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SUSTAINABLE TRANSPORT, NEW TECHNOLOGIES AND INDUSTRY DEVELOPMENT

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ABSTRACT

The motor vehicle as currently designed in conjunction with present road traffic management systems will not remain viable once the costs of traffic congestion, air pollution and global warming are taken into account. These issues are influencing research on new technologies for vehicle engines and new car designs, as well as new systems of traffic management. The resulting changes in vehicle design and traffic management systems will have a significant impact on the structure of the global motor vehicle industry.

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INTRODUCTION

The economic and social costs associated with traffic congestion, air pollution and global warming are beginning to pose questions in relation to the future viability of motor vehicles as a transport mode. In order to minimise such costs, a range of new technologies are being intensively explored. These technologies could dramatically alter the design of future road vehicles and the way in which road traffic is managed. They could also have a significant impact on the future structure of the global motor vehicle industry. This paper provides a brief introduction to what is intended to be a major study into the subject of sustainable transport, new technologies and industry development.

We begin this introductory study by defining, and illustrating, the concept of sustainable transport. The second section of the paper indicates the new technological options being explored as a result of the pursuit of the goal of sustainable transport. The third section of the paper examines the way in which the future structure of the global motor vehicle industry might be shaped by these new technological developments.

THE CONCEPT OF SUSTAINABLE TRANSPORT

Sustainable transport is a new concept being given prominence by international institutions like the World Bank. It combines the separate notions of economic efficiency, environmental sustainability and social sustainability.

The World Bank defines these concepts in the following way:

> *Economic and financial sustainability* requires that resources be used efficiently and that assets be maintained properly. *Environmental and ecological sustainability* requires that the external effects of transport be taken into account fully when public or private decisions are made that determine future development. *Social sustainability* requires that the benefits of improved transport reach all sections of the community. (World Bank 1996, pp. 4-5)

Economically Efficient Transportation

The World Bank argues that 'to be economically and financially sustainable, transport must be cost-effective and continuously responsive to changing demands' (World Bank 1996, p. 33).

In many cities around the world, securely protected transport monopolies have failed to satisfy demands for expanded service or improved quality of service and have neglected the needs of growing low-income peripheral areas around the major metropolitan centres. Costs are often far too high. Road systems are often poorly maintained and not designed to service many of the needs of users. Many of the costs associated with road use are not directly borne by users, and traffic congestion has become a major problem.

In the United States, studies have shown that somewhere between 49% and 61% of the total social costs of motor vehicle use are paid for entirely by motor vehicle users (OTA 1994, pp. 12; 104-109). Examples of costs not taken into account when travel decisions are made by individuals are road construction and maintenance, environmental impacts (discussed in the next section), congestion travel time costs inflicted on others and aspects of the costs of accidents.

Congestion costs are an externality to the extent that drivers during congested periods impose costs on all other drivers sharing the road but do not account for these costs in their decisions to drive. Congestion costs not only reduce the economic efficiency of urban centres, they also add to environmental costs because stop-go driving both wastes fuel and generates more pollution per kilometre than free-flowing driving.

Congestion or peak pricing is widely applied in mass transit, urban rail and bus, and air transport. Congestion pricing can also be applied to capture the added costs of road use during peak periods. Singapore was the pioneer for road congestion pricing in 1975, and it was followed by cities in Norway and northern Italy. Regular or non-peak road pricing is used more widely than congestion pricing and provides a means of incorporating some of the costs of road usage that are external to the individual user into travel decisions. It can, however, lead to distortions in road use if applied only on a narrow basis by diverting traffic onto non-tolled roadways.

Environmentally Sustainable Transportation

Externalities associated with the environmental impacts of transportation are an important issue for the future. Air pollution, global warming, leaking tanks and oil spills are the major problems. In many of the industrialised countries, emission controls on new vehicles and inspection and maintenance requirements on the vehicle fleet have reduced the potential air pollution impacts of road transportation. However, the benefits associated with such policies are likely to be overwhelmed in the next two decades by further growth in vehicular traffic in many urban areas in the industrialised world. Moreover, in many of the developing countries even elementary anti-pollution policies are lacking.

Road traffic is the primary source of some categories of air pollution: lead and carbon monoxide, nitrogen oxides and hydrocarbons. It is also an important source of particulate matter. These emissions are damaging to health. Lead is particularly harmful to the development of younger children. Carbon monoxide hinders the transfer of blood into tissue, ultimately stopping the heart. Nitrogen oxides react with other pollutants in the atmosphere to produce a form of ozone which provokes asthma attacks and other respiratory problems. The release from car exhausts of volatile organic compounds derived from hydrocarbons increase the risks of cancer, while particulates aggravate bronchial diseases.

Local conditions with respect to air quality have improved in many industrial countries over recent years. The catalytical converters installed in newer cars remove most of the carbon monoxide previously emitted into the atmosphere, and the introduction of lead-free petrol has had significant benefits. However, further technological improvements will be required to avert a resurgence of difficulties next century. Projections indicate that the increased volume of traffic will lead to major environmental problems in the larger cities of the industrialised economies in the absence of new initiatives. The situation in many third world countries continues to deteriorate in the absence of the strict measures adopted in high income localities. These air pollution problems affect not only the major metropolitan centres but also broad regional areas downwind from the polluted cities.

Transport also damages the global environment. Pollution from motor vehicles produces about one-fifth of the incremental carbon dioxide in the atmosphere arising from human activity (which potentially contributes to global warming), one-third of the chlorofluorocarbons (which contribute to the depletion of the ozone layer), and half of the nitrogen oxides [1] (World Bank 1996, p. 52).

