buses. It began with a series of small improvements guided by a long-term plan. It first added a modest express route system with dedicated bus lanes. It sought out ways to improve and extend the system. The result is a surface system that provides the high quality service of well-known underground systems at a much lower capital cost. These low costs mean that mass transit is entirely financed by passenger fares.

The present system provides a range of benefits. The systematic approach to urban transportation has reduced travel times and increased convenience. Curitiba's buses now attract more passengers per operating kilometer than in any other Brazilian city. This intensive use occurs even though Curitiba also has one of the highest automobile ownership rates in Brazil. Rider surveys suggest that at least 20% of these new passengers previously used automobiles to commute. With less automobile congestion, the city has replaced several downtown streets with broad pedestrian malls and shopping areas. Reduced traffic appears to result in substantial fuel savings as well as reduced pollutant emissions. Calculations suggest that the reduction in automobile traffic saves 27 million liters of fuel/year.

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ACRONYMS

CIC
Cidade Industrial de Curitiba (Curitiba Industrial City)

CONAMA
Conselko Nacional do Meio Ambiente (National Council for the Environment)

DETRAN
Departamento de Transito - Parana (Traffic Department of Parana State)

EPAT
The Environment and Natural Resources Policy and Training Project (USA)

FCC
Fundacao Cultural de Curitiba (Cultural Foundation of Curitiba)

IAP
Instituto Ambiental do Parana (Environment Institute of Parana State)

IBGE
Instituto Brasileiro de Geografia Estatistica (Brazilian Institute of Geographical Statistics)

IPPUC
Instituto de Pesquisa e Planejamento Urbano de Curitiba (Curitiba Research and Urban Planning Institute)

ITN
Integrated Transportation Network in Curitiba

MTS
Mass Transit System in Curitiba

MUCIA
Midwest Universities Consortium for International Activities (USA)

PMC
Prefeitura Municipal de Curitiba (Curitiba City Hall)

SANEPAR
Companhia de Saneamento do Parana (Sanitation Company of Parana State)

SOFRETU
Societe Francaise des Reseaux des Transports Urbains (French

Association for Public Transport)

UNDP
Programa das Nacoes Unidas Para o Desenvolvimento (United Nations Development Programme)

URBS
Urbanizacao de Curitiba (Urbanization of Curitiba)

CONTENTS

CURITIBA'S EXPERIENCE AND GUIDING PRINCIPLES

The Curitiba metropolitan area has been one of the fastest growing urban areas in Brazil during the last 30 years. In 1965, the population was 400,000, and, by 1990, it surpassed 1.6 million. Unlike many cities in Brazil and around the world, quality of life and the quality of transportation has not been a casualty of rapid growth. Curitiba has used its transportation system to obtain the benefits of growth: access to jobs, to homes, and to recreation. It has helped control and guide the direction of growth as well as be a means for moving people.

The present transportation system works in marked contrast to its predecessors. As late as the 1960s, Curitiba's public transportation was unreliable and erratic. Areas of the city that offered low potential revenue went unserved. Travel routes were set by custom and in delayed reaction to new growth. Most bus routes began in the city center and fanned outward. The result was the tendency for a typically congested city center since most buses and their passengers passed through the center--even if their origins and destinations were on the outskirts. For individual bus companies, uncertain investment returns gave little incentive to improve quality. All buses had truck chassis that reduced both costs and comfort. Small bus doors and steep stairs reduced possibility of fare evasion but impeded passenger access and exit. The results were longer delays at stops and increased travel times.

Beginning in the late 1960s, Curitiba's city government began to take a different path. The city began to direct growth to enhance the quality of urban life. The government viewed land use, the road network and transportation planning as key tools for guiding and coordinating growth. Planners designed five arterial corridors to fan out from the central city. They used previously existing streets and made only minor physical modifications. Corridors were to act as high density pathways for both transportation and settlement growth. Within each corridor, buses had exclusive use of center lanes.

Within Curitiba's management approach, the transportation system and land use planning complement each other. Land use controls limit high density growth within the city center. These density limits push new growth into the corridors, known in Curitiba as structural sectors. These structural sectors are also the main transportation arteries served by high capacity express and direct buses. This complementary policy eases congestion in the city center. It has replaced crowded gridlocked streets with pedestrian malls in central shopping areas.

Transportation and density controls guide development throughout the city. Before developing the corridors, the city strategically acquired nearby land and built low income housing. This allows low income households low cost access to commerce, jobs, and recreation. With good intra-urban transportation, the city has encouraged new industries to locate at an industrial park at the city's edge. In addition, the city activity sought to recruit low polluting firms. The Curitiba Industrial City now generates one fifth of all jobs in the city. Finally, planners strategically set aside green space and parks throughout the city--smaller parks at the center and larger ones at the outskirts between the growth corridors. They also linked parks with the bus system as well as 150 km of special bicycle and pedestrian paths.

Curitiba's present transportation system is not the one-shot result of a single, ideal plan. The master plan of the 1960s set out broad goals for growth. Actual implementation took place in small steps, sometimes on a trial and error basis, and in concert with private and public interests. Ten private firms provide the

actual buses, drivers, maintenance, and capital. Through a city-owned corporation,[note 2] the city provides route planning, roads, terminals, scheduling, and enforcement of standards. It also collects all fares, provides public accounting, and distributes revenues on the basis of negotiated contracts. The overall system is a partnership of public and private interests. The city corporation acts as an agent for the community's interest in effective transportation.

Curitiba's successive improvements in transportation reduced travel times and increased convenience. They also created new challenges to address. For instance, direct "interdistrict" connections between corridors allowed passengers to travel directly between points without passing through the city center. These transfers created a problem for sharing revenues between companies and for transferring passengers without undue delays. A single fare and dedicated transfer points solved these problems. The single fare brought the challenge of how to share revenues between different firms--an issue that led to successive stages of administrative innovation. The transfer stations were once so unpleasant that they were known as "pig stalls." They have now evolved into attractive, covered stations with amenities such as flower and refreshment stands. Other innovations that increased convenience and timeliness include high-service boarding tubes and three-door buses. The government recycles older buses that are no longer serviceable for continuous operation into special use transportation and mobile classrooms.

We do not intend to depict Curitiba's approach as a turn-key model for reproduction elsewhere. Cities are too different in context and resources for such a wholesale adaptation. The Curitiba experience, however, does demonstrate that it is possible to significantly improve systems by increments and at relatively low cost: both in terms of the direct money costs as well as the costs of eventual mistakes and opportunities foregone. The transportation system continues to struggle with the challenges of growth and change. The difference in Curitiba is that there is a continual effort to upgrade equipment, to improve the system, and to offer greater convenience and quality to passengers. In this regard, Curitiba has had many successes. The objective of this working paper is to explore the processes and events that, over time, created the present system.

Guiding Principles

A set of guiding principles stand out from Curitiba's experience and achievements. As the transportation system evolved, these concepts served both as goals and as guides to the solution of the next set of problems.

* Effective urban transportation does not develop in isolation from a city's evolving settlement pattern. A transportation system integrates the individual activities that contribute to urban change. The integration network--a city's transportation

system--may encourage welcome development or provoke unwelcome decay.

* Transportation development and land use controls are powerful tools for guiding the quality and quantity of growth along desired lines. To use these tools effectively, a city must collectively know where it is growing to, how, and why.

* Quality transportation places a first priority on an effective system rather than on a particular mode of transportation. The key is to transport people, not to encourage the use of private vehicles. Buses, cars, bicycles, and trams are modes of transportation, not end goals in themselves. Convenience, travel time, flexibility, and cost are key features of a user-oriented transportation system. A user-oriented system combines modes, routes, transfer terminals, fuel, and management into a system centered on people's demands for transport.

* Land use controls and the transportation system should complement each other and promote the easy interchange of people between their different activities. The objective of land use control is not to establish strict, rational, and segregated zoning. It is to provide opportunities and direction for human settlement and services.

* An explicit hierarchy of city roads and streets support people's demands for access to services and for residential quality of life. High volume, arterial routes allow timely and convenient transportation between residential, commercial, and recreational activities. Low density collector streets provide a foundation for quieter residential neighborhoods.

* A sustainable city is one that wastes the least and conserves the maximum. This is the principle of recycling. For example, old buses make good mobile schools. Planners looked for locally-developed innovative technologies and made it work within the Curitiba system. Most importantly, it means making the existing system of people and resources work better--rather than throwing it away and trying to replace it with a single, capital-intensive project such as a subway or a rail-based system. Curitiba began with buses because it had buses; it did not have a subway. The city developed a surface, bus-based system it could afford. At each step in its evolution, officials viewed problem solving as a continuing process--not as a one-shot effort leading to a final fix. They now apply the same practical principle of recycling and continuous improvement throughout the city--from dealing with solid wastes to improving social services such as day care and vocational training.

* Smaller, incremental steps toward an explicit long-term goal can bring about large changes. Officials view these incremental steps as experiments that solve an existing problem but may create new challenges in need of new solutions. For instance, unpaid transfers between bus routes reduce travel times and fare collection costs, but they also raise issues regarding transfer structures and revenue sharing between firms.

* This practical, incremental approach is markedly different than the conventional transportation planning model. With the conventional approach, long delays separate the data collection, analytical, and implementation phases. By the time a project is implemented, the analysis and its solution may be obsolete. With Curitiba's incremental approach, analysis, improvement, and implementation are continuous, interactive processes. Planners anticipate errors and use them as grist for further progress.

* Creativity, information, and recycling are often substitutes for financial resources, but sustainable decisions are financially sound. Officials base them on good technological choices. They use public institutions for project evaluation, benefit-cost analysis, and adaptive planning. They monitor operating costs, revenues, and contracts by strict financial controls that are open to public scrutiny and auditing.

* A sustainable transportation system is a partnership between government, the private sector, and citizens. The role of the city is to formulate and express the community interest in effective transportation. It does this through planning processes, by defining routes and service standards, and by monitoring and enforcement. The role of private firms is to provide transportation services. They do this by hiring people, by investing in capital, and by competing with other firms and with themselves to reduce costs and increase profits while maintaining enforced standards for convenience, timeliness, and safety. The role of citizens is to pay the fares to cover the full cost of the service. Through their use, disuse, praise, and complaints, citizens are the final judges of a system's worth.

HISTORY AND DEMOGRAPHICS

Figure 1 shows the location of Curitiba in southeastern Brazil. Curitiba was founded in 1693 and grew due to its strategic location between the Atuba and Belem rivers. In 1842, Curitiba was officially declared the capital of the state of Parana. From mid-1800s through the 1940s, the city enjoyed moderate economic prosperity, riding a series of economic booms in wood, cattle, coffee, and "yerba mate," a local kind of tea herb.

Curitiba became a key service center for new economic activities after World War II. Rapid economic and demographic growth in the last few decades transformed the city into an important industrial and commercial nucleus. In addition, it has become a processing center for agricultural goods exported via the Paranagua seaport, 70 km away.

