TRAMWAY COST REDUCTION.

The cost of implementing tram and light rail schemes has risen to ridiculous levels, and guided buses are often seen as a better solution. The reasons for this must be explored fully. Buses are relatively cheap, and lightweight, whilst trams have become very expensive and have excessive weight. However, both vehicles have the same purpose, namely to carry a given number of passengers. 100 passengers would weigh about 8 Tonnes. To do this with current trams would take a vehicle of about 20 Tonnes, and only about half the passengers would be seated, and the vehicle would cost about £1M. With ordinary buses, the weight per 100 passengers would be around 10 Tonnes, and about three quarters of passengers would be seated, and the cost would be around £200K. (A guided bus would be slightly more expensive, with the guide wheels and supports).

Why is there this differential in weight and cost? The main reason is that trams are seen more as scaled down heavy rail vehicles than as road vehicles. Rail vehicles have technology that has evolved slowly, and total rethinks using the technology of the time are very rare. The last major one that affected trams was 80 years ago in the USA, where a total re-design of the tram took place, and all modern trams to some extent are derivations of this technology. This was the Presidents Conference Committee car, known as the PCC. These cars were made to outperform the private car of the day, and were designed to give a good ride on poor track, which they certainly do. Unfortunately, this design came to Britain too late to save most of the remaining tramways. One of the reasons was high energy consumption to provide high acceleration rates. West German manufacturers, while taking some of the PCC ideas, went their own way and produced long articulated trams, which reduced staffing costs. However they somewhat ignored the ability to ride well on imperfect tracks, and almost perfect track was provided. Ironically, most PCC cars have been produced in Eastern Europe, their ability to cope with poor track being a great advantage.

Conventional rail vehicle technology has had two wheels fixed to an axle, these themselves in all except very short vehicles being suspended in pairs in a bogie. The reason for this is to negotiate curves, where short wheel-bases are the only way to achieve it with these conventional axles. This became the norm until about 25 years ago, when it became desirable to have low vehicle floors, and the bogie made this difficult. After many various designs that gave some parts of the vehicle a low floor, tram design now has settled down to using many short body sections suspended between effectively short four wheeled units, the latter having independent wheels, to the extent that there is no axle between them. These designs work reasonably well, but are very expensive, requiring many articulations.

In the meantime, buses have become articulated to increase capacity, these use the technology of the conventional bus for the front section, with a steering front wheels, and the rear section has two wheels and usually the engine. The question is why can't this also be used for the format of a tram? There have been in the past some attempts to do this, but they have failed due to the technology of the day being insufficient.

This has now changed, and I am involved with such a project. The idea in this case is that independent wheel-motors will be steered round curves by having them in suspensions that have a vertical pivot for each wheel. These wheel-motors comprise a wheel with an integral permanent magnet synchronous motor built into them. A synchronous motor has one great advantage that it rotates at a PRECISE speed, determined by the frequency of alternating current supplied to it. In this way, the wheels can be steered round curves simply by supplying the right frequency. This is simply a control problem, and all sorts of characteristics can be adopted in software. The main problem is where to get the control signal from. In the first trials, which were successful, this came from a detector array at the front of the vehicle, which by electromagnetic means measured the divergence angle ahead of the vehicle. In this way, a ninth-scale tram with a scale 10 m wheel-base negotiated scale 25m curves with the wheels remaining tangential to the rails.

A reverse curve and points were built into the test track, and these were coped with.

I think that it should be possible to derive the control signals from the electrical conditions of the motors, one characteristic of synchronous motors is that the load current is very sensitive to any attempt to change their speed externally, such as when going round a curve, where the outer wheel should rotate faster, and the inner one slower. In a conventional rail vehicle, the wheels are coned to allow slight speed differentials, this works for shallow curves, but on sharp curves the wheels slip, resulting in noise, wear and higher energy consumption.

A major problem with a steering system is what happens with a system failure, the original test rig that had wheel pairs with a central pivot; it resulted in derailment, not a good thing! I have since developed a suspension where flange guidance comes into play. I have built such a system into a model tram for my miniature garden tramway, and unpowered it will negotiate all the track, including sharp curves and points, indeed it obvious that there is much lower resistance to taking curves than a conventional bogie.

Full sized wheel-motors are in production, and four have been fitted to a Blackpool tram for trials. These are not steered, and mounted into a conventional bogie, though each is independent. This tram did over 2,000Km of trial running successfully.

Each wheel-motor weighs 400Kg complete with resiliently mounted tyre and stub axles, and can deliver 5.7KN of tractive effort, and is nominally rated at 50KW. They offer a very high efficiency, up to 97% over a large part of the speed / torque range. They automatically operate as brakes down to standstill, very high rates of energy return, over 60%, being possible during regeneration.

Using such technology, it should be possible to attain a weight of 10Tonnes per 100 passengers, half that of conventional trams, and an energy consumption of 0.5KWh per 100 passengers per Km; and there is no reason if bus body technology is used that the price should not be similar to that of a bus on a per passenger basis.

Having a vehicle offering possible high rates of energy recovery, it would be sensible to see how this can be always possible. Direct storage of electrical energy of the quantity released from recovery of kinetic energy of a tram is now possible using Ultra capacitors. These are relatively cheap and light, and as they use a large number of small individual units, can be distributed round the vehicle. In this way, most of the kinetic energy can be stored electrically, ready for re-use when the vehicle next accelerates. As the rolling resistance is very low, this means that the input energy from the line is considerably reduced; this is not all, because the input will be a relatively constant low current, rather than high peaks when accelerating followed by virtually nothing, then a negative peak during regeneration (if the line is receptive). This enables the electrical distribution system to be considerably down-sized (overhead line, cables and substations). There is an added advantage that the voltage in the rails drops to very low levels, removing any requirement to insulate rails.