Socially Sustainable Transportation

Transportation is of vital importance to the poor because it provides the means of accessing employment, education and health services. Reducing the costs of access to these services through improved transportation contributes directly to the reduction of poverty (World Bank 1996, p. 72). Public transport is of particular importance to the urban poor in terms of affordability and accessibility. Road or public transport systems that fall into disrepair because of funding bottlenecks or general inefficiency have socially damaging consequences.

Sustainability as the Basis of Transport Policy

Economic, environmental and social sustainability are often mutually reinforcing. Road or public transport systems that fall into disrepair reduce economic efficiency and hinder access for the poor. Measures to improve asset maintenance, the technical efficiency of supply, and safety can produce substantial economic, environmental and social benefits. However, the simultaneous achievement of these three goals is not always easy, and difficult tradeoffs may be required. A sustainable transportation strategy is one that both identifies and implements the win-win policy instruments and explicitly confronts the tradeoffs in order to achieve deliberately chosen outcomes (World Bank 1996, p. 29).

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which contribute to continental scale acidification and ecological damage.

TECHNOLOGY AND SUSTAINABILITY

The Impetus for Technological Development

Pressures to achieve sustainable transport systems are likely to be encouraged through fiscal incentives and/or penalties, regulations and public investment. There will be significant encouragement from both market forces and public intervention to innovation in such industries as the manufacture of motor vehicles and systems relating to traffic management.

New Technologies in the Motor Vehicle Industry

Accelerating Change in the Vehicle Industry

The surge in oil prices that occurred during the 1970s combined with increasing concern about the environment led to a wave of innovations impacting on the design of the motor vehicle. New materials (lightweight alloys, plastics, composites and ceramics), aerodynamic styling, improved braking, suspension, and transmission systems have been adopted. Electronics has become an essential feature of vehicles and plays a key role in improving engine efficiency and overall performance. Computer-aided design and engineering is reducing the lag between new concepts and their introduction into production. Product reliability has been significantly increased as a result of improvements in manufacturing systems.

This process of change can be expected to accelerate over the coming decades. Key features of the expected change will be:

- increased energy efficiency;
  the use of alternative fuels;
- improvements in the tradeoff between energy efficiency and safety;
- new innovations affecting the internal combustion engine;
- significant developments with respect to electric vehicles;
- further changes in materials technology; and
- even greater use of electronics.

New Programs

Since 1994, the American motor vehicle manufacturers have been trying to attack the pollution problem by refining the design of existing cars. The Program for a New Generation of Vehicles joins together the government's national laboratories with the research departments of the big three car makers, providing pooled knowledge which is then utilised in the individual designs for new vehicles by the automakers. The program aims to refine existing technology to produce an ordinary mid-sized saloon car by the year 2004 capable of achieving 80 miles to the gallon instead of today's 27.5. Greater fuel economy will also mean lower emissions. The program aims to achieve this goal for increased fuel efficiency while maintaining the affordability, safety standards, performance, and comfort of contemporary vehicles. The means for achieving this goal include the greater use of lightweight plastics, more sophisticated electronic engine management and, perhaps, hybrid petrol-electric power systems ('Survey on Living with the Car', 22 June 1996).

Conventional improvements to automobile efficiency have the potential to stabilise carbon dioxide emissions for a decade or two in the United States. To outreach rising travel demand and achieve reductions in emissions in the industrialised countries, and to keep up with the rapid growth in travel demand and overcome deteriorating air quality in many Asian cities, will require more radical changes. The alternatives are using incentives to reduce travel demand, the major redesign of urban areas (which would take many decades to have significant impacts), or radical changes in the design of motor vehicles. The challenge is to gain public acceptance of such changes by maintaining the basic amenities offered by current designs (space, performance, safety, reliability, convenience in refuelling) while retaining competitive prices. Reducing the cost of key technologies will be the major means of achieving these goals (OTA 1994, p. 163).

The American State of California has offered substantial incentives to the development of advanced light-duty vehicles because of its zero emission vehicle (ZEV) regulations. The ZEV require automakers to achieve at least 2% of their in-state sales with vehicles emitting no criteria pollutants by 1998, and 10% by 2003. A number of northeastern States have adopted identical regulations. There is currently some uncertainty about how rigorously these goals will be enforced given the current state of technological development.

New Technological Options

Major improvements in the energy efficiency of motor vehicles could be achieved through a radical shift in technology and design (OTA 1994, pp. 24-26). The basic features of an advanced automobile incorporating radical new technologies might include:

- new body materials (most probably carbon-fibre or other composite materials);

  enhanced streamlining aimed at reducing the vehicle's drag coefficient from the current state-of-the-art 0.3 to 0.2 or lower;

  high-pressure, low-rolling resistance tyres similar to those used in General Motor's Impact electric vehicle;

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an advanced engine (either a super-efficient four-stroke design with four or more valves per cylinder, adjustable valve lift and timing, and other low-friction measures, or a two-stroke design);

extensive use of aluminium and other light-weight materials in suspension and other components (such as brake fittings, sway bars, and wheels);

major redesign of seats, bumpers and other components to reduce weight; and

advanced transmissions (probably a five or six-speed automatic).

The use of alternative, non-petroleum-based fuels in vehicles offers opportunities to reduce overall energy use and greenhouse emissions. Methanol and natural gas have higher octane ratings than gasoline allowing engines to use higher compression ratios, thereby raising thermal efficiency. Differences in the carbon content and general chemical make-up of alternative fuels yield different fuel cycle emissions of greenhouse gases. Alternative fuels can be used in internal combustion engines for light-duty vehicles, the primary fuels under consideration being methanol, ethanol, natural gas, liquefied petroleum gas and hydrogen. Hydrogen can also be used in fuel cells, and methanol and natural gas can act as hydrogen-carriers for fuel cells. A further alternative is reformulated gasoline (gasoline reblended to reduce exhaust and evaporative emissions and/or to reduce the photochemical reactivity of these emissions, in order to avoid the formation of smog).

