Appendix

Drivers of travel demand in cities of the developing world

A synthesis of eight case studies

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Introduction to the cases

The developing country city cases provide snapshots – with a relatively fine degree of resolution – of the range of urban transportation challenges developing urban areas face. Originally, the idea behind the cases was to have them serve as "archetypes" – individual examples of more general conditions

We selected developing world cases based on data availability, contacts, and our own local knowledge and experience. We sought to present cases that span main continental regions of the world and incorporate widely different cultures, economies, and forms of governance.[2] We have included some megacities, where magnitudes of phenomena and problems have already attracted world attention, as well as some "non-celebrity" cities. The cases selected show that, overall, the cities of the developing world are more different from one another than those of the North.

For these cases, we have collected data on transportation details that portray the quantity, quality, and style of mobility, together with background variables representing phenomena that drive travel demand, all at the metropolitan level. This is an audacious effort that forms a platform for further work, enabled, for example, by the internet and data sharing technologies that amplify information-gathering possibilities (with caution, however, regarding the potential dissemination of inaccurate information). In its present form, the information and data we collected comes from sources that are often not systematically related and do not yet take data collection as a serious obligation. In their present form, then, the cases leave numerous problems to be solved and voids to be filled, as well as internal contradictions to be resolved. Nonetheless, we feel that the cases, in spite of such drawbacks, provide a useful picture of these turbulent, rapidly changing travel demand environments.

[1] We would like to acknowledge the following co-authorships of the cases from which this Overview is drawn: Mark Emmert (Belo Horizonte and Dakar); Anjali Mahrendra (Mubai and Chennai); Apiwat Ratanawaraha (Kuala Lumpur); and Jinhau Zhao (Shanghai and Wuhan) – all of the Department of Urban Studies and Planning, Massachusetts Institute of Technology. We received assistance from the Municipality of Wuhan and the Malaysia University of Science and Technology, Program on Transportation and Logistics. The work was financially supported by the Sustainable Mobility Project of the World Business Council for Sustainable Development.

[2] You will note that absent from the cases are the "economies in transition" – those countries, primarily of Central and Eastern Europe (although China is often considered a transition economy), that often fall through the simplified world division of "developed" and "developing."

The cases exemplify large variations in the magnitudes of selected traits (see Table A.1). For example, between some cities, GDP per capita and population differ by a factor of 10 (Kuala Lumpur to Chennai; Mexico City to Dakar), population growth rate differs by a factor of eight (Shanghai to Dakar), and public transport mode share by a factor of three and a half (Shanghai to Belo Horizonte). Some cities have populations with very high shares of residents under 15 years-old (Dakar at 43%), while others have age profiles similar to industrialized nations (Shanghai). Two of the Asian cities exhibit perhaps the greatest possible extremes in private automobile motorization rate: Wuhan with approximately five autos per 1000 residents and Kuala Lumpur with 300.

Even within these wide differences and the even greater differences between these and developed cities, we are often inclined to begin with an assumption that accessibility and mobility problems are categorically similar for all cities, and that the problems differ only in magnitude. But we must be very cautious in making such an assumption because the differences may be in similar variables, but of such great magnitude that they change the qualitative nature of the problem. When considering a city where 70 percent of trips are by public transport, a typical figure in Latin American, compared with a city where transit trips are less than 10 percent, a number of aspects of understanding have to be adjusted. Clearly public transport plays a more important role in the developing city than in the Northern city. But that forms only the beginning of the analysis. The politics of public transit in developing countries are very different. The reach of useful technologies is different. The significance of land use decentralization is different. Issues surrounding fare levels are different. The relationships between other modes – including cars and non-motorized vehicles – are different. And so on.

Table A.1 **Overview of main traits of developing country city cases**

City	Belo Horizonte	Chennai	Dakar	Kuala Lumpur	Mexico City	Mumbai	Shanghai	Wuhan
Region	Latin America	South Asia	Africa	South East Asia	Latin America	South Asia	Asia	Asia
GDP per Capita (US$)	$6,000	$800	$1,500	$8,000	$7,500	$1,200	$4,200 *(2000)*	$2,000
Population Millions	4.2	7	2.5	4	18-23	18	13-17	4-8.5
Average Annual Growth Rate	1.5%	2.4%	3.2%	2%	2%	3%	0.42%	1%
Density (Population/Hectare)	4-63	59-288	35	10-58	50-120	120-460	14-460	10-160
Age Distribution	26%<15 4%>65	26%<15 8%>60	43%<15 5%>55	27%<15 4%>65	30%<15 5%>65	26%<15 6%>60	12%<15 12%>65	16%<15 12%>65
Trip Rate (Trips/Day)	1.43 *(1995)*	1.24 *(1993)*	2.3 *(1998)*	2.4 *(1997)*	1.2-1.4 *(1994)*	1.26	1.95 *(1996)*	2.25 *(1998)*
Personal Vehicles/1,000 Pop.	225 *4-Wheelers* 22 *2-Wheelers*	40 *4-Wheelers* 171 *2-Wheelers*	42	300 *4-Wheelers* 170 *2-Wheelers*	110 8 *2-Wheelers*	27 *4-Wheelers* 25 *2-Wheelers*	4-20 *4-Wheelers* 35 *2-Wheelers*	14 *4-Wheelers* 31 *2-Wheelers*
Rail Transit	1 line metro	1 line metro 3 suburban rail	1 suburban rail	3 lines LRT 2 suburban rail	11 line metro	2 suburban rail services 3 lines	3 metro lines	none
Fare (US$)	$0.30	$0.10		$0.20-0.60	$0.20		$0.12-0.50	
Non-Motorized Transport	5-7% *(1995)*	44%	44%	NA	NA (possibly 15%)	NA (26% in 1981)	72% *(1995)*	61%
Public Transport	69% *(1995)*	47%	45%	20% (of motorized)	70% (of motorized)	88% (of motorized)	17% *(1995)*	22%

Notes:

1. Belo Horizonte: Except for population and density, the figures given are only for the Municipality of Belo Horizonte; the density range: 4 is average for the entire metropolitan area, 63 is for the Municipality.

2. Chennai: Population, trip rate and mode shares are for the metropolitan area; GDP per capita for the state of Tamil Nadu was US$ 480 in 2000, the Chennai figure is an estimate based on the state's; density range: 59 is average for the entire metropolitan area, 288 is for Chennai City; age distribution is for the State of Tamil Nadu; public transport mode share includes auto-rickshaw (5%).

3. Dakar: GDP per capita is for the country, no data for Dakar was available.

4. Kuala Lumpur: GDP per capita and age distribution are for the city of Kuala Lumpur; density range: 10 is average for the entire metropolitan area, 58 is for the city of Kuala Lumpur; motorization rate is for the entire metropolitan area; mode share for non-motorized trips unavailable.

5. Mexico City: Density range: 50 is for new fringe developments, 120 is average for the metropolitan area; trip rate in 1994 did not include walk trips, 1.4 is an upward estimate, assuming 15% of all trips in city are walk trips; 2-wheelers per 1000 is for the Federal District only, reliable data for State of Mexico was unavailable.

6. Mumbai: GDP per capita based on World Bank estimate that 5% of India GDP is produced in Mumbai; density range: 120 is average for entire metropolitan area, 460 is for island city; motorization rate (vehicles per 1000) is for Mumbai City, rate may be higher if less dense suburban areas are included, but data unavailable.

7. Shanghai: population range: 13 mn is "official" estimate, 17 million includes "floating" population; density range: 14 average density in new developments; 460 average density in central city; subway fare is distance-based.

8. Wuhan: the population figures range from 4 million for Wuhan City to over 8.5 million for the entire metropolitan area (much of which is still rural; this population range explains the high range of densities.

While it is true, in the simplest sense, that the developing cities face the same accessibility and mobility problems as the North (congestion, inadequate infrastructure, insufficient rolling stock capacity, and high costs of transport), the developing cities present differences that ultimately figure importantly in potential solutions. Critical examples of differences include income levels, rapid rates of change, and urban densities.

POVERTY

The developing countries, by definition, are poorer than their industrial counterparts, meaning that substantial populations cannot afford adequate transport. Distribution of income further complicates this reality, typically dividing cities into two groups: those who can easily afford high quality transportation – and whose cars congest the streets – and those, typically a very large group, whose transport needs must be met with a very low budget. This reality contrasts with the cities of the North where the market for mobility can, to a greater extent, be considered something of a single market. For much of the developing world, improved accessibility comes in the form of the change from a walking trip to a public transport trip.

