Diesel versus compressed natural gas in Transmilenio-Bogotá: innovation, precaution, and distribution of risk

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During the period 1998–2000, municipal officials in Bogotá implemented a new transportation system for the city. Transmilenio became the first major mass transportation system in the world to use only buses. The authors examine here the process that led to the design decision to power all of the buses with diesel fuel. The main finding is that the various public and private partners sought to accommodate themselves to the alternative that was deemed to be less risky. The diesel option was the outcome of contingent negotiation and distribution of responsibilities among the different interests. The dynamics of these processes were heavily influenced by a precautionary posture.

KEYWORDS: motor vehicles, urban environments, technology policy, risk factors, public health, cost-benefit analysis

Introduction

On December 1, 2000, 450 new articulated buses began to provide transportation services along the main urban transit corridors in the city of Bogotá, Colombia. The fleet replaced approximately 1,140 older buses and served about 850,000 passengers per day. From a technological perspective the new fleet represented a radical change for the city, but in one significant way the new vehicles were entirely consistent with the previous public transportation system. The replacement buses were powered by diesel fuel.

The design and implementation of the new system involved numerous organizational and technological decisions of which one of the most controversial was the use of diesel fuel rather than compressed natural gas (CNG). From a broad sustainability perspective, both diesel and CNG are fossil fuels that generate greenhouse gases, and both appear to be at or near peak production on a global level. However, several factors might have favored the selection of CNG. Colombia has extensive natural gas reserves and government officials had been encouraging transportation authorities to convert their fleets to natural gas. Moreover, Bogotá had earned an international reputation for sound urban planning and a demonstrated responsiveness for creatively fusing sustainability and innovation (Jones, 2002; Institute for Transportation and Development Policy, 2006). However, several factors might have favored the selection of CNG. Colombia has extensive natural gas reserves and government officials had been encouraging transportation authorities to convert their fleets to natural gas. Moreover, Bogotá had earned an international reputation for sound urban planning and a demonstrated responsiveness for creatively fusing sustainability and innovation (Jones, 2002; Institute for Transportation and Development Policy, 2006). Furthermore, when the decision was being made during the late 1990s, CNG was deemed a much cleaner fuel that promised significant environmental and health benefits for the Bogotá region. In contrast, continued use of diesel as the main fuel for the public transportation system presented long-term uncertainty regarding increased cancer, asthma, and other diseases (International Agency for Research on Cancer, 1989; International Programme on Chemical Safety, 1996; El Tiempo, 2006). Indeed, as city council member Alfonso Prada noted, “In the city council, the debate was around what was the cleanest fuel. That is what really matters; it was the essence. Which one pollutes less? There is no debate about costs.”

Prada’s comment suggests that the precautionary principle, rather than a narrow cost-benefit calculus of the trade-off between the health risks of continued diesel emissions versus the operational costs of CNG conversion, guided at least some council members as they deliberated over the complex issues of vehicle emissions, air quality, and fuel preferences. Had the precautionary principle been translated into system-design choices, Bogotá’s model-bus system might have in the end been fueled by CNG. However, something happened on the way from principle to practice. The following analysis provides a post-mortem analysis of Bogotá’s CNG-diesel controversy. This history is interesting in one sense as a basis for comparative, cross-national insights on the CNG-diesel controversy (see also Hess, 2007). However, the case study is also used here to open a broader discussion about some of the problems that can emerge in public-private partnerships where public risks related to health and environmental quality collide with private risks of businesses concerned about profitability and possible technological failure. Although we note, like Ferguson (1997), that privati-
zation has some limits, we attempt to delineate strategies for successful public-private partnerships where two different notions of risk need to be negotiated and the technological choices are not straightforward.

**Theoretical Background**

Scholars agree that transportation is a key sector in the discussion on sustainability (Hall, 1993; Rosen, 2001; Crane & Schweitzer, 2003; Amekuzdi & Meyer, 2006). Continuing use of the internal combustion engine to power airplanes, trains, trucks, ships, buses, and cars around the world is having pronounced impacts on global climate change even though the extent of these effects remain difficult to measure. Urban transportation, in particular, is a key area for inquiry because it has direct implications for proximate populations (Hall, 1993). If we consider definitions of sustainability such as “the use of renewable resources at below their rates of regeneration” and “the use of non-renewable resources below the rate of development of renewable substitutes,” we have a basis for considering air pollution under the first definition and depletion of fossil fuels under the second one (Amekuzdi & Meyer, 2006).