The Internal Combustion Engine

Piston engines in conventional motor vehicles can be adjusted to run on alternative fuels (e.g. ethanol and methanol) which reduce nitrogen-oxide emissions. Motorists are wary of using alternative fuels in case they are unable to replenish supplies, and filling stations are reluctant to move unless assured of a reasonable demand. A new technology known as the flexible-fuel vehicle is being developed (Volkswagen is a leader) which will detect which type of fuel its tank has been filled with and automatically adjust the engine; this would increase the flexibility of the vehicle for operational purposes.

Among the new types of internal combustion engines likely to appear in the next decade or so is an advanced two-stroke engine accompanied by new electronically controlled fuel-injection techniques designed to both raise the efficiency of the combustion process and reduce emissions of unburnt fuel. General Motors, Ford and Toyota are all testing prototypes of two-stroke cars.

A second type of combustion engine with potential is the gas turbine. To be efficient, the gas turbine has to work at a very high temperature, high enough to melt iron and aluminium, the traditional engine block materials. New and more tractable ceramic materials, together with electronic combustion controls, would make a small powerful gas turbine engine possible for automobiles. Such an engine would emit negligible pollution, and could run on a variety of fuels.

Mitsubishi Motors has developed a new gasoline direct injection engine used in models introduced in Japan in late August 1996. Direct injection into the cylinder has long been used in diesel engines, but Mitsubishi has made it work with petrol engines, and claims that the motor uses 35% less fuel, produces 35% less carbon emissions, and 95% less nitrogen oxides in its exhaust and still turns out 10% more power than the conventional injection system used in existing petrol engines. Toyota is planning a release of cars using a similar power plant, and Nissan, Honda, and several companies in Europe and America are working on their own direct injection designs ('Car Engines: A Little Squirt', 7 September 1996).

A further new development in engine technology is the MDI-EV3 engine being tested by the Luxembourg engineering company ADMP. This engine has separate compression and expansion cylinders, a technology which is theoretically 50% more efficient than the conventional two-stroke engine, and can also work on cold compressed air, thereby producing zero emissions, or in a hybrid compressed air/fuel injection form ('Car Engines, not all Hot Air', 26 October 1996).

Electric Vehicles

Instead of an advanced internal combustion engine, a radically redesigned automobile might use electric motors powered by batteries or fuel cells. Alternatively, it might use a hybrid combination including batteries and a motor/generator (or one of a variety of other combinations of power sources, including flywheels). Recent significant technical advances have placed such vehicles closer to reality, albeit still a considerable distance from commercialisation. The key hurdles remaining to be overcome before commercialisation is possible include improving the manufacturing capability and reducing the cost of advanced materials, designing adequate safety systems for small vehicles, and achieving significant improvements in fuel cell and battery technology.

Electric vehicles (EVs) use either batteries, fuel cells, or a combustion engine-generator combination to provide electricity to power electric drive motors. An advanced EV would use small variable speed alternating-current (AC) motors mounted at the wheels rather than the larger, heavier direct-current (DC) motors used on current EV designs. Recent advances in electronics have greatly reduced the size and weight of equipment to convert the DC power provided by fuel cells and batteries into AC power for motors. AC motors can attain very high drivetrain efficiencies and no transmission is required. The main constraint on EVs is the difficulty of storing enough energy on-board: the energy density of battery storage is a small fraction of that of gasoline; and also hydrogen, needed for fuel cells, is lacking in energy density (OTA 1994, p. 165).

A fuel-cell-powered vehicle is essentially an electric car with the fuel cell and storage tank (for hydrogen or for a hydrogen-carrying substance such as methanol) substituting for the battery. If the fuel is a hydrogen carrier (methanol or natural gas), an onboard reformer is required to release the hydrogen from the carrier fuel. Excess electricity from the fuel cell, as well as electricity obtained from regenerative braking,[2] can be shunted to battery storage. The vehicle can then use a high-power-density battery (or other storage devices such as an ultracapacitor or flywheel) to provide the necessary power boost for acceleration, so that the fuel cell does not have to be sized for the vehicle's maximum power needs.

Fuel cells are particularly efficient energy converters, they generate no harmful emissions,[3] and they can be refuelled quickly, so that range constraints are less of a problem than with battery electric vehicles once sufficient refuelling infrastructure is put into place. Three types of fuel cells may be suitable for light-duty vehicles: proton-exchange membrane (PEM) fuel cells, alkaline fuel cells, and solid-oxide fuel cells. Of the three, the PEM fuel cells are closest to commercialisation; the patenting of a method to achieve an 80-fold reduction in the amount of platinum needed in the cell has greatly enhanced the commercial possibilities. However, technological uncertainty remains higher than for battery electric vehicles (OTA 1994, pp. 166-167).

The crucial element for successful commercialisation of a battery electric vehicle is the development of a battery that combines high energy density for range, high power density to allow competitive acceleration performance, long life-time under relatively adverse conditions, and moderate cost. A variety of battery types are under development, including lithium-aluminium-iron disulfide, several different types of other lithium-based batteries (including lithium polymer and nickel-metal hydride) and new variants of the traditional lead-acid battery (which seek higher energy density and longer life through design alterations and use of new materials).