RAPID CHANGE

Most developing cities find themselves in a condition of rapid change. In China, for example, urban land has only recently acquired a priced value, introducing revolutionary changes in land development patterns and location decisions of firms and households. In Mexico, the changing political situation and ongoing decentralization of authority introduces vexing managerial challenges and political competition that manifests itself in, for example, bus services that are prohibited from crossing state boundaries. In Dakar, the population growth rate of greater than 3 percent – shared by cities in, for example, the Middle East – means that the city's population will double over the next 20 years, introducing special stress on transportation systems but also offering the possibility, in principle, for adapting future urban growth to better match transportation needs. And, of course, rapid motorization (accompanying a welcome growth in income) makes for a specialized environment because dependent urban systems cannot conceivably keep abreast of this change rate, even with the most draconian measures so far attempted in cities of the developing world. Many of these changes make future requirements extremely difficult to forecast. For example, in China, most women work; in India most women do not work. What will the picture of work trips per person in those countries' cities look like 10 years from now?

DENSITIES

In most cases, developing cities are denser (in residential population and other measures) than cities of the North. Though notoriously difficult to estimate accurately, density figures from developing cities show average and peak figures in orders of magnitude greater than Northern cities. In Mexico City, for example, estimates put the overall Metropolitan Area density – covering some 1,500 square kilometers – at a higher level than that of Manhattan (New York), the most densely populated slice of urban life in the United States. Central areas of Shanghai have population densities five times greater than Manhattan. Such densities carry two important implications. First, high densities facilitate the viability of high volume public transport, while making individual transport more difficult. Secondly, historically high densities, in environments of higher incomes and increasing motorization (i.e., Shanghai), eventually explode into decentralization with nearly uncontrollable force.

Several common, interrelated factors that propel travel demand in developing cities are population and income growth, auto and two-wheeler availability, social change, and urban decentralization. Common obstacles cities face in meeting demand include poverty, congestion, poor transit performance, and poor institutional performance in general. Based on these and the aforementioned key differences between developed and developing cities, we have chosen five issues critical to developing city mobility. They are:

1. Motorization. Does a foreseeable motorization "ceiling" exist for cities of increasing personal income?

2. Motorized two-wheelers. What role do the two-wheeled motor vehicles play in the motorization process?

3. Public transport. What are the issues and solutions related to the poor transit performance in most developing cities?

4. Land development and decentralization. How does increased travel demand interact with land development in the cities?

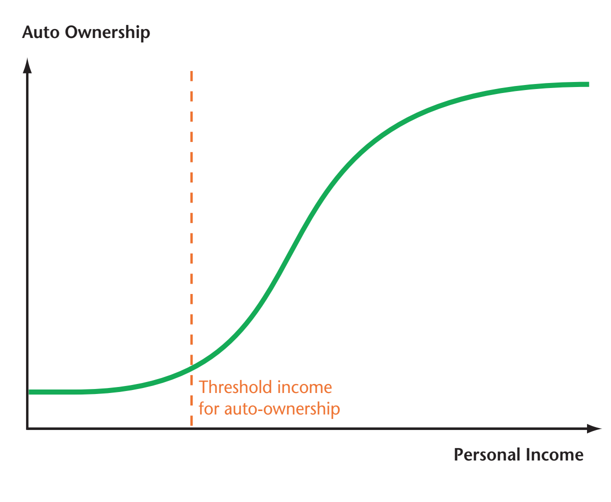
5. Institutions. Can institutions effectively react to these incredibly dynamic conditions?

1. Motorization

Does a foreseeable ceiling exist for motorization (vehicles per capita) in cities of the developing world? Will resource constraints or the accumulation of externalities produce an attenuation of motorization? In the cases studied here, and in other data, few indications exist that cities with currently low motorization are on a path toward lower total future levels. Several factors play a role…

International comparative evidence shows a strong, virtually linear, relationship between income and motorization. This relationship clearly exists at the level of a given country or city as well, but at this level, one sees the role of key local influencing factors. One must first keep in mind that personal car ownership versus personal income actually follows a pronounced S-curve (logistic curve), as shown in the stylized Figure A.1. Obviously, an income threshold for vehicle ownership exists; ownership increases very slowly with income until it approaches the threshold, when a sudden sharp increase takes place. As income further increases, the increase of auto ownership attenuates – the situation that most of the developed world currently faces (although forecasts of where this leveling off occurs have been notoriously premature).

Figure A.1 **Stylized Auto Ownership Curve**



In much of the developing world, the vast majority of the population is still at income levels well below the rising portion of the S-curve. Even in places with high GDPs per capita (as measured in straight averages), motorization levels may be far lower than predicted, due to highly skewed income distributions *(see, i.e., Gakenheimer, 1999)*. Thus, absent continuing or even exacerbating disparities in income distribution or general economic stagnation, all developing country cities remain far from any theoretical motorization saturation point as suggested by the S-curve.

Most of the city cases we studied have offered further glimpses into local-level phenomena influencing motorization rates. For example, local industrial and trade policies play an important role in nearly every case: in Brazil and Malaysia, government promotion of the motor industry has further stimulated motor vehicle ownership, evidenced particularly in the high vehicle ownership levels in Kuala Lumpur. In Dakar, the Senegalese liberalization of trade and the opening of the borders to used car imports increased vehicle ownership levels, a phenomenon seen in parts of Latin America (i.e., Peru) as well as Central and Eastern Europe. Shanghai's motorization rate is lower than what might be expected given the city's relatively high income; a function, in part, of historically high vehicle ownership fees. The Chinese government's industrial policy focusing on the motor vehicle industry may soon change that reality.

Other local policies, not originally aimed at affecting vehicle ownership per se, also play a role. For example, Mexico City's famous "Hoy No Circula," a restriction on driving by certain vehicles (based on license plate numbers) during high pollution days, created the perverse impact of promoting the purchase of second hand vehicles by many families – increasing the motorization rate. The government has more recently adapted the ban to create an incentive for purchasing cleaner vehicles, an approach also adapted in the case of Santiago (Chile), which uses a similar restriction policy. Cities like Mexico City and Santiago, with grave pollution problems and relatively forceful government efforts to deal with them, show that there are few indications that increasing motorization attenuates on account of externalities caused by increasing numbers of vehicles.

In fact, one can argue that increasing motorization and its attendant impacts actually further induce motorization. For example, motorization certainly fuels spatial decentralization, which then further drives motorization. While motorization exacerbates congestion, congestion may then create the perverse incentive of increasing automobile ownership and use. Since increasing congestion further encumbers main arteries and slows buses and other surface transit, there is increasing advantage to using a car because it enables substitution of a circuitous route that avoids traffic or substitution of a destination in a less congested direction.

As a result, if there are concerns about greenhouse gas emissions, land conversion to urban uses, dependency on foreign petroleum, urban structure preferences, or infrastructure costs that would be exacerbated by further motorization, then controls would have to be imposed externally. What country or city in the developing world will be willing, however, to impose such controls, either pushing the s-curve outward or flattening it? Will any developing city be willing to lead the way with an "artificial ceiling," becoming the world's next Singapore?

2. The role of two-wheelers in motorization

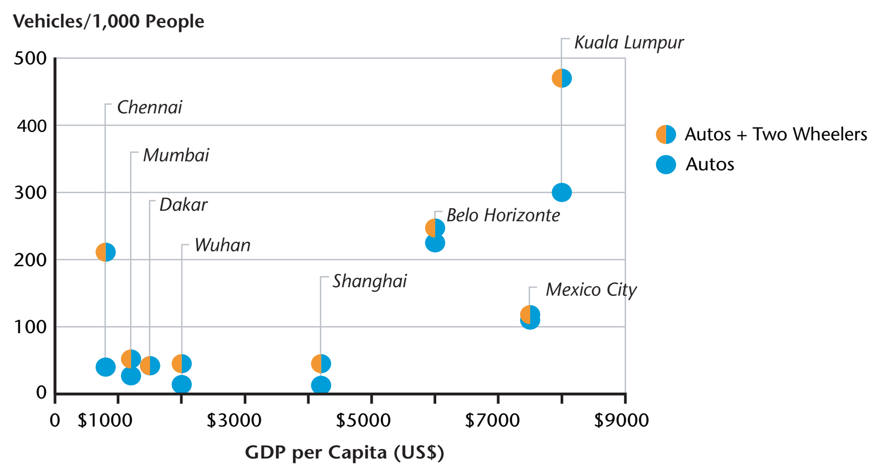
Motorization analyses have historically focused on the automobile, or more generally motor vehicles. However, the role of motorized two-wheelers (motorcycles and scooters) cannot be ignored in the developing world's motorization patterns. Asia accounts for more than 75 percent of the world's fleet of two-wheelers, and of that China accounts for roughly 50 percent and India 20 percent. Among the cities represented by our case studies, two-wheelers account for 80 percent of the total motorization rates in Chennai, Shanghai, and Wuhan; 50 percent in Mumbai; and 40 percent in Kuala Lumpur. In the Latin American cities, two-wheelers are much less prevalent, accounting for less than 10 percent of the motorization rate in both Belo Horizonte and Mexico City (see Figure A.2). There are many cases in which the addition of two- and four-wheeled vehicles in "two-wheeler" cities brings their motorization rates to the same level as cities of much higher incomes. In fact, if we believe the data, Mexico City has a GDP per capita 10 times higher than Chennai, but a lower car plus two-wheeler motorization rate than Chennai (see Figure A.2). Two-wheelers are a mobility equalizer.