However, sustainability refers to a macro level; some would say to an ecological level. Therefore, a growing literature points to the relationship between sustainability and “environmental justice” or “social exclusion.” Developed in the United States, environmental justice is not only a theoretical concept, but also serves as a policy mandate. Under Executive Order 12898 from 1994, all federal decisions are to benefit all social groups equally and, if negative impacts are unavoidable, no social group, especially ethnic and poor minorities, should suffer more than others. This mandate has been included in transportation-planning processes undertaken by federal agencies in the United States (Pfeffer et al. 2002; Agyeman & Evans, 2003; Chakraborty, 2006). In the United Kingdom, a similar debate has centered on groups traditionally excluded from formal planning processes. The aim, as proposed recently by Lucas (2006), should not be to plan for mobility, but to promote accessibility. That is, planners should seek to ensure better access to employment, shopping, and family and leisure activities, and not only in terms of enhancing physical mobility.

Environmental justice proponents also contend that it is important to assess the impact of planned or constructed projects on actual populations (Mills & Neuhauser, 2000; Pfeffer et al. 2002) and to better incorporate sustainability and environmental justice considerations into early planning. This approach implies the revision of current practices among agencies and the formulation of strategies to influence initial planning decisions (Amekuzdi & Meyer, 2006).

The incorporation of sustainability and environmental justice or social inclusion in the planning process is not straightforward. It is necessary to develop methods and technologies to anticipate and measure the impacts of changes in transportation (Forkenbrock & Schweitzer, 1999). Planners must also understand the political face of these processes and how technical decisions are often inherently political decisions (Rosen, 2001; Hess, 2007).

This article contributes to an understanding of the political dynamics among parties in critical planning processes by looking in detail at **Transmilenio**, a comprehensive transportation system in Bogotá that is often described as the world’s most impressive effort to modify urban transportation during the past decade. The first phase of the project affected 12% of the 7 million trips that take place daily in the city. As the next section describes, this change was critical, because it involved coordinating city agencies, private investors, and international suppliers, all in a climate of delicate political tension and uncertainty regarding how new technology would work in practice. Given these circumstances, all technical decisions impinging upon the overall project were actively debated, though in retrospect these outcomes were strongly influenced by political considerations structured by the power positions of the various stakeholders. The most interesting aspect of this account with respect to sustainability and environmental justice is that it demonstrates how new projects inevitably entail a good deal of financial, social, environmental, and political risk and ostensibly technical decisions can hide how—as well as to whom—the responsibility for those risks is assigned.

**Case Background**

The term **Transmilenio** designates three different entities: the government agency Transmilenio S.A. that manages Bogotá’s transportation system; the long-term public works project **Transmilenio** that includes both public and private sector partners; and the infrastructure and functioning of the transportation system itself. As an organization, **Transmilenio** refers to the public agency that coordinates construction and maintenance of the infrastructure and manages contracts with the bus operators and money collectors, both of which are private sector firms. However, the term **Transmilenio** also refers to the agency’s ongoing project, developed between April 1998 and December 2000 that has drawn on the expertise of engineers, economists, managers, and attorneys to design and implement an entirely new...
technological system for Bogotá’s main corridors. The plan involved various phases, of which only the first (Avenida Caracas, Avenida 80, and Autopista Norte) is at present fully completed. The second phase (Avenida Suba, Avenida Norte Quito Sur, and Avenida Américas) was still under construction in 2006, and subsequent stages have been planned with the goal of eventually having a system in which no point in the city will be farther than 500 meters from a transit stop (see Figures 1 and 2).

As infrastructure and technology, the term Transmilenio refers to the bus rapid transit design that separates public bus traffic from private automobiles and taxis and that provides passenger access via stations located in the middle of the roadway (see Figures 3 and 4). The body of the new, articulated buses has been completely reconfigured by teams of professional designers and engineers. In addition, the engines for the new buses feature state-of-the-art technology and the gearbox uses the latest transmission innovations to ensure smooth vehicle acceleration. The vehicles have a capacity of 160 passengers and an average speed of 28 kilometers per hour (kph) in contrast with the previous capacity of 80 passengers and average speed of 15 kph.