Hybrid electric vehicles combine two power sources with at least one powering an electric motor. The range of alternative power sources includes batteries, flywheels, ultracapacitors, and heat engines. Hybrid systems come in a variety of configurations. One would use a small, constant speed internal combustion engine as a generator to power high-efficiency electric motors at the wheels, with a high-power-density battery or ultracapacitor used to provide a current boost to the motors for acceleration or hill climbing. The internal combustion engine in this case could be small, efficient and clean because it runs at one design speed. Alternative systems could rely exclusively on batteries for most trips, with the engine-generator for extended range only, or they could use both electric motors and a small internal combustion engine to drive the wheels, perhaps with the electric motors providing high power only when necessary (OTA 1994, pp. 167-168).

The Rosen Motor, likely to be in prototype form by late 1997, uses a turbine engine rather than an internal combustion engine in its version of a hybrid electric vehicle, and has a special booster generator that is used whenever the driver accelerates. The booster is driven by a flywheel which collects and stores energy when not in use. It is set spinning by both heat from the turbine and by a regenerative braking system which turns the flywheel every time the brakes are applied.

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[2] using the motors as generators to provide braking force and storing the electricity thus generated in the batteries.

[3] although the total system will generate emissions if the vehicle fuel is a hydrogen carrier such as methanol and must be converted into hydrogen on board.

The United States Advanced Battery Consortium comprises General Motors, Ford, Chrysler, the Department of Energy, and the Electric Power Institute. It is completing a major research and development program on the improvement of battery technology, concentrating on chemical-battery technologies ('The Electric Car's Achilles Axle', 19 September 1992).

Major initiatives to encourage electric and alternative-fuel vehicles are occurring in several states in America, as well as in Japan, France, and several countries in northern Europe. General Motors has recently commenced production of a battery-powered car, whose price has been reduced by more than a quarter through various subsidies. It is being marketed in a number of locations in southern California and Arizona, but it is not regarded as being suitable for the colder conditions experienced in the northern parts of the United States. It has a range of between 70 and 90 miles in normal conditions, and recharging can take up to ten hours. Honda, currently the leading Japanese company in electric vehicles, announced a purpose-built electric car in April. Toyota is undertaking developmental work on a fuel-cell-powered vehicle. Daimler-Benz has built a concept car powered by fuel cells which, in turn, have been developed by Ballard Power Systems of Vancouver. This vehicle uses methanol as a feedstock, converted on-board into hydrogen. Peugeot will bring out a purpose-built electric vehicle in less than three years, but it will be heavily subsidised.

Opinions differ as to how close the widespread use of zero-emission electric cars is. Chrysler does not see it having a long-term prospect at all. Other analysts believe it may not be viable for 20 to 25 years, arguing that people have less and less time for their activities and want more and more convenience, which will be difficult for the electrical vehicle to provide. General Motors recognises the environment as being an issue for competitiveness in the market place in five to ten years and sees the need to be prepared for this trend. However, it is generally considered that the hybrid electric vehicle offers better prospects than the other alternative electrical vehicles ('Survey on Living with the Car', 22 June 1996).

Materials Technology

Reconciling safety with environmental sustainability offers a considerable challenge to materials technology. Light composite structures can be even stronger than steel, although the assessment of the robustness of composites to accidental impacts is more difficult than for traditional metals. The manufacturing technology for strong, lightweight composite materials is still accomplished largely by hand and costs are prohibitive. Much research needs to be done on the feasibility of automated manufacturing processes for new materials. Nevertheless, materials technology and its application to transportation in terms of motor body construction and for components is a key area for research in both the United States and Japan.

Electronics

Electronics embedded in motor vehicles is a growth area. Most of the new engine technologies imply an enhanced role for electronics, as do innovations with respect to steering, braking and throttle control. Moreover, as our later comments on new technologies and transportation systems imply, on-board electronics associated with navigation and other uses will become an important application.

The Freight Sector

Improving energy efficiency in the freight sector rests largely on measures related to trucks: the introduction of new, more energy-efficient trucks, retrofit technology for the existing truck fleet, changes in operations to reduce waste, increased linkages with other transport modes, and shifting to other transport modes. There is considerable potential for improved truck energy efficiency from using commercially available and new technologies: incentives may be needed to encourage purchase of the most efficient vehicles and to reduce the age of the average truck fleet. Regulatory or fiscal policies will need to be established to encourage energy efficiency in commercial and road transport because of the great variety of truck types and cargo (OTA 1994, pp. 28-29). It should be noted that currently available technology will not allow automakers to improve light-truck fuel economy to the same extent that they improve passenger vehicles. Load carrying requirements impose structural and power needs that are more of a function of the payload weight than the body weight of the truck, yielding fewer flowthrough benefits from weight reductions. Open cargo beds for pickups and large ground clearance limit potential for aerodynamic improvements. Additional safety and emission requirements would create penalties for fuel economy.

New Technologies and Transportation Systems

Economic and environmental pressures are encouraging new technological approaches to road traffic management. The main features of these technologies are electronic road pricing and intelligent vehicle-highway systems.

Electronic Road Pricing

Electronic road pricing had its origins as a means of implementing toll charges on major motorway projects. However, its application to time-sensitive roadway charges that discourage congestion is now attracting attention. Direct congestion charges have been implemented by a cordon of toll points around the congested area in Singapore. That city is now planning to implement a more technologically sophisticated electronic tolling system that will make more complex time-sensitive applications easier in future (World Bank 1996, p. 88).

The European Commission has developed a program known as Eurotoll. It has the objective of ascertaining how high charges need to be pushed in order to change drivers' behaviour. Earlier research conducted in the city of Stuttgart has shown that different tariffs for peak and non-peak hours and for alternative routes did affect the flow of traffic, but charges were less effective in persuading drivers to give up their cars in favour of other means of transport, although demand for park-and-ride facilities was increased ('Road Pricing, Testing the Limits', 4 May 1996).