Table 1 shows that the population in Curitiba grew at a relatively slow pace between 1940 and 1950. The city's population growth rate picked up sharply during the 1960s and

remained high through to the 1980s. In contrast, population growth in the surrounding state of Parana peaked during the 1960s at 7% and later declined. During the 1980s, Parana's population growth was much smaller than that of the capital, remaining at 1%. This contrast between the city and the state implies that in the state as a whole Curitiba's growth was offset by even larger population losses in rural areas and smaller cities within the state. Population growth in Parana remained at little more than half that of Curitiba through the 1990s (Rabinovitch and Leitman 1993).

Table 1. Demographic Trends in Curitiba and the State of Parana

Year	Curitiba	Curitiba Growth Rate in Prior Decade (%/year)	Parana State	Parana Growth Rate in Prior Decade (%/year)
1940	140,656		1,236,276	
1950	180,575	2.5	2,115,547	5.3
1960	361,309	7.0	4,277,763	7.0
1970	609,026	5.2	6,929,868	4.8
1980	1,024,975	5.2	7,629,392	1.0
1990	1,608,151	4.5	9,818,373	2.5

Source: Brazilian Institute of Geographical Statistics 1940, 1950, 1960, 1970, 1980, 1990.

The key economic activities in Curitiba are services, manufacturing, and commerce. After 1973, the creation of the Curitiba Industrial City accelerated an on-going shift from agricultural to industrial service activities. The Industrial City occupies an area of approximately 40 km squared on the western edge of the city. Planners created it to limit industrial activity within the city limits as well as to attract more industries and employment. As of 1992, the Industrial City contained 409 industries and businesses. These firms accounted for one-fifth of the city's total employment.

The cost of living in Curitiba is similar to that of other cities in southern Brazil. The climate is cooler than in northern Brazil. The colder climate may raise the cost of housing and other basic goods. Table 2 shows that 4.9% of Curitiba's households earn no more than the minimum monthly wage of US$75. This low income percentage is slightly larger than that of Sao Paulo but is less than one third that of the entire country. Curitiba's percentages for middle income households are similar to Sao Paulo. The percentage of upper middle income households in Curitiba is slightly greater than in Brazil as a whole. Curitiba's percentage for the highest income category is similar to Brazil as a whole but is less than that of Sao Paulo.

Table 2. Household Earnings Distribution in Curitiba, Sao Paulo, and Brazil

Monthly Earnings (US$)	Curitiba (% of households)	Sao Paulo (% of households)	Brazil (% of households)
75	4.9	4.4	18.0
75-225	28.1	29.9	38.5
225-375	25.7	17.6	18.4
375-750	25.6	27.2	14.1
750-1500	11.4	13.6	6.8
1500+	4.3	7.0	4.0

Source: Curitiba Research and Urban Planning Institute 1990a,

Brazilian Institute of Geographical Statistics 1990.

CURITIBA'S STRATEGIC APPROACH TO URBAN PLANNING

A French planner, Alfred Agache, developed the first plan to direct urban growth in Curitiba in 1943. The government did not implement the plan. Its main legacy was to introduce the concept of urban planning to Curitiba's citizens and government. This awareness edged closer to action in 1964 when the city administration commissioned a Preliminary Urban Plan. To encourage an influx of new ideas, the city held a competition for the best plan among local and national professionals. The result was the Curitiba Master Plan. In 1965, the city created the Curitiba Research and Urban Planning Institute to implement the plan and to continue the planning process.

>From 1965 to 1970, the city administration gave the master plan a low priority. It did, however, provide the Institute with resources to detail procedures for implementing the plan. In 1971, a new administration began to put the plan into practice (Curitiba Research and Urban Planning Institute 1965).

Political will and political skill were important factors in initiating the practical steps to implement the plan. Officials had to adapt each of the plan's elements and sometimes set them aside as the two-dimensional planning concepts met a three-dimensional reality. This interaction between concept and reality led to a practical, repetitive planning process.

Today, Curitiba's practical planning process is firmly established. When ideas are proposed, they are tested conceptually and then in application. These tests generate feedback that leads to further improvements and applications. The ongoing process allows Curitiba to fashion solutions that fit real problems. Rather than being stymied by feedback, it refreshes and redirects the process along a progressive path. After two decades of successes, the Urban Planning Institute is now well established as the local incubator for an urban planning tradition that emphasizes interplay between planning, analysis, participatory planning and implementation.

Planning Principles

The implementation of the Curitiba Master Plan addressed transportation, land use controls, and a hierarchical structure of the road network. Planners viewed them as complementary tools for guiding city growth. The plan combines these tools to direct growth out of the central city and into arterial growth corridors. Arterial and feeder roadways as well as land use controls on settlement densities defined these corridors.

The purpose of the five structural growth corridors was to redirect growth out of the central city and into the corridors. This displacement of growth more evenly distributes settlement densities in the city center and in the growth corridors. This avoids a sharp peak in central city densities and the concomitant traffic congestion and noise. The more even density distribution reduces congestion enough to facilitate uncongested travel while maintaining passenger numbers at high enough levels to allow public transportation to be financially self-sustaining.

Convenient transportation and more balanced densities also:

* encourage economic development by reducing the costs of mobility, trade, and exchange within the city;

* reduce the indirect costs of other infrastructure improvements such as water, sewage, electricity, and communication; and

* assist in preserving historic buildings and areas within the city center.

Consequences

The gradual development of Curitiba's integrated transportation system is the most visible result of the city's planning processes. While this paper focuses on transportation, it is important to remember that planners in Curitiba do not isolate transportation as an entity apart from other aspects of urban

life. They do not view streets only as paved surfaces but as elements in a larger network and hierarchy of roads. A building is not an isolated box but a traffic/public transport-generating element in a larger pattern of settlement.

Curitiba analyzes travel as a movement and exchange between activities. Traditional city planning approaches tend to be static and oriented toward physical features. Traditional transportation planning tends to be excessively data-demanding, equation-based, and technocratic. Curitiba's planning focuses more on the relationship between space and movement. It emphasizes the dynamic features of urban activities. It considers how much should be invested where.

The city uses transportation to heighten the socio-economic payoff from its planning activities. One example is the city's role in low income housing. Rather than build isolated, large scale, and uniform housing projects, the city took advantage of effective transportation. Curitiba acquired land near some of the planned structural corridors before developing them. As the transportation routes were put into place, the city subsidized low income housing close to these transportation routes and close to the Curitiba Industrial City. It also located other small scale, low income, housing developments throughout the city. These are near the transportation corridors and thus are 'near' in time and cost to employment and other activities. These small scale developments blend into the surrounding residential areas. They integrate rather than isolate low income households into the economy and culture of the larger city. As a result of this strategy, the city has built housing for 17,000 families.

The road hierarchy system is another element of Curitiba's planning system. Each road has a function in relation to its location and importance. Curitiba uses four basic categories to define roads by location and function. There are arterial structural roads that are at the core of five growth corridors. Priority linkages run between and connect the city center to the city's outskirts. Collector streets are common urban streets typically lined with commercial activity and allowing all forms of traffic. Connector streets link the structural roads to the industrial city.

Land use controls target two basic parameters: the land use type and the density of development. The four basic land use categories are residential, commercial, industrial, and services.

Allowable densities vary in relation to available transportation.

Along most structural routes, buildings can have a total floor area of up to six times the plot size. On lower capacity roads that are well served by public transportation, the city permits floor space up to four times plot size. The permitted ratio of floor space to plot size decreases with the distance a land site is from public transportation.

The land use density controls encourage a shift of development activity from the central city to and around the structural axes.

This locates high density residential and commercial in the same areas and matches density to the availability of public transport. This eases traffic and human congestion in the central city. Planners converted wide central avenues in the central city into open air pedestrian malls and walkways. These malls and walkways reinforce the city center as a pleasant locale that preserves historic elements and where pedestrians have priority.

EVOLUTION OF THE TRANSPORTATION SYSTEM

Public transportation in Curitiba began with the introduction of horse drawn vehicles in 1887. Shareholders operated and organized these vehicles under a contract with the city. In 1906, the system had 18 km of routes, a 6000 square miles central office with two depots and garage for repairs, 20 passenger vehicles, 15 vehicles for cargo, and 150 horses. In 1912, electrically powered street cars replaced the horse drawn vehicles. The city gradually improved and used the street cars until the early 1950s (Roteiro da Cidade/Documento-Do Bonde de Mula ao Onibus Expresso 1975).

The first bus company emerged in 1928 as a public subsidiary of the state electrical company. In 1930, the first private bus companies began to operate in competition with the public bus company and with street cars. In 1938, 11 million people rode the lower fare street cars in contrast to 2.6 million people who rode buses. As the city grew, the speed and flexibility of buses proved more advantageous than the lower cost street cars. During the 1940s, bus routes gradually replaced the street car routes. Street cars went out of service entirely in 1952. In 1954, the city administration set up concession contracts with 10 bus companies operating in eight pre-established areas of the city.

Deficiencies in the Mid-Century Transportation System

As the city evolved, substantial conflict occurred between the different transportation modes and suppliers. There were conflicts between owners of horse drawn vehicles and street cars that later continued between bus and street car owners. There was competition for passengers between the public and private bus fleet. There were frequent salary disputes involving drivers, unions, bus companies, and city governments. Labor disputes culminated in the great strike of 1960 when a lock-out organized by the private companies left Curitiba without public transport for more than a week.

The ebb and flow of these conflicts meant that public

transportation was often unreliable and inconvenient. The following features characterized transportation in Curitiba at mid-century:

* The city did not have a transportation system. Rather, it had a collection of mismatched concessions granted to private companies.

* There were few guidelines to encourage transportation firms to provide effective service to the city as a whole. The city simply assigned each company an exclusive area of operation within the municipality. Transportation evolved in reaction to the location of commercial, industrial, and residential activities rather than in concert with them.

* Transportation companies operated without competition within their concessions. They ignored districts with medium and low demographic densities and, when route schedules did exist, did not enforce them.

* Bus routes merely linked origin and destination pairs within the city. The city center was typically one element in these pairs. The confluence of routes in the central city increased central traffic congestion. Transfer between routes required payment of a second fare. The necessity of transfers increased queuing and travel times.

Integration of Development Planning and Transportation Policy

The first attempts to integrate transportation, land use, and urban development began in 1965 under Mayor Ivo Arzua Pereira and the technical coordination of the Curitiba Research and Urban Planning Institute. The administration of Mayor Omar Sabbag developed a preliminary mass transit plan in 1969. The 1971 mass transit terminals plan, developed under the first administration of Mayor Jaime Lerner, further refined this initiative. Mayor Lerner also renewed the commitment to implement the 1965 master plan. This paper does not concentrate on the plans themselves but on their results.