The inclusion of two-wheelers certainly changes the perception of the motorization phenomenon. Returning to the stylized motorization S-curve and including two-wheelers, we can see, not surprisingly perhaps, that two such curves exist – one for two wheelers and one for cars. The case of Chennai (Figure A.3) exemplifies this. In India, one can buy inexpensive two-wheelers for as low as USD 200. As incomes rise, the two-wheeler curve crosses the income level of a much larger part of the population. So, we can say that two-wheelers accelerate the motorization process.

Of course, in detail, these are not necessarily neatly separate curves. As even the Chennai graph suggests, they overlap. Higher priced two-wheelers cost more than lower priced cars. Of course, in detail, these are not necessarily neatly separate curves. Higher priced two-wheelers cost more than lower priced cars, and choice may depend on factors other than price, such as details of social role, age, or gender.

The question remains, however, as to why two-wheeled motor vehicles are so prevalent in some regions of the world, while they are virtually insignificant in others, even those of roughly the same income levels. Thoroughly answering this question clearly requires more detailed analysis, but at first glance, the

Figure A.2 **Motorization rates including and excluding motorized two-wheelers compared with GDP per capita**



answer seems to lie in the fact that two-wheelers dominate in regions where bicycles were previously numerous. In other words, two-wheelers have fairly directly replaced bicycles. In regions where bicycles appeared in substantial numbers before or during the early motorization movement, they established a place for themselves in traffic on busy streets – a place readily taken over by two-wheelers.

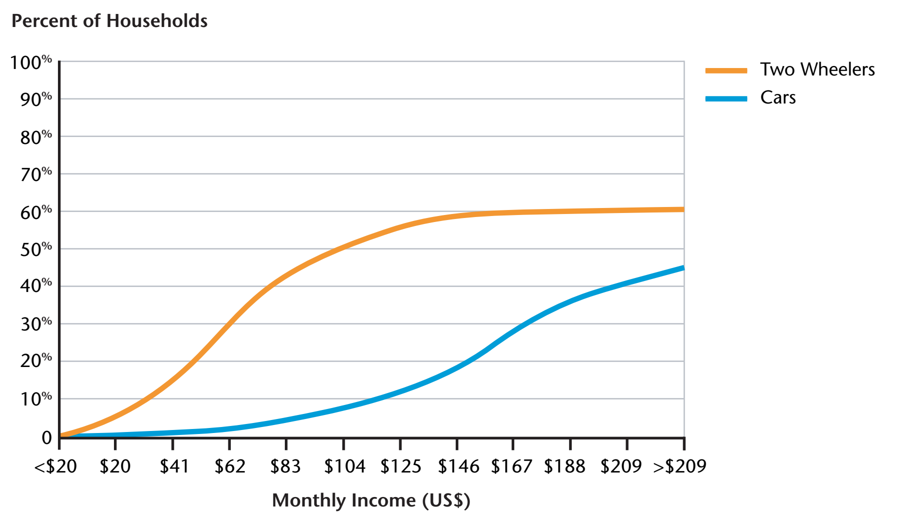
Motorized two-wheelers decrease the physical burden associated with bicycle use, reduce travel times, and offer the opportunity to more effectively maneuver in (or at least keep up with) the higher-speed motorized traffic. Motorized two-wheelers then supersede the bicycles, the latter being endangered by their faster and heavier motorized cousins. This dynamic is dramatically evident in metropolitan Taipei, for example. Ironically, in a city where millions of bicycles are made for export all over the world, bicycles are very seldom used on the streets of Taipei. The rights of way are fully crowded with motor vehicles traveling at high speeds, including the side lanes reserved for two-wheeled vehicles.

The result is that bicyclists are forced up the "ladder of mobility" to two-wheelers if they can afford them because bicycles are no longer viable in traffic. This transition will be extremely important in China, where bicycles are much more prevalent than any other vehicle (in Shanghai there are about 1.8 bicycles per family at all income levels). In fact, in some Asian cities, attempts have been made – explicit or otherwise – to discourage bicycle or non-motorized three-wheeler use, with the justification that such vehicles disrupt traffic, occupy too much road space, and dilute the market for public transport (lest this argument seem strange to Western readers, note that in the late 1800s in US cities, bicycles were considered to be the principal threat to adequate passenger volumes for the new electric streetcar).

Interestingly enough, as they become more prevalent, motorized two-wheelers become a perceived problem. They have a penchant for using their narrow profile to dart in and out of traffic, which disturbs auto drivers, bus service, and law enforcers. If the right of way is divided between cars and bicycles, motorized two-wheelers prove disruptive because they do not fit either facility. So, some governments then take steps to suppress motorized two (and three) wheelers, whether as a form of public transport (i.e., auto-rickshaws) or as private vehicles. For example, the Beijing government has recently been taking various steps to suppress two-wheelers (through restricting registrations, limiting their entry into jurisdictions where they are not registered, limiting parking, etc.). This is an incentive, then, for two-wheeler users to move up to a car if they can possibly afford it.

All of the above suggests something of a "ladder of mobility improvement" – it is a small jump from two wheels without a motor to two wheels with a motor. A somewhat similar small jump takes one from an independent motor vehicle on two wheels to four wheels. If we believe this ladder of mobility, then motorized two-wheelers offer a stop on the route to auto ownership. The concurrent decentralization and de-densification of cities, particularly in Asia, only further fuels the transition, as additional urban space is opened up for automobile maneuverability and travel distances grow.

Figure A.3 **Relationship of income to vehicle ownership in Chennai, 1993**



While certainly not authoritative, the two-wheeler picture enlightened by the case studies suggests answers to several crucial questions:

- Do two-wheelers extend mobility in regions where they are used? *Answer:* They do so dramatically.

- Do two-wheelers accelerate the overall growth of motorization? *Answer:* They definitely do.

- Are two-wheelers a stage toward auto ownership? *Answer:* We believe they are, as a point in a procession of modal adoption brought on, in part, by traffic pressures.

There are, of course, some arguments contrary to these expectations. For example:

- There are permanent advantages to the use of bicycles, which hopefully will remain in place, especially for those whose income makes them the most viable mobility form. They are so far the most prevalent form of wheeled mobility in many two-wheeler regions.

- There are also permanent advantages to the use of motorized two-wheelers because of their prices and their maneuverability. Thus, their roles should be retained in a multimodal system.

- The countries with two-wheeler regions have not yet dealt with the auto as a source of congestion, probably because cars are so few in number and used largely by people of privilege. As this phase is passed, actions to limit auto use may well change these circumstances.

3. Public transport performance

The single condition that perhaps most suppresses mobility in the cities of the developing world is the poor performance of public transport.

Although the vast majority of trips depend on public transportation, in most cities services suffer from poor financial conditions, inadequate passenger capacity, low network integration, slow operating speeds, and deteriorating physical conditions. As a result, transit serves declining modal shares and performs in a context of congestion, crowded vehicles, and high rates of personal injury. Our case studies cover the full spectrum of public transit problems and show some glimmers of hope.

What are the obstacles? At the most basic level, of course, the problem is poverty. People cannot afford to pay a fare that sustains good service. For example, The Halcrow-Fox/TRRL (now TRL; Allport et al. 1990) study of metro starts in the late eighties concluded that while none of the metros in developing cities break even financially, most of them could if they were able to charge a fare of about one US dollar, more than double the fare of most rail transit systems operating in the developing world today, nearly 15 years later (see, i.e,. Table A.1). Even in the case of developing cities' road-based public transport systems, many of which are operated by the private sector, fares are often too low to sustain reasonable service levels, and operators essentially cannibalize their capital through poor maintenance practices. Any improvements to the system face the equity challenge of forcing the lowest income groups to finance upgrades via fare hikes.

The share of public transport in daily trip-making varies widely among the case studies. Belo Horizonte, Mexico City, and Mumbai have the highest public transport share of all cities, at 65-70 percent. Shanghai, Wuhan, and Kuala Lumpur have low mode shares, the former two because of heavy reliance on non-motorized modes and the latter due to competition from private motorized modes. Both Dakar and Chennai have mode shares split almost evenly between public transport and non-motorized transport.

In most of the cities, the vast majority of public transportation providers are privately owned, including – somewhat surprisingly – Chinese cities. Indian cities, where virtually all public transport remains in the hands of government, unquestionably has the largest publicly-owned fleets in the developing world.

Several of the cases studied offer examples of the challenges that public transport systems in the developing world face:

- Since the eighties, Dakar's buses have experienced a 20 percent decline in ridership, despite a rapidly growing population. The principal cause? The rise of the para-transit services, "car rapide" and "Ndiaga Ndiayes."

- Chennai's public transport mode share declined by 20 percent in the 25 years preceding 1995, largely due to a rapid rise of the number of motorized two-wheelers.

