

# Urban Mobility in the 21st Century

November 2012



Prepared by

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## **A Report for the NYU BMW i Project on Cities and Sustainability**

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*BMW i is BMW's forward-thinking and sustainable brand dedicated to the development of progressive new vehicles and services aimed at solving the mobility challenges facing the world's most densely populated cities. The first two vehicles under the BMW i banner, the BMW i3 and BMW i8 will represent the first two purpose built electric and hybrid electric production vehicles to be made primarily from carbon fiber when they come to market in 2013 and 2014, respectively. However, the overarching purpose of BMW i is to work towards increasing freedom of mobility for individuals whether it be by car, train, bus or foot.*

# Introduction

Between 2010 and 2050, the number of people living in the world's urban areas is expected to grow by 80 percent – from 3.5 billion to 6.3 billion. This growth will pose great challenges for urban mobility – for the networks of transportation facilities and services that maintain the flow of people and commerce into, out of and within the world's cities.

Addressing the challenge of urban mobility is essential – for maintaining cities' historic role as the world's principal sources of innovation and economic growth, for improving the quality of life in urban areas and for mitigating the impact of climate change. It will require creative applications of new technologies, changes in the way transportation services are organized and delivered, and innovations in urban planning and design.

This report examines several aspects of the challenge of urban mobility in the twenty-first century – the growth of the world's urban population, and changes in the characteristics of that population; emerging patterns of urban mobility; and changes in technology design and connectivity.

The report was prepared by the Rudin Center for Transportation Policy and Management at New York University's Robert F. Wagner Graduate School of Public Service with the assistance of Appleseed, a New York City-based consulting firm.

# 1

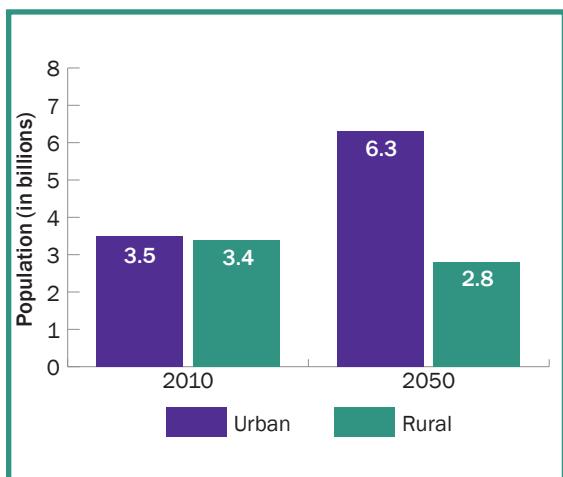
## Urban Growth in the 21st Century

Urban mobility during the next thirty years will be influenced by changes in the demography of cities across the globe, in conjunction with related cultural shifts that will affect urban residents' transportation choices. This part of the report focuses on three trends:

- The growth of the world's urban population;
- Growth in the number of single-person households; and
- The aging of the urban population.

### A world of cities

**Figure 1: Urban and rural population (in billions), 2010-2050**



In 2010, according to the United Nations Population Division, the world crossed a significant demographic threshold: For the first time in history, the number of people living in cities exceeded the number living in rural areas. This trend is expected to continue. The U.N. Population Division estimates that between 2010 and 2050 the world's urban population will grow by 80 percent – from 3.5 billion to 6.3 billion. During the same period the number of people living in rural areas is expected to decline by about 18 percent – from 3.4 billion to 2.8 billion.<sup>1</sup>

<sup>1</sup> U.N. Population Division, *Population Distribution, Urbanization, Internal Migration and Development: An International Perspective*, 2011, p. 1.

**Table 1: World's 25 largest cities (2012 estimates)**

	City	Country	Population	Population/ km <sup>2</sup>
1	Shanghai	China	17,836	6,845
2	Istanbul	Turkey	13,483	2,481
3	Karachi	Pakistan	13,052	5,700
4	Mumbai	India	12,478	20,694
5	Moscow	Russia	11,810	4,705
6	Beijing	China	11,716	7,400
7	Sao Paulo	Brazil	11,316	7,383
8	Tianjin	China	11,090	1,494
9	Guangzhou	China	11,071	2,881
10	Delhi	India	11,008	7,923
11	Seoul	South Korea	10,575	17,473
12	Shenzhen	China	10,358	5,201
13	Jakarta	Indonesia	9,588	14,476
14	Tokyo	Japan	8,888	14,700
15	Mexico City	Mexico	8,873	5,973
16	Kinshasa	Congo	8,754	4,342
17	Tehran	Iran	8,430	10,359
18	Bangalore	India	8,426	11,876
19	New York City	United States	8,245	10,519
20	Dongguan	China	8,220	3,335
21	London	United Kingdom	8,174	4,863
22	Lagos	Nigeria	7,938	7,938
23	Lima	Peru	7,606	2,848
24	Bogota	Colombia	7,468	4,697
25	Ho Chi Minh City	Vietnam	7,163	3,419

