Transportation and Energy: Designing the Route to Prosperity and Sustainability

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The physical movement of humans and products over space and time is essential to the functioning of societies and economies. Fundamental to the movement is the existence of infrastructure networks, in particular, transportation networks, which allow for the physical movement to take place. Indeed, the very organization of societies and economies themselves is increasingly taking on the structure of networks with both transportation and telecommunication networks forming the underlying foundations. Transportation directly affects all of us as we travel to work, to school, to visit friends and family, to shop, and to attend sporting and cultural events.

The transportation of humans and products cannot be realized without vehicles and vehicular production comprises the biggest manufacturing industry in the US today. In the middle of the twentieth century there were 2.6 billion people on the earth and 50 million cars. Half a century later, the number of people had risen to 6 billion and the total number of cars to 500 million with the total number of vehicles including trucks and motorcycles being 777 million. The tenfold increase in the number of cars has occurred in only $2\frac{1}{2}$ generations.

Vehicles and, in particular, cars have provided the medium for enhanced mobility and freedom for individuals. Indeed, there are few aspects of today's modern life that have been untouched by the car, and auto availability and usage have has led to the evolution of the spatial structure of cities and regions as we know them today, while the production of cars has revolutionized modern industry.

Moreover, ground transportation alone provided in 1994 a $900 billion contribution to the gross domestic product (GDP). Between 1960 and 2003 the number of cars registered in the US more than doubled to 135 million. In 1995, it was estimated that the United States had 30% of the world's motor vehicles and yet only 4.5% of the world's population.

Nevertheless, despite the positives of vehicle ownership and use, the negative effects, notably, traffic congestion, are now well-recognized. For example, in the United States, congestion results in over $100 billion in lost productivity annually. Traffic congestion in many metropolitan areas in both the United States and abroad is growing annually with conditions expected to only worsen in the future. In the 2001 National Household Travel Survey, conducted by the US Department of Transportation, half of those surveyed said that they were somewhat to severely concerned about congestion.

In addition, in the United States, the increasing suburban sprawl results in greater distances between residences and places of work, stores, schools, and other amenities. The average American car driver traveled approximately 12,000 miles in 2003, with a typical trip being 8.4 miles, whereas the European driver travels only about 8,400 miles annually. In the United States, buses and trains account for only about 3% of the travel mileage, whereas in Europe the percentage exceeds 15%.

The impact of congestion on wasted time, frustration, and losses in productivity is major. In addition, the impact of traffic congestion on energy consumption is immense. In the past two decades, vehicles in the US have seen an increase of 440% in the waste of fuel due to congestion, even though the energy intensity in btus/mile for automobiles has decreased by 20%. In the Boston metropolitan area, the number of gallons of fuel wasted due to congestion in 2003 was 60 million with a 362% increase since 1982. In the Springfield, Massachusetts metropolitan area 2 million gallons of fuel were wasted due to congestion, in the same year, a doubling since 1982. On the Pacific Coast, according to the Texas Transportation Institute, a typical traveler in the Los Angeles area wasted 93 hours stuck in traffic in 2003, about the same amount of time as he had for vacation.

The Energy Information Administration reports that, since 1950, the transportation sector's use of energy in the US has experienced a tremendous amount of growth with a tripling of its energy consumption and today the energy consumption by the transportation sector is 27% of the total US energy consumption. Petroleum accounts for 97 percent of the transportation sector's energy, with gasoline accounting for two-thirds of all the petroleum used in transportation. Transportation is the largest consuming sector of petroleum, greatly exceeding that of the industrial, residential and commercial, as well as electric power sectors since 1950. In 2004, 14 million barrels of petroleum products were consumed for transportation purposes per day, 66 percent of all petroleum used in the US. The US has 3 percent of the world's oil reserves but 25 percent of the world's demand. Hurricane Katrina in 2005, one of the greatest natural disasters in US history, produced not only a cataclysmic catastrophe along the Gulf Coast with huge losses to life and property, but had rippling effects throughout the country through increases in the price of gas. Oil markets had already been tight due to the political instability in the Middle East as well as growing global demand, especially in the US and China.