- Kuala Lumpur's transit mode share declined from 35 percent in 1985 to 20 percent transit in 1997, coinciding with efforts to promote the automobile industry through the "National Car."

- In Mexico City, the publicly owned bus system collapsed during the eighties and the massive Metro system's ridership stagnated, due in large part to the rapid rise of the para-transit "Colectivos," privately operated minivans and minibuses.

These challenges shed light on the multiple institutional and operational problems underlying the public transport crisis in the developing world cities. For example:

- Transit is difficult to manage as a private industry in the public service. Selective competition for concessionary arrangements does not work because there is virtually no use for transit equipment except in the public service.

- Transit operators have strong political leverage (including the option of paralyzing strikes as in the case of Mexico City). As a result, officials find it hard to budge from the status quo of contractual arrangements (or lack thereof).

- The fare is a conspicuous element of the cost of living. Political leadership therefore remains very hesitant to permit the increase of fares and sometimes suffers acutely when it does so (e.g. Mumbai).

- Innovations and new services are often intentionally isolated from the existing system to avoid its historical resistance to change and its accumulated petty political obligations. As a result, systems are unintegrated (e.g. Kuala Lumpur's LRT system).

- Government agencies responsible for operations arrangements and control are often weak and isolated from the strong elements of the transportation bureaucracy that are responsible for infrastructure construction. Often, this isolation results from an effort by the government to keep the turbulence of transit operations from affecting the stability of capital flows for infrastructure investment.

- Ambivalence towards supporting informal sector transit services has further complicated the problem. Informal sector transit adds significant increases in service levels (i.e., door-to-door) and serves as an employment source, but cripples government sponsored transit service markets and system management (e.g. Mexico City).

- Inter-jurisdictional problems within metropolitan areas sometimes impede system integration in very harmful ways. (e.g. Mexico City, where maximum age for transit vehicles is different in the surrounding urbanized State of Mexico, and agreements to extend metro lines across the boundary have been difficult to reach).

- The selection of new service options and modes is often politically complicated and subject to misplaced expectations. Many cities are forgoing simple solutions while waiting for metro systems they will likely never fully realize or counting on relatively unproven technologies (e.g. Shanghai).

Despite these problems, the same cases show that a remarkable capability exists for facilitating public transport and enhancing its share in absorbing trip making (e.g. Belo Horizonte's transit share of nearly 70% of trips in the face of a motorization rate of 225 cars per thousand population). Mumbai's publicly owned BEST (bus company) increased its daily service by around 20 percent (passengers) during the 1990s and increased its earnings in the same period by more than two and a half times. A few cities have committed large budgets to public transport (e.g. Shanghai with 28% of its infrastructure budget going towards its rail system and Mexico City's historic emphasis on expanding its Metro). If Mexico City's ambitious Metro expansion holds lessons for Shanghai, however, it is that the Metro will not retain a high mode share unless efforts are made to curtail urban expansion, promote development near Metro stations, and curb competition from road-based modes.

Kuala Lumpur, to a certain degree, typifies the most problematic case, with incomes and motorization high enough to make it scarcely characterizable as a "developing" city, relative to the others. In this case, public management of the sector has left the service-providing companies near collapse. During the nineties, the private sector embarked on the development of three rail-based transit systems (two light rail systems (LRT) and one monorail). The LRT systems, now operational, have shown the difficulty in making this mode a profitable private endeavor. The two systems have recently been combined under one owner; details on the financial conditions are unavailable. The monorail system, with construction delays caused by the late 1990s financial crisis, has yet to open. At present, these systems do little to pick up the transit share of trip making or to relieve pressing street congestion in the city. While formal data since the inauguration of the rail systems does not exist, it seems unlikely that public transport mode share in the city has increased beyond 20 percent.

At the other extreme is Belo Horizonte, with, ironically, the same size metropolitan population and roughly the same residential density as Kuala Lumpur. Yet with public transit accounting for 69 percent of all trip making, Belo Horizonte features three and a half times more public transit use than Kuala Lumpur. Belo Horizonte has no "special technology" transit systems, and in general, operational bus speeds are slow. That this system manages to maintain high mode share is testament to some degree of effective regulatory structure and perhaps a persistent willingness on behalf of citizens to continue using buses, even when they might own a motor vehicle (although data inaccuracies regarding mode share cannot be discounted as a partial explanation either).

Several developments offer glimmers of hope for the future of public transport in the developing world. First, the "revolution" of bus rapid transit (BRT) systems, sparked by the well-known case of Curitiba over two decades ago, is now beginning to spread across Latin America (e.g. Bogota, Santiago, Lima, and Mexico City) and other parts of the world (including, recently, Dakar). Second, the Global Environment Facility (GEF), has initiated a number of programs (mostly directly related to BRT projects and World Bank loans) aimed at improving public transport performance. Finally, one cannot ignore the value that entrepreneurs have brought to public transport delivery in the developing world. The plethora of private "informal" transit modes plying the streets of developing world cities is typically viewed as something of a plague – an unjust judgment in our view. While management of these systems certainly poses a problem, their existence owes to the fact that they have obviously figured something out – lessons that ought not to be lost, in developing world cities or the cities of the North.

4. Land development

Perhaps the most visible consequence of growth in travel demand and motorization is in the decentralization of urban growth. To some degree decentralization is desirable given the incredibly high densities of some cities, but for most cities the process of decentralization is uncontrollable. Interesting examples from our cases include Navi Mumbai (in Mumbai) and Shanghai's Pudong.

Cities of the developing world enter this era with very high residential densities. Among our cases, Wuhan shows an average density of 166 persons per hectare, Mumbai 225 and the city of Belo Horizonte 63. If Shanghai's population were distributed at the same density as the New York metropolitan area it would occupy about 16 times its current area. Clearly this extreme example of such redistribution of Shanghai's population is unrealistic, but the fact cannot be denied that the cities of the developing world almost universally find themselves in a process of explosive decentralization and structural transformation. Although very difficult to quantify, this process is very visible, representing changing life-styles and altering the structure and the overall amount of travel demand.

The debate over urban decentralization and concomitant reductions in density cannot be answered in these pages. Nonetheless, the matter almost certainly poses a problem in the developing cities, where resources are limited and efficient development is important. Decentralization imposes auto dependency because it generates a residential pattern where public transport does not function easily. Auto dependency, in turn, tends to further decentralization. Automobile dependency can create its own attendant problems, such as local and global pollution and increased dependency on foreign petroleum. Furthermore, as many cities in the developing world are situated in rich agricultural areas, urban decentralization threatens to exacerbate problems of food security.

In the face of these potential problems, can or should decentralization be reduced or, at least, constructively guided? In the case of constructive land development guidance, can the problem be improved in a reasonable length of time? In principle, rapid urban growth provides possibilities. For example, a city growing at over 3 percent a year, as in the case of Dakar, doubles in size in 20 years. If this growth occurs at prevailing densities, then an entirely new urbanization the size of the existing one will arise in less than 20 years. In reality the density of new development will likely be lower than the existing city, implying a greater than doubling of the urban area; in principle, a more efficient form of growth could be pursued, but the question persists: how?

Motorization is only one of the factors fueling decentralization and may well be a minor one in many cases. Parallel conditions and actions also propel cities outward. Many cities in the developing world (i.e., Mumbai, Shanghai) often seek decentralization to relieve overcrowding (as seen, for example, in the drastic increase in living space per person in Shanghai over the past decade). However, combined effects typically tend to accelerate decentralization beyond that expected. Developers exacerbate the problem by seeking low cost land at the periphery. In globalizing economies new transnational locators often seek big campus-like settings for their establishments inevitably at the metropolitan periphery. In Chinese cities the transitional aspects of the economy also play a role. For example, valuation of land on a price per square meter basis results in recognition for the first time that central land is more valuable than peripheral land. This stimulates a retreat to decentralized location by lessees who transfer center city land to users who profit more from central location. When a municipality purchases urbanizable land from contiguous work groups the full revenue coming from that land is collected at the time of first leasing. After that the municipality receives no more revenue from that land. Therefore the city needs to continue acquiring land in order to have a continuing stream of revenue. Thus need for revenue drives decentralization.

Accordingly, Shanghai fully doubled its area during the 1990s, stimulated especially by a desire to capture new transnationals attracted by WTO accession. In the suburbs of Nanjing, exurban centers are being implemented at densities so low they appear to be parodies of American southwestern suburbs. Local planners have now concluded that these densities are excessively low, yet with China's current dynamic social and economic profile, it is very difficult to make lasting decisions about matters of this kind.