**Table 2: Large urban areas (minimum estimated population of 2 million as of 2012) with highest projected average annual rates of population growth, 2006-2020**

	City	Country	2012 population (est.), in 000's	Average annual population growth (%), 2006-2020
1	Sana	Yemen	2,497	5.00
2	Surat	India	4,687	4.99
3	Kabul	Afghanistan	3,327	4.74
4	Lagos	Nigeria	11,547	4.44
5	Dar-es-Salaam	Tanzania	3,676	4.39
6	Chittagong	Bangladesh	2,985	4.29
7	Luanda	Angola	5,204	3.96
8	Kinshasa	Congo	9,046	3.89
9	Nairobi	Kenya	3,479	3.87
10	Dhaka	Bangladesh	15,414	3.79
11	Antananarivo	Madagascar	2,006	3.73
12	Patna	India	2,093	3.72
13	Jaipur	India	3,140	3.60
14	Maputo	Mozambique	2,584	3.54
15	Delhi	India	22,242	3.48
16	Pune	India	5,156	3.46
17	Addis Ababa	Ethiopia	3,112	3.40
18	Indore	India	2,215	3.35
19	Faisalabad	Pakistan	3,111	3.32
20	Rawalpindi	Pakistan	3,047	3.31
21	Karachi	Pakistan	20,711	3.19
22	Asuncion	Paraguay	2,158	3.17
23	Lahore	Pakistan	7,734	3.12
24	Riyadh	Saudi Arabia	5,037	3.09
25	Dakar	Senegal	3,092	3.06
26	Jakarta	Indonesia	26,063	3.03
27	Brasilia	Brazil	2,362	2.99
28	Port-au-Prince	Haiti	2,266	2.98
29	Jeddah	Saudi Arabia	3,351	2.93
30	Accra	Ghana	3,792	2.93

Sources: Demographia, Demographia World Urban Areas, January 2012; [www.citymayors.com](http://www.citymayors.com)

Most of this growth in the world's cities will be concentrated in developing countries. From 2010 to 2050 the urban population of these countries will double – from 2.6 billion to 5.2 billion. In developed countries, the number of people living in urban areas will grow from 900 million to 1.1 billion. Developing countries will account for about 93 percent of all growth in urban populations worldwide.

The central role of developing countries in the growth of the world's cities is widely recognized. Table 1 lists the 25 largest cities as of 2012.<sup>2</sup> As the table shows, all but five of these cities (Moscow, Tokyo, Seoul, New York and London) are located in developing countries.

The role of developing countries in the growth of the world's urban population is especially striking when we focus on where cities are growing most rapidly. Table 2 lists 30 urban areas with populations of at least 2 million that are projected to experience the fastest growth between 2006 and 2020.<sup>3</sup> They are heavily concentrated in South Asia and Africa, with some located in the Middle East and South America. No European or North American cities make the list.

In addition to accounting for most of the world's largest cities (and virtually all of the fastest-growing), developing countries are home to a majority of the world's most densely populated cities. Fourteen of the fifty largest cities have densities of more than 10,000 residents per square kilometer, all but two of which (Tokyo and New York) are located in developing countries.