Transmilenio was conceived as a solution to the manifold problems of the city’s existing bus system, known as the transporte colectivo. When Transmilenio was inaugurated in 2000, the 850,000 passengers that it soon carried represented only about 12% of the total daily trips on public transit in the city. By 2006, the transporte colectivo was responsible for approximately 64% of all bus trips in metropolitan Bogotá. The still co-existing transporte colectivo bus system, based on private carriers, results in an excessive number of vehicles on the streets—approximately 22,000 when transportation planners deemed that only 8,000 are needed. The surplus buses create unnecessary air pollution and traffic congestion, and contribute to numerous traffic-related accidents and fatalities (see Figure 5).

The transporte colectivo system operates as follows. Passengers pay drivers directly for the trip and

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1 Private cars comprised 20% of the overall number of vehicle trips in the city and Transmilenio provided a further 16% (Secretaría de Transito y Transporte, 2002).
drivers remit a share of this revenue to the bus owners. The vehicle owner then pays a bus company a fee for the right to drive on a specified route. This arrangement results in comprehensive but over-lapping coverage of the city, high frequency, intense competition, and passenger pick-ups at any point on the street rather than at designated stops. Although the system functions in a limited sense, it also creates numerous opportunities for corruption, especially among the regulatory bodies ostensibly responsible for establishing and enforcing the routes for the city’s 68 bus companies. The advent of Transmilenio changed the underlying principles so that passengers paid their fares in the station rather than on the buses. Drivers were given a formal contract with the operating companies as well as schedules, uniforms, training, rest and lunch breaks, and other benefits (see Ardila, 2004).

The transition to the new system was critical because it implied a reconfiguration of the private companies that profited from the main corridors. Municipal officials were challenging an economic arrangement whereby private transit companies had been operating with little oversight for decades. Many of these operators had effectively captured the regulatory agencies, dampening any impetus for change. Nonetheless, the combination of forceful political support from a strong and popular mayor with a delicate and inclusive planning process directed by a skillful and prestigious strategist resulted in a successful transition (for a review, see Ardila, 2004). Furthermore, the planning, implementation, and operation of Transmilenio in Bogotá has attracted global attention because the project is the first comprehensive urban bus system. The general approach has come to be known as “high performance bus rapid transit.” Prior to this project, transportation experts regarded heavy rail systems as the only viable technological approach for mass transportation on the scale available in Bogotá (Willumsen & Lillo, 2005).

The following analysis is based on a review of documents from the various public agencies associated with the Transmilenio initiative and interviews with ten planning officials involved in different aspects of the project. We also draw on personal knowledge of the Transmilenio bus system and professional experience working with engineers in Colombia. In accordance with standard practices within the sociology of technology, we assume that system-design decisions are motivated by a combination of both social and technical factors and that technical design elements are often aligned with broader political and social prerogatives (see, e.g., Bijker & Law, 1992).

Compressed Natural Gas, Petroleum, and National Energy Policy

It is fair to assume that the extensive organizational and technological innovation embodied by Transmilenio might have led to transition in the fuel
source that would power the buses. After all, the fourth largest city in the country, Barranquilla, had already demonstrated the viability of CNG as a fuel source for public buses by successfully operating a fleet of 4,000 vehicles outfitted with the necessary combustion equipment. This experience had resulted in the diffusion of considerable knowledge throughout Colombia regarding the use of CNG technology for public transit (Ministerio de Transporte, 2001). Bogotá also had a few stations that provided CNG, and many vehicles (mostly taxis) had already been converted to the less polluting fuel. By the late 1990s, other countries such as the United States already had experience in converting existing bus fleets to CNG (Hess, 2007).