Congestion and its impact on energy consumption, however, is not only a passenger vehicular problem. It also affects the movement of products and their prices in today's increasingly globalized supply chains. The revolution in manufacturing has enabled the implementation of just-in-time concepts, lean supply chains, resilient networks that are responsive to disruptions, as well as the consolidation of manufacturing and distribution facilities. Truck miles traveled per year have greatly exceeded that of other vehicle types and, according to the Energy Information Administration, have grown 118 percent from 1966 to 2003. Between 1966 and 2003 the fuel consumption per truck has doubled while the fuel consumption per auto has actually decreased by about 30%. During the past decade, the average haul has increased by about 23 percent for trucking, 8.5 percent for rail, and 11.8 percent for air freight, demonstrating the centralization of manufacturing and distribution as well as the wealth of choices that consumers now have in ordering their products through the growing availability and popularity of electronic commerce, as online sales during the December 2005 holiday season vividly demonstrated. The increase in average haul directly increases congestion. In the same period, the average value per ton of shipments has increased by 36 percent for air, 13 percent for truck, and 16 percent for rail, reflecting the selection of air transportation for the rapid delivery of highly priced commodities. As the value per ton of a shipment increases, the cost of having a valuable cargo in transit increases, so shippers tend to shift more of the shipments to faster, and more expensive modes of freight transportation, such as truck and air.

No essay on transportation and energy would be complete without a discussion of environmental impacts. Environmental pollution is one of the most pressing public policy problems faced by our societies today and the degradation of the environment due to adverse environmental effects such as air pollution from vehicular exhaust emissions is well-documented. The average car during its lifetime travels 100,000 miles, and uses over 3,000 gallons of gas. It discharges through its exhaust more than 35 tons of carbon, with the world's 500 million cars producing 10 trillion cubic meters of exhaust fumes annually.

Despite 25 years of engineering progress and efforts and substantial reductions in transportation-related emissions, motor vehicles remain important sources of emissions of carbon monoxide, organic compounds, nitrogen oxides, and other forms of air pollution, mainly due to the growth of vehicular fleets. Presently, about 15 percent of the world's emissions of carbon dioxide, the principal global warming gas, is generated by motor vehicles. A decade ago, for example, automobiles in China consumed 10 percent of the oil whereas today cars consume one third of the oil in that country. Whereas a decade ago, congestion in Beijing meant bicycle congestion; today, rising car ownership has been accompanied by significant traffic congestion as well as pollution.

In 1999, the transportation sector carbon dioxide emissions overtook industrial sector emissions in the US. Furthermore, transportation is responsible for approximately 50 percent of the nitrogen oxide emissions, which, in combination with other pollutants, form nitric acid which then falls to earth as acid rain. Finally, 90 percent of the carbon monoxide generated comes from emissions from the transportation sector. Cars and other motor vehicles are responsible for at least 50 percent of the air pollution in urban areas. With the number of cars expected to double by 2030, even with potential engineering improvements to internal combustion engines, without intervention, pollution will not be significantly reduced.

So, given the above discussion, what can be done to ensure that our route to prosperity and sustainability is well-designed?

The Human Dimension

We are not the first generation to be worried about transportation and congestion, nor will we be the last. The Romans were concerned about congestion in central Rome during ancient times and instituted a time-of-day chariot policy whereby individual chariots were banned from central Rome during certain hours of the day. A not so different policy was in effect in New York City in December 2005 during the short-lived transit strike whereby only cars with four occupants or more could enter parts of Manhattan. Clearly, however, the energy requirements for chariots are quite different from those required by motorized vehicles.