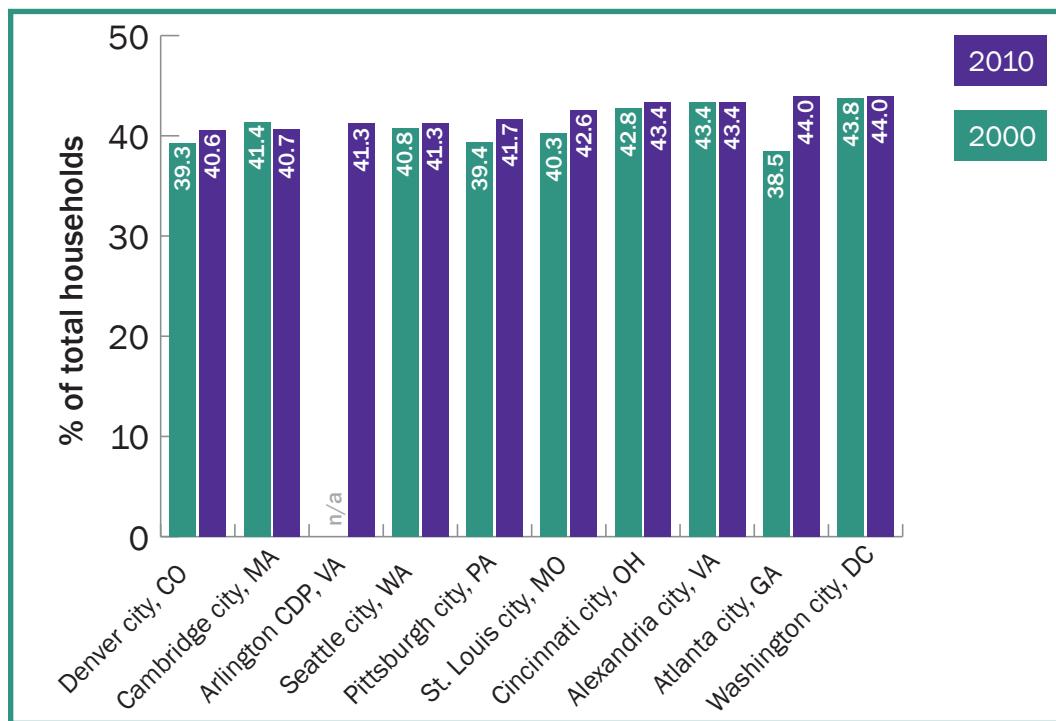
While urban densities can vary greatly from country to country, it is clear that much of the projected growth in the world's cities will occur in areas – including South and Southeast Asia and parts of Africa – that are generally characterized by very high urban densities.

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2 Ranking of cities by population is complicated by country-to-country variations in the reliability of current estimates, and by the lack of consistent standards for defining what constitutes a city. The figures used in Table 1 are generally based on municipal or other core city boundaries, rather than broader urbanized or metropolitan areas or provinces.

3 "Urban areas" as used in Table 2 are broader than the city definitions used in Table 1; they are generally comparable to metropolitan areas, as that term is used in the U.S.

**Figure 2: Top ten cities of 100,000+ population with the highest percentage of one-person households: 2000 and 2010**



Source: U.S. Census Bureau, 2010 Census Summary File 1

## The rise of single-person households

One of the most notable trends during the past decade has been the growth of single-person households – both in absolute numbers and as a percentage of all households. Figure 2 shows the top ten cities ranked by single-person households as a percentage of all households as of 2010, and the increase in single-person households' share of total households between 2000 and 2010. In both Washington D.C. and Atlanta, singles account for 44 percent of all households.

Atlanta is particularly notable for the growth in singles relative to total households – between 2000 and 2010 singles grew from 38.5 to 44.0 percent of all households. Other cities with high ratios of or a notable increase in singles as a share of all households include Washington D.C., Pittsburgh and St. Louis.

**Figure 3: Proportion of single-person households by region: 2001 and 2011**



Source: Euromonitor International from national statistics

This trend is not solely a U.S. phenomenon. As Figure 3 shows, the rise in the number of people living alone is a worldwide trend. In Western Europe, single-person households are a larger percentage of total households (31 percent) than they are in North America. In Asia, Eastern Europe and Latin America, single-person households represent a smaller share of all households than they do in Europe or North America – but in all three regions, singles' share of all households is growing more rapidly.

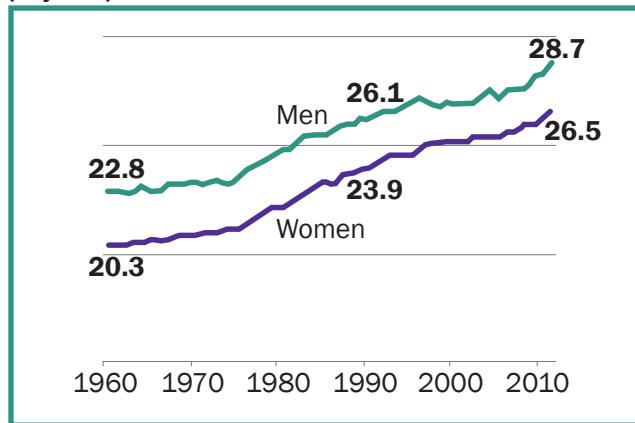
Several factors are responsible for the global trend toward single living.

- In developed and developing countries alike, a growing number of young adults are marrying later, or not at all. In the U.S. for example, the median age at which men first get married has risen from 22.8 in 1960 to 28.7 in 2010; for women, the median age of first marriage rose from 20.3 to 26.5.<sup>4</sup>
- The percentage of all adults who report that they have never been married is also rising. In 1960 only 15 percent of all U.S. adults reported that they had never been married; by 2010, the “never married” group had risen to 28 percent of the adult population.<sup>5</sup>

4 D’Vera Cohen, Jeffrey Passel, Wendy Wang, Gretchen Livingston, *Barely Half of U.S. Adults Are Married – A Record Low*, Pew Research Center, December 14, 2011, p. 2

5 Ibid.

**Figure 4: Median age at first marriage, 1960-2011  
(in years)**



Source: Current Population Survey, March and Annual Social and Economic Research Supplements (PEW Research Center)

As with the trend toward single living, the trend toward later marriage is a worldwide one. A U.N. report published in 2011 found that since the 1970's, the age at which women marry had risen in 75 out of 77 countries studied.<sup>6</sup>

Increased participation of women in the workforce reinforces this trend. It means that more women are free to delay marriage, to remain single – or, because they are less dependent on their husbands' income, to seek a divorce.