The case of Navi Mumbai is also illustrative. The corporation of the State of Maharashtra that began planning Navi Mumbai in the 1970s aimed to relieve crowding and inaccessibility of the peninsula on which the principal part of the metropolitan area is located by designing a series of centers across the bay from it. These centers were specified in great detail, including the employment elements by sector and size, specific infrastructure requirements, residential areas, etc. They were to be developed in sequence with a balance among different components such that travel demand would be minimized. While existing in the overall metropolitan area of Mumbai, the objective was to minimize the need for travel to the city center. In fact, while development was stimulated, the planned development pattern was not honored and the entire area became a sprawling residential suburb of Mumbai, requiring most workers to get across or around the bay to the city center to get to work. This has resulted in further crowding of the city center, the need for very high expenditures on bridges and highways across the bay, and great crowding of Mumbai's remarkably complete commuter rail network.

The job of effectively integrating land planning with the transportation system is daunting in nearly all developing (and developed) countries. Development needs to decentralize, but not too much. Ideally, the means of controlling the situation is to plan for decentralized clusters of development that relieve crowding, but at the same time include densities that can be viably served with infrastructure and transportation services. Yet, as the case of Navi Mumbai shows, even when planners have the "right idea" implementation continues to vex us. The contrasting example is Pudong, across the river from the center of Shanghai. Planned by a government with a great deal of authority over land development, it was intentionally prepared at densities compatible with motorization but under good control, and with a balance between employment and residential areas. Attempts have been made to connect it with the center of Shanghai with public transport and tunnels. With construction begun around 1995, it now houses well over a million people and has industrial, office and commercial employment. Of course, the match between housing and jobs could not be made by everyone, so employers use chartered buses to bring employees from locations elsewhere in the metropolitan area. Basically it works and is a tribute to government authority that is able to take comprehensive control of a development project. Of course, few governments in the world have the authority to embark on an undertaking such as Pudong.

Overall, the problems are difficult, but the payoffs are high. Land development management is, perhaps, the only really stable answer to the problem of burgeoning travel demand. Experience of the developing countries suggests that a limited kind of equilibrium (still unsatisfactory) is eventually reached. And the adaptation is painful.

5. Institutions

The ultimate challenge pervading every aspect of transportation – including project preparation, regulation, operations management, maintenance, and planning – continues to be institutions. Any discussion of the institutional issues facing developing cities must begin by saying that they are swamped by increasing demand and obstructed by limited resources. China, with a still highly centralized government structure, faces these challenges, as does Mexico City, operating in a context where the Federal Government, at least two state governments, plus 50-odd Municipal governments each vie for its slice of control and political capital. Growth in democracy and governmental decentralization generally come hand-in-hand with development; and, few would effectively argue against the greater good that these bring. However, as cities grow and the jurisdictions within their urban areas expand, the institutional problem of managing the system –

transportation or otherwise – at times seems to increase exponentially.

In the developing world, these conditions are worsened by financial realities and subsequent problems for the bureaucracy and civil service. Salaries are often very low, generally attracting young professionals at the very beginning of their careers, those who can profit privately from government employment (e.g. through parallel consulting), and those who occupy key positions out of a sense of obligation to society. And each of us knows more than a few heroic individuals in this last category who are responsible for important action.

Further problems arise from the lack of clarity of administrative responsibility among linked agencies. Since lower level agencies are often impoverished, they are likely to delay action in the hope that the national government will bail them out. For example, in many government traditions, infrastructure is a national responsibility, but its maintenance is a local responsibility. Accordingly, the local government – which usually barely has enough funds to collect the trash – allows the roads to deteriorate, hoping that when deterioration reaches the level of requiring full rebuilding the national government will step in.

Transportation agencies are often decapitated, with all principal officers replaced, when a newly elected government administration arrives, resulting in program discontinuity (this often happens even when the same party is re-elected but the personalities of leadership are changed). This poses a serious impediment to the collection of useful data for analyzing transportation problems and the ongoing development of methodological advances, often forestalling any reasonable transportation planning capability in relevant agencies. Transport plans are usually accomplished by a consortium of consulting firms. These plans usually advise follow-through which is not undertaken, and the plans themselves are often very limited in circulation in order to confine decision strength to a select group. Subsequently, coherent policy fails to emerge since actions are built on isolated reports from a succession of consultants. Data, if it is collected, is rarely collected systematically and is guarded closely – information is power.

Finally, regulatory action and enforcement are often very difficult because a single societal code has simply not yet arisen. In Middle East and African environments, there are sometimes even two or more entirely different legal systems in simultaneous use. Without agreement on regulatory matters, they are hard to enforce. In many cities throughout the developing world, public transport vehicles operate without a concession agreement, vehicle registrations are notoriously incomplete and even a significant portion of personal drivers' licenses are falsified. Solving such problems would go a long way towards improving the conditions of transport in the developing country city.

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Background to case selection

A1. The cases in context: urban archetypes?

We undertook the developing country cases with the original intention of selecting a spectrum of cities that could effectively represent the range of urban transportation conditions and influencing factors in the developing world. The cases would, in other words, attempt to serve as urban transportation "archetypes"; assuming a fundamental urban structure, the archetypes should represent the variations in that structure. As such, the archetypes could serve to provide stakeholders and others with a reference point, facilitating identification with an "archetype city", and helping to roughly understand any given city's relative condition. The idea behind the "archetype city" is not to explain the individual city, but to develop a classification system that extrapolates a systematic pattern from the archetypes.

The challenge with such an undertaking, however, rests in striking a balance between breadth and the depth, or providing a manageable number of meaningful descriptive characteristics while at the same time giving enough resolution to roughly "situate" any given city within the archetype framework. As it turns out, such a task is not straightforward. Is it possible for a select group of cities to effectively capture the range of differences in the world's urban areas? Or, are cultural variations, ethnic and historical differences, expectations and tastes, and political approaches so varied as to make any generalizing archetype meaningless? Furthermore, from a mobility perspective, perhaps the differences in conditions across cities only reflect various stages on a converging global path. Part of the intention of this project is to understand the possible convergence or divergence of urban transport patterns across the developing world.

Several precedents exist for classifying urban areas, either from a strict mobility perspective or more broadly. For example, the SESAME project *(SESAME, 1999)*, specifically focused on "improving the state of knowledge on the interactions between land use, behaviour patterns and travel demand" in European cities. Using a sample of 40 cities across Europe, the SESAME project highlights the challenges of data collection and harmonization, even in places with relatively good data availability. Problems include: unequal data collection areas and different data sources, biases introduced by the definition of the urban area (which typically differs from place to place), and the overall availability of land use and transport data. The SESAME project makes the same point as we make above: the need to strike a balance between being relevant (i.e., having

Table A.2 **Example of classifications of European urban transport city types**

City Type	Cities in Cluster
Car Cities	Bordeaux, Nantes, Toulouse (France), Saarbrücken (Germany)
Car and Walk Cities	Aachen, Essen, Gelsenkirchen, Kassel, Wiesbaden (Germany), Grenoble, Lyon, Nancy, Saint-Etienne, Strasbourg (France), Bristol, Leicester, Manchester (UK)
Public Transport Cities	Barcelona (Spain)
Public Transport and Walk Cities	Bochum, Bonn, Chemnitz, Dresden, Düsseldorf, Halle, Hannover, Karlsruhe, München, Nürnberg, Rostock (Germany), Bern, Zürich (Switzerland)
Bike Cities	Amsterdam, Breda, Eindhoven (Netherlands)

Source: **SESAME 1999**.

meaningful data) and being operational (i.e., actually having access to the necessary data). As part of the effort, the SESAME project used the mathematical technique of cluster analysis to identify groups or clusters of cities that, for certain variables, exhibit similar characteristics. The project found it difficult to typify cities across a range of indicators and ultimately found that, beyond basic demographic indicators (population or density), the most useful typology relates to mode share (see Table A.2).

More generally, and more qualitatively, Hall & Pfeiffer (2001) distinguished three basic city types, based on demographic and socio-economic evolution. According to this typology, developing country cities can be characterized as either "informal hypergrowth" cases or "dynamic growth" cases, with most of the industrialized world fitting into the category of "mature city" (Table A.3). While interesting, such a categorization is too broad to provide a meaningful archetype framework for urban transport analysis.

The recent series of reports on transportation and climate change in the developing countries published by the Pew Center on Global Climate Change also helps identify a number of characteristics by which prevailing factors of influence can be distilled, as suggested by Sperling and Salon (2002). Such factors included political authority, the policy environment, land use patterns and social norms (see Table A.4).

A2. Attempts at an archetype framework

Drawing from these and other precedents, we attempted to derive a framework by which archetype cities could be selected for more detailed study, the idea being that situating the archetypes within such a framework could facilitate the "generalization" of the archetype cases to a broader number of cities. To develop such a framework, we used the statistical technique of factor analysis, which basically attempts to help discover how variables in a given data set form coherent subgroups that are relatively independent from one another. Factor analysis can be used either to explore the relationships between variables or to confirm the hypotheses about underlying structures. The technique is particularly well-suited to defining "coherent structures in a variety of situations" *(Berry, 1971)* and can aid in constructing typologies (archetypes) "on a stable empirical base rather than on ad hoc impressions" *(Jones and Jones, 1970)*. The use of factor analysis in helping to understand urban areas dates back to at least the 1960s.

