Motor Vehicles
in the developing world: options for sustainability

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A
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REPORT

Abstract

The idea that conventional motor vehicles may not be the most appropriate solution for developing countries as part of a sustainable energy future is introduced, and discussed with reference to some existing and previous efforts in the field; intermediate technology development in the Schumacher idiom is found to be a worthwhile approach. Fuel and material technologies are then considered to determine the most appropriate options.

Introduction

The MG Rover debâcle was current whilst this paper was in preparation, and central to what was a tragedy for many—employees, enthusiasts and those who see a David crushed by many Goliaths—was the desire of two Chinese companies, Shanghai Automotive and Nanjing, to gain control of technology which they need to build and mass-produce their 'own' cars, with Shanghai's aim production of around a million cars per year [1] initially, rising to six million per year by 2020 [2].

Now, whether or not China's car market in the short term can absorb such vast volumes, especially as Beijing introduces measures to "slow the booming economy" [3], the bigger picture is that in the coming years, China's contribution to global warming and atmospheric pollution through many millions of extra cars could be very significant (alongside its heavy—and increasing—usage of coal-fired electricity generation): it is the "rousing giant of global warming" [4].

Alongside other emerging economies, at present particularly in Asia, but ultimately, worldwide, an assumed adoption of the motor car is proceeding unchecked, with apparently little in the way of adaptation or innovation suited to local conditions, or indeed to a more sustainable future.

"People spend about 45-90 minutes per day travelling, whether they live in an African village or Europe or Asia or the US" [32], yet the most appropriate mode may be very different; whilst there have been previous efforts to produce indigenously-suitable cars for developing countries, which technologies give us opportunities to make a real difference in addressing users' needs whilst also having less of an environmental impact?

Some previous efforts in the field

From cast-offs to Chinese BMWs

Apart from a few notable exceptions—examined in due course—the majority of vehicles produced in developing countries have been based on obsolete or (rarely) current products from western manufacturers. Well-known examples include Iran's Paykan [5], based on the Rootes/Chrysler Arrow series, India's Hindustan Ambassador [6], based on the Morris Oxford and the almost ubiquitous former Peugeot models assembled across Africa, including Nigeria, Kenya and Zimbabwe [7]. These models have succeeded largely because the models built were chosen or modified for the road conditions likely to be encountered, or modifications made to the bodies offered to accommodate local needs.

It remains to be seen how successful the more recent waves of much more conventional, up-to-date vehicles such as the BMW 3-series being built in Shanghai by Brilliance China [8] will be once demand in the well-paved cities is satiated. Adye Good, who has taken on some development of the Africar (see below) comments, regarding rural China:

> "The spares infrastructure is just not there; they do not have scrap yards full of bits. They hardly have any main dealers. The

> terrain will treat any vehicle very harshly, i.e. 1 European mile equals 5 miles in these countries, therefore [appropriate vehicles] must be able to take this type of punishment all the time" [25].

There is an important distinction to be made between what are effectively assembly operations of imported parts (often from 'knocked-down' kits which take advantage of cheap labour and low levels of automation)—e.g., the Chinese BMWs use more than 60% imported parts [8]—and genuinely locally manufactured products which encourage the economic development of local supply chains.

The Africar model

Whilst China, being something of the 'workshop of the world,' is well placed to move into entirely local car manufacturing, as shown by companies such as Geely [9], these nevertheless follow the western model fully: they are vehicles which require western levels of road infrastructure. For the many developing countries where such infrastructure is neither feasible nor desirable, the economic and social advantages of motor transport could perhaps be attained in a more appropriate manner:

> "It is in the Third World that one can clearly see a relevance and future for the car. It is in countries without adequate roads and established public transport systems that there is a genuine application and need for the various forms of light motor vehicles. Yet, because of its inadequacies and consumer-orientated origins, the car is virtually useless where it is most required." [10]

This quote is from one of the most high-profile attempts at employing 'appropriate' technology to develop a vehicle for local manufacture in developing countries, adventurer Anthony Howarth's 1980s Africar project (which, however well-intentioned, ended in ignominy, a fraud trial and gaol for Howarth [11]).