Humans are ultimately those who do the driving, select their modes of transportation from bicycles and walking to private cars and/or mass transit. They are also the ones who make the purchasing decisions and decide as to where to live, work, got to school, and how and when to conduct their activities. Changes in behavior from such simple actions as checking tire pressure, obeying the speed limit, keeping cars tuned and using fuel-efficient engine oils in order to conserve fuel are all eminently doable. Taking actions to reduce congestion and energy consumption by car-pooling, taking advantage of mass transit options, including buses, subways, and trains, were available, and bicycling and walking whenever feasible and possible, also can make major positive impacts on energy consumption and air quality. Indeed, public transportation can be very effective in these dimensions when it is efficient, comfortable, reliable, and competitively priced.

Of course, we must also support and assist those who may because of advanced age, disability, or infirmities not be able to operate vehicles and avail themselves of other transportation options.

Better Design of Transportation Networks

In 1968, Braess demonstrated through a transportation network example that the addition of a new road (without a change in travel demand) could make everyone worse off in terms of travel time. The example has since become known as the Braess paradox and instances have been identified in New York City, for example, when 42nd Street was closed on Earth Day in 1990 and travel time actually improved, and in Stuttgart, Germany, when the residents complained after the addition of a new road downtown, and, as a consequence, it was ultimately torn down. The original Braess article, which was in German, was recently translated by Dietrich Braess, Tina Wakolbinger, a doctoral student at the Isenberg School, who hails from Austria, and me and appears in the November 2005 issue of the journal *Transportation Science*, along with a preface. My earlier research has shown how to add roads so that the Braess paradox never occurs. Fascinatingly, the occurrence of the Braess paradox on the Internet has now been discovered since that network increasingly is characterized by behaviors of users similar to that of travelers on transportation networks, who act independently and in a decentralized manner in choosing their optimal routes of travel between origins and their destinations.

In addition, we have discovered that so-called "improvements" to a transportation network may actually result in an increase in total emissions and that the addition of a link that generates zero emission as, for example, in the case of a telecommunication link associated with telecommuting, may result in an overall increase in emissions. The results depend crucially on the behavior of the individuals concerned and the structure of the underlying network(s) and the associated link costs.

Similarly, the addition/deletion of new modes to existing transportation networks need to be carefully assessed before implementation of changes.

Hence, transportation networks must be designed and also improvements to them made with an understanding of travelers' behavior!

Congestion Pricing

Congestion pricing is, oftentimes, politically unpopular, but, effective, and, in particular, variable tolls, are a policy instrument to mitigate the negative externalities associated with congestion and the accompanying pollution. Congestion pricing has been recognized by economists since the early 1900s and it has been implemented in various parts of the globe, with such policy instruments showing increasing promise due to today's technology, including electronic tolls. Congestion pricing seeks to implement surcharges for the use of selected congested routes/facilities during peak traffic periods with the consequence that vehicular trips are shifted to off-peak periods, to routes away from the congested ones, to different modes of transportation, or to higher-occupancy vehicles, or by discouraging trips all-together (and perhaps supporting telecommuting instead). The London experiment has been deemed a success and Oslo and Singapore charge similar tolls. Stockholm, Sweden recently began a seven month experiment to charge drivers entering or leaving the city with a maximum fee of $7.50 a day. The charges are intended to reduce the amount of traffic and to cut pollution in Stockholm. Residents will vote in September 2006 as to whether the fees should be made permanent. Of course, congestion pricing also holds the promise of generating new revenues which can then be used to provide enhanced transportation alternatives or for other purposes.

Similarly, road pricing is being implemented in various parts of the globe as a means to generate revenues for road construction. In particular, in China, policies associated with road pricing are being explored as a means to pay for new roads and their usage.

Global positioning technology (GPS) is now being explored to track vehicle location and to transmit data for billing purposes. This technology (privacy issues aside) is also being investigated in order to obtain more accurate data for the purposes of predicting traffic flows on transportation networks and the associated travel times as travelers navigate their routes from their origins to their destinations. This is another example of technology being explored to address issues of congestion/transportation management. We discuss additional innovations of technology regarding transportation below.