In 1971, Mayor Lerner took the first steps to implement the city's settlement and transportation plans. As one of the first steps, Curitiba developed the first pedestrian network in the country, giving priority to pedestrians in its central area. At the time, most Brazilian cities favored automobiles over other forms of transportation and were busy building viaducts and motorways within their city centers. In contrast, Curitiba refurbished historical buildings in the city center. These refurbished buildings played new roles in support of arts, culture, and local history. The city improved older parks and set aside green areas and floodplains as undeveloped areas and parks in the city's outlying districts. A new industrial park opened on the city's edge to attract non-hazardous industries and manufacturing activities.

The first significant changes in the transportation system began in 1974 with implementation of the road hierarchy and land use control system. Implementation began with the construction of the first two out of five arterial structural roads. These were to form the core of the growth corridors.

Figure 2 shows that the structural corridors are triple road systems with the central road having two restricted lanes dedicated to express buses. Two local roads flank the central road. Running parallel to the central roadways but offset one block on each side are two one-way, high capacity roads for traffic flowing in and out of the central city.

Figure 2 also shows relative settlement densities within the growth corridor by building height. The figure shows that allowable densities decline as one moves away from the center of a corridor. These declining densities place the greatest number of people within easy reach of transportation. This placement also prevents the high volume routes from disrupting the sense of place within low density, residential neighborhoods.[note 3]

The first two structural roadways ran north and south within the city. In 1974, express buses on these routes carried about 54,000 passengers/day. By 1982, the city completed five structural roads and complemented them with interdistrict and feeder lines. The integrated system carried about 400,000 passengers/day. The system continued improvements in fare collection and distribution, vehicles, and route extensions. By 1982, it carried about 774,000 passengers/day. Including the remaining conventional routes and the integrated system, the transit system within Curitiba today now transports more than one million individual paying passengers a day, without considering transfers. This is about 75% of the city's commuters.

There are presently five structural roads in Curitiba. The dedicated bus lanes at the center of each structural corridor accommodate express bus routes. "Padron" buses with a capacity of 110 passengers first served these routes but later "articulated" buses with a capacity of 170 passengers replaced them. The articulated buses are so long that turning on city streets could be impractical--they would jut out into opposing lanes of traffic as they attempted to turn. This disadvantage in length is overcome by constructing the buses around an articulation point--a pivot point at mid-frame that allows them to bend around corners. This pivoting allows articulated buses to use standard traffic lanes. Many cities worldwide operate public transport services with articulated buses. In late 1991, Curitiba supplemented articulated buses with "bi-articulated" buses that have a capacity of 270 passengers. These vehicles were developed in Curitiba and assembled by Volvo at the Curitiba Industrial City. These latter buses are even longer and contain two pivot points built into their frames. At the present moment, there is no information on any other city worldwide regularly operating "bi-articulated buses" for mass transit purposes.

Hurdles and Lessons

The Curitiba transportation system overcame a number of significant hurdles as it developed. In operation, there were problems of route design, fare collection, increases in passenger loads, and personnel problems to resolve. In administration, there were difficulties in revenue sharing, in developing a system of monitoring and enforcement of standards, and in information processing and scheduling. Finally, the city made significant efforts to develop improved transportation vehicles.

Stages in Route Design

Curitiba's transit system has three complementary levels of service. Feeder lines pass through neighborhoods and make the system easily accessible in lower density areas. Feeder lines share roads with other vehicles and connect with the express system along the structural roads. The express system uses dedicated bus lanes and transports large numbers of passengers in high density corridors. Interdistrict routes connect the axes of the express lines without passing through the city center.

An effective integrated system is well coordinated. It has and meets an accurate schedule. Transfers from feeder to express require time to transfer passengers from one line to another. Without careful scheduling, the time savings of an express route are lost in delays queuing for transfers, waiting for a connecting bus, and boarding. Thus, as Curitiba's route system evolved, it required advances in fare payment, refinements in the transfer system, personnel training, revenue sharing between firms, and scheduling.

Physical and Fare Integration

An integrated system of feeder and express routes might require passengers to pay a fare with every transfer. However, incremental fares result in delays and inconvenience. Even small delays add up to significant amounts of time when aggregated across hundreds of thousands of passengers.

To avoid passenger delays due to fare payment at each transfer, Curitiba's system initially allowed unpaid transfers between lines and routes. Transfers, however, require a means of identifying transfer passengers from those who have not yet paid. When the single fare was first implemented, passengers received a paper transfer token. The token allowed them to transfer without having to pay another fare. Six to seven months after starting this paper token approach, the city discovered major forgery of the paper tokens and had to abandon the procedure.

To replace the paper tokens, the city set separate fares for feeder and express buses. This two-fare system did not last long for operational and social reasons. First, it resulted in delays

as people had to pay and be checked twice. In addition, it favored those who lived nearer to the structural corridors and express routes. In particular, it raised costs for lower income people who used the feeder buses to come in from the periphery of the city. The city considered it unfair and inappropriate to impose a higher cost on lower income people.

A year and a half after implementing the two-fare system, the city dropped the second fare for the feeder buses. Passengers rode the feeder buses for free and paid only when they entered the express system. This free feeder option had unforeseen consequences. A few months after beginning the free feeder option, no driver wanted to work on the feeder buses. The vehicles became home for the homeless. They also served as mobile gathering places for unemployed people. There was no reported violence but there were many protests from citizens regarding the conditions on the feeder buses. The city learned that it cannot offer any free public service and dropped the free feeder system.

Officials than returned the system to a single fare approach. Rather than returning to paper tokens, the next solution was a physical one to separate transferring passengers from those who have not yet paid their fares. The city built fenced runways at transfer points between stops for the express and feeder buses. These runways worked for a limited period of time but, as the passenger numbers grew, the areas became overcrowded. The runways also lacked aesthetic appeal. They soon became known as "pig stalls." Convenience declined and complaints increased.

In 1980, the system began to significantly improve conditions at the transfer points by constructing enclosed, transfer terminals. Though the word "terminal" may imply a final destination, in Curitiba terminal refers to any transfer station. People refer to middle terminals ("terminal do meio") and to end terminals ("terminal de ponta"). End terminals are larger in order to cope with inter-municipal transfers.

The post-1980 terminals follow the same basic design, working like subway stations on the surface. Flowers, trees, shops, glass walls, and a pleasing architecture make them as lively and transparent as possible. Passengers are free to walk inside the terminals, shop, chat, make phone calls, buy newspapers, and change from one bus route to another without having to pay another fare. People who live in the neighborhood pay their fare when they enter the terminal through turnstiles. These transfer stations allow people to switch from one route to another with as little delay and inconvenience as possible.

Increasing Demand

A balance between supply and demand is crucial to the profitable operation of any transportation system. Soon after the introduction of the express buses in 1974, the city realized there was something wrong. The popularity of the express buses resulted in overcrowding and delays. The city planners at the

time did not anticipate that, in parallel with the evident demand for a certain route, there was also a "repressed potential demand" (Curitiba Research and Urban Planning Institute 1991/1992). It mainly consisted of new passengers attracted to the system, many of whom used private cars before the express buses became available. Overcrowding caused delays in boarding at stops and terminals. To compensate for the delays, drivers would exceed the maximum speed allowed and occasionally cause accidents. As a stopgap measure, the city strictly controlled speed limits and required buses to operate with their lights on in order to improve their visibility to other drivers and pedestrians. Officials gradually solved the problem of increasing demand with improvements in bus design, high service boarding tubes, and other measures explained below.

Method of Paying Fares

>From 1974 to 1980, passengers paid their bus fares in cash as they entered the system. To reduce the time needed for fare payment on buses, the city introduced automatic ticketing in 1980. Passengers now pay either with money or a metal token. The token is available for sale in shops, newsstands, and bus terminals. In 1990, there were 37 million tokens in circulation. The result is a small improvement that results in significant time savings across the system as a whole. Buses circulate more rapidly to provide more frequent service with the same number of vehicles.

Personnel

The development of Curitiba's integrated system was the first time in Brazil that a local government had set operational standards and timetables for a metropolitan bus system. The city accomplished resulting improvements without specialized transportation planners or transport engineers to outline the final system. Planners, architects, and engineers from Curitiba Research and Planning Institute (IPPUC) and Urbanizacao de Curitiba (URBS) knew the city well and developed their own solutions. The experience gained in designing and implementing these solutions gradually grew into a systematic and practical body of knowledge. This knowledge places special emphasis on personnel training and flexibility. It recognizes that personnel and technology need to work together if the overall system is to function smoothly.

Bus drivers are a key part of the system and received special training from the outset of the integrated system. When the system opened, it used buses designed from the bottom up as buses. This new design placed the engine in the rear of the vehicle to reduce the weight and noise. Until this time, all Brazilian cities had used buses built on truck chassis. These chassis placed the engine at the front of the vehicle and drivers changed gears by listening to the engine. Hence, a first task was to train drivers to shift gears without the assistance of noise from the engine. Drivers also had to learn how to drive on

dedicated bus lanes and to learn procedures for operating in crowded terminals. When the city introduced high service boarding tubes, express drivers had to learn to approach and park buses in proper relationship to the boarding entrances.

Revenue Payment System for Private Operators

During the last 40 years, transportation costs have been paid through several different revenue collection systems. From the 1950s to the 1970s, the city granted bus companies concessions to eight non-overlapping areas. Within these areas they charged a fare previously negotiated with the city administration. Their revenue corresponded to the number of paid passengers that they transported within those areas.

The interdistrict routes begun in 1979 cut across the territorial concessions to connect the five express routes. These interdistrict routes weakened the space monopolies of the concessions. Bus operating firms put up substantial resistance to the interdistrict routes, but the city remained committed to them. These lines connected routes operated by different companies. Since a single fare covered the entire integrated system, passengers would commonly pay to enter a route operated by one company and then transfer to another line run by another company. To maintain the solvency of the cooperating companies, some form of revenue sharing was necessary. Without revenue sharing, a company would incur an unpaid cost in proportion to the number of transfers accepted from other companies.

To solve the revenue sharing problem, the city developed a revenue compensation mechanism based on operating and capital costs. Surveys helped estimate operating costs and the number of passengers transported by each company. This gave the city detailed data about the revenue and costs of each company. Over several years, the city tried various formulas for distributing revenues across firms.

In 1987, the city settled on a revenue sharing formula based on the number of kilometers traveled by vehicle type for a given company. Each company has a given number of route kilometers and a given timetable. It obtains maximum revenues by meeting its scheduled route. The formula makes no adjustment in revenue for the number of passengers transported by a company. Each company competes only with the schedule, subject to specified quality standards.

All fares go into a common bank account that is audited and open to public scrutiny. The city also monitors the performance of individuals companies. The monitoring system is funded by the collected revenues. There are routine checks on the number of kilometers covered by each company.