The Africar prototypes, using air-cooled Citroën engines and epoxy-coated plywood body panels and chassis (see later discussion), were extensively tested and successfully rallied in a variety of challenging environments throughout their development programme, including driving from the Arctic Circle overland, across the Sahara and Sahel to the Equator (in Uganda) and on to the Nairobi motor show [10] in four months. Making use of a track width the same as that of the heavy trucks (e.g. the Unimog) which have formed the ruts in many African roads, and with superlative ground clearance and independent suspension derived from Howarth's frustration with using conventional live axle 4 × 4 vehicles (such as the Land-Rover) where the axles would become grounded and complete lack of traction result, the Africar engineering philosophy was impressive, and persuasive.

It was thus particularly unfortunate that the project did not have the chance to reach the stage where its promise could be fulfilled. The field of designing vehicles for developing countries is beset with political loading and financial problems, as we will see with the Izuogu and World Transport Authority cases.

Technology lessons learned from the Africar have parallels in other projects, many of them indigenous. The Uri, designed and manufactured in Namibia, is a straightforward, rugged, wide-tracked off-road vehicle planned for simple assembly (e.g. using flat glass) and "mostly used on farms, in mines, for policing and related heavy duty environments" [12]. South Africa has the Nvubu 6 × 6 amphibious off-roader [13] similar to the Crayford Argocat, and the Rotrax El Macho 4 × 4 patrol vehicle (based on a British kit car) [14].

Two attempts by western car manufacturers

Some western manufacturers have instigated programmes to develop vehicles specifically to meet the needs of developing markets and the level of production capabilities present in those countries. FIAT's Palio 'world car' is a recent example, produced in a number of different variants in Brazil, Argentina, Venezuela, India, Turkey, Morocco, Egypt, South Africa, Poland and North Korea [15], but aside from a stiffer bodyshell, uprated suspension and better ground clearance than an average European supermini, the Palio is largely the standard western vehicle model, merely transposed. It does not offer anything radical in sustainability or technology terms.

From the 1950s onwards, the specialist British vehicle engineering company Reliant devised its 'package deal motor industry' concept, which used materials and techniques suited to low-volume assembly (hand-lay GRP bodies on simply fabricated steel chassis) and bespoke designs developed to meet exactly the needs of the countries concerned [16]. These were usually intended to operate as 'stepping-stones' for a country in the early stages of economic development—in Israel, much of the focus was on utility vehicles (the 'Sussita'); in Turkey, on the first Turkish family car to ease the country's balance of payments (the 'Anadol'); in Greece, on lightweight, manœuvrable 3-wheeled trucks for use on mountain roads (the 'TW9') and a small 4-wheeled pick-up (the 'Fox'), also intended for production in Barbados. Other Reliant package deals included the Dolphin, an economy car (60+ mpg) produced in Bangalore, India, and the Super Helicak, a larger capacity rickshaw for Indonesia. It is worth detailing some of the package deal concept since, despite its age, it offers the flexibility that may be key to sustainable transport development in partnership with a company from the 'developed world':

> "The 'package deal' is comprehensive and includes:
>
> 1. Design of factory, recommendation of plant and plant layout; supply of imported requirements
>
> 2. Full training of key workers at Tamworth [UK] factories
>
> 3. The supply of all moulds, jigs and fixtures necessary for production
>
> 4. The supply of all drawings and technical information that may be required in support of local purchasing
>
> 5. The supply of detailed assembly instructions and quality control procedures
>
> ...
>
> 8. Continued development of the vehicle in the UK including variants to the model or additions to the range by arrangement." [16]

In practice, the countries involved were free to move on to develop their own variations on the product, often in conjunction with the UK firm, and the percentage of imported components dropped as local supply chains were established. Sometimes the enterprises became industrial giants (e.g. Turkey's Otosan, which now mass-produces various Ford models [17]); in other cases the low-volume production ticked over sustainably for decades (e.g. MEBEA in Greece).

Self-started innovation : a political & economic issue

The formula of hand-laid GRP bodyshell and simple steel chassis also appears to have been followed by Dr Ezekiel Izuogu, who created Nigeria's first indigenous car, the Z-600, in 1997. This is a 20 mpg family car using 90% locally made components, and intended to sell for around $2,000 (at 1998 prices), "making it making it the most affordable car in Africa—and probably the world" [18]; the factory was planned to manufacture 30 cars per year. The self-developed 1.8 litre engine "could also be mass produced and put to other uses like agricultural mechanisation, standby electricity generator and tricycles" [19].

