Electric and improved cycle rickshaw as a sustainable transport system for India

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Most cities in India have high air and noise pollution caused by transport vehicles, especially petrol/diesel-powered three-wheelers. An improved and electric cycle rickshaw can provide a non-polluting and silent transport system for urban and rural areas of India. It can also provide large-scale employment to millions of urban and rural poor. Nimbkar Agricultural Research Institute has developed two types of rickshaws – improved pedal cycle rickshaw and motor-assisted pedal cycle rickshaw – the details of which are given in this article. It is shown that these rickshaws can provide a safe, environment-friendly, energy-efficient and cost-effective transport system in cities and towns of India. Commercialization, technology, social and policy issues are discussed for large-scale introduction of these rickshaws.

MOST of the cities and towns in India are highly polluted. The main reason is the air and noise pollution caused by transport vehicles, especially petrol and diesel-powered two- and three-wheelers. In India, there are presently close to 18 million petrol-powered two-wheelers and about 1.5 million petrol- and diesel-powered three-wheelers and their population is growing at a rate of about 15% per annum[1]. Besides being a major hazard to people's health, these machines are guzzling huge amounts of petrol and diesel for which the country has to pay dearly in foreign exchange outflow. It is a common sight in India and in other developing countries that during traffic jams in congested areas of the cities, these vehicles produce tremendous air pollution[1].

For example, three-wheeler diesel tempos in Lucknow city (capital of Uttar Pradesh) produce close to 70–80 decibel noise at a distance of 1–2 m, besides belching out huge amounts of particulates into the air. These diesel tempos have been recently banned in certain parts of Lucknow, and have been replaced by the equally polluting Tata Sumos. Similar data exist for almost all major towns where diesel/petrol three-wheelers are being introduced. The recent incident of banning of six-seater diesel tempos in Pune attests to this pollution problem[2]. Even in rural areas in taluka/tehsil towns, the spread of diesel/petrol three-wheelers has started affecting air quality[1].

There is therefore an urgent need to introduce an environmentally sound transport system in cities and towns of India which is cost-effective and also provides large-scale employment for urban and rural poor. An electric cycle rickshaw can provide a non-polluting, point-to-point and a silent transport system for urban and rural areas of India. Besides, it is an energy-efficient and cost-effective vehicle. Work done at the Nimbkar Agricultural Research Institute (NARI) has shown that improved cycle rickshaw powered by an electric motor and batteries has the potential to provide an attractive alternative to petrol and diesel-powered three-wheelers. It can also provide large-scale employment and extra income to the rickshaw puller.

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Existing cycle-rickshaw scene

It is estimated that close to 2 million cycle rickshaws ply on Indian roads, carrying about 6–8 billion passenger-km/year[1]. The exact number could be even greater, since there are no reliable records available. In some cities and small towns, they are the major means of transport. They provide employment to more than two million rickshaw pullers, are manoeuvrable, completely non-polluting and hence an environment-friendly means of transport. In the narrow lanes of towns and cities, probably they are the only transport system to provide point-to-point travel. It is, however, unfortunate that deliberate policies in most of the urban towns of developing countries have been made by the concerned authorities to phase out these rickshaws. These non-polluting vehicles are being replaced by polluting (both air- and noisewise) petrol and diesel-powered three-wheelers.

However, the existing rickshaws are so poorly designed that running them takes a heavy toll on the health of a rickshaw puller. The existing cycle rickshaw has hardly changed since it was introduced in India in the early 1920s from the far east (rickshaw is derived from the Japanese word *jinriksha*, which means hand-drawn cart). Apparently in the early 1920s, a Jesuit priest in India put a cycle wheel and pedals in front of the original rickshaw and this design has been used since then[3]. The gearing and the mechanical advantage of the pedal is poor. Hence the rickshaw puller has to work hard while climbing even a slight slope. A common sight is that of the rickshaw puller getting down and pulling on foot the rickshaw with passengers. The braking system is also poor, with only front brakes on the rickshaw. Thus, when going downhill at high speeds, sudden braking produces a catapult effect which results in overturning of the rickshaw. Similarly, the seating arrangement is uncomfortable, and the aerodynamic drag of the system is high. It is therefore humanly degrading to pull the existing inefficient cycle rickshaw. Yet because of poverty and no other source of income, migrant labourers do become rickshaw pullers and suffer adverse health consequences. There are estimates that rickshaw pulling is far more stressful than even hard labour. The rickshaw manufacturing presently is an unorganized footpath industry with no quality control, and there are as many rickshaw designs as the cities in which they ply. These rickshaws are so poorly made that they have to be replaced completely in about two years. Thus there is a need to improve the design of the existing rickshaw to make it user-friendly and bring quality control in its manufacture.