Monitoring System and Enforcement

The relationship between the city and entrepreneurs has traversed

a long, occasionally tortuous, path. The transition from small independent lines to a large integrated system run in partnership with private companies required practicable mechanisms to monitor the performance of individual companies and ensure the operation of the overall system. The monitoring and enforcement system includes the following elements:

* Buses use tachographs that record speed and travel time, including maximum speeds and stops.

* Buses have turnstiles, also located in boarding tubes, that record the number of paying passengers. People over 65, school children in uniform, police officers, fire fighters, and mail carriers in uniform ride free.

* Garage surveys systematically determine the number of buses in circulation.

* Random surveys also determine the total number of passengers for certain trips on specific routes.

* Supervisors trained and employed by Urbanizacao de Curitiba work in all bus terminals.

* Occasional terminal surveys determine the number of people using the transfer terminals.

Information System

Curitiba began to computerize routing and schedules soon after it implemented express routes in 1974. Before this a time-consuming manual process controlled routing and scheduling. After two years of work, Urbanizacao de Curitiba developed special custom software for bus timetables. This program, later named NETBUS, is still in use, and the city continues to refine it. It has also been successfully transferred from Curitiba to other Brazilian capitals, such as Vitoria (state of Espirito Santo) and Aracaju (state of Alagoas). The Curitiba Industrial City also houses the Curitiba Software Pole, which commercializes NETBUS and various other software products.

Vehicle Design

When Curitiba began to develop its integrated system, buses in Brazil had truck chassis. Assembly companies would install a standard bus body over a truck chassis and call it a bus. These buses had small doors, steep and narrow stairways, vertical exhaust pipes, and were bumpy, noisy, and uncomfortable.

The Brazilian subsidiary at Cummins, in northeast Brazil manufactured the first Brazilian bus chassis. When Cummins stopped manufacturing vehicles, Curitiba had to buy buses from Mercedes Benz, which refused to manufacture the bus chassis. This forced the city to operate buses with truck chassis until Volvo installed a bus assembly plant in the Curitiba Industrial

City.

A second problem was the bus body design. Afraid of fare evasion, bus companies wanted doors as small as possible. They also insisted on buses with only two doors. People would board the bus through the rear door, pay at the turnstile located toward the back of the bus, and exit through the front door at their desired stop. At peak times, those riding for a short distance found it difficult to reach the exit door on time. This internal bus layout was not convenient for high capacity vehicles.

To improve the two-door bus, Curitiba worked with bus manufacturers in Brazil to assemble a three-door bus: two doors for exiting and a front door for boarding. This vehicle permitted a better internal distribution of passengers during peak times. At first, some manufacturers argued that a bus with three doors was not structurally sound. Today, buses have advanced beyond three doors. All major assembly groups now operating in Brazil manufacture urban buses with turbo engines, lower floor levels, wider doors, and a convenient design for mass transit. As a ready buyer of improved vehicles, Curitiba has helped develop the market and the standards for Brazilian mass transit buses.

Curitiba's most significant innovation is the system of direct route buses that operate in parallel with the dedicated bus lanes of the structural corridors. These direct routes make use of high service boarding tubes and high capacity buses. The direct route system combines vehicles, routes, and high service boarding tubes to reduce travel times and increase convenience, comfort, and passenger capacity. The main features of the system are:

* The vehicle uses a conventional bus modified so that the doors open directly onto a patented boarding tube station. The floor from bus to boarding tube is level. Without stairs to climb or having to step onto uneven pavement, passengers embark and disembark quickly.

* At each direct route stop, passengers enter the route system via a stationary aluminum and glass boarding tube that lies parallel to the roadway. Embarking passengers enter one end and disembarking passengers exit the other after a bus has stopped. Embarking passengers pass a turnstile and pay their fare to a conductor in charge of the boarding tube. The entry point contains a full color map of direct route system painted on the exterior glass. Passengers can verify that they are at the correct embarking point before they pay a fare and enter the tube.

* Passengers wait for the next bus on an elevated platform at the same floor level as the bus. Passengers wait in comfort and security and board swiftly when the bus arrives.

* When a direct route bus aligns itself with the boarding tube, the bus driver opens the doors of bus and tube using a remote control system. Disembarking passengers exit one set of doors

and embarking passengers enter immediately afterwards, as if in a subway system. Entry and exit is rapid. With the passengers secure, the doors close and the driver pulls away into the dedicated bus lane. Swift boarding times reduce route times and increase the peak capacity of the system.

* The direct system makes route information easily available to potential and actual passengers. In addition to the color-coded map painted on the boarding tube near the entry door, both buses and boarding tubes conveniently display stylized route maps. Moreover, the name of each bus stop is printed on both the color coded and stylized maps. The exterior of the boarding tubes display bus stop names in bold letters so that bus passengers can easily identify their location on a route.

* The tubes' level access easily accommodates disabled passengers, strollers, and passengers with bags and parcels. In addition, a small lift beside the entrance of the tube, makes access for these passengers almost immediate.

Bi-articulated 270-passenger buses that also use the boarding tubes have further extended the capacity of the system. Curitiba has 33 bi-articulated buses operated primarily in the high demand, lower income district on the southeast periphery of the city.

The next innovation may be to incorporate an electric tramway into the system. To increase capacity, the city has prepared a plan for an electric tramway that will circulate in the central lanes of the structural corridors. The road network and land use legislation would remain basically the same. The mode would change from bus to tramway with a capacity for 400 passengers, with only minor modification of existing roadways.

THE PRESENT SYSTEM

The System and Its Routes

The Curitiba Integrated Transportation Network (ITN) is the core system composed of transfer terminals, express routes, direct routes using boarding tubes, feeder routes, and interdistrict routes. The main ITN system is supplemented by center city routes, neighborhood routes, night routes, special education routes for disabled people, and the pro-park routes. Conventional routes complement the ITN and are largely the remnant of the territorial concessions that pre-dated the ITN. The system as a whole--the ITN and its complements--is referred to as the Curitiba Mass Transit System (MTS).

Figure 3 shows the design of the ITN as a trunk and branch

system. The trunks of the system are the high volume direct and express routes running along the structural corridors. At terminals along these corridors, the high volume routes connect with the lower volume feeder routes. The feeder routes fan out into lower density neighborhoods to give residents convenient access to the overall system. Interdistrict routes also connect to the terminals. The interdistrict routes run from corridor to corridor--trunk to trunk. The interdistrict routes allow passengers to travel between outlying points within the city without traveling through the city center.

This integrated trunk and branch system makes the ITN function very much like a metropolitan subway. Passengers pay one fare to get into the system. Scheduled connections within the system provide consistent service and convenience. The integrated, trunk and branch system offers several important advantages over conventional, non-integrated lines. First, compared to underground systems, the capital costs of the surface bus system are low. Routes use ordinary city streets; there are no large scale excavations and no tunnels to maintain. The city maintains bus speeds by setting aside dedicated bus lanes along some downtown city streets and along the structural corridors.

Second, the integrated trunk and branch system offers convenience and timeliness to passengers. Transferred passengers pay their fares once, rather than paying for each leg of a journey. This means that passengers do not have to line up to pay a fare at a transfer point. Without lines, passengers can complete a multiple-stage journey in less time. Shorter transport times increase the capacity of the overall system and reduce peak hour congestion.

A third advantage is that the city can adapt the bus fleet profile to fit demand volumes along different types of routes. It buys large, high volume buses for the high volume routes and smaller buses for the lower volume, feeder routes. This tailors the system's capacity to meet the demands of specific routes. The system operates with minimum excess capacity. This reduces the number of largely empty buses in circulation to waste energy, labor, and capital.

The reduction in excess capacity leads to a fourth advantage--the system uses fewer resources to transport a given number of people. This means that there are fewer empty buses in circulation. The reduction in empty buses reduces capital costs and wastes less fuel and labor per passenger carried. Fewer buses mean less traffic congestion because there is a better relationship between bus routes and passenger destinations. Passengers and buses do not have to pass through the city center in order to travel between two outlying points. With passengers and buses traveling fewer miles, there are fewer unnecessary buses on the road--thus reducing the potential for congestion. Reduced congestion means that buses operate at lower resource costs, but the efficiency of private vehicles is also improved. Fewer cars sit idling at congested intersections. Average speed increases. This in turn saves fuel and time for both the bus system and operators of private vehicles.

In addition to lower social costs, lower resource costs allow the Network to offer a high level of service at reasonable passenger fares. Reasonable fares are a certain savings for middle income passengers. They are a substantial savings for lower income households that tend to live on the periphery in Brazilian cities. The standard fare in the Curitiba Public Transport System is US$.30. This single fare gives all households access to the entire city for purchases, employment, or other economic opportunities.

Several specialized routes, described below, supplement the ITN system of express, direct, interdistrict, and feeder routes.

Express Routes

The dedicated express routes circulate within the structural cores forming the core structure of the Curitiba Mass Transit System. The express buses circulate independently from automobile traffic. This frees the core system from traffic jams at peak times and provides greater comfort, safety, and timeliness. The 13 express lines use higher capacity buses. Express routes going through the higher density district of Boqueirao use the higher capacity bi-articulated buses with boarding tubes.

Direct Routes

Direct routes run in parallel with the structural corridors and in other high demand routes, providing fast, high capacity service. All direct routes use the high service boarding tubes, located at all direct route stops and in the transfer terminals. The transfer terminals link the direct routes to other levels of service. There are currently 10 direct routes using padron buses and boarding tubes equipped with a special lift for wheelchairs, strollers, elderly people, and other people with special needs.

Interdistrict Routes

Interdistrict route buses make orbital trips between the structural express and direct routes. They link various districts without ever going to the city center. There are 6 interdistrict routes that allow transfers to the express, direct, and feeder routes. The routes use green padron buses.

Feeder Routes

Feeder routes circulate within residential zones, linking them to the various terminals. There are 111 feeder routes using orange simple and padron buses that allow transfers to express, interdistrict, and direct routes.

Conventional Routes

Conventional routes are the legacy of the bus routes that pre-dated the ITN. Conventional routes run from the city center to four terminals in districts located away from the structural routes. These districts are Bairro Alto, Barreirinha, Fazendinha, Santa Felicidade. The four terminals are also linked by feeder, interdistrict, and direct routes. There are 6 conventional routes serviced by yellow simple and padron buses. In addition, there are 86 "traditional" conventional routes that are not integrated with other routes. These traditional lines, serviced by yellow simple and padron buses, go from specific districts to the city center and occasionally cross it.

City Center Routes

The city center routes use white 40-passenger mini-buses circulating only around the city center. The reduced fare and clockwise and counter-clockwise routes help shoppers and people who need short trips within Curitiba's central area. The mini-bus interiors are designed for short trips: instead of seats, the vehicles have side cushions, so that passengers just lean against them while in transit.