Whilst this project has ultimately not yet come to fruition (with interest from South Africa and Senegal being the latest twist [20]), it has become something of a political symbol. Dr Izuogu's house was stormed by an armed gang in 2003 [21] and much of the speculation surrounding the vehicle is associated with lessening African reliance on western technology. Nigeria's Chief of General Staff, Oladipo Diya, said at the Z-600's launch that "Izuogu had demonstrated the spirit of self-reliance... the theory of technology transfer was a myth" [19] and Izuogu has recently linked technology development to the movement for a pan-African language—"Technology determines whether a people will be rich or poor, strong, weak or influential at the UN or onlookers, borrowers or lenders... The moment a people can describe a technological feat and process using the mother tongue, technology becomes part and parcel of their culture" [20].

This idea of self-started, appropriate innovation has gained much currency from the work of organisations such as the Intermediate Technology Development Group, founded by E. F. Schumacher and espousing the notion of "finding out what people are doing and helping them to do it better" [22]. The ITDG takes the philosophy of

Schumacher's classic Small is Beautiful, particularly the chapter 'Technology with a Human Face' [23] and applies it to finding "practical answers to poverty" [22].

Whilst it appears that transportation development is not currently among the ITDG's priorities, in the 1980s it published a comprehensive manual, The Design and Manufacture of Low-cost Motorized Vehicles [24], in conjunction with the UN's Centre for Human Settlements (Habitat) and the ILO, which reviews indigenous designs of minimal transport from across the world, including one-off conversions of motorcycles into 3-and 4-wheeled load-carriers and rickshaws, simple agricultural vehicles with power-take-offs for farmers, and moving on to small-scale production vehicles, the construction of larger pick-up trucks, utility vehicles and taxis from a mixture of scrap parts and hand-made bodies, as with the Jeepneys [10] of the Philippines. The aim was to disseminate this information more widely, so that best practice from one community could be spread to others with similar needs and circumstances.

An impressive recent initiative along these lines is the Basic Utility Vehicle, a rugged 3-wheeled load carrier described as a "car for humanity," developed by the Institute for Affordable Transportation, a non-profit organisation based in Indiana [26], along with students from a number of universities. The BUV has already been trialled in Honduras and Zimbabwe; other countries will follow, as the design evolves. IAT's philosophy is to help by "giving people a tool that enables them to provide for themselves," the aim being local production in 'micro-factories.'

Current commercial interest

Developing markets hungry for appropriate vehicles present a major opportunity in commercial terms for manufacturers willing to involve themselves. Among others, the grandly named World Transport Authority, Inc., based in Beverly Hills, developed the WorldStar range, GRP-bodied (with balsa wood core floorpan) utility vehicles with engines (remanufactured VW units) able to run on diesel or propane, and, like the BUV, intended to be built in licensed micro-factories across the developing world, perhaps only producing a single car each day. The WTA "business model probably has more in common with multilevel marketing than with conventional auto industry ventures" [27]; so far, at least, the WorldStar appears to have suffered the same fate as many MLM schemes, with the SEC filing a suit against WTA's founder, Douglas Norman, on securities fraud charges [28]. A reconstituted company, Millennium Autotech International Corporation, is now operating in the Philippines [29].

Technology options

Electric propulsion

It's worth noting that none of the schemes examined is for an electric vehicle. The lack of charging facilities and the expense, weight and poor energy density of traction batteries effectively rule out most forms of conventional electric propulsion, at least in rural areas. Indeed, when this author was investigating the potential for designing a powered wheelchair for use in the developing world, he was told by a major wheelchair aid organisation [30] that a petrol-engined wheelchair would be the only real option, for exactly these reasons.

Could photovoltaics be used? They are currently still too expensive per unit area to be suitable for any low-cost application as energy-intensive as transportation, regardless of how effective they might be in many equatorial countries. Whilst university teams compete successfully in many solar car challenges [e.g. 33], these are, as yet, always ultra-lightweight, low-drag vehicles designed for smooth roads. However, lowering costs is "a major focal point of the PV industry" [31] and in time there may be scope for using this low maintenance, durable technology with a 10-30 year lifetime [31] in some form, ideally with local manufacture of some kind. The weight of the batteries remains an issue, as, unfortunately, do environmental & sustainability concerns with respect to the PV cell manufacturing. Small-scale hydrogen production plants making use of abundant sunlight may also be possible, but this technology (along with fuel cells) is more likely to be deployed first in developed countries which can afford the R & D costs.