Singapore aims to have a city-wide electronic road pricing system in operation by late 1997. It will enable specific charges to be levied for different kinds of vehicles travelling in different places at different times of the day. Eventually, the system could be extended across the whole island. Each of Singapore's vehicles will be fitted with an in-vehicle unit (IVU) linking the car to a system of gantries along the roads. It will pick up information about the price of the road the car is using and deduct the charge from credit stored on a card slotted into the IVU. A digital display in the car will show how much credit is left on the card. Cards will be sold at banks and shops. One type of card will carry an embedded microchip allowing it to be recharged with credit by taking it to a bank. Software is being developed to allow users to do this directly from their account through a cash machine. The technology used will be similar to the electronic toll booths on the Italian autostrade and at the Thames tunnel and bridge at Dartford, near London. However, it will be applied on the open road and have to cope with high speeds, multiple lanes and vehicles bunching and weaving together. In order to resolve this problem, multiplexing is likely to be used whereby individual vehicles will be connected to the scanning antennae on the gantries by different frequencies. American plans are to take the technology a stage further and do away with the large gantries. This would involve the use of satellite monitoring and electric navigation.

Intelligent Vehicle-Highway Systems

Intelligent vehicle-highway systems (IVHS) encompass several different technologies that can provide services ranging from timely information about congestion and alternative routes to fully automated control of vehicles on limited access roads. Drivers can obtain real-time information about road and traffic conditions, directions to unfamiliar or distant sites, identification of alternative routes, and determinations of optimal and safe driving speeds and automobile spacing on roads. These technologies have the capacity to increase road capacity by 10-20% by encouraging the optimal use of road space, improving the flow of traffic, and reducing congestion, although they will not, by themselves, totally eliminate congestion problems (OTA 1994, p. 244).

IVHS technologies include advanced traffic sensing and signal control technologies to improve traffic flow, as well as on-board systems to help drivers interpret highway system data to reduce travel time and improve safety. IVHS comprise three major groups of technologies: advanced traffic management (ATMS), advanced traveller information (ATIS), and automated vehicle control (AVCS).

ATMS technologies are designed to monitor traffic by using radar and other remote traffic systems to analyse data derived from these monitoring systems, to alter traffic flows electronically by adjusting signal timing and freeway ramp controls, and by providing information on roadside bulletin boards. ATMS bypasses direct participation and interaction with the driver. The Tomei Expressway, Japan's busiest motorway, has been using ATMS technologies for some years on a 250 kilometre stretch leading out of Tokyo ('The Endless Road, a Survey of the Car Industry', 17 October 1992).

ATIS technologies are on-board systems that impart information about traffic conditions and alternative routes and may include electronic maps and navigational tools. ATIS information may be tailored to an individual driver's travel plans. They are particularly useful for drivers with multiple route options. Such systems could also pre-book parking spaces and even hotels. For some European countries, BMW now offers a built-in electronic road map with information on the state of motorway traffic,[4] and a similar system is available in some Avis rental cars in the United States.[5] There are at least fourteen different navigation systems available in Japan.

AVCS technologies are on-board technologies geared towards traffic safety. They can assist drivers with such facilities as adaptive cruise control, obstacle detection, and infrared sensing to improve safety for night driving. Other AVCS technologies are designed to intervene directly in driving. They include automatic braking and manoeuvring. The rationale behind these technologies is to maintain optimal, but safe, distances between vehicles to improve driving and traffic flow. The most ambitious AVCS technologies under development involve automated driving, where human drivers essentially become passengers until reaching their destinations. They may have their first practical applications on motorways. Already, some Greyhound buses in America carry microwave radar to monitor their distance from other vehicles and their closing speeds, and many American school buses use another version of this system to alert the driver to children behind or beside the bus where they cannot be seen in mirrors. Systems currently operational include speed monitors that warn drivers who go too fast, or alert drivers who stray out of lane or show signs of sleepiness, and which brake or steer automatically in certain circumstances ('Jam Tomorrow?' 29 April 1995).

In August 1997, the middle two lanes of an eight-mile stretch of highway near San Diego, California, will be taken over for an experiment with AVCS technologies. Squads of 10-12 vehicles equipped with sensors, radar scanners and dedicated on-board computers will communicate with each other and a control centre, and will be capable of operating on automatic control, travelling a distance of two metres apart at motorway speed. The experiment will ascertain the degree of automation that works best. The US Government has spent around US$1 billion on AVCS technologies so far, working with a consortium of companies that includes General Motors, Lockheed Martin and Bechtel. They believe that they will have a fully-tested prototype intelligent highway system up and running by December 2001. Toyota is also undertaking a major program on an automated highway system ('Survey on Living with the Car', 22 June 1996).

As with electronic road pricing, IVHS technologies will work best through broad applications across traffic systems and the vehicle fleet rather than through incremental investments. Moreover, many on-board technologies require driver interaction and attention which may reduce safety by distracting drivers. Finally,

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[4] A network of sensors equipped with radio beacons to collect and transmit traffic information from along the motorways and major trunk roads in Britain (the so-called Trafficmaster system) and several other European countries is now available.

[5] Delco, the components arm of General Motors, is developing a sophisticated new navigation system for America, and the European Union is supporting similar research in conjunction with Mercedes-Benz, BMW, Fiat, Renault, Ford and GM Europe.

concerns about legal liability in cases where AVCS technologies fail and cause accidents may limit industry interest in these tools. Nevertheless, the development of IVHS technologies in the United states has been considerable, and the use of technologies to improve the timing of traffic lights has indicated the substantial gains that can be made through the application of newer technologies (OTA 1994, pp. 245-246).