A data reduction technique, factor analysis studies the correlations among a large number of inter-related variables by grouping the variables into a few factors. To conduct this analysis for urban transportation across the globe, we utilized the Millennium Transportation Database, developed by researchers at Murdoch University's Institute for Sustainability and Technology Policy. It should be pointed out that in this database it is not entirely clear where the data comes from and which data is actual data versus data derived from assumptions. To utilize the data, we had to pare down the original database of 229 variables for 100 cities, to account for incomplete data for many cities (particularly developing country cities). We also attempted to eliminate repetitive variables, consolidate some variables (i.e., on forms of rail transit) and strike a balance between the number of cities represented and the number of variables present. The final dataset used for factor analysis consisted of 54 variables on 83 cities. In this process, a number of developing country cases was lost (see Table A.4).

Using the factor analysis technique of principal components (and Varimax Rotation), we analyzed the variation in transportation variables across the 83 cities, aiming to understand how the cities vary based purely on transportation system characteristics (vehicles/capita, mode share, energy consumption, etc.) and thereby attempting to reveal an underlying fundamental structure. Ultimately, we selected nine factos that accounted for 70% of the cumulative variance in the data. The meaning of the factors is suggested by relative loading of the variables (we selected variables with loading greater than 0.6). Table A.5 shows these factors and the principal contributing variables.

The results of the factor analysis essentially confirm "intuition" and suggest the need for an archetype to represent many dimensions in order to effectively capture the range in variation in the cities' fundamental structure. And, this analysis only considers transportation variables; adding even a few non-transportation variables further complicates the dimensionality. In order to effectively select representative archetype cases, we also need to capture "qualitative factors" that are important to city representation in the "Archetypes," such as region (i.e., Africa, Asia, demographics, and socioeconomic. Again, this introduces a challenge of multi-dimensionality; the more aspects to consider, the more subjective the ultimate decision becomes. Ultimately, as discussed in the Introduction to this Synthesis Report, we chose an approach to case selection that balanced intuition, data availability, geographic coverage, among other factors.

Table A.3 City types in the global system		
City Type	**Found In**	**Characteristics**
Informal Hypergrowth	Sub-Saharan Africa, India, Muslim Middle East and poorer Latin America	Rapid population growth (migration and natural), informal sector-dependent economy, widespread poverty, widespread informal housing, basic environment and public health problems, governance problems.
Dynamic Growth	Middle income rapidly-developing world (Eastern Asia, Latin America and Middle East).	Population growth slowing, aging population increasing, ongoing rapid economic growth, environmental problems.
Weakening Mature City with Aging	OECD	Stable or declining population, aging and household fissioning, slow economic growth and adaptation, social polarization, widespread dispersion and reconcentration, spurring smaller city growth in area of influence of major urban poles.

Source: **Hall and Pfeiffer 2001**.

Table A.4 Major factors influencing transportation in the developing world	
Factor	**Characteristic**
Authority	Degree of centralization
Policy Environment	Enforcement capability, drivers (i.e., air pollution)
Land Use Patterns	Densities, extension, constraints
Social Norms	"Group Orientation"
Interest Groups Strength	Businesses, NGOs, etc.
Infrastructure Precedents	Concessions, investment climate

Source: Derived from **Sperling and Salon 2002**.

Table A.5 Factors accounting for transport system variation across 83 cities			
Factor	**Total Variance Explained**		**Major Contributing Variables**
	% of Variance	**Cumulative %**	
Auto Transport	19.74	19.74	Road density, cars/capita, average road speed, trips/capita, CO emissions, auto energy consumption
Motorcycle	9.14	28.88	Motorcycles /capita, intensity of motorcycle use
User Cost	8.49	37.36	Average cost per trip, average cost of public transit trip, percentage of GDP on private transport operating cost
Bus Transport	6.80	44.17	Buses/capita, bus VKM/capita, price of fuel/kilometer, public transport energy use
Pollutant Emissions	5.75	49.91	CO/capita, SO2/capita, NOx/capita, VOC /capita
Extent of Public Transport	5.11	55.02	Kilometer of public transport line, average distance of public transport trip
Trip Distance and Time	4.93	59.95	Average trip distance, car trip distance, car trip time
Bus Priority	4.21	64.17	Bus route priority per capita and per hectare
Infrastructure Investment	3.89	68.06	Percent of GDP on public transport investment, percent GDP on road investment

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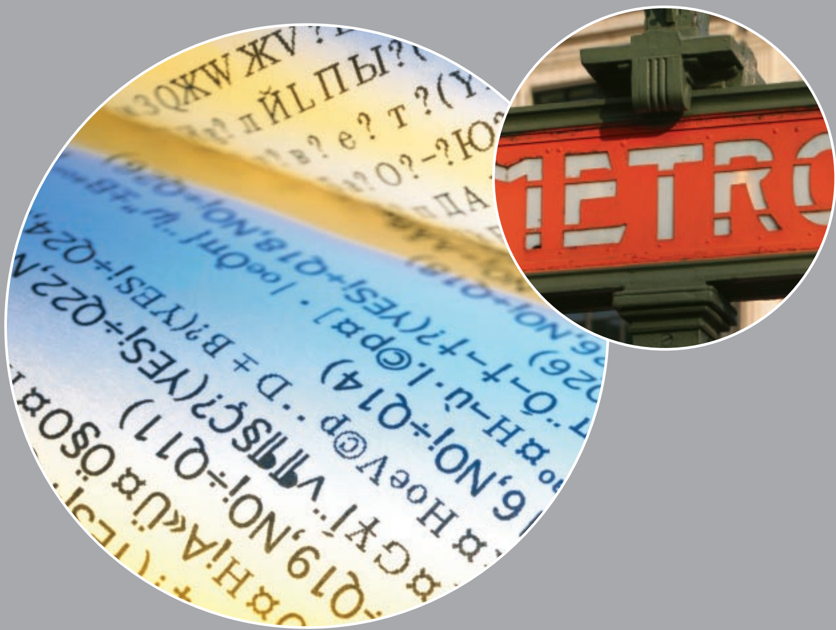

Abbreviations

glossary of terms

Abbreviations

AC – Alternating current

ADAS – Advanced Driver Assistance Systems

AEO – Annual Energy Outlook (published by the US Energy Information Agency)

ASK – Available seat kilometre

BAC – Blood alcohol content

BTL – Biomass To Liquids

CAFE – Corporate Average Fuel Economy

CAI – Controlled Auto Ignition

CIDI – Compression Ignition Direct Injection

CIF – Cost, insurance and freight

CNG – Compressed natural gas

CO – Carbon monoxide

CO2 – Carbon dioxide

COE – Certificate Of Entitlement (Required to purchase vehicle in Singapore)

CONCAWE – Conservation Of Clean Air And Water In Europe

CRA – Charles River Associates

CTS – Cybernetic Transport Systems

CVT – Continuously Variable Transmission

DALY – Disability-Adjusted Life Years

DC – Direct current

DfT – Department for Transport (UK)

DI – Direct Injection

DME – Di-Methyl Ether

DPF – Diesel Particulate Filter

DRL – Daytime Running Lights

DTLR – Department Of Transport, Local Government And The Regions (UK)

DWI – Driving while intoxicated (Drinking And Driving)

ECMT – European Conference Of Ministers Of Transport

EEA – European Environment Agency

EMD – Electro-Motive Division (Division of General Motors)

EU – European Union

EU-15 – Group Of The Following Countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom

EU-25 – Eu-15 + Acceding Countries (Cyprus, Czech Republic, Estonia, Hungary, Lativa, Lithuania, Malta, Poland, Slovak Republic, And Slovenia)

EUCAR – The European Council For Automotive Research & Development

EV – Electric Vehicle

FAME – Fatty Acid Methyl Esters (see "biodiesel" in glossary)

FCV – Fuel Cell Vehicles

FKA – Forschungsgesellschaft Kraftfahrwesen mbH Aachen (German Research Institute)

FSU – Former Soviet Union (Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, And The Baltics (Estonia, Latvia, And Lithuania)

F-T – Fischer-Tropsch

G-7 – Group Of Countries Made Up Of the US, Canada, France, Germany, Italy, UK, and Japan.