New design of rickshaws

NARI has therefore designed and developed two types of cycle rickshaws: (i) improved pedal cycle rickshaw (IMPRA); and (ii) motor-assisted pedal cycle rickshaw (MAPRA).

Improved pedal cycle rickshaw

The existing cycle rickshaw has been completely re-engineered for the safety and comfort of passengers, and to reduce the workload on the rickshaw puller. IMPRA has three-speed gears, reduced length of long chain drives, back-wheel shaft braking, better suspension and less aerodynamic drag than the existing ones. Figure 1 shows the IMPRA. Tests done on IMPRA have also shown that it enables a rickshaw puller to take two passengers on a 6–10% slope quite easily and without getting down from his seat. This rickshaw is made of mild steel angles, is light in weight, sturdy, and has ample luggage and leg space. The weight of IMPRA is 85 kg compared to 90–95 kg of the existing rickshaws. Its life is estimated to be between 7 and 10 years[1].

Our data (based on interviews with more than 300 rickshaw pullers and owners) from urban towns have also shown that a large number of rickshaw pullers are migrant labourers from villages, and sometimes have the rickshaw as their sole possession[1]. Hence, when they sleep at night, they sometimes do so on the cramped seat of the rickshaw for the fear of it being stolen. Our design allows the seats to be arranged in such a way that a long bed results, which allows a rickshaw puller to sleep properly, without the fear of his rickshaw being stolen at night. The cost of IMPRA is estimated to be Rs 7000 in mass production and compares well with Rs 4000–6000, which is the cost of existing cycle rickshaws[4].

Motor-assisted pedal cycle rickshaw

Discussions with a large number of rickshaw pullers also revealed that their drudgery will be reduced drastically if a small motor is attached to the rickshaw, so that it can assist their pedaling whenever they experienced load, or while going uphill. The extra power may also allow the rickshaw pullers to ply the rickshaw for longer distances and thus increase their earnings per day. Consequently, the MAPRA has been designed, built and tested (Figure 2). It has the following components:

(a) IMPRA chassis with seating arrangement and an extended hood for both passenger and driver.

Figure 1. Improved pedal cycle rickshaw.

Figure 2. Motor-assisted pedal cycle rickshaw.

(b) A 375 W, four-pole permanent magnet DC (PMDC) motor attached to a planetary gearbox.
(c) Gear drive train so that both pedal and motor power work in tandem.
(d) Two 40 Ah, deep discharge lead acid batteries to drive the PMDC motor.
(e) A stand-alone battery charger to charge the batteries overnight.
(f) High current switches.

All these components, except batteries, were specially designed and developed for MAPRA[4]. The weight of MAPRA (with batteries) is 150 kg. Test results have shown that MAPRA can easily take two passengers at a speed of 10–15 km/h to 40–45 km in continuous running and 50–60 km in stop/start mode, as experienced in congested city-traffic conditions[4]. Presently, the cycle rickshaws ply a distance of about 20–25 km/day, since plying longer distances is taxing on the rickshaw puller. Hence MAPRA can double the distance that a rickshaw puller can cover in one shift. A simple strategy has been applied in MAPRA, where the motor can be switched on by the rickshaw puller by a high current switch whenever he experiences increased loading conditions. On level roads or while going downhill, he needs to only pedal the rickshaw. Another strategy could have been to use an IC electronic sensor/controller, so that the motor would have come on automatically when the load increased. However that would have increased the cost of MAPRA by about Rs 10,000–15,000 (ref. 5). Besides, these controllers have to be imported.

Twenty MAPRAs have been fabricated at NARI and tested under varying conditions[4]. They have logged more than 5000 km in trial runs. Five of these MAPRAs are running in the Pune University campus and a couple are running in Phaltan. Efforts are on to put them in Hampi (world heritage site) in Karnataka and in various university campuses in different parts of the country.

Test data have also shown that when a rickshaw puller has no stake in the MAPRA, he has the tendency to mostly run it on the motor. However, with a stake of either ownership or of earning maximum amount of money, the rickshaw pullers normally pedal (in motor assist mode) and drive the MAPRA to cover maximum distances before the batteries get discharged. Thus data show that some rickshaw pullers cover up to 50–60 km on one battery charge.