ITS America, a government-backed pressure group, suggests that the introduction of 'intelligent vehicles' and 'intelligent highways' could cut expected congestion by 20% and accidents by 8% by the year 2011. Their introduction could also create new options for car design, including lighter car bodies and propulsion systems requiring less power ('Jam Tomorrow?' 29 April 1995).

Electronics and the Minimisation of Air Pollution

A further application of electronic technologies relates specifically to air pollution minimisation strategies. Surveys indicate that a large part of the air pollution attributable to motor vehicles is caused by older vehicles that have been poorly maintained. Environmentalists in Germany have suggested installing a smart card in the electronic engine-management system that would record the pollution emitted by a vehicle. It would be read during periodic inspections and the information passed on to the tax authorities. Another method is being tried in Sacramento County in California. The program involves running an infra-red beam across the tail-pipes of passing cars. Excessive levels of smoke or pollutants will distort the beam and trigger a camera to take a picture of the offender's licence plate.

SUSTAINABLE TRANSPORT, NEW TECHNOLOGIES AND THE DEVELOPMENT OF THE MOTOR VEHICLE INDUSTRY

The Demand for Superefficient Vehicles

How rapidly is the demand for superefficient vehicles likely to increase? Three particular factors are expected to stimulate the demand for such vehicles:

- government regulations and incentives aimed at encouraging such demand;
- increasing concerns about the costs of traffic congestion and the need to improve the productivity of existing roadway networks; and
- increased attention to the problems of urban air pollution and the issue of global warming.

The major constraints on the demand for superefficient vehicles are expected to be:

- the vulnerability of radically new vehicle designs to product liability challenges; and
- the potential need for substantial new investments in such infrastructure as charging stations for electric vehicles, distribution networks for alternative fuels, and capital equipment for advanced electronic road pricing systems and IVHS technologies.

The United States will be a leading market for superefficient vehicles. The regulatory initiatives pioneered by California, the concerns about the capital productivity of infrastructure assets, the existing dependence of the current American urban environment on the motor vehicle, the head start it has in new technological developments, and the capabilities in applied electronics and other engineering skills gained by the huge American defence industries are encouraging factors. The major constraint particular to the American scene will be the importance of product liability challenges.

The other leading markets for superefficient vehicles will be Japan and Western Europe. In Japan, considerable attention is being given to these technologies by the local industry, and consumers have normally been quick to respond to product innovation. In addition, Japan has the largest metropolis in the industrialised world in Tokyo and the third largest metropolis in Osaka; both these huge urban centres facing unique transport problems. Western Europe is also investing in relevant technological development, and is environmentally conscious.

Traditionally, the economies of the developing world (and the so-called Economies in Transition) have not been intensive consumers of advanced vehicle technology. Instead, they have been a market for yesterday's motor vehicle technology facilitating the full realisation of scale economies on earlier vehicle designs. Characteristic of these markets has been the survival of the Volkswagen 'Beetle' in production in Brazil. However, there is now in train a process of catch-up occurring in many of these economies whereby demand for current technology is escalating, and local distributors and assemblers are taking up options for state-of-the-art models. This trend is particularly evident in Latin America. Rising incomes are an important factor. Major problems with traffic congestion in the large cities of Asia and Latin America, and problems with air pollution in Asia, Latin America and Central and Eastern Europe are likely to encourage the more rapid takeup of new technologies in these markets in future. Moreover, as the size of these markets grows, they may start seeking unique technological solutions to meet their particular problems.

Supplying Superefficient Vehicles

The development of a supply capability for superefficient vehicles will be influenced by a range of factors summarised below.

1. Governments are becoming involved in researching, designing and commercialising superefficient vehicles. In the United States, several important projects involve partnerships between the public sector and the major three vehicle producers which provide R&D outcomes which can then be utilised in the individual product development of the three major vehicle manufacturers. One particular aspect of this approach to technological development is its implications for international trade rules. Will exports of new products that arise as a long term outcome of such joint R&D be in conflict with the World Trade Organization regime?

2. The supply capability for superefficient vehicles will also be influenced by the particular challenges confronting technological research in such areas of complexity as fuel cell and battery technologies. Difficulties in developing low cost methods of manufacturing in relation to new technologies, of particular importance in relation to new materials, will also need to be resolved.

3. The availability of financial resources and skilled personnel in the existing motor vehicle industry, given requirements for continued evolutionary updates in existing vehicles and compliance with new safety and emission standards will be a constraint on the development of superefficient vehicles. As a consequence, there is a potential for important shifts in market power away from the traditional vehicle manufacturers, especially if the new vehicles are electric.

The Motor Vehicle Industry in the United States

The American motor vehicle industry will undoubtedly play a leading role in the supply of superefficient vehicles. Over the past three years there has been a major revival of the industry. Each of the big three automakers has undergone extensive restructuring, with the improvement of manufacturing technology and a significant improvement in quality control. Ford is working hard to turn itself into a fully integrated global company that manufactures global cars, and there are major changes under way at General Motors.

Cooperation between the public sector and the major automakers is occurring in a number of technological development projects, including the Program for a New Generation of vehicles, the United States Advanced Battery Consortium, and the cooperation on AVCS technologies (which also involves major enterprises from outside the motor vehicle industry, including Lockheed Martin and Bechtel). Major research and development is occurring across the board in vehicle technology, in new direct-injection engines, two-stroke engines, battery technology, electric vehicles and hybrid-electric vehicles, materials technology, navigation systems, vehicle pollution detection systems, and AVCS technologies.