Furthermore, changes in Colombia’s national energy policy had to some degree facilitated conversion to CNG. In 1999, the government deregulated gasoline prompting a rapid price rise. In contrast, both diesel and CNG market regulation continued and their prices remained comparatively low. Under these circumstances, owners of public transportation vehicles, who had primarily used gasoline, began to convert their vans and buses to either diesel or CNG. Due to the location of Barranquilla on Colombia’s northern coast, within proximate distance of the first major commercial deposit of natural gas in the country and a coastal pipeline connecting the gas field to the city, it is here that the process of converting to CNG had progressed the furthest (see Figure 6).

Colombia’s newly discovered endowment of natural gas encouraged the government to actively champion the conversion of motor vehicles to CNG. However, the country is also a major oil exporter. Despite a drop in petroleum production during the 1990s, producers in the country were eventually able to improve the security situation and increase drilling to prior levels (United States Department of State, 2006). During this timeframe, the government pushed for CNG conversions, but did not offer incentives to facilitate the preference for CNG over diesel. In cities such as Barranquilla that are located near natural gas resources, conversion tended toward CNG, but in much of the rest of the country the transition from gasoline followed the path of least technological resistance toward diesel, a process so extensive that it became known as dieselization. As a result, by the time that the Transmilenio project was under construction in the late 1990s, the general trend was toward diesel (Rodríguez-Padilla, 2002; Yepes, 2004).

By 2006, the CNG option was becoming more attractive as petroleum prices rose above US$60 per barrel and new public anxieties about peak oil gained credence, both in Colombia and at the global level. As Juan Baquero, a mechanical engineer with over 30 years of experience investing in transportation projects, explained:

If Colombia had consumed more CNG, we would have been able to produce enough diesel for the country’s needs, and we would even be able to export a surplus. Instead, today the whole country is extensively consuming diesel. Not only do we have to use all the local production, but we also have to import diesel at international prices. As a result, we are losing money.

If the national government had defined CNG as a national energy priority during the 1990s, the Transmilenio planners might have built natural gas into the project specifications. Instead, the contracts were written to allow individual bus companies to choose between CNG and diesel (Transmilenio, 2000). The ensuing agreements also specified that the city of Bogotá would not be legally obligated in the event that the new bus technology proved a failure. By not signaling a clear preference for CNG on either health or environmental grounds, and by shifting the risk of system failure (both in a technological and economic sense) onto the bus companies, the city set the stage for a choice in favor of diesel.

**Risk and Diesel**

The system designers for Transmilenio faced a number of problems that clearly shifted fuel preference toward diesel. First, they argued that the Barranquilla experience was not relevant because Bogotá’s physical environment was distinctly different. Due to the city’s high altitude (2,600 meters above sea level), the air has 21% less oxygen than it does at sea level. As Ricardo Wagner, a mechanical engineer
with 35 years of experience designing engines, explained, “There was no experience in the world with a fleet of those features at the elevation of Bogotá.” At the time, there were no articulated, two-body buses with a capacity for 160 passengers successfully operating in a city like Bogotá, not even in Mexico City, which has similar elevation and other conditions. Under such circumstances, the engineers were skeptical about using Bogotá as a test bed for CNG technology. As Jaime Loboguerrero—a mechanical engineer, professor, and entrepreneur—noted, “The Third World is always experimenting and paying the costs for others to benefit. We said, ‘No,’ we can’t allow CNG to be the option.”

More generally, there was concern that switching to an unproven technology, at least in the high-altitude environment, could wreak havoc on a complex urban transportation system and jeopardize the credibility of the Transmilenio project. There were also fears that the change would undermine plans to replace the existing system, an arrangement that was functional despite the chaos and corruption. As Juan Carlos Díaz, the first engineer involved in the project, commented:

The system has to be reliable. In a mass transportation system that serves a city like Bogotá, with six or seven million inhabitants, it cannot be so fragile that it would stop at any given moment. That would generate a problem of public order that would threaten the functioning of the city.

Another consideration that favored diesel-powered buses was the scale of the change in a relatively short period of time. Given the size of the purchase, the contractors (private firms that owned and operated the buses under the coordination of the public agency Transmilenio S.A.) faced difficulties buying buses suitable for diesel fuel. For example, when attempting to acquire a fleet of articulated buses in Brazil, contractors found that the normal production quantity in 1999 was only eight buses per year. The required number of new buses in Bogotá for the year 2000 was 450 and the contractor that contacted the Brazilian companies had been tasked to acquire 160 functioning units. To shift to CNG, which had a much smaller market, would have only magnified the problem of acquiring the needed quantity within the planned schedule.