Hybrids would (currently) appear to add expensive complexity without much immediate gain in the context of affordable personal transport for the developing world, although it is worth noting that the Toyota Prius, originally sold at "at a sizable loss... something like $16,000 for every Prius" [34] is now said to be profitable [35]. Whilst perhaps not suitable for personal transport, there may be an opportunity for diesel-electric hybrid use in public transport—buses or minibus taxis—as cities develop. Electric running would prevent immediate air pollution in the city centre; diesel running would allow efficient progress out of the city on poorer roads.

As an important aside, it is clear that appropriate public transportation, even if on an individually small scale such as the Jeepney, is a much more sustainable way for developing countries to become mobile than simply moving into car production. As Jane Jacobs said in The Death and Life of Great American Cities, "we went awry by replacing, in effect, each horse on the crowded city streets with half a dozen or so mechanized vehicles, instead of using each mechanized vehicle to replace half a dozen or so horses" [36]; if cities in developing countries can learn from our mistakes, a sustainable transport system may be possible.

Internal combustion : fuel choice

Some vehicles, such as the WorldStar, are able to run on multiple fuels (diesel and propane), which certainly adds versatility. Along with the Africar, it uses an air-cooled, horizontally-opposed engine (converted VW for the WorldStar, Citroën for the Africar), reducing complexity in component count and potentially increasing reliability.

In expediency terms, a well-proven, simple engine with widespread parts availability may be more sustainable than a more technologically advanced design, even if it is less efficient thermodynamically. The ability of local engineers or even blacksmiths to machine or forge replacement parts allows old engines to be kept running for much longer, often outliving the vehicle structures themselves (as with many highlighted by the ITDG report [24], and with the Jeepneys); Anthony Howarth mentions the story of an African truck engine salvaged and rebuilt with hardwood pistons in order to make a much-needed journey [10].

One point that becomes apparent is that even as global oil prices increase—whether peak oil occurs sooner or later—diesel fuel will continue to be available in one way or another for the large trans-continental trucks (and railway locomotives) which are vital lifelines for many remote areas, as well as for marine engines and generators. This suggests that diesel engines may be a prudent choice for other transport vehicles; the lack of a requirement for spark plugs also reduces the dependence on outside components and the higher torque outputs are suited for heavily loaded vehicles, perhaps being used as taxis and load-carriers.

There is still the legacy of existing petrol (gasoline) vehicles and their engines, but diesel engines also have the advantage that they can be run on a large range of oils with minimal adjustment, from the peanut oil and hemp oil which Rudolph Diesel used in his early demonstrators [37] to recycled cooking oil, modified soybean oil [38], animal fats or biodiesels made from energy crops (such as rape) specifically grown for the purpose. In most cases these fuels can be used in existing diesel engines rather than requiring new equipment: the typically long life of diesel engines, due (usually) to robust cast iron construction, is an extra advantage.

Clearly, this is an extremely attractive route from the sustainability angle, since these fuels tend towards carbon neutrality—taking into account harvesting, processing and transport energy, “a 1998 biodiesel life cycle study, jointly sponsored by the US Department of Energy and the US Department of Agriculture, concluded biodiesel reduces net CO_2 emissions by 78 percent compared to petroleum diesel” [38].

The US National Biodiesel Board asserts that use of biodiesel in a diesel engine results in “substantial” reductions in unburned hydrocarbon, CO and particulate emissions (hence lessening the need for complex filtration systems), and the “effective” elimination of sulphates and SO_2 [38], although it concedes that NO_X emissions can be increased; “however, a reduction in emissions of nitrogen oxides of 4% can be achieved by if the fuel injection timing is retarded by 2 or 3 degrees” [39].

Many of the disadvantages of biodiesel also apply to biofuels in general, such as Brazil’s ethanol (from sugar cane) and Russia’s methanol (from eucalyptus). The most intractable problems are that, simply, every acre used to grow biofuel crops is an acre less for food production (which in many areas in developing countries with poor agricultural resources already, is critical); and that biomass itself, as “a solar energy conversion process... operates at about 1% efficiency, so the energy content is relatively low per unit planted area” [32]. Indeed, it has been stated that, for example, if an area the size of Germany were to be given over entirely to sugar cane, this would still provide only half of Germany’s energy needs [40].