The big three automakers, and especially General Motors, have embarked on a wide range of developmental work which is designed to keep their options open as the vehicle market becomes transformed in the coming decades. As the new technologies develop, it is not clear whether or not the major automakers will retain the breadth of their current involvement in directly manufacturing a substantial proportion of the final vehicle. New areas of specialisation may arise. Electronics is one example, where the experience and ability of major defence contractors may be usefully employed. Engine technology is another, particularly in relation to electric vehicles.

The Motor Vehicle Industry in Japan

Since the 1960s, Japan has become the world leader in such aspects of motor vehicle manufacturing as car quality, and manufacturing systems. Over the past few years, however, it has been facing a number of challenges: the saturation of the domestic market, high cost structures when exchange rates are taken into account, and new sources of competition. It is confronting these challenges through increased ties with manufacturers and parts suppliers in North America, the Asia-Pacific region and Europe, and shifting towards improved margins rather than sales maximisation. Toyota is pioneering a new production facility which is designed to take its manufacturing systems into the 21st century. This new facility has cut back on automation and given greater emphasis to the control of the manufacturing process by teams of workers. Toyota is also developing a new car, the so-called 'Asia Car' pitched at urban workers in South East Asia and designed for tropical climates. It will be in direct competition with the new Honda City.

Japanese vehicle manufacturers are developing new direct injection engines, a prototype two-stroke engine, and purpose-built electric vehicles. Significant research is being conducted on materials technology and IVHS technologies. The affiliation of Japanese manufacturers in the keiretsu groups enables technological linkages to be formed embracing electronics and engineering. This will be a source of strength for Japan in confronting the technological challenges of the future. Moreover, Japan continues to be an impressive innovator in developing improved manufacturing technologies, an attribute of particular importance in relation to the commercialisation of new materials technology.

The Motor Vehicle Industry in Western Europe

The third leading area for research and development of superefficient vehicles is Western Europe. New technologies are being developed in relation to the flexible-fuel vehicle, direct-injection engines, electric vehicles, electronic tolling, and ATIS. Along with this work on advanced technologies, European car makers are developing new models at an accelerated pace and investing in incremental technologies. Despite these developments, the European car makers continue to lose market share. With high costs in Europe they are increasingly shifting large parts of their operations abroad, particularly to Asia and Central and Eastern Europe. It is unlikely that all the major European vehicle manufacturers will survive beyond the next decade. The pressures associated with accelerating technological change will reinforce existing trends towards a major shake-up of the European vehicle industry.

The Motor Vehicle Industry in Other Parts of the World.

The United States, Japan and Western Europe have been the centres for innovation in the global motor vehicle industry, while vehicle manufacturers in other parts of the world have tended to be followers. Developments in Asia and Australia will be discussed later. The current situation in the Economies in Transition and in Latin America is worthy of comment.

New car sales are beginning to boom in those Economies in Transition located in Central and Eastern Europe. Despite favourable aggregate demand trends, local manufacturers of vehicles are battling to survive, given their obsolete facilities, management problems, and outmoded products. Foreign investment from Western Europe, the United States and Korea in greenfield plants is growing.

In Latin America, the two countries possessing integrated vehicle industries are Brazil and Argentina. Both countries are experiencing a boom in vehicle production. European and American producers are the dominant influences on the industry, although Toyota and Honda are now establishing new investments. After decades of utilising outmoded designs, the Brazilian and Argentinian industries are rapidly moving towards the same technology, models and quality requirements as the European industry. The Mercosur free-trade area, covering parts of South America, is enabling multinational companies to merge their operations in Brazil and Argentina, and these countries are developing exports throughout Latin America and have the potential to export more widely. Given the unique characteristics of the rapidly developing markets for vehicles in the major urban centres of Latin America, it is possible that local technological innovations could occur at some future point.

The Motor Vehicle Industry in Asia

An Overview of Demand and Supply

The demand for sustainable transport innovations in Asia is growing rapidly. This is especially true of the mega-Asian urban agglomerations. Asia contains some of the largest cities in the world, traffic congestion is becoming a huge problem in many of these cities (Bangkok, Jakarta and Manila, for example), the need for new mass transit systems is evident (Bangkok and Jakarta), and air pollution is as bad as anywhere in the world in many Asian cities (notably Calcutta, Delhi, Beijing, Shanghai, Guangzhou, Shenyang, Xian, Manila and Bangkok).

The capacity of Asian manufacturing industries to play a role in developing the necessary technological innovations is significant. Japan is a leader in the world motor vehicle industry, and in the application of electronics in other manufactured goods. Outside of Japan, however, independent vehicle producers have yet to become technologically competitive with the Japanese and American producers.

The Vehicle Industry in South Korea

The motor vehicle industry in South Korea is dominated by three local producers – Hyundai, Daewoo and Kia. With domestic demand for new vehicle levelling off and local costs rising, production is starting to be shifted abroad. Billions of dollars are being spent on developing Asian assembly plants, building local dealer networks, and providing seed money for local parts suppliers and support for local partners. Taiwan, the Philippines, Thailand, Indonesia, India and Vietnam are all receiving significant investments, and Daewoo is tackling Eastern and Central Europe. However, the Korean industry is yet to approach Japanese quality standards, and there is little home-grown technology as yet. The development of superefficient vehicles by the United States and Japan will create new competitive pressures for the Korean industry which will have to consider developing its local research and development facilities.

The 'ehicle Industry in Thailand

Thailand is the largest vehicle producer in South East Asia. General Motors, Ford, Chrysler, Toyota, Honda, Mazda and Volvo all have a local presence, and a domestic auto-parts industry has developed to service these car manufacturers, and car components are exported to the Asia Pacific region. Whole vehicles are being built in Thailand, although there is no national car as such. Thailand is the base of the new Toyota and Honda vehicles that are aimed at the rapidly expanding Asian urban market. The Philippines is emerging as the main source of competition for Thailand as a regional vehicle producing centre. Neither country is aiming to establish an independent industry.