Due to the lower production levels of CNG buses relative to diesel, their up-front costs were higher. As a result, to be an attractive investment, the CNG buses had to offset their purchase price with lower costs of operation. One of the key factors in determining operating expenses is maintenance. As Juan Carlos Díaz commented: “The CNG providers argued that it was more economical, that maintenance was less expensive, and that the engines would last longer.” Although the CNG manufacturers insisted that upkeep was lower for their buses than for diesel, the experience of Brazilian agencies that had been experimenting with CNG technology suggested that the CNG buses might also have higher breakdown rates. Víctor Raúl Martínez, the CEO of Si99, the largest and first contractor for Transmilenio, stated that a Brazilian colleague reported a higher rate of CNG failure events:

The number of failure events of 60 CNG vehicles compared with another 60 diesel vehicles in the same route was much higher, making maintenance costs higher for CNG... Overall, the operating costs were also higher for CNG.

In 1999, Colombian banks were unwilling to lend money to the contractors who won the public competition and Si99 consequently ended up obtaining financing in Brazil. As a result, the negative Brazilian experience regarding maintenance for CNG buses became especially relevant.

In short, this combination of technical and financial factors created widespread uncertainty among the various engineers and bus companies involved in the system design. Resolution of the CNG-versus-diesel choice was exacerbated by the prospect of a major and unprecedented change in the city’s underlying urban transportation infrastructure. Although the controversy was resolved by 1999, it may resurface in the future. Between 2000 and 2006, there was one experiment with a high capacity CNG bus in Bogotá, carried out by the contractor Transmasivo S.A. The performance of this vehicle has clearly been inferior to the ones powered by diesel, especially on steep roads. A transporte colectivo company (Expreso Bogotano) plans to test a fleet of 60 CNG buses between 2006 and 2008. Furthermore, during the next few years, a new CNG-powered bus rapid transit system will begin operation in the nearby Peruvian capital of Lima. Colombia is also slowly deregulating diesel prices, which have been rising relative to CNG. This convergence of factors may ultimately trigger a reevaluation of the efficacy of diesel in Bogotá. Furthermore, the Transmilenio project is set up to permit experimentation and to provide for ongoing turnover of buses. These features provide the resilience that may allow for overcoming past missteps—that is, of course, if the diesel choice ends up being considered a flawed decision (Newman, 2005). To put it another way, the constellation of factors that configured diesel as the least risky choice in 1999 is
Discussion and Conclusion

The CNG-versus-diesel controversy in Colombia articulated two different types of risk. At the outset, we noted that a city-council member defined the problem as choosing the vehicle design and fuel that would produce the least pollution, regardless of costs. This view expressed risk from the perspective of the general public and prioritized the protection of human health and the environment. This approach is consistent with the precautionary principle in emphasizing adoption of the safest technology in the face of known and unknown health risks.

However, if we follow the city’s contracts, municipal officials did not stipulate that the contractors should develop a system that would generate the lowest level of health and environmental risk. Rather, these agreements achieved the opposite outcome, leaving the decision over fuel and bus technology up to the contractors and also shifting technological and financial risk onto them. From the perspective of the engineers and managers who designed the system, there was too much technological and financial uncertainty to warrant a shift to CNG, even if it was the cleaner fuel option at the time. If the private sector partners were going to shift to CNG, they would have to absorb on their own the projected higher costs, as well as the risk of potential failure. As Víctor Raúl Martínez of Si99 commented, “There is a fundamental unanswered question: if CNG vehicles are more expensive, and their operation and maintenance costs are also higher, who is going to pay for the higher costs?” Because the local government did not specify that it wanted a targeted level of emissions reduction, the issue of which technology was cleaner disappeared from the decision-making process. It is not entirely clear why the municipal officials did not define a specific emissions-reduction target. Our most plausible explanation is that when the contracts were issued environmental concerns were a less prominent policy issue than they are today and any heightened public health risk associated with transportation was perceived to result from traffic accidents.