As the population ages, there is a natural progression from aging couples to aging singles – especially given differences in life expectancy between men and women. In 2009, according to the Centers for Disease Control, average life expectancy in the U.S. was nearly five years greater for women (80.9 years) than for men (76.0 years).

Overall, Americans age 65 and older account for 36 percent of all single-person households in the U.S. However, this overall statistic masks two divergent trends. In many cities with high concentrations of single-person households, the growth of this demographic group is being driven by young single people moving into the city – while in many rural areas (especially in the Midwest and Plains states) and some smaller cities, the growth in single-person households is driven primarily by older residents who stay behind.<sup>7</sup>

<sup>6</sup> United Nations Population Division, *World Fertility Report 2009*, United Nations, 2011, p. xii  
<sup>7</sup> U.S. Census Bureau, *Households and Families: 2010*, 2010 Census Briefs, April 2012 pp. 11-15.

**Table 3: Population projections, selected major U.S. cities, 2010-2030**

	2010		2030		<b>Growth in share of total population</b>	<b>% of projected growth in total population</b>		
	Total population	Population age 65+	Total population	Population age 65+				
Chicago (Cook county)	8,956,456	994,617	11.1%	10,372,988	1,826,017	17.6%	6.5%	58.7%
Charlotte (Mecklenburg county)	923,144	82,132	8.9%	1,268,257	188,312	14.8%	6.0%	30.8%
Seattle (Kings county)	1,931,249	210,679	10.9%	2,277,160	416,445	18.3%	7.4%	59.5%
Phoenix (Maricopa county)	4,217,427	506,409	12.0%	6,207,980	1,068,119	17.2%	5.2%	28.2%
New York City	8,175,133	993,158	12.1%	8,641,196	1,353,560	15.7%	3.5%	77.3%

Sources: County governments; Cornell Program in Applied Demographics; Appleseed calculations

## The aging of the urban population

Growth in the number of city residents age 65 and older – both in absolute terms and as a share of total population – has implications for urban mobility that go beyond those associated with growth in the number of single-person households. Older city residents have transportation needs and preferences and patterns of mobility that differ significantly from those of their younger counterparts.

In New York City, for example, between 2010 and 2030 the population age 65 and older is expected to grow by more than 36 percent – from 993,000 to 1,354,000. During the same period, older New Yorkers’ share of the City’s population is expected to grow from 12.1 percent to 15.7 percent. Between 2010 and 2030, people age 65 and older will account for more than 77 percent of the City’s total population growth.<sup>8</sup>

8 Cornell Program in Applied Demographics

This pattern is repeated in other U.S. cities. In some cases, the growth of the 65-and-older population is expected to be even greater than it will be in New York. In Cook County (Chicago) the 65-and-older population is expected to grow by 84 percent between 2010 and 2030 – and to account for 59 percent of total population growth during those years.

Like growth in the number of single-person households, the growth of the over-65 population is a worldwide phenomenon. The U.N. Population Division estimates that China's 65-and-older population will grow by 109 percent between 2010 and 2030 – from 109.8 million to 229 million.

**Table 4: Population projections, 65+, selected major urbanized countries, 2010-2030  
(in thousands)**

	2010		2030		% Change, 2010-2030
	Age 65+	%	Age 65+	%	
United States	40,534	13.1%	72,000	19.9%	97.83%
Canada	4,801	14.1%	9,147	23.0%	113.8%
Germany	16,775	20.4%	22,278	28.0%	42.63%
United Kingdom	10,290	16.6%	14,634	21.1%	60.08%
Russian Federation	18,297	12.8%	26,109	19.1%	44.34%
Turkey	4,348	6.0%	9,881	11.4%	215.0%
South Africa	2,324	4.6%	4,270	7.8%	105.7%
China	109,845	8.2%	229,446	16.5%	188.7%
India	60,278	4.9%	126,006	8.3%	184.6%
Japan	28,707	22.7%	36,404	30.3%	34.64%
Mexico	7,201	6.3%	15,826	11.7%	218.5%
Brazil	13,652	7.0%	30,160	13.7%	190.3%

Source: United Nations Population Division

## 2

# Emerging Patterns of Urban Mobility

Changes in urban demographics and in automotive technology, design and connectivity have significant implications for patterns of urban mobility, and how those patterns will evolve over the next thirty years.