The Vehicle Industry in Malaysia

Malaysia has two local car manufacturers. Proton, by far the larger of the two local producers, has been developed on the basis of technological inputs from Mitsubishi. However, dissatisfaction with the rate of technological transfer from Mitsubishi and the dependence on high-priced Japanese parts and materials has led to the development of a new model by Proton which is a variant of a car produced by Citroen. Proton is protected by a 200% tariff on automobile imports and a paucity of domestic competition. However, commitments under the World Trade Organization and the Asian Free Trade Agreement will force Malaysia to slash import duties as early as the year 2003. Proton is not yet ready for stiff competition, some of its manufacturing techniques being antiquated, just-in-time production being precluded by supply irregularities, and product quality, although improving, is not world competitive. Perodua is the second local car manufacturer, and represents a joint venture with Japan's Daihatsu. A car components industry is gradually developing in Malaysia.

The Vehicle Industry in Indonesia

A new joint venture between Kia Motors of Korea (30%) and the local group Putra (which holds 70% of the venture and is headed by Tommy Soeharto, a son of the Indonesian President) is aiming to develop a 60% Indonesian car, to be called the Timor, by 1999. The venture is receiving exclusive tax exemptions (sales tax and duties on imported components) over a three year period, providing it with a roughly 50% advantage over the Japanese-dominated local assemblers of new vehicles. The development of this venture reflects Indonesia's dissatisfaction with the low rate of technological transfer by foreign assemblers to Indonesia. In the first year of operation (from September 1996 to September 1997) the car will be largely manufactured in Korea but with 20% of local parts, but the local content has to rise to 60% to maintain the tax concessions. The Timor partners are now looking for collaboration with Australian interests, and BTR Nylex, Hendersons, Hella Asia Pacific, Millard Design and the Orbital Engine Corporation are all negotiating joint venture arrangements. The future success of the Timor is being threatened by the possibility of actions against the tax concessions it receives by the United States, the European Union, and Japan under the provisions of the World Trade Organization.

The Australian Motor Vehicle Industry

The local market for motor vehicles , which has stagnated for many years, is expected to show modest growth over the next decade. Qualitative change in this local market will take place, although the economic and environmental pressures for change are not as great as likely to be experienced in Asia, for example.

The key to future demand for Australian-made vehicles, parts and components lies in export markets. Exports are increasing rapidly, and growth is expected to be significant over the next decade. The main markets being serviced are New Zealand, South Korea, Japan, the United States, the European Union, and ASEAN. The principal exports comprise finished vehicles, engines, and engine parts.

Motor vehicles are manufactured in Australia by Ford, General Motors Holden, Toyota and Mitsubishi. Some 600 component producers supply domestic and export markets. The industry is experiencing a very high rate of investment currently.

In June 1995, Australia's four car manufacturers and 600 component producers reached agreement on the adoption of uniform standards across the industry. The global Quality System 9000, covering such areas as finished-product quality, manufacturing systems and product development, replaces a plethora of separate quality systems. All suppliers will undergo training and will have their quality systems subjected to an independent audit. Australia becomes the only car producing country in which all suppliers to the industry have a common internationally recognised system. The policy will increase the recognition of local component manufacturers by overseas markets. A further development in the local industry is the plan to establish an 'automotive precinct' in Melbourne. It is expected to become a regional centre for skills and training for the automobile design industry.

In 1993-94, all innovation spending by the motor vehicle industry in Australia totalled A$789.7 million, the highest for any manufacturing industry in this country, and representing 5.24% of sales, compared with 2.85% for manufacturing as a whole (Department of Industry, Science and Technology 1996, p. 12). Australia is well placed to make a contribution to the refinement of technologies and manufacturing standards for the superefficient vehicle.

In July 1996 the 'Australian concept car' project was launched. It will receive funding of A$5.7 million in State and federal funds and more than A$14 million contributions 'in kind' pledged by more than 65 companies. Powered by a two-stroke Orbital engine, the car will promote the capabilities of the Australian components sector. Millard Design, a Melbourne-based design and prototype house, will oversee the design and construction of the Australian concept car. The vehicle is planned to feature readily available technologies that offer manufacturers superior performance and lightness. In addition to the Orbital engine, the car is expected to feature:

- a multiplex wiring system designed to reduce the weight and complexity of electrical wiring, provided by the Sydney-based company, Utilix;
- a lightweight braking system developed by PBR Automotive;
- lightweight magnesium castings from Lawrenson Diecasting; and
- lightweight steel body technology provided by BHP Steel.

This project should boost the development of the Australian industry in South East Asia and adjoining regions. The vehicle industries in this region are seeking to reduce their technological dependence on the big car producers which have not always been happy to part with the latest technologies and designs ('Concept Car a Rolling Ad for our Know-how', 15 July 1996).

CONCLUSIONS

Once the issue of the sustainability of transport systems is taken into account, there are powerful incentives to develop new technologies. These new technologies will lead to dramatic changes in the design of road vehicles, with new types of internal combustion engines, electric vehicles, the use of new materials, and the enhanced utilisation of electronics being characteristics of the superefficient road vehicle of tomorrow. Sustainable transport systems will also require the sophisticated use of electronics in traffic management. These new technologies will have significant implications for the structure of the global motor vehicle industry. Some shift in market power away from the current leading vehicle producers is likely, although the United States and Japan should retain their leading positions in the industry. Changes on both the demand and the supply side are expected to affect the industry in Asia, and the Australian motor vehicle industry will be presented with some interesting new opportunities.

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