GDP – Gross Domestic Product

GHG – Greenhouse gas (see glossary)

GNI – Gross National Income

GTL – Gas to liquids (see glossary)

HOT – High Occupant Toll (see glossary)

HOV – High Occupant Vehicle (see glossary)

ICE – Internal combustion engine

IEA – International Energy Agency

IMF – International Monetary Fund

IMTS – Intelligent Multimode Transit System

INRIA – French National Institute For Research In Computer Science And Control

IPAI – International Primary Aluminium Institute

ITS – Intelligent Transport Systems (see glossary)

JRC – Joint Research Centre Of The European Commission

kg – Kilogram

LDV – Light Duty Vehicle (see glossary)

LNG – Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

LTR – Light Rail Transit

MCMA – Mexico City Metropolitan Area

MG – Milligram

MIT – Massachusetts Institute Of Technology

MJ – Megajoules

ML – Milliliter

MRT – Mass Rapid Transit

MV – Motor Vehicle

NBER – National Bureau Of Economic Research

NEDC – National Economic Development Council (UK)

NOX – Various Oxides of Nitrogen

OECD – Organisation For Economic Co-Operation and Development

OEM – Original Equipment Manufacturer

OPEC – Organization For Petroleum Exporting Countries

Pb – Lead

PEM – Proton Exchange Membrane

PERS – Porous Elastic Road Surface

PGMS – Platinum Group Metals

PISI – Port Injection Spark Ignition

PKM – Passenger-Kilometers

PM-10 – Particulates Having A Diameter Of 10 Microns Or Greater

PPM – Parts Per Million

PPP – Purchasing Power Parity

PRT – Personal Rapid Transit

RME – Rapeseed Methyl Ester

RPK – Revenue Passenger Kilometer

SMP – Sustainable Mobility Project

SOX – Sulfur Dioxide

SUV – Sport Utility Vehicles

TCRP – Transit Cooperative Research Program (US)

TDM – Traffic Demand Management

TKM – Tonne-Kilometers

TONNE – Metric Ton

TRB – Transport Research Board (US)

TRC – Tire-Road Contact

TTW – Tank-To-Wheels

USEIA – US Energy Information Agency

V/C – Ratio Of The Average Projected Traffic Volume Over An Element Of Infrastructure To The Infrastructure's Rated Capacity

VAL – Light Automatic Vehicle - Is A Fully Automated, Unattended Metro System

VMS – Variable Message Signs

VOC – Volatile Organic Compound

WBCSD – World Business Council For Sustainable Development

WEO – World Energy Outlook (published by the International Energy Agency)

WHO – World Health Organization

WTT – Well-To-Tank

WTW – Well-To-Wheels

Glossary of terms

Alcohol fuels – See “ethanol” and “methanol.”

Anthropogenic – Resulting from or produced by human beings.

Biodiesel – Biodiesel, also known as Fatty Acid Methyl Esters (FAME), is produced from vegetable oils, usually via the base-catalysed transesterfication of the oil with methanol and sodium hydroxide. This removes the glycerine from the oil, which is necessary to conform to fuels standards. The first biodiesel to be produced commercially was manufactured from rapeseed (or canola) in 1988.

Bio-fuels – Fuels produced from biomass crops and wastes. The main biofuels are synthetic diesels, which can be burned in compression ignition (diesel) engines, and bioethanol, which can be burned in spark ignition (gasoline, or petrol) engines.

Biomass –the term “biomass” covers a wide range of energy crops such as corn, soybeans, sugar, poplar, willow and switchgrass, as well as agricultural waste and forestry residues. It also includes landfill gas and municipal solid waste. Biomass can be used for conversion into liquid fuels, such as ethanol, methanol, biodiesel and F-T diesel, and also electricity and hydrogen.

Biomass gasification – the production of synthesis gas from biomass.

Carbon neutral – Emitting no net carbon into the atmosphere.

Choke points – points in an infrastructure network where congestion is especially likely to occur due to the convergence of traffic or the reduction in the capacity of the infrastructure.

Carbon sequestration – the addition of carbon containing substances to a reservoir.

Compressed natural gas (CNG) – Natural gas (see below) in gaseous form stored at high pressure.

Conventional pollutants – Substances emitted by the combustion or evaporation of fuels that, either individually or in combination, produce health effects in humans at certain concentrations. The term “conventional pollutants” is generally used to refer to emissions of carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), sulfur oxides (SOx), and unburned hydrocarbons (HC). The latter are sometimes referred to as volatile organic compounds (VOCs) or non-methyl organic gases (NMOG).

Cryogenic tanks – tanks designed to hold extremely cold liquids (e.g., liquid hydrogen).

Dieselization – the use of diesel engines to power transport vehicles.

Di-methyl ether (DME) – Currently used as a chemical solvent and as a propellant in aerosols, but not as a transport fuel. A combination of methanol and DME has been suggested as an alternative fuel for diesel engines, as has “neat” (i.e., 100%) DME, which is sulfur-free, low aromatic fuel, and offers potentially better local emissions characteristics than diesel. DME has also been suggested as a potential replacement for LPG and LNG.

Economies of scale – reduction in unit costs resulting from a greater rate of output per unit of time. Differs from “experience curve” in that the latter refers to reduction in unit costs resulting from cumulative production of a product.

Electrochemical – The production of electricity by chemical changes.

Enzymes – Any of various proteins originating from living cells and capable of producing certain chemical changes in organic substances by catalytic action.

Ethanol (C2H5OH) – Otherwise known as ethyl alcohol, alcohol, or grain-spirit. A clear, colorless, flammable oxygenated hydrocarbon. In transportation, ethanol is used as a vehicle fuel by itself (E100 – 100% ethanol by volume), blended with gasoline (E85 – 85% ethanol by volume), or as a gasoline octane enhancer and oxygenate (10% by volume.)

Fatty Acid Methyl Esters (FAME) – See “biodiesel”.

Feedstock logistics – the process of gathering raw materials for the production of fuel.

Fossil CO2 emissions – emissions of CO2 resulting from the combustion of fuels from carbon deposits such as oil, gas and coal.

FT gasoline – A fuel manufactured from natural gas using the Fischer-Tropsch process for use in spark-ignition engines.

Fuel cell – An electrochemical device that continuously changes the chemical energy of a fuel (hydrogen) and oxidant (oxygen) directly to electrical energy and heat, without combustion. The electrical process causes hydrogen atoms to give up their electrons. It is similar to a battery in that it has electrodes, an electrolyte, and positive negative terminals. It does not, however, store energy as a battery does. Because there is no combustion, fuel cells give off few emissions; because there are no moving parts, fuel cells are quiet. Fuel cells can be used in stationary applications like generating electricity or heating buildings, and for powering vehicles, buses and trains.

Fuel cell stacks – A collection of fuel cells. To produce power in large amounts, many fuel cells are combined into a fuel cell stack.

Fuel infrastructure – Systems that distribute fuel from its point of production to the point at which it is put into a transport vehicle.

Gas to Liquids – The process of producing liquid fuels (either gasoline or diesel) from natural gas. The first step is the production of natural gas to hydrogen and carbon monoxide by partial oxidation, steam reforming, or a combination of the two processes. The product, known as sythesis gas (or syngas) is then converted to a liquid hydrocarbon by a chain growth reaction of carbon mononide and hydrogen on the surface of a heterogeneous catalyst. The catalyst is either iron- or cobalt-based and the reaction is highly exothermic (i.e., heat-generating). The temperature, pressure, and catalyst determine whether a light or heavy synthetic crude is produced. At 330 C mostly gasoline and olefins are produced, whereas at 180 to 250 C, mostly diesel and waxes are produced.

Greenhouse gas – Those gaseous constituents of the atmosphere, both natural and anthropogenic (i.e., resulting from or produced by human beings), that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surfaces, the atmosphere and clouds. Water vapor (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) and the primary greenhouse gases in the Earth’s atmosphere. There are several entirely human-made greenhouse gases. Regulatory attention has focused on sulphur hexaflouride (SF6), hydrofluoro-carbons (HFCs) and perfluorocarbons (PFCs)

Harsh road environments – Operating conditions in which roads are unpaved, poorly maintained, and/or little more than trails.

Heavy road vehicles – Generally refers to freight trucks larger than small delivery vans, intercity buses, and public transport buses.

High emitter – A vehicle that emits considerably more “conventional” pollutants than permissible under the emissions standard to which the vehicle was certified. There is no single definition that is universally accepted. The US EPA defines “high emitter” as a vehicle emitting a level of emissions at least twice (for some pollutants, three times) the standards to which they were certified. In the work of Professor Stedman and his colleagues, “high emitters” are defined as the “dirtiest 10%” of vehiciles.

High expansion cycle engine – an engine in which the expansion ratio is higher than the compression ratio.

Homogeneous Charge Compression Ignition (HCCI) – A relatively new combustion technology that is a hybrid of the traditional spark ignition (SI) and the compression ignition process (such as a Diesel engine). Unlike a traditional SI or Diesel engine, HCCI combustion takes place spontaneously and homogeneously without flame propagation. This eliminates heterogeneous air/fuel mixture regions. In addition, HCCI is a lean combustion process. These conditions translate to a lower local flame temperature, which lower the amount of Nitric Oxide (NOx) produced in the process.

HOV Lane – A traffic lane limited to carrying high occupancy vehicles and certain other qualified vehicles. A high occupancy vehicle (HOV) is a vehicle carrying more than a minimum specified number of passengers. HOVs include carpools, vanpools, and buses. HOV requirements are often indicated as 3+ (three or more passengers required) or 4+ (four or more passengers required).