Neighborhood Routes

The neighborhood routes serve specific neighborhoods where there is sufficient intra-neighborhood traffic. The Portao neighborhood route has a circular configuration and the Xaxim neighborhood route has a radial configuration. The vehicles are mini-buses, painted white, with a capacity of 40 passengers.

Night Routes

Night routes operate from 1 to 5 a.m., with a one hour interval between each bus. There are 17 routes, designed to be not more than 1 km apart. There are express, feeder, and conventional night routes.

Special Education Routes

Special education routes serve some 2,200 physically or mentally disabled students. There are 27 routes operated by specially-converted simple buses, equipped with seat belts and lifts for wheelchairs. The buses pick up students in their neighborhoods and take them to a special terminal where they transfer to other buses that take them to special schools. At the end of the day, buses follow the same procedure from the schools to the students' homes. Trained helpers, paid for by the students' parents, assist the students. The route, subsidized by the ITN, includes a special terminal with added features to give comfort and safety to users.

Pro-Park Routes

Pro-park routes operate only on Sundays and holidays, connecting the city center to the main parks. The three routes use special buses which resemble old street cars with wooden seats, imitating park benches. The design of the bodies of these buses allows maximum transparency, with broad, arch-shaped windows.

Job Routes

Job routes are not part of the transportation system but perform an educational function. Curitiba uses a bus for public transportation for 10 years. After that time, it recycles the buses into mobile training offices for carpentry, word processing, handcrafts, metal works, electricity studies, and other courses. The buses, with locally-recruited instructors, park in different low-income neighborhoods on scheduled days of the week. This jobs training program, in operation since 1991, has graduated more than 17,000 students.

Soup Routes

Although soup routes are not part of the public transport system, they use recycled buses as restaurants. They serve free soup and bread during the evenings to low-income population.

Management and Operation

Urbanizacao de Curitiba (URBS), a publically administrated, privately funded (parastatal) company founded in 1963, monitors the routine operation of the ITN and the MTS. Responsibility for both the extension of the Curitiba master plan and for planning extensions of the ITN and MTS lies with the Curitiba Research and Urban Planning Institute (IPPUC). These agencies work closely together to ensure that long-term planning is carefully linked to the system's present condition. The IPPUC shapes transportation and land use initiatives to complement each other.

URBS acts as the property manager for the publicly-owned transportation infrastructure and as liaison with private companies. URBS administers the city's bus terminals, monitors the performance of the ITN and MTS, collects and distributes revenues, and negotiates with concessionaires to provide terminal services such as newsstands and flower stands. Its most important role is to negotiate contracts with private buses companies and ensure that these companies provide service that meets the system's standards.

URBS currently operates under parameters established by a municipal decree in 1987. The decree cancelled the territorial concessions let to private bus companies. In place of

concessions, the decree established a system of permissions. Under Brazilian law, permissions are simpler to execute and to terminate when its conditions are not met. There is no fixed contract period for a permission, and the city may cancel them for due cause at any time. As presently written, the permissions reimburse bus companies subject to the number of scheduled kilometers that they actually travel. Municipal Law #7556 of 1990 and Municipal Decree #210 of 1991 (Prefeitura Municipal de Curitaba 1990) establish URBS as the sole agent allowed to sign transportation contracts for the permissions and grants URBS the sole responsibility to plan and manage the ITN and MTS. Specific responsibilities for URBS include those listed below:

Planning

In collaboration with the Curitiba Research and Urban Planning Institute (IPPUC), URBS undertakes the following planning responsibilities:

* Analyze organizational, technological and space options for transportation in Curitiba. Pursue this analysis in collaboration with IPPUC and following the general urban planning guidelines for the city.

* Propose new routes, services, and terminals to meet the system's demands for growth.

* Monitor the level and quality of existing services.

* Study and propose the development of information systems for operational purposes.

* Manage the level and quality of information for users of the system.

Administration

URBS also has administrative/financial responsibilities summarized as follows:

* Organize, implement, and supervise the mass transit system.

* Manage the finances of the ITN including the collection and distribution of revenues.

* Set, monitor, and enforce performance standards for private bus companies. Determine and enforce penalties for violations of standards.

* Establish technical agreements with universities and other institutions for the improvement of the system.

* Establish collaborative agreements for mass transit purposes with other municipalities within Curitiba Metropolitan Region.

Operation

The operational duties of URBS are well known and visible. The accumulation of such responsibilities under a single institution contribute to the effective management of Curitiba's Public Transport System. The duties include:

* Establish timetables and operational parameters.

* Establish standards for comfort, safety, and regularity in bus services.

* Establish locations of bus stops, terminals, and routes.

* Implement and change bus routes and scheduling to meet shifting passenger demands.

* Carry out data collection for statistical control of the bus system.

* Establish technical parameters and specifications for buses. Register and inspect the buses in operation.

* Monitor the level of service and adherence to timetables. Penalize violations with fines or, in the worst cases, revoke a company's permission to operate.

* Establish procedures for setting fares. Monitoring adherence to the agreed upon fare schedules. Update the data needed for calculating the fare schedules.

Existing Permissions to Operate

There are currently 10 bus companies with permission to operate specified routes in Curitiba: Marechal, Gloria, Luz, Cristo Rei, Carmo, Redentor, Agua Verde, Curitiba, Merces, and Cidade Sorriso. A simple two page document sets out the basic legal framework and standard form for all permissions.

Certain companies tend to concentrate their routes in certain areas of the city. There are some shared routes, however. These include central area routes, interdistrict routes, direct routes, and certain express and feeder routes that serve more than one area of the city.

Classification of companies and consequent assignment of routes depends on the size of bus fleets. Carmo with 209 buses, Cidade Sorriso with 205 buses, and Gloria with 203 buses are large companies. Mediumsize companies are Cristo Rei with 138 buses, Luz with 126 buses, Agua Verde with 119 buses, and Marechal with 117 buses. Curitiba with 96 buses and Merces with 61 buses are small companies.

Fare Calculation

Fares in Curitiba are set by a calculation schedule based on the costs experienced by URBS and by the private firms. The schedule includes factors related to operating costs such as those that depend on kilometers traveled, maintenance costs, personnel costs, administrative costs, and capital costs. Costs dependent on kilometers traveled include those for fuel, lubricants, and depreciation. Maintenance costs include items for parts, accessories, and maintenance personnel. Personnel costs include uniform costs and wages for drivers, conductors, supervisors, and porters. Administrative costs include administrative wages, supplies, equipment depreciation, and depreciation of buildings and physical assets. Capital costs include depreciation and a fixed return on investment. Each of these cost categories is detailed below.

Cost Apportioned to Kilometers Traveled

Fuel

Companies are divided into two groups that represent operational and urban physical characteristics that affect fuel consumption. For example, companies that operate in hilly areas, or areas with heavier traffic near the Curitiba Central Area, would have higher fuel costs. After the companies are divided, ongoing surveys determine the average fuel consumption for each type of bus in liters per kilometer. Table 3 shows fuel consumption estimates.

Table 3. Fuel Consumption Indexes (liters/km)

Vehicle	Simple Bus	"Padron" Bus	Articulated Bus	BiArticulated Bus	Microbus
Group 1	0.3502	0.4667	0.6449	0.7464	0.2265
Group 2	0.3799	0.4797	0.6482	0.7464	0.1859

Source: Urbanizacao de Curitiba 1992a.

Lubricants

Survey data, dating from 1987 and 1988, help estimate lubricant consumption indexes. Table 4 lists the lubricant consumption estimates in liters of lubricant per kilometer.

Table 4. Lubricants Consumption Indexes (liters/km)

Lubricant	Index
Carter Oil	0.0077891
Gear Box Oil	0.0004211
Brakes, Oil	0.0002034
Grease	0.0002034

Source: Urbanizacao de Curitiba 1992a.

Tire Depreciation

A survey conducted from January 1988 to December 1988 established depreciation parameters for tires. The number of kilometers traveled during this period established technical averages. Table 5 lists these depreciation estimates in terms of the proportion of useful life exhausted in one kilometer of travel.

Table 5. Depreciation Indexes

Component	Depreciation Index
Diagonal Tires	0.0000194
Radial Tires	0.0000351
Protecting Caps	0.0000961
Inside Tire (air compartment)	0.0001034
New Rubber Layer	0.0000787

Source: Urbanizacao de Curitiba 1983.

Maintenance Costs

Personnel

URBS estimated the cost of maintenance personnel for each company according to the company's fleet characteristics. URBS issues a monthly table to update the amounts allocated for each company's maintenance personnel.

Parts and Accessories

URBS developed a preventive maintenance plan for all transit vehicles used in Curitiba. Survey data established maintenance cost as a percentage of a vehicle's value. Buses receive routine maintenance at 5, 10, 25, 50, 75, 150, 300, and 600 thousand kilometers.

Personnel Costs

Drivers, Conductors, and Porters

URBS sets a 36 hour average work week for transit employees. This includes a time of 30 minutes for drivers and conductors to check the condition of their vehicle and turn in revenue. Personnel work in shifts of 6.5 hours per day. These wage and working

conditions surpass those found in most other cities in Brazil.

Administrative Costs

These include personnel, expenses, equipment depreciation, depreciation of buildings, supplies, and remuneration equipment and building costs. After long term surveys, URBS set average values that are proportional to the bus fleet of each company. Total administrative costs average 13% of operational costs.

Capital Costs

Depreciation

URBS reimburses depreciation based on linear schedules of 8, 10, or 12 years depending upon the anticipated level of use. Depreciation is a proportion of the initial purchase price. At the end of its schedule, the value of a bus is 10% of its initial purchase price, adjusted for inflation. The city receives 90% of a vehicle's resale value after the scheduled number of years in service. The city often recycles depreciated vehicles for the pro-park, job, and soup routes.

Payment

The city pays companies for a return on investment capital at 1% per month, updated according to inflation indexes used by the federal government.

Ridership

Evolution of the ITN and MTS

Table 6 shows how MTS and ITN ridership has evolved during the last 20 years. In 1974, the first year of the ITN, the MTS as a whole carried an average of 677,000 passengers per day. Conventional lines carried 623,000, and the ITN lines carried 54,000. At this time, the ITN had only two of its arterial corridors in place and a total of 19.9 km of express routes. The express routes connected to neighborhoods with 45 km of feeder routes.

Table 6. Evolution of Curitiba's Integrated Transit Network and Passenger Load

Year	Passengers Carried Per Day (thousands)			Extent of ITN by Route Type (kilometers)		
	Total	Conventional	ITN	Express	Feeder	Interdistrict
1974	677	623	54	19.9	45	0
1978	728	497	231	31.0	119	0
1979	730	481	249	31.6	119	44

1980	748	467	281	49.3	188	82
1982	730	372	358	54.0	242	122
1989	1,056	486	570	54.0	270	185
1992	1,028	398	630	80.0	266	166

Source: Urbanizacao de Curitiba 1994.