Nevertheless, it is possible to produce biofuels from harvest waste (just as it is possible to release energy by burning it), and this can allow food crops to be used for their intended purpose whilst still producing fuel; this could be a route for smaller-scale biofuel production in a developing country where fertile land may be at a premium—provided, of course, that sufficient animal fodder can be found to compensate for the loss of the waste [40].

Depending on the climate, fertility and circumstances of the regions in question, it does not seem unfeasible for biofuels—particularly ethanol and biodiesel or diesel replacements— to play an important part in a sustainable fuel system for motor vehicles.

Construction materials

Conventional modern car plants with robotised welding lines for pressed steel (or aluminium) bodies have large fixed costs which must be amortised over large production runs (to some extent this explains the rationale behind exporting obsolete production lines once the costs have already been written off). In contrast, hand-lay GRP construction as purveyed by Reliant (qv) and GM with the Corvette is much more scalable, whilst keeping marginal costs comparable to those of steel; it also allows for lighter vehicles, thus lower fuel consumption. In a market which may be very small, a car can be turned out to order from a master set of moulds: exact customisation for users' needs is much easier than with mass-produced steel bodies. However, it is worth noting the many small workshops around the world producing hand-crafted steel body panels for vehicles, from Charles Ware's Morris Minor workshops in Sri Lanka [44] to the Sarao Motors Jeepney works near Manila [45].

The example set by the Africar, using plywood laid into epoxy resin to construct both chassis and body (similar in fact to how some wind turbine blades are manufactured) has been followed successfully for many years in low-volume production of boats, aeroplanes and some kit-cars (e.g. the Marcos [41]) and offers many of GRP's advantages, but in an even more sustainable form. Proper sealing of the wooden laminate means that softwood can be used confidently—a renewable resource compared to the hardwoods often used in boat construction, for example.

Hand-laying wooden laminates and epoxy resin is a labour-intensive process, but for small-scale production, it requires an absolute minimum of equipment and resources. The barriers to entry are extremely low—moulds can even be made from existing vehicles [42] and damage to bodies can easily be repaired by the owner.

Other lightweight composites, including metal composites such as the stainless steel 'sandwich' material being developed at Cambridge [43] may soon become much more prevalent in cars from major western manufacturers, as they attempt to reconcile the demands of greater crash-protection (often meaning more bulk) with a need to cut fuel consumption. In time, these advances may become cheap enough for small-scale production in the developing world, but at present, the resin and wooden laminate model seems especially attractive.

A brief note on life cycles

Life cycle analyses of motor vehicles normally show that the energy employed in the use phase (including the manufacture of the fuel) is far more significant than the embodied manufacturing/extraction/recycling energy of the car itself [e.g. 32]. Since technology is usually assumed to improve the energy efficiency of products over time (vacuum cleaners being a notably exception as newer models have more powerful motors with few improvements in efficiency), some have suggested optimum lifetimes for cars—a point where less energy will be used by recycling the old vehicle and buying a new one than by continuing to use it.

This assumed obsolescence and 'disposability' of cars is, to a large extent, a reflection of its "consumer-orientated origins" [10]: in societies where people do not have the means simply to buy a new vehicle when the old one reaches an 'optimum' lifetime, analyses need to consider this factor. Vehicles need to last longer when they are a tool, a workhorse rather than a consumer product, especially so if they are going to be heavily used (multiple passengers, load-carrying, rough terrain). Hence, there are two points which seem to follow:

- The much longer life required of vehicles in the developing world means that the energy of the use phase is even more significantly greater than with most vehicles in the developed world—to the extent that the embodied energy is vanishingly small in comparison
- Thus, unless some genuine efficiency breakthrough occurs in an alternative fuel or propulsion system, the optimum lifetime of these vehicles is infinite

Conclusion

Simple, customisable vehicles designed—using expertise gleaned from others' experience, perhaps in partnership with companies, perhaps independently—to cope with poor roads, with large passenger and load carrying abilities, adaptable engines able to run on both conventional diesel and biofuels, and able to be constructed in low volume with low entry costs, from renewable softwood laminates, with the aim of a very long lifetime, could allow motor transport to address the needs of developing countries as part of a more sustainable energy future.

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