## Implications for urban population growth

In 2010, the population of the world's urban areas for the first time surpassed 50 percent of the world's total population; by 2050, the U.N. Population Division estimates that nearly 70 percent of the world's population will live in urban areas. With the number of people living in these areas expected to increase by 80 percent, the ability to move people and goods within these areas will be critical – especially since nations around the world rely on their cities to be the primary sources of innovation, productivity and economic growth.

The concentration of urban growth in developing countries means that future approaches to improving urban mobility must consider the conditions of the cities in the developing world. This will require developments in mobility that are within reach of people at various income levels in these countries; and that are adapted to the extraordinary density that characterizes so many of these cities.

## The impact of single-person households

Growth in the number of single-person households in cities across the U.S. will change the way people travel. Single-person households generally spend a larger share of their total income on housing and related expenses (such as utilities), leaving fewer resources available to support car ownership.

At the same time, car ownership may be less necessary for single people living alone, or for couples without children. This may especially be the case in cities where alternatives to private automobile ownership – including public transit, car-sharing services, taxis and other for-hire vehicles and well-designed bike routes – are readily available.

For much of the twentieth century (especially in the post-World War II era), cars were for many young people more than just a means of transportation – they were a medium of social interaction. During the past decade, advances in digital and mobile communications technologies, especially in large cities, have resulted in the automobile being increasingly connected to the global information infrastructure. At the same time, access to automobiles is no longer defined by car ownership but is possible through car-sharing and other new techniques for accessing an automobile without formally purchasing a car.

## The aging of the urban population

Growth in the number of older residents will increasingly shape patterns of urban mobility. Many older Americans are particularly attracted to “walkable” city neighborhoods – those in which basic necessities as well as various amenities are available within a relatively short distance, and can be reached without a car. As the 65-and-older population grows, the spatial distribution of both public services and commerce may gradually shift to one that places greater emphasis on walkability.

A symbol of this change toward locally provided services is the recent announcement by Walmart – the largest American “get in the car and drive to the supercenter” retailer – that the company is accelerating the opening of new stores in its “neighborhood market” format. Walmart, which now has 170 neighborhood markets in the U.S. – stores of about 35,000 to 50,000 square feet, as opposed to 140,000 to 200,000 for conventional Walmart operations – plans to open 240 more in 2013, mostly in urban areas. The company is also experimenting with an even smaller urban format – Walmart Express, with stores of 10,000 to 15,000 square feet – but has not yet decided whether to go beyond the twelve it currently operates.

At the same time, there is going to be heightened demand for auto-based accessibility for the elderly with limited physical mobility. For both short and long trips within cities, the growth of the 65-and-older population could result in increased demand for taxis and other for-hire vehicles.

## Automobiles as contributors to the quality of urban life

Changes in automotive technology, design and connectivity will radically reduce the negative externalities traditionally associated with the use of private automobiles in urban areas. As described by Miller, Borroni-Bird and Burns, a new generation of smaller all-electric vehicles will consume less energy per passenger-mile, and emit less carbon per passenger mile, than conventional transit buses. And when traveling in “platoon” formation, these vehicles could potentially achieve higher throughput rates (the number of people who can be transported over a given length of roadway over a given period of time) than buses.

Moreover, these gains will be achieved while retaining (and possibly improving on) many of the advantages of private automobile use that are so valued by travelers, including flexibility of scheduling and routing, shorter travel times and privacy.

Urban planners have long criticized the automobile as a source of urban problems, yet a new generation of cars – specifically designed for use in densely developed and populated cities – could become a major contributor to the improved quality of life in cities around the world.

The advent of a new generation of automobiles – cars that do not harm the physical environment – represents a major turning point in urban mobility. Clearly, cities will continue to depend on a multiplicity of modes in the twenty-first century. Fixed rail systems, buses, ferries, bicycling and walking can all contribute to improvements in urban mobility. For many cities and urban regions, the best strategy is likely to be “all of the above,” in whatever combination best fits local conditions.

## Freeing up resources devoted to parking

Over time, smaller, more maneuverable cars will greatly reduce the amount of land and building space devoted to parking. Today’s typical on-street parking space, for example, could easily accommodate three of MIT’s CityCars. Efficiency gains in garages could be even greater, since the smaller size and greater maneuverability of these vehicles means that less space would need to be devoted to entry and exit ramps and interior circulation.

Increased use of car-sharing could also reduce somewhat the volume of land and building space needed for parking, since the average shared car spends more time in transit and fewer hours in a parking space than the average privately-owned vehicle.