MTS ridership grew by 53% from 677,000 to more than 1 million passengers per day from 1974 to 1992. This is an average annual growth rate of 2.36%, about half of Curitiba's 1970 to 1990 population growth rate of 4.9% per year. As overall MTS ridership grew during this period, the number of conventional lines contracted. This contraction and the growth of the ITN led to a reduction in ridership on conventional routes of 37% from 1974 to 1992. During the same period, the ITN grew in both extent and in the number of passengers carried. From 1974 to 1992, ITN ridership grew an average rate of 14% per year from 54,000 to 641,000. In 18 years, market share of the ITN grew from 8% in 1974 to 64% in 1992.

The last three columns in table 6 give some insight into the relative contribution to ridership of the express, feeder, and interdistrict lines. Between 1974 and 1980, the number of kilometers in express lines grew only slightly less quickly than the feeder lines. In 1974, express lines were approximately 30% of the system, dropping to 26% in 1980. The interdistrict routes grew from zero kilometers in 1974 to 82 kilometers in 1980. Ridership grew at an average annual rate of 27% with this even growth in the extent of the express, feeder, and interdistrict routes.

>From 1980 to 1989, growth in the express system slowed to a mere 9%less than 1% per year. ITN ridership, however, grew by 86% during this same period or by about 7% per year. The source of this growth in ridership appears to be growth in the feeder lines, up by 44%, and interdistrict lines, up by 125%. This apparently shows the importance of convenient access to the core express lines. For people who live in the higher density growth corridors, access to the express lines is no problem. The feeder and interdistrict lines are essential for easy access to people who live in outlying neighborhoods. Extension of these lines apparently reduced the time costs of access for people in outlying neighborhoods. This reduction in travel time cost contributed to almost a doubling of ITN ridership between 1980 and 1989.

The data may also indicate the success of the direct lines served by boarding tubes, introduced in 1989. The kilometers covered by the direct lines are included in the express column. From 1989 to 1992, express and direct lines increased in extent by 48%. The extent of the feeder and interdistrict routes contracted during this same period slightly diminished. Ridership on the ITN, however, increased by 23%apparently due only to the increase in express and direct routes.

The ITN ridership and route statistics suggest that high volume

express and direct routes and the lower volume feeder and interdistrict routes are strong complements. The high volume routes offer fast, convenient service to those who live in the high density neighborhoods near the high volume lines. High volume routes do not realize their full potential without feeder and interdistrict lines. Lower volume lines link the high volume routes into low density neighborhoods and with each other. The lower volume routes provide convenient, low time cost access for people who live further from the express and direct routes. The integrated system balances the convenience of local access with the high volume speed of arterial routes.

Present Performance of the ITN and MTS

Table 7 shows the number and performance of different MTS routes for May, 1993. The first five rows of table 7 describe ITN routes. The next three rows describe the conventional and special routes. The last row describes the overall MTS characteristics.

Table 7. Ridership Characteristics for May, 1993

Route Type	Number of Routes by Type	Kilometers Traveled per Weekday (thousands)	Paid Fares/Bus Average per Weekday	Passengers Carried/Bus Average per Weekday
Express	13	58	1,283	2,039
Direct	10	41	532	1,563
Interdistrict	6	34	789	1,446
Feeder	111	74	615	1,138
Total ITN	140	207	839	1,533
Conventional	93	90	879	879
Special Ed.	27	2.8	0	481
Neighborhood & City Center	3	1.8	481	481
Total MTS	263	301.6	829	1,309

Source: Urbanizacao de Curitiba 1993.

In the ITN, there are 13 express routes, 10 direct routes, 6 interdistrict routes, and 111 feeder routes. On a typical weekday, buses on the express routes travel 58,000 kilometers. Buses on the feeder routes travel 74,000 kilometers. This is 4,460 kilometers per express route and only 670 kilometers per feeder routes. The large distances covered on the express routes reflect both the number and speed of buses on these routes. ITN routes account for more than half the number of routes within the MTS. Conventional routes compose about 35% of the total route system.

URBS estimates the number of fares paid to enter a particular route type within the system. Table 7 lists these paid fares on a per bus basis in the fourth column. The number of paid fares is lowest on the direct routes. In contrast, the number of passengers carried per bus is second highest on the direct routes.

The discrepancy between fares paid to enter the direct routes versus the number of passengers carried is due to the passengers who transfer between lines. People may enter the ITN through an express line, direct route, feeder line, or interdistrict line. At their first entry point, they pay fares which are credited to that line. Many passengers take the line that they board to a terminal. At the terminal, they may transfer to another type of route. For instance, a passenger may initially board a feeder line at a neighborhood stop and then transfer to a direct line for a quick transfer to the central city. These transfers do not pay an additional fare, but they do count as a passenger carried.

These transfers are the hallmark of the integrated system and they account for the discrepancy between fares credited to a particular type of line and the actual number of passengers carried by that route type [note 4].

The average number of paid fares per bus is slightly higher for the conventional routes than for the average of the ITN routes. However, the number of passengers carried per ITN bus is almost 74% greater. Thus, the ITN collects a slightly smaller number of fares per bus but apparently uses its capacity to a fuller extent than the conventional routes.

There are 27 special education routes. Each bus carries about 481 passengers per day. These routes are entirely funded through revenues of the ITN.

There are three neighborhood and city center routes. No transfers are necessary from these routes to the ITN. The number of fares collected and the number of passengers carried both equal 481 per day.

Performance Comparison with Other Brazilian Cities

The relative effectiveness of transportation in different cities is difficult to quantitatively compare. Cities differ in their geography and in settlement densities. Some cities are mountainous and others are on flat plains. These geographic features mean that transit performance varies even when the planning, financial resources, and technology are the same. These differences warn us against any comparison since unmeasured differences in context make it difficult to assess how different cities are responding to their transportation needs. Despite these concerns, it is useful to compare Curitiba with other cities if only to form rough hypotheses as to how its transportation system really differs from those found in other Brazilian cities.

Table 8 compares the features of Curitiba's transit system with those of six other Brazilian cities. Curitiba is one of the moderate sized cities listed in the table. Sao Paulo stands out as the largest city with a population of 16 million. Belo Horizonte and Porto Alegre are the next largest cities with 3.8 and 2.7 million people, respectively, within the boundaries of their metropolitan transit systems. Curitiba, Fortaleza, and Brasilia all have populations of 1.6 million. Santos is the smallest city listed with a population of 600,000.

Urban residents are likely to use a system more often when it offers convenience, timeliness, and good value for a given fare. In terms of available statistics, the desire to use mass transit is best represented by annual per capita use the annual number of trips taken in a city divided by a city's population. In this respect, Belo Horizonte and Curitiba appear to offer their residents a high quality and value. Belo Horizonte and Curitiba have the highest per capita use of their transit systems. In Belo Horizonte, residents take 208 trips per capita per year. In Curitiba, residents take 202 trips per capita per year. These per capita statistics are about 10% higher than the next highest city, Fortaleza, and almost 30% higher than Sao Paulo. They are almost 60% higher than the per capita use statistics for Brasilia and Porto Alegre.

Table 8. Mass Transit Performance in Brazilian Cities [note a]

City	Population (millions)	Passenger Journeys per Capita	Fleet Buses/1,000 Inhabitants	Route km/1,000 per Capita
Curitiba	1.6	202	0.97	0.76
Belo Horizonte	3.8	208	0.98	2.47
Brasilia	1.6	129	1.15	na
Fortaleza	1.6	184	0.61	0.96
Porto Alegre	2.7	120	0.58	na
Sao Paulo	16.0	158	0.66	4.09
Santos	0.6	140	0.47	1.76

City	Kilometers Traveled per Capita	Kilometers Traveled/km Routed (1,000 km)	Passengers/km Traveled
Curitiba	56	74	3.59
Belo Horizonte	75	30	2.77
Brasilia	53	na	2.42
Fortaleza	52	53	3.58
Porto Alegre	na	na	na

Sao Paulo	na	na	na
Santos	na	na	na

[Note a] Three Brazilian cities are listed in Bushell (1993) but not in this table: Recife extensively uses minibuses and its data is approximate. Rio de Janeiro has a unique system that includes railways and mountainous terrain. Salvador is not included because of its approximate data.

[Note b] Population is the city or metropolitan area population depending upon whether the described system serves the city or the metropolitan area.

[Note c] Using Bushell (1993) data, the estimate of Curitiba's passenger journeys/capita is about 15% less than the estimate obtained using official URBS data. In this table, however, we use the Bushell data in order to maintain consistency in data definitions across all Brazilian cities. In addition, Bushell does not present data for the same year for all cities. The years by city are: Curitiba, 1991; Belo Horizonte, 1990; Brasilia, 1988; Fortaleza, 1986; Porto Alegre, year not reported; Sao Paulo, 1991; and Santos, 1991.

Source: Bushell 1993

Horizonte and Curitiba attain high per capita use with almost identical numbers of buses per capita. Each has approximately one bus in its system for every thousand residents. These are not the highest bus per capita figures, but a high number of buses per capita does appear correlated with high per capita use. Four of the other five cities with lower per capita use also have lower bus per capita figures 0.66 per thousand inhabitants in Sao Paulo and only 0.47 per 1000 inhabitants in Santos. Brasilia is the only exception with a bus per capita statistic of 1.15 and per capita use of only 129.

Belo Horizonte and Curitiba are quite different in other features of their transportation systems. Belo Horizonte's route system is much larger than Curitiba's on a per capita basis. Belo Horizonte has 2.47 kilometers of routes for every 1000 inhabitants. Curitiba has only 0.76 kilometers of routes. Indeed, Curitiba's is the smallest route system on a per capita basis of any of five cities for which data is available. Curitiba's small system and high use may reflect another advantage of an integrated, carefully planned system: it provides maximum access and convenience for the smallest number of route kilometers. It avoids route duplication and spaces routes to meet real transportation demands.

Fewer route kilometers mean that a given number of vehicles may provide more frequent service even if the number of kilometers traveled by buses declines. The sixth column of table 8 shows that the number of kilometers traveled by vehicles is 25% smaller in Curitiba than in Belo Horizonte. In Curitiba, buses travel

about 56 km/year/capita while they travel about 75 km/year/capita in Belo Horizonte. Curitiba's statistic of 56 km/capita is about equal to that of Fortaleza and Brasilia. These figures may mean the Belo Horizonte's buses simply have to travel further because of a larger route system or that, perhaps in addition, they provide more frequent service.

The next column shows that Curitiba's integrated system provides more than double the frequency of service relative to Belo Horizonte's system. Curitiba's vehicles travel approximately 74,000 km/route km while Belo Horizonte's vehicles travel approximately 30,000 km/route km. This suggests that Curitiba's integrated system allows it to provide more frequent, better value service while travelling fewer kilometers per capita.