Innovations in Technology

While it is unlikely that significant efficiency or pollution reducing improvements will be made to internal combustion engines in the near future, there are several promising vehicular-related technologies that may, in the long run, reduce pollution. Furthermore, there are ideas that also have the potential, if fully implemented, to significantly reduce emissions. For example, the more widespread use of alternative fuels such as natural gas or ethanol, or even hydrogen, is likely to both reduce our dependence on oil as well as to curb the pollution associated with transportation. Currently, alternative fuels are practical for fleet usage in an urban setting, but the widespread lack of availability of alternative fuels renders them less likely to be used in other settings.

The Department of Energy has estimated that about 1% or 4 million gallons of gasoline daily are wasted while drivers of vehicles wait in various lines, be it at the drive-in windows of banks, fast food restaurants, etc. While the associated fuel can be saved of a driver would shut off his/her motor if the wait is more than 30 seconds it is unlikely that most drivers do this. Having a "smart" vehicle that would automatically shut down and restart after idling for a time might yield measurable energy savings.

Hybrid vehicles that incorporate a stored energy system to power the drivetrain, as well as an efficient engine to recharge the energy would also mitigate the effects of pollution as well as reduce energy consumption. Vehicle-makers are being challenged to produce such vehicles in large quantities at competitive market prices.

Auto and truck-makers are continually assessing materials technology to ensure that the vehicles are as lightweight as possible, consistent with strength requirements to satisfy safety of the occupants and the carried cargo. Aerodynamics is also a major consideration, although, in the case of cars, often becomes, secondary in comparision with style. A fully electric vehicle would, of course, eliminate the point source pollution from the vehicle, but does not address the emissions caused by the generation of electricity. As we in New England have found the pollution resulting from electric power generation is a national problem.

Finally, in a competitive, globalized market, the answers to these technology challenges are driven by the potential to recover the investment needed to incorporate the technologies into vehicles.

Smart cars, along with intelligent transportation systems, from highway to logistical ones, that couple the latest in technology with appropriate mathematical methodological and scientific tools, hold great promise for our as well as future generations.

Education

The pathway to increase the understanding of the above issues begins in the schools, colleges, and universities. As good citizens, concerned about our society and the future, we must educate everyone about congestion, energy consumption regarding transportation (and beyond) as well as pollution problems. Universities such as our Great State University, must continue to research these problems to ensure that decision-makers have the knowledge to understand the complexity of the issues and the public interest of these topics and that our scientists and engineers have the tools to advance the state-of-the-art. Finally, those who affect and make public policy, as well as transportation practitioners, should be educated and even reeducated since knowledge grows quickly.

In summary, the design of the route to prosperity and sustainability should be paved not only with scientific and engineering rigor, with a full understanding of the critical human component, but also with adventure, creativity, and fun. We need to design not only the infrastructure appropriately but also the engineered vehicles and fuels, and the management systems, with the understanding that it is finally up to us as individuals and as citizens of the great Commonwealth of Massachusetts and this great nation to act in a manner that is best not only from the individual point of view but from that of society, as a whole.

This year on a weekly basis I have commuted from Cambridge to Amherst (and back), while officially in residence in Cambridge while a Fellow at the Radcliffe Institute for Advanced Study at Harvard. Yes, I take the T to South Station in Boston and then commute via Peter Pan Bus Lines from South Station to UMass Amherst (via Springfield) in order to not only get work done during the commute but also to take advantage of existing transportation options in the state. I can honestly say that these journeys have been both adventuresome, memorable, and fun, and I am on a first-name basis with most of the bus drivers by now. Plus, at the end of the journey in Amherst I get to see my family and my wonderful UMASS Amherst students!

Resources for Additional Background and Information

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