Cities could benefit from reducing the space they devote to parking – most notably by freeing up space for other uses. For example, even in Manhattan – which in relative terms probably devotes less space to parking than any other major urban center in the U.S. – surface parking lots currently occupy about 85 acres; parking garages account for 9.3 million square feet of built space (more than the total square footage of the two original World Trade Center towers); and we estimate that on-street parking takes up nearly 39.5 million square feet of street space – more than 900 acres.<sup>9</sup> To put this in perspective, the amount of land devoted to on-street parking in Manhattan is in the aggregate larger than Central Park.

The fact that small urban vehicles need only one-third as much (or less) parking space as a conventional car does not, of course, mean that the amount of space devoted to parking can be reduced by two-thirds, since small urban cars won't completely replace larger urban vehicles, and the greater utility and efficiency of small cars could well result in a significant increase in the number of small vehicles in use in the city. Nevertheless, even a 20 to 25 percent reduction in space needed for parking could free up approximately 20 acres of essentially vacant land, about 2 million square feet of built space and 8 to 10 million square feet of street space.

## Changing investment needs

Changes in automotive design, technology and connectivity will also lead to major changes in the kinds of investments that are required to sustain urban mobility. Even in the context of a growing urban population and a growing economy, the need for investment in new highway and street capacity – at least as measured by lane-miles of concrete and asphalt – will be reduced, because it will be possible to use existing infrastructure more efficiently.

However, much greater investments will be needed in the “soft” infrastructure of information and communications systems – in-pavement and roadside sensors, the infrastructure needed to support communications between individual vehicles and central servers, and the capacity needed to process, analyze and act on massive amounts of data. Investment will also be needed in electric power generation, transmission and distribution systems, and in electric vehicle charging infrastructure.

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<sup>9</sup> New York City Department of City Planning, PLUTO database; New York City Department of Transportation; Appleseed calculations.

# 3

## Technology, Design and Connectivity

During the next thirty years, advances in automotive technology, design and operations will transform the automobile and its role in urban mobility. These changes include:

- Changes in propulsion and control systems, and the impact of these changes on the design of automobiles; and
- The automobile's evolution from a stand-alone, independently operated vehicle to one that operates as part of a network.

This part of the report describes and analyzes these changes and their implications for urban mobility.

### Changes in technology and design

While automotive technology and design have evolved over the years, the fundamental character of the automobile has not changed in more than one hundred years. While there are some variations, the typical automobile is a vehicle:

- Powered by an internal combustion engine;
- Guided by the driver, primarily through a system of mechanical controls;
- Designed to travel several hundred miles without refueling, at speeds up to 100 miles per hour or more; and
- Typically designed to carry at least four passengers.

Today, a confluence of economic, environmental, demographic and technological factors is leading – more than at any time since the early twentieth century – to a fundamental re-thinking of the design of the automobile. To date, the reinvention of the automobile has encompassed several dimensions of automotive design:

- Innovations in propulsion technology;
- A shift from mechanical to electronic control systems; and
- Redefinition of size, functional and performance requirements.

Each of these dimensions is briefly explored below.

## New propulsion and control technologies

Over the past several decades, the automobile industry has introduced a variety of incremental improvements in the internal combustion engine and in vehicle control systems. None of these improvements, however, has altered the basic design or operating characteristics of the automobile.

Hybrid vehicles – especially plug-in hybrids – represent a more significant change. Plug-in hybrids dramatically improve energy efficiency – to the equivalent of more than 100 miles per gallon – and reduce greenhouse gas emissions commensurately.

But despite their advantages, hybrids don't change the basic configuration of the automobile. Instead, hybrids make the basic design more complex, by adding batteries and an electric motor to a conventional internal combustion engine.

All-electric propulsion systems, in contrast, are much simpler. As a result, they provide an opportunity to redesign the vehicle itself – literally from the wheels up. Battery packs and electric motors take up less space and are much more flexible in terms of how they are configured and where within the vehicle they are placed. This opens up a range of opportunities for redesigning cars to better fit the changing needs of the world's drivers.

Battery packs and electric motors will also generate the electric power needed to replace traditional mechanical controls with drive-by-wire systems. This could, for example, allow designers to eliminate the steering column, accelerator and brake pedals, and hydraulic braking systems. The transition to drive-by-wire will further open up new possibilities for a fundamental redesign of the vehicle. Moreover, as the greater simplicity of electric propulsion and drive-by-wire systems leads to simpler vehicle design, manufacturing costs will also decline.

## A new generation of urban vehicles

Major auto manufacturers and academic research centers such as the MIT Media Lab have produced a range of concept cars designed to take advantage of the opportunities that new propulsion and control systems provide. Despite having significant differences, these cars have several features in common.