Fewer kilometers per capita mean, in turn, fewer financial and physical resources spent on transportation. At the same time, Curitiba's system high per capita use suggests a high degree of service and value. Taken together, the two imply Curitiba provides a high level of service that makes the most use out of limited resources. This is a desirable feature from both a financial and environmental perspective. Use of fewer resources means that a system is more likely to at least break even, a desirable feature for long term sustainability. It also means that the system is producing less waste such as used up fuels, materials, and machines. With less material passing through the system, it is likely to produce less air, water, and solid waste pollution.

The financial sustainability aspect is further borne out by the last column in table 8. This column lists the number of passengers carried per kilometer (PKM) traveled by vehicles within a system. Curitiba's statistic is the highest of the those for the four systems for which data is available. Curitiba's statistic of 3.59 paying passengers/km traveled is about 30% larger than Belo Horizonte's figure of 2.77 paying passengers/km traveled. The passenger/km ratio is closely linked to financial sustainability since the number of paying passengers reflects revenues and kilometers traveled reflects costs. For the same costs, a higher passenger/km ratio implies a greater financial return and a greater chance of financially maintaining a given level of service.

Despite its high performance, the data in table 8 may understate the service and financial quality of Curitiba's system. The downward bias comes from the way Curitiba counts passenger journeys and short trips compared to how other Brazilian cities count them. Curitiba's ITN is an integrated system of routes. A passenger enters the Curitiba system using one route and may switch to another route at a transfer terminal without paying an additional fare. This means that passenger journeys within the Curitiba system typically involve multiple trip segments. Other cities in Brazil do not have Curitiba's system of integrated routes and unpaid transfers. In networks without transfers, other cities count each trip segment as a separate journey, paid for separately with each involving a different bus route.

URBS's passenger survey data indicates that the number of trip segments, including transfers, is about 1.4 times greater than the number of passenger journeys. That is, the average Curitiba passenger makes 1.4 transfers during a journey within the system.

This implies that the number of passenger trips per capita is about 1.4 times greater than the number of passenger journeys per capita in Curitiba. Similarly, the number of passenger trips per kilometer traveled by ITN vehicles is 1.4 times greater than Curitiba's passenger/km statistic listed in table 8. This adjustment for trips versus journeys clearly underscores Curitiba's strong performance compared to other transit systems in Brazil.

Financial Performance

Both the ITN and MTS operate without any direct financial subsidy from the city. The municipal government provides the physical and administrative infrastructure such as paved roads, lighting, bus stops, terminals, planning, and system management. It also monitors the bus companies, through inspections and surveys, to see that they are providing the service agreed to by contract, including the number of kilometers that they are paid to traverse.

In buses and terminals, the city collects fares daily and deposits them in a municipal transport fund. Ten days later, the city pays companies according to the number of kilometers served as specified in the route permissions. Law requires the city to use the fund's resources only to pay the costs of the companies participating in the ITN.

As stated above, the monthly rate of return to the private bus companies is 1% of the capital invested in the bus fleet. This return is approximately 11% of the revenues collected in fares. A secure 12% annual rate of return gives companies a strong incentive to invest in the renovation of the bus fleet. This incentive means that Curitiba has the newest bus fleet in Brazil, with an average of 3.5 years of use. Another element of the companies' profits is a 3% return on administrative costs for equipment and infrastructure, representing 0.39% of the fare. The total return to bus companies is therefore approximately 11.39% of the revenues from fares.

Brazil has experienced high rates of inflation. In February, 1994, the monthly inflation rate was approximately 40%. Under such circumstances, the city constantly has to increase fares to cope with rising costs caused by inflation. The city does not index these inflation adjustments directly to inflation rates, otherwise they would have to readjust fares practically every day. Rather, they negotiate the fare readjustments, which are subject to technical data about inflation rates, political skill in handling negotiations, and citizens' opinions. The bus companies naturally pressure to have fares increased as often as

possible whereas riders demand constant or lower fares. The city has to contend with the interplay of these political forces and arrive at negotiated bus fare increases that are affordable to the public and profitable for the private sector.

Interviews with bus company owners reveal general owner satisfaction, but there are conflicts. An owner and former president of the organization that represents bus companies says:

"I do not need money. I need credit. The bank is as important a partner as the city. If I am investing US$140,000 in a padron bus or US$450,000 in a biarticulated bus, the loan officer and his bank have to trust what I am doing. The only transportation system that the banks I know invest in is Curitiba's. This is because there are enforced standards and because the permissions to operate buses can be revoked anytime. This procedure eliminates the bad entrepreneur. The bank knows that public transportation in Curitiba is taken seriously" (Rabinovitch 1993).

The same entrepreneur had the following complaints:

"The problem here [in Curitiba] is that we have a first world public transport system with a third world fare. The cost of new buses went up 30% and the depreciation that the city pays went up only 15%. I also think the city should diminish the number of nonpaying passengers by reducing the number of allowed transfers."

It would be important as well to have the names of the retailers from which the city obtains updated prices for the fare calculation table. The city should be more open about the price surveys since the prices I find are always higher than those surveyed" (Rabinovitch 1993).

These latter comments illustrate the conflicting pressures experienced by the city and its agent URBS. The city does not release the names of retailers to avoid pressure from bus entrepreneurs or formation of a cartel. Reducing transfers may increase revenues to the municipal transportation fund and allow larger revenue distributions to the bus companies. However, effective fares would also increase and citizens would receive less convenient service for a higher price. The overall revenue of the system may increase but with negative and undesirable social consequences.

ENVIRONMENTAL AND QUALITY OF LIFE IMPACTS

The ITN has brought direct and indirect improvements to the environment and quality of life in Curitiba. These impacts are an important reason for the city's active involvement in transportation planning and administration. Transportation has

proven to be a very useful tool to deal with urban development issues, particularly in a fast growing urban setting. However, improved transportation is only one element contributing to some of these impacts. Indeed, it is best to view urban transportation as one key element in a set of tools that include land use controls, road network planning, housing, and commercial development. The following sections consider some results from these tools (United Nations Development Programme 1992).

Pedestrian Areas

Curitiba developed its first central pedestrian mall in 1972, before the beginning of ITN. Growth of the ITN reduced automobile congestion in the city center and complemented the development of a network of downtown pedestrian malls. Approximately 49 downtown blocks now exclusively use pedestrian streets which link squares and bus terminals in the central area.

These streets have special lighting, kiosks, newsstands, landscaping, and other amenities. The malls also connect with conventional parks and green areas in the downtown area. One North American planner, Richard Kahn, Urban Assembly, New York, remarked that Curitiba is one of the few large cities he knows where, "despite its scale, one can see and hear native birds in the downtown area."

The city has also encouraged the development and maintenance of residential housing in the downtown area. With parking limited, access to public transportation by downtown residents is fundamental to maintain the residential use in balance with services and commerce. Downtown residences, in turn, support a mix of residential services in the downtown area such as restaurants, bakeries, pharmacies, supermarkets. These give a 24 hour a day vitality to the downtown area. This vitality contrasts sharply with the after hours silence found in other cities' downtown areas that serve primarily as commercial employment centers.

Traffic and Circulation

The ITN and MTS partially absorb the demand for automobile traffic in the city. One recent survey suggests that 25% of commuters who once used their cars for commuting have now switched to using the direct route buses. In addition, 75% of Curitiba's commuters use either the ITN or MTS. The ridership figures demonstrate a high level of per capita use. Curitiba has one of the highest bus system use rates in Brazil.

Land Use Controls and Housing Densities

Land use controls in Curitiba have encouraged a pattern of settlement that both complements and is complemented by the metropolitan transportation system. Transportation is more effective if the most densely populated areas are near high volume transportation routes. This reduces the need for low volume, higher average cost feeder routes. Effective transportation complements urban settlement. Effective transportation also provides urban residents with access to the services, jobs, and relationships that are the fundamental reason for urban settlements to exist.

Curitiba's land use controls encourage the most dense populations along the high volume structural corridors. While this settlement pattern might evolve even in the absence of controls, it has three distinguishing features. First, it integrates with the transportation system as the city plans and develops land use and transportation jointly. This reduces uncertainty for urban developers and discourages false speculation on undeveloped lands. Second, the city develops land use and transportation plans in advance of actual settlement. This avoids the costly problem of a transportation system always attempting to catch up with a population just beyond its reach. Third, the controls place both a floor and a ceiling on densities within the structural corridors. The density ceiling in the urban center pushes growth out of the city center and into the structural corridors. This reduces congestion at the city center. Reduced congestion and low densities, in turn, facilitate pedestrian malls and landscaping that improve access and quality of life.

The land use controls encourage a declining pattern of density as one moves away from the structural corridors. Controls allow the highest residential densities within the structural corridors and the residential area surrounding them. Planners call these areas the Structural Sector and Residential Zone 4. Medium density surrounds the high density areas and includes Residential Zone 3.

The lowest densities occur farthest from the structural corridors and include Residential Zones 2 and 1.

Table 9 gives area and population statistics for the five primary residential zones in Curitiba. The statistics are for 1985, 14 years after the introduction of Curitiba's Master Plan. The first column lists the five residential zones as well as a category that includes all five zones. The five zones together encompassed about 41% of Curitiba's land area of 43,422 hectares and about 75% of its population of 1.276 million. The average population density of the five zones was 54.1 persons per hectare, almost double Curitiba's average density of 29.4 persons per hectare. The overall population growth rate in the five zones was 25.7% between 1980 and 1985, just 1.2% larger than the Curitiba's average rate of 24.5%.

Table 9. Five Primary Residential Zones: Area, Density, and

Population Growth Rates, 1985

Primary Residential Zones	Area (% of city total)	Population (% of city total)	Density (persons /ha)	Population Growth (% 1980-85)
All Five Zones	40.8	74.8	54.1	25.7
Structural Corridor	1.6	5.7	105.1	98
Zone 4	4.5	13.8	89.9	29.4
Zone 3	10.2	19.7	56.8	14.5
Zone 2	21.1	32.8	46.0	25.3
Zone 1	3.4	2.8	24.2	9.5

Note: In 1985, Curitiba's total population was 1.276 million. Its area was 43,422 hectares. Its population density was 29.4 persons/hectare. And its population growth rate for 198085 was 24.5%.

Source: Curitiba Research and Planning Institute 1985.

The Structural Corridor and Zone 4 residential areas encompass less than 7% of the land area but provide residences for almost 20% of the population. Thus, consistent with the land use controls, population densities in these zone are about three times larger than Curitiba's average rate. Population densities in Zones 3 and 4 are about double the average density and that in Zone 1 is slightly less than Curitiba's average density.

The growth rates listed in the last column of table 9 indicate that Curitiba is having success in using land use controls and transportation to direct residential growth to the higher density zones. Between 1980 and 1985, the resident population in the Structural Corridor increased by a striking 98%. Zone 4 population grew by 29.5%well above Curitiba's average population growth rate of 24.5%. Growth in Zone 3 was 14.5% and in Zone 2 it was 25.3%. The growth rate in Zone 1 was well below Curitiba's average rate at only 9.5% (Curitiba Research and Planning Institute 1992).