One general conclusion from this case study is that a government intent on cleaning the air and promoting public health cannot presume that its private partners, when given a choice, will select the least polluting technology and absorb the costs and risks of implementing untested alternatives. Under such circumstances the private sector partners are likely to select the least risky and most profitable options and to justify them as environmentally acceptable. In other words, the lack of cost and risk buffering by public authorities invites the private sector partners to ignore the public risk of air pollution and to give singular preference to its own priorities. To encourage the adoption and diffusion of new technologies, governments need to incorporate health and environmental standards into the system-design specifications (such as clearly mandating acceptable emissions levels for new buses), and then they need to create contractual arrangements that fairly distribute financial costs and technological risks of implementing new socio-technical systems.

Under this scenario, the government establishes the system standards and the private sector firms decide which alternatives offer the lowest technical uncertainty and financial risk toward achieving these targets. We recognize that the ideal division of labor between public agencies and their contractors is not as easy to implement as it might first appear. In many cases involving innovative technologies, the optimal alternative is often not transparent. The CNG firms claimed that their technology was cleaner, but from a technical and operational perspective the emissions issue was much more complicated. As Jaime Loboguerrero, one of the engineers in charge of testing the vehicles, pointed out:

CNG engines have a very good range of operation when correctly calibrated. Under those circumstances they contaminate the air less than diesel. Conversely, diesel engines that are correctly calibrated pollute less than CNG engines that are not properly calibrated. Furthermore, diesel engines are more forgiving of calibration errors than CNG engines.

Because the technical issues surrounding system selection remain unresolved, municipal officials are not able to solve the problem engendered by uncertainty by defining an acceptable level of public risk (in the form of emissions standards) and then leaving implementation up to the experts. Instead, in cases where the technology is complicated, in flux, or subject to controversy, government may also need to intervene by mandating at least some design features. This is exactly what happened in the case of Transmilenio. Once it became apparent that diesel was emerging as the preferred fuel choice, municipal officials added a contract provision stipulating that the new buses must have catalytic converters. However, this decision immediately became enmeshed in the technological debate. In Colombia, the sulfur content of diesel is about 3,000 parts per million (ppm), whereas Euro 2 diesel engines are designed for 500...
ppm and Euro 3 engines for 50 ppm. As Víctor Raúl Martínez of Si99 recalled,

I remember that there was a disagreement between the president of Mercedes-Benz and the head of the Environmental Agency of Bogotá regarding the contractual requirement that mandated catalytic converters in the buses. Mercedes-Benz, Scania, Volvo, and other manufacturers have their own laboratories that do precise and reliable tests. They argued that to install catalytic converters in buses with engines at a Euro 2 standard and with a fuel that had more than 600 ppm of sulfur was useless. We finally installed the converters, but we do not think that it really helped in any way...Instead of requiring all buses to have a catalytic converter, we feel it would be better to ask the Colombia Petroleum Company to produce better diesel by upgrading the refinery in Cartagena or elsewhere.

Although it could be alleged that municipal officials in Bogotá failed by mandating the use of catalytic converters rather than both catalytic converters and ultra-low sulfur diesel fuel, we submit that they were actually on the right track. A consistent approach to the negotiation of public and private conceptions of risk would need to involve two stages—first define an acceptable level of pollution and then determine the technologies that are needed to meet the standard (e.g., particulate traps, catalytic converters, low-sulfur diesel, or even a non-diesel fuel such as CNG) rather than leave the second part of the decision up to private sector partners. It is possible to construe Bogotá’s Environmental Agency as having failed only to the extent that it did not understand the complexity of the interface between the design of the technology and the various risks to human health and the environment. Yet, in situations where the experts do not agree, or in instances where they may be biased in favor of existing systems, the public partner needs to step in and take a position on the technological controversy. Government planners cannot simply draw a line demarcating an acceptable air quality or emissions standard and then expect system designers and contractors to resolve outstanding discrepancies over relative performance. They need to be able to articulate both an acceptable standard of air quality and an appropriate technological system to meet that goal. Once these dual objectives have been clearly stated, the private sector partners can develop proposals that provide the desired capital and services based on their own appraisals of the underlying financial and technological risks.

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