The retail price of a MAPRA has been estimated to be Rs 27,000 (ref. 4). Economic analysis of running a MAPRA shows that an owner can make a net profit of Rs 25,000 per year[4]. This assumes that loan for the MAPRA will be available at 12% p.a., repayable in ten years. Such loans are available from Indian Renewable Energy Development Agency for non-conventional energy projects. Other assumptions are that the MAPRA will run for 300 days per year, the fare is Rs 3/km, and it will ply for 40 km/day. Presently, the cycle rickshaws charge anywhere between Rs 3 and 5/km and hence the assumption of Rs 3/km for the MAPRA is reasonable. With higher tariff, a MAPRA owner will make even better profit. Our data on existing cycle rickshaw pullers' income show that they make an average profit of Rs 12,000 to 18,000/year. With the MAPRA they can double this profit, since they can cover twice the distance compared to existing cycle rickshaws.

Besides being economically viable, the MAPRA is also energy efficient. Thus it is instructive to look at the energy efficiency of MAPRA *vis-à-vis* petrol- or diesel-powered autorickshaws. From power-plant to traction-energy point of view, the MAPRA consumes 86.5 Wh/passenger-km compared to 175 Wh/passenger-km consumed by petrol autorickshaws. Thus the MAPRA consumes half the energy that is required by a petrol-powered autorickshaw. The following assumptions were used in the calculations:

MAPRA:

- The efficiency of electric power plant, including transmission and distribution losses is 0.255 (ref. 1).
- Charging/discharging efficiency of batteries is 0.64.
- MAPRA takes two passengers to a distance of 40 km per battery charge.
- MAPRA puller consumes 8.3 MJ of energy in food per day. Since he will pedal continuously, this energy input has also been taken into account.

Petrol autorickshaws:

- Average mileage is 25 km/l of petrol[6].
- Calorific value of petrol is 31.5 MJ/l[6].

Issue of commercialization

With increased pollution in cities of India and various courts passing strictures on polluting vehicles, there is a need to introduce environmentally sound transport systems on the roads. In addition to the CNG-powered buses and three-wheelers, quite a number of major companies have introduced electric-powered three-wheelers. However, all these vehicles are expensive, with their prices ranging from Rs 2.75 to 4.28 lakhs[7]. One of the major reasons for this high cost is imported batteries and their weight. Around 50% of the weight of the vehicle is because of the batteries, which results in increased motor power and hence the increased cost of vehicle. Present level of battery technology precludes high power output from light-weight batteries. We therefore feel that small transport systems like rickshaws are more suited for electric vehicle development. Thus reasonably priced, small size, indigenous batteries have been used to power the MAPRA.

With the IMPRA costing Rs 7000 and the MAPRA with its price tag of Rs 27,000, they may be some of the cheapest environmentally sound vehicles for India. Besides, they also have the unique ability to provide large-scale employment to urban and rural poor.

Both the MAPRA and the IMPRA are designed in such a way that they can be shipped from the manufacturing plant in a completely knocked-down condition and can be assembled by any cycle rickshaw fabrication or bicycle shop. Efforts are also under way to reduce the weight of the MAPRA by making its structure with tubular parts. A light-weight MAPRA will allow the rickshaw puller to ply it over longer distances, thereby increasing his earnings.

Since the MAPRA is essentially a pedal rickshaw with motor, the existing norms of pedal rickshaw commercialization may have a bearing on its marketing. In most cities, each owner has 50–200 pedal cycle rickshaws. These owners either use their own resources for buying these rickshaws or borrow money from local touts at high interest rates. These rickshaws are then let out on hire to labourers at daily charges running from Rs 15 to 20. Most of the rickshaw pullers are migrant labourers and are either known to the owner or to other rickshaw pullers who are driving the owner's rickshaws. This ensures that rickshaws are generally not stolen. Most of the nationalized banks have been given a mandate by the Government of India to give loans to rickshaw pullers so that they can own the rickshaw, but the terms and conditions of these loans are so tough that no rickshaw puller is able to get these loans. Thus majority of rickshaw pullers run the rickshaws on hire basis.

When the MAPRA was shown to rickshaw pullers in different cities, they immediately wanted it and were ready to pay higher daily rental charges so that they could eventually own it. The rickshaw owners on the other hand, did not want the MAPRA because of its higher cost. It is ironic that for rickshaw owners, the difficult conditions faced by rickshaw pullers driving a poorly-designed existing rickshaw are of no concern. They want a cheap vehicle and want to earn whatever they can from the daily hiring charges collected from the rickshaw puller. For rickshaw pullers, availability of user-friendly rickshaws like the IMPRA and the MAPRA is the first real attempt at making a difference in their lives. Thus there is a dichotomy in the approaches of rickshaw pullers and rickshaw owners. This problem can be solved largely by making finance available to rickshaw pullers, so that they become rickshaw owners. One of the possible ways to do it is by setting up rickshaw pullers' cooperative societies in different cities. These societies can facilitate loans from the banks and allow the rickshaw pullers to eventually own the rickshaws. The cooperative societies can also create better living conditions for the MAPRA and IMPRA rickshaw pullers by providing a place for them to sleep at night and to charge the batteries. Presently, majority of rickshaw pullers cook, eat and sleep on the footpath.