- Their “footprint” is smaller than those of conventional cars. This is especially true of those that are designed to carry two people, rather than four or more. While a Ford Explorer measures 193 inches in length, MIT’s CityCar is only 100 inches long – and when parked, can be “folded up” so that it is only 60 inches long. Similarly, they weigh much less – 1,000 pounds for the CityCar, versus more than 2,900 pounds for a Toyota Prius and more than 3,900 pounds for a Ford Explorer.
- The combination of electric propulsion and much lower weight makes these vehicles especially efficient. William Mitchell, Christopher Borroni-Bird and Lawrence Burns, for example, estimated in 2010 that based on total energy consumption, a 1,000-pound all-electric “ultra small vehicle” (USV) such as the MIT CityCar would achieve the equivalent of 263 miles per gallon – more than ten times the energy efficiency of a Chevy Malibu, and more than five times the efficiency of a Toyota Prius.

USV’s are not only more efficient than conventional autos and hybrids – measured by total energy consumption per

passenger mile, they are more efficient than diesel-powered buses. Mitchell Borroni-Bird and Burns estimate that a two-passenger, 1,000-pound all-electric vehicle would consume 44 percent less energy per passenger-mile than a 40-foot-long city transit bus.<sup>10</sup>

- Battery-powered all-electric USV’s will have a limited range – depending on a number of factors, probably in the range of 50 to 100 miles. “Extended range electric vehicles,” however, which combine electric propulsion systems with a small internal combustion engine, could – like today’s plug-in hybrids – travel about 40 miles on electric power and up to about 300 miles on gasoline, diesel or bio-fuel.
- The combination of small size and drive-by-wire technology can make these vehicles easier to maneuver. Steer-by-wire systems, for example, allow each wheel to be controlled independently. In heavy traffic, this improves drivers’ ability to avoid collisions; and in tight quarters also makes parking easier.

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10 William Mitchell, Chris Borroni-Bird and Lawrence Burns, *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*, p. 177.

**Table 5: Energy efficiency of selected vehicles**

Vehicle	Mpg or equivalent	"Well-to-wheels" energy consumption (mega-joules per passenger-mile)
Chevy Malibu	22	3.45
Smart Car	33	2.33
Toyota Prius	48	1.61
1,000-lb USV	263	0.88
40-foot transit bus	4	1.56
60-foot articulated bus	2.4	1.78

While small all-electric vehicles offer distinct advantages, some prospective car-owners may still consider their size and limited capabilities as being inadequate. When assessing whether these vehicles can meet owners' needs, however, it is important to recognize the capabilities of U.S. passenger cars and the ways most Americans use cars, especially in urban areas.

- The average U.S. passenger car has room to carry five people – but the average number of occupants on U.S. auto trips is about 1.7.
- The typical U.S. passenger car has a range of about 300 miles – but half of all U.S. car-owners drive fewer than 25 miles per day; and about 80 percent drive fewer than 50 miles per day.
- Conventional U.S. automobiles are typically capable of reaching highway speeds in excess of 100 miles per hour – but in urban areas auto speeds generally average 30 miles per hour or less.

Conventional cars are bigger, more powerful and faster, and have greater range, than is required for the great majority of trips – an excess of capability that is exacerbated by the fact that in the U.S. private autos are only driven about two hours per day. The new generation of automobiles will be much better suited to the needs of urban drivers – and to the needs of the cities where they live.

## Networked automotive ecosystems

Just as important as changes in automotive technology and design is a shift in the automotive ecosystem from one made up of individual units operating independently to one in which automobiles operate as part of a highly connected, interdependent network. This transition is already under way, with some important technologies already in place. They include:

- GPS navigation systems;
- Sensor-based driver assist technologies such as parking assist, collision avoidance and adaptive cruise control systems;
- On-board communication systems such as On-Star.

As valuable as these technologies are in themselves, they can also be seen as stepping stones on the path to a much more effectively networked automotive ecosystem. Elements of a more comprehensive network could include:

- Vehicle-to-vehicle (V2V) communications systems, which allow a vehicle to transmit operating data in real time to other vehicles in the surrounding area, while simultaneously receiving data from those vehicles;
- Vehicle-to-infrastructure (V2I) systems, which transmit data in real time from individual vehicles to roadside infrastructure and to a central data processing unit, and send data back;
- Other sources that feed information – about weather and road conditions, the availability of parking in downtown areas, etc – into central data processing facilities;
- Supercomputer facilities that have the capacity to analyze rapidly massive amounts of data and transmit the results of its analysis back to individual users; and
- Software that can make the system work.