HOT Lane – HOV facilities that allow lower occupancy vehicles, such as solo drivers, to use the facility if they pay a toll. This offers users three options: drive alone on an unpriced but congested general purpose lane, drive alone and pay to use a less congested lane, or rideshare (carpool, vanpool or ride transit) to use a less congested lane without any additional fee.

Hybridization – The process of using multiple propulsion devices (e.g., a spark ignition engine and one or more electric motors) to propel a vehicle.

Intelligent transport systems (ITS) – Intelligent transportation systems encompass a broad range of wireless and wireline communications-based information, control and electronics technologies. When integrated into the transportation system infrastructure, and in vehicles themselves, these technologies help monitor and manage traffic flow, reduce congestion, provide alternate routes to travellers, enhance productivity, and save lives, time and money.

Internal combustion engine – An engine that transforms fuel into mechanical energy by means of combustion inside a cylinder.

Light duty vehicle – Passenger cars and other light personal-use vehicles. In the UK, includes 4-wheeled and 3-wheeled cars, Land Rovers, Jeeps, minibuses, motorcaravans, dormobiles and light vans. In the US, includes passenger cars, pickups, SUVs, and minivans under 10,000 pounds (4546 kg) gross vehicle weight. Does not generally include powered two and three-wheelers.

Lean burn engine – A lean burn engine is designed to operate with a very lean air-fuel ratio during light load conditions. Most modern gasoline engines are controlled to run at a chemically correct (stoichiometric) air fuel ratio (about 14.7:1) to make the three-way catalyst operate at high efficiency, reducing tail-pipe emissions. Lean burn engines mix more air with the fuel when full power is not needed, resulting in better fuel economy. Air/fuel ratio in lean burn engines can be as high as 22:1. When full power is needed, such as during acceleration or hill climbing, a lean burn engine reverts to a stoichiometric (14.7:1) ratio or richer.

Lignocellulosic material – Any of various compounds of lignin and cellulose comprising the essential part of woody cell walls of plants.

Liquefied petroleum gas (LPG) – A mixture of hydrocarbons, primarily propane and butane, with some propylene and butylenes. The gas is a by-product of oil and gas extraction, and of oil refining. LPG is gaseous at standard temperature and pressure, but can be liquefied at pressures of up to 6-8 bar, and is normally stored and transported in liquid form.

Methanol (CH3OH) – A colorless highly toxic liquid essentially no odor and very little taste. In transportation, methonol is used as a vehicle fuel by itself (M100 – 100% methanol) or blended with gasoline (M85 – 85% methanol).

Naptha – A colorless, volatile petroleum distillate, usually an intermediate product between gasoline and benzene, used as a solvent, fuel, etc.

Natural gas – A mixture of hydrocarbon compounds, primarily methane (CH4), and small quantities of various non-hydrocarbons existing in the gaseous phase or in solution with crude oil in natural underground reservoirs at reservoir conditions.

Noise barriers – Structures constructed adjacent to a road, railway line, or airport to reduce noise from transport vehicles using the facility.

Paratransit – Literally, "alongside transit." It includes all public and private mass transportation in the spectrum between the private automobile and conventional public transport.

Powered 2 and 3 wheeler – A two or three-wheeled vehicle powered by some form of motor or engine. Includes, among other vehicles, motorcycles and scooters.

Powertrain – All the components between a road vehicle's engine and wheels.

Proton electric membrane (PEM) fuel cell. – Considered the most promising fuel-cell technology for use in vehicles. PEM fuel cells use a proton (a hydrogen ion) conducting solid membrane -- much like kitchen plastic wrap -- as the electrolyte. The solid membrane allows the PEM fuel cell to be smaller and operate cooler than liquid electrolytes used in alkaline and phosphoric acid fuel cells.

Rolling resistance – A measure of the amount of resistance that is generated as a tire rolls on the road surface.

Spark ignition engines – Engines that ignite their fuel using a spark plug.

Steam reforming of natural gas – A process by which steam at a temperature of 700-1,100 °C is mixed with methane gas in a reactor with a catalyser at 3-25 bar pressure. Steam reforming of natural gas is currently the least expensive method of producing hydrogen, and used for about half of the world's production of hydrogen. In steam reforming of natural gas, 7.05 kg CO2 are produced per kilogram hydrogen.

Telematics – A general term referring to emerging technologies in automotive communications, combining wireless voice and data capability for management information and safety applications. Applications include vehicle-based electronic systems, mobile telephony, vehicle tracking and positioning, on-line navigation and information services and emergency assistance.

Water electrolysis – The production of hydrogen from water using electricity.

Assurance Group statement

An Assurance Group was established to advise the WBCSD Secretariat on the quality and integrity of both the substance and the process of the Mobility Project. The membership of the Group was: Rt Hon Simon Upton (Chair), Mr. David Ashley, Professor John Heywood, Professor Peter Jones, Professor Suzana Kahn Ribiero and Professor Martin Wachs. The Assurance Group also benefited from the advice of Professor Akio Morishima.

Statement of the Assurance Group

The Assurance Group has contributed advice on the process, scope and conclusions of the Mobility Project to assist the WBCSD Secretariat in its monitoring of the project.
We believe that the Project has been well served by Dr George Eads whose task it has been to stay abreast of a vast and rapidly expanding literature as well as to work closely with the participating companies.

A project that embraced so many key players was always going to pose a challenge to those charged with finding a consensus view. Bearing in mind the inevitable constraints of a project of this size and complexity, we believe the companies have provided a useful contribution to the evolving debate on how the pressures placed on human communities and the environment by the mobility sector - in particular the road transport sector - should be understood and where potential solutions may lie.

The Group has enjoyed free and frank exchanges with the project team throughout the life of the study with a view to making the participating companies aware of any limitations or shortcomings in the approaches they have chosen. It is not, however, the role of the Assurance Group to endorse the final report of the project or its conclusions. The report represents the views of the member companies.

Given the expertise of the companies it is not surprising that the report's main focus is on the contribution vehicle and fuel technologies can make to a more sustainable mobility system. Other issues, particularly those related to demand management, are less fully developed. While the report acknowledges the dominance of developing country growth in influencing the future shape of mobility, it has been hampered by a lack of data.

That said, we believe the report identifies many of the key issues that societies concerned with the future of mobility must confront. If the very significant investment that the report represents is to be turned to advantage, the challenges raised by it will need to be taken up with a sense of urgency by the participating companies, by related sectors, by governments and by the broader public.

Acknowledgements

Many people have contributed to the Sustainable Mobility Project during the past four years. They have generously given of their time, contributed new perspectives, and helped to pull together this report. Listed below are the individuals that represented their companies in the Working Group and Workstreams, as well as supporting consultants and analysts, members of the Assurance Group, and the WBCSD project secretariat staff. In addition the sponsor companies have called upon the expertise of many people working within their respective firms. These individuals are not named here but have provided information, feedback and other support. Many stakeholders have also given valuable advice and comments at workshops, dialogues and other forums. To all contributors – named as well as unnamed – we express our sincere thanks.

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About the WBCSD

The World Business Council for Sustainable Development (WBCSD) is a coalition of 170 international companies united by a shared commitment to sustainable development via the three pillars of economic growth, ecological balance and social progress.

Our members are drawn from more than 35 countries and 30 major industrial sectors. We also benefit from a global network of 50 national and regional business councils and partner organizations involving some 1,000 business leaders.

Our mission

To provide business leadership as a catalyst for change toward sustainable development, and to promote the role of eco-efficiency, innovation and corporate social responsibility.

Our aims

Our objectives and strategic directions, based on this dedication, include:

Business leadership

> to be the leading business advocate on issues connected with sustainable development

Policy development

> to participate in policy development in order to create a framework that allows business to contribute effectively to sustainable development

Best practice

> to demonstrate business progress in environmental and resource management and corporate social responsibility and to share leading-edge practices among our members

Global outreach

> to contribute to a sustainable future for developing nations and nations in transition

What is the Sustainable Mobility Project

The Sustainable Mobility Project is a member- led project of the World Business Council for Sustainable Development (http://www.wbcsd.org). The project develops a global vision covering the sustainable mobility of people, goods and services in road transport. The project shows possible pathways towards achieving sustainable mobility that will address environmental and economic concerns if society is prepared to recognize the issues and act upon them.

Disclaimer

Mobility 2030 has resulted from collaborative work among executives from the twelve member companies of the WBCSD's Sustainable Mobility Project, sponsored by the WBCSD as a member-led initiative and supported by the WBCSD secretariat. Like other WBCSD projects, the SMP has involved extensive stakeholder engagement in locations around the world. Prepared with the help of Charles River Associates and several other consultants, the report was reviewed by all project members to ensure broad general agreement with its principal views and perspectives. However, while a commendable level of consensus has been achieved, this does not mean that every member company necessarily endorses or agrees with every statement in the report.

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