Besides creating a non-polluting transport system for India, the MAPRA will also provide dignity to rickshaw pullers. Presently, rickshaw pullers are treated as belonging to the lowest rung of society. Many rickshaw pullers told us that a motorized rickshaw would give them dignity. It is felt that the police and the people in general treat the drivers of motorized vehicles with slightly more respect compared to rickshaw pullers.

Other issues

We feel that the following technological and policy issues need to be looked at for the MAPRA to spread and become a viable transport system in India.

Technological issues

1. There is need to develop a low cost sensor/controller for sensing the load of the MAPRA and to switch on and off the motor accordingly.
2. There is need to develop a low cost battery charger based on switch-mode power supply (SMPS) technology, which should be rugged and could be mounted on the MAPRA, so that the batteries could be charged anywhere. Presently, such rugged and low-cost battery chargers are not available.
3. The issue of battery charging has to be solved before large-scale deployment can take place. It can be addressed in two ways: (a) The MAPRA puller/owner can take the rickshaw home for overnight charging, if he has an electric connection. (b) The rickshaw pullers' cooperative society can also set up a battery-charging station where the rickshaw batteries can be charged. The charging can either be done by regular electricity supply or from a suitably sized solar photovoltaic (PV) unit. With PV charging, two sets of batteries will be required so that one set could be charged during daytime.
4. In the long run, there is need to develop high performance capacitors as battery substitutes. These types of capacitors are being introduced in the US and Europe for electric vehicles[8] (EVs). EVs are presently limited by the battery technology. An excellent and cheap energy storage system can make EVs the transport vehicles of tomorrow.

Policy issues

1. There is need to permit only environmentally sound vehicles to operate in the congested areas of the cities. Automobiles and buses can be parked at suitable locations from where these types of rickshaws can ferry the passengers. A cluster of such rickshaw stands even in big cities, will help reduce the pollution and

congestion in the cities. Similarly, in zoos, university campuses and areas of tourist attraction like heritage sites, these rickshaws should be encouraged.
2. Since both MAPRA and IMPRA are environmentally sound and user-friendly vehicles, they should get all the financial benefits available to renewable energy projects. Besides, all the Government of India schemes for providing employment to weaker sections of society should be used to give loans to rickshaw pullers who want to drive these rickshaws.
3. There is a need for the concerned authorities in India to exempt MAPRA from the purview of Motor Vehicle Act since it is essentially a pedal rickshaw with a small motor.

Finally, it should be pointed out that the evolution of cities and towns has been driven by the transport system. The sprawling cities of the US developed because of automobiles. However, most European cities have integrated the public transport systems like rail, subway, bus and tram with private cars, taxis and cycles to cover the 'last mile'. This could also be possible in India where rickshaws can provide transportation to cover the last mile or kilometre. If we consciously promote vehicles which are human propelled, then we can help reduce the growth of cities and at the same time drastically reduce the energy used in transportation. This can show us a way towards a sustainable transport system of the future. I also hope that this article will generate interest in the large S&T community of the country to work for producing better cycle and electric rickshaws, which will help the environment and the lives of the poorest of poor of our country.

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REVIEW ARTICLES

Swarming: A coordinated bacterial activity

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Swarming is an intrinsically surface-linked and cell density-dependent phenomenon involving cell differentiation, extensive flagellation, contact between neighbouring bacteria, and in particular, highly coordinated migration of swarm cells. Various extracellular compounds such as biosurfactants and polysaccharide also facilitate surface translocation. Recently, two regulatory systems, namely, Flagellar master FlhD-FlhC and AHLs-based quorum sensing systems have been identified, which play an important role in regulation of swarming behaviour. Interest in bacterial multicellular bahaviour is increasing not only as a focus for study of developmental regulation, but also in its role in virulence, biofilm formation and its connection with pathogenicity. So far, only a few of the *Serratia liquefaciens* quorum-sensing target genes have been identified. Some of these genes may encode potential virulence determinants, whose expression is sensitive to furanones. This may form a valuable model system for understanding the structure and function of bacterial signaling systems. The information on interaction of cognate signals with other modulatory signals may help to develop new strategies in the battle against infectious diseases.

UNTIL recently, bacteria were considered as unicellular organisms that grew and multiplied independently of each other. However, bacteria can undergo cell differentiation when they grow in colonies. Recently, various intercellular communication systems have been discovered, which indicate that bacteria are much more interactive than believed earlier and these communication capabilities are considered to be essential for coordinated

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