Much of the discussion about development of this type of network has focused on its potential role in the development and deployment of “self-driving” cars. Google’s work in this area has demonstrated self-driving cars are feasible, at least for individual vehicles. Whether the technology is scalable, however – whether it will prove technically and commercially feasible to develop a system that can simultaneously orchestrate the movement of hundreds of thousands of vehicles in densely trafficked urban areas – remains to be seen. Progress toward fully self-driving vehicles may take considerably longer than anticipated, but increased connectivity along the lines described could reshape the automotive ecosystem in a variety of other ways.

- Long before the development of full-fledged self-driving cars, increased connectivity could be used to enhance the effectiveness of driver assist systems. The network could be used, for example, to warn drivers that they are approaching a stretch of black ice, or a road that is starting to flood.
- Greater connectivity can enhance the efficiency and utility of a variety of car-sharing, for-hire and mobility-on-demand services. Recently-developed mobile phone applications provide an early indication of how these services might work. To cite just two examples:
  - » Rather than being limited to specifically-designated pick-up and drop-off locations, BMW's DriveNow car-sharing venture – which is now operating in San Francisco and several European cities – keeps its vehicles parked on the street, and lets subscribers use a mobile phone app to find the nearest available vehicle. When finished using a DriveNow car, the subscriber can simply leave it in any legal parking space – to be picked up by the next user – rather than returning it to a pre-designated drop-off location.
  - » Uber's mobile phone app allows users to summon a taxi simply by entering their locations on their phones; Uber then alerts taxi drivers in the area who are participating in its service, and they respond. When the ride is completed, Uber charges the fare, a tip and a \$1.00 booking fee to the user's credit card.
- An area-wide network connecting vehicles to central servers could also make it possible to adjust traffic signal timing in response to emerging changes in traffic conditions. More intelligent traffic management systems would make it easier to optimize the flow of traffic, and thus reduce congestion. Such a network might similarly be used to adjust on-board systems such as adaptive cruise control, which could also help optimize traffic flow.

- An integrated network could also provide a platform for more sophisticated forms of road pricing. Road pricing today is generally limited to charging tolls for use of a specific bridge, tunnel or toll road, and cordon pricing systems (such as London's) that charge drivers for entering the central business district.
- Integrated networks could make it easier to create more seamless connections between different modes of transportation. An inter-city train traveler, for example, might be able to use a mobile phone to pick up a shared car near home, check the train schedule, buy a ticket, find out which platform the train will be leaving from, and get information on the availability of parking spaces close to the station – all in a single transaction.

An integrated area-wide network could instead use GPS technology to track where, when and how far a car is driven. The driver would then be charged for the total trip, perhaps using a low basic per-mile rate combined with charges that vary from one area, highway or street to another, based how congested they are, and by time of day or day of the week. Additional charges could be levied for use of a particularly expensive facility, such as a new bridge or tunnel.



## The Future is Now

This report highlights the way in which the world's population is increasingly concentrated in large cities. In the 21st century, cities will become increasingly important as the centers of innovation and economic growth. How people and goods move in, through, and out of such large urban centers will require a multiplicity of modes: automobile, fixed rail, bus, bicycle, ferry, and walking.

We have identified emerging patterns of population change: the rise of the single-person household, the aging of the population in cities throughout the world, and the rapid growth of cities in developing nations. In addition, we explore the way in which advances in technology and design will influence the development of automobiles and their use in large cities.

As Hurricane Sandy, which struck the northeastern United States in October 2012 demonstrated, transportation is vital to the economic and social well-being of large urban centers. The ability to be mobile – to travel to and from work, home and other essential services – is essential for cities to survive and prosper. We can learn much from the way humans behave and adapt when their transportation choices are curtailed by a natural disaster – the closure of mass transit and commuter rail systems, limited access to bridges and tunnels, and serious shortages of gasoline to fuel vehicles.

The more pervasive the destruction from a disaster, the more we depend on transportation to evacuate people, rescue those in danger, provide emergency relief supplies, and mobilize for economic and physical recovery. In addition, cities that have a mix of transportation systems, that are not dependent on just one mode, offer more resilience and capacity for adaptation during and after a disaster. In the immediate days after Hurricane Sandy, with mass transit systems and commuter rail shut down, the car, bicycle, and ferry became the primary modes for getting to and from work.

An urban center's capacity to have multiple, varied modes of transportation is vital to that city's ability to prosper and to withstand adversity. That the New York Metropolitan Region had multiple modes of transportation – and did not rely on just one – was a critical factor in helping the City survive and then recover from Hurricane Sandy.

Mobility is increasingly important to the future of large, dense cities. The ease, safety, and reliability of transportation influences the capacity of individuals to do business, obtain health care, and participate in social and recreational activities. Mobility can take many forms, and projected advances in technology and design will be undoubtedly shape the physical development and quality of life of cities in the 21st century.