Parks and Green Areas

In 1970, Curitiba had 0.5 square meters of green area per capita.

In 1992, the rate was 50 square meters per capita. This increase is a result of a conscious policy of protecting floodplains, public acquisition of private land, and a concerted effort to develop parks and public gardens (Curitiba Research and Urban

Planning Institute 1983).

The transportation system's function has been to take a very explicit and proactive role in guiding the spatial direction of development. Transportation development is the concrete action to back up and reinforce land use planning. This combination prevented green and low density areas from being purchased and held in speculation for future development. The direction of development was clear and public and discouraged further land speculation. By reducing speculation, the city reduced the consequent political pressures to develop transportation solely to make land investments prosper.

Development of bike paths that serve both pedestrians and bicycles encourage use of the parks and green areas. These cycleways have signs, a visible route, maps, and lighting. Where possible, the city developed cycleways on the banks surrounding small streams and surface water drains and away from motor vehicle roads. The combined length of these cycleways is nearly 150 kilometers. They not only connect to the parks but also to residential and commercial areas including the industrial city and the city center. People increasingly view bicycles as a potentially important transportation option (Curitiba Research and Urban Planning Institute 1980).

Employment

The MTS provides an average of 1 trip per inhabitant on a typical workday. The system places any inhabitant within easy reach of any location in the city for a single low fare. This low cost and extensive network gives even low income households access to employment and service opportunities regardless of their location in the city. In addition, the system itself employs 5,000 people. It also stimulates additional employment through the purchase of equipment and services.

Air Quality

The state agency, Instituto Ambiental do Parana (IAP), is responsible for environmental monitoring and control for Curitiba as well as within the entire state of Parana. The IAP monitors three kinds of air pollutants: sulphur dioxide, particulates, and ammonia as required by the National Council for the Environment (CONAMA) under Federal Law #03/1990 (National Council for the Environment 1990).

The last report of the IAP (Environment Institute of Parana 1993) showed that air quality in Curitiba is acceptable and the annual average is within all limits established by the law. In this last report (June 1993) the IAP also concluded that the high levels of particulates (dust) came from renovation of the Santa

Casa building. The monitoring station is located on the Santa Casa grounds and is also opposite to the largest bus terminal in Curitiba on Rui Barbosa square. The Rui Barbosa terminal serves as the central city terminal for all express buses and for various conventional routes.

The Santa Casa station is the IAP's only air quality monitoring site in Curitiba. Table 10 lists average monthly measurements for the last seven years. The smoke and dust measurements show a good deal of variability and probably relate to local conditions such as the renovation of the Santa Casa building.

Table 10. Air Quality in Curitiba (Micrograms/cubic meter)

		Dust	Smoke	Sulphur Dioxide	Ammonia
June	1987	120	161	77	68
	1988	139	68	62	6
	1989	75	--	81	3
	1990	111	133	89	9
	1991	--	73	57	4
	1992	105	57	50	12
	1993	146	56	39	7

Source: Environment Institute of Parana 1993.

Sulfur dioxide shows a good deal of variability as well but appears to be declining in recent years. The reason for this decline is not clear. One possibility is an improvement in the quality of diesel fuel or improved maintenance of bus and truck engines.

The measurements for ammonia show less variability overall but they include a sharp upward spike in 1992 followed by a higher than average reading in 1993. Reasons for these readings need investigation, but they may relate to the shift to greater use of gasoline rather than alcohol fuels for automobile transportation.

Overall, there is little evidence to suggest a trend due to impacts of the MTS. The major observation is that air quality in central Curitiba meets and certainly does not exceed national standards, perhaps due in part to the MTS and in spite of the comparatively high level of automobile ownership in Curitiba.

Reduced Energy Consumption

The MTS contributes to reduced fuel consumption in Curitiba through vehicle design and by attracting high levels of

ridership.

Vehicle Design

The goal of the ITN is to match the capacity of a bus to the trip quantities demanded on different routes to match the available space in buses to the number of passengers desiring to board. The goal is to use smaller conventional and "padron" buses in low density areas and higher capacity articulated and biarticulated buses on structural, high density routes. This places bus capacity on the routes where it obtains the highest use. It also ensures the lowest quantity of energy used per passenger traveled. The smaller buses have the lowest absolute levels of fuel use. Hence, for a small number of passengers, the small buses have a lower fuel consumption per passenger. As passenger demand increases, the larger buses have a lower average fuel consumption provided the number of passengers increases sufficiently to offset an additional fuel use.

Table 11 illustrates the relationship between capacity and fuel use. The shift from conventional to "padron" bus increases capacity by 38% and increases absolute fuel consumption by 21%. A shift from "padron" to an articulated bus increases capacity by 55% and fuel consumption by 39%. Finally, the switch from articulated to a biarticulated bus increase capacity by 59% and fuel consumption by 16%. These figures underscore the importance of matching capacity to trips demanded. Unused capacity wastes fuel while matching high use with high capacity promises real fuel savings. This is precisely the goal of the ITN to match route capacity with route use.

An Alternative to Automobiles

Public transportation draws passengers from those who would not travel if it were not available and from those who would use another transportation mode if the public option were not available or available in a less convenient or lower quality form. Private car drivers are part of the latter group. Private car drivers are part of the latter group. A survey performed by the Parana based Bonilha Institute in 1991 with direct route users showed that 28% of them would use their cars to commute if the direct routes were unavailable. These survey data are consistent with Curitiba's per capita use of public transportation. In Curitiba, the average annual number of trips per inhabitant is 202 trips. A more typical use level for Brazilian cities is Sao Paulo's 158 trips per inhabitant per year. These use levels suggest that the convenience, timeliness, and cost of Curitiba's system may increase transit use by as much as 28%, with a large proportion of this likely to come from other transportation modes.

Table 11. Fuel Consumption by Bus Type

Vehicle	Passenger Capacity	Diesel Consumption (liters/km)
Conventional	80	0.38
"Padron"	110	0.46
Articulated	170	0.64
BiArticulated	270	0.74

Source: Urbanizacao de Curitiba 1993.

Using the survey and per capita use statistics as rough estimates, it may be that the shift from automobile passengers to transit passengers may result in a 20 to 25% increase in transit ridership and a concomitant decline in automobile traffic. A 20% increase in ridership represents approximately 54 million trips per year in Curitiba. Supposing that there are 2 people per automobile, this implies a reduction of 27 million trips by automobile. If the average trip is 7.5 kilometers and average fuel consumption is 1 liter per 7.5 kilometers, the reduction in automobile traffic would save 27 million liters of fuel per year.

CONCLUSIONS

Curitiba's experience in developing a sound transportation system suggests a number of principles that may be applicable elsewhere. One of the most important is an understanding of how transportation is tied to the success or failure of other urban policies. When used in concert with other urban policies, transportation policy can become a strong inducement for beneficial growth. Transportation, land use, housing, and economic development policies are all elements in a package of tools that can guide urban growth and improve quality of life.

To realize the benefits of growth, the city adopted an unorthodox approach to mass transit planning and practice. It viewed transportation as an integrated system, a system that linked housing, land use, the road network, commercial development, and recreational investments such as parks, green spaces, and preservation of historic sites. Curitiba set off with a small set of long term goals. These goals then served as guides for 30 years of incremental, practical change.

Curitiba's approach placed a priority on effective transportation rather than a particular mode of transportation. It recognized that the goal was to transport people between places where they wanted to go rather than to encourage the use of a particular type of vehicle. Rather than view transportation as the only adjustable variable, however, Curitiba's planning process recognized that there are three sets of variables to work with: origins, destinations, and transportation routes and modes. It

therefore used land use planning, economic development policy, and transportation to coordinate the locations of homes, work, recreation, and transportation.

>From the outset, the planning process was practical. It recognized financial and social constraints. Curitiba began with buses because it had buses. Rather than replace its bus system with a one step, grand plan using a subway or rail system, Curitiba began with a series of small improvements. It first added a modest express route system with dedicated bus lanes. During the 20 next years, it sought out ways to improve and extend the system. The result is a surface system that provides the high quality service of well known underground systems at a much lower capital cost. These low costs mean that passenger fares entirely finance the mass transit system.

Curitiba is using its experience in transportation to improve other areas of urban policy. As in Sh-transportation, the approach in these other areas is repetitive and practical. It uses long term planning but is also aware that a plan must change as a city's reality changes. This approach views the city not as a provider of services but as a means of coordinating and voicing private interests. Final services are provided in partnership with private firms. The city sets standards and enforces standards. Private firms provide the capital, labor, and management to provide the service.

The city has successfully extended this approach into other areas of urban policy, housing, solid waste disposal, solid waste recycling, jobs training, and park and greenspace development. Practicality and recycling are core principles using real problems and practical solutions. The approach recognizes that solutions are temporary that they bring subsequent problems as the system adapts. The city is therefore prepared to deal with the next round of problems. Recycling is key since the approach begins with existing resources and finds ways to improve them rather than replace them. The result is a series of small improvements that add up to dramatic change over time (Rabinovitch 1992).

ENDNOTES

1. Jonas Rabinovitch began to work for the Curitiba Research and Urban Planning Institute (IPPUC) in 1981. An architect and urban planner with a master's degree in Economics in Urban Development Planning (University College, London) he served as Chief of Cabinet of IPPUC and later as Curitiba's Director of International Relations and Adviser to Mayor Jaime Lerner. Apart from Curitiba, Rabinovitch has worked as a consultant with the planning effort to develop the integrated urban transport system in Rio de Janeiro and several other cities worldwide. He is currently a senior urban development adviser within the United

Nations Development Programme (UNDP) in New York City, New York.

John P. Hoehn is an environmental economist and associate professor at Michigan State University in East Lansing, Michigan. He obtained his Ph.D. from the University of Kentucky in 1983. He held research appointments at the University of Kentucky and the University of Chicago before joining Michigan State University. He did research on environmental policy in the United States and several countries in Latin America. He is presently working with the Environmental Policy and Training Project (EPAT) managed by the Midwest University Consortium for International Activities for the U.S. Agency for International Development.

2. The corporation is technically a mixed capital, municipal parastatal (publically administrated, privately funded) entity.

3. Curitiba's complementary pattern of roads, densities, and human uses is similar to the organic pattern of pre-nineteenth century growth in many cities. It contrasts sharply with the grid pattern used in many planned cities of North America. Grid cities tend to have more street area per square foot of private property than the organic, hierarchical forms (Moudon and Untermann 1991).

4. A small fraction of the difference between paid fares and passengers carried comes from passengers who pay no fare. This no fare group includes students, the elderly, uniformed postal workers, and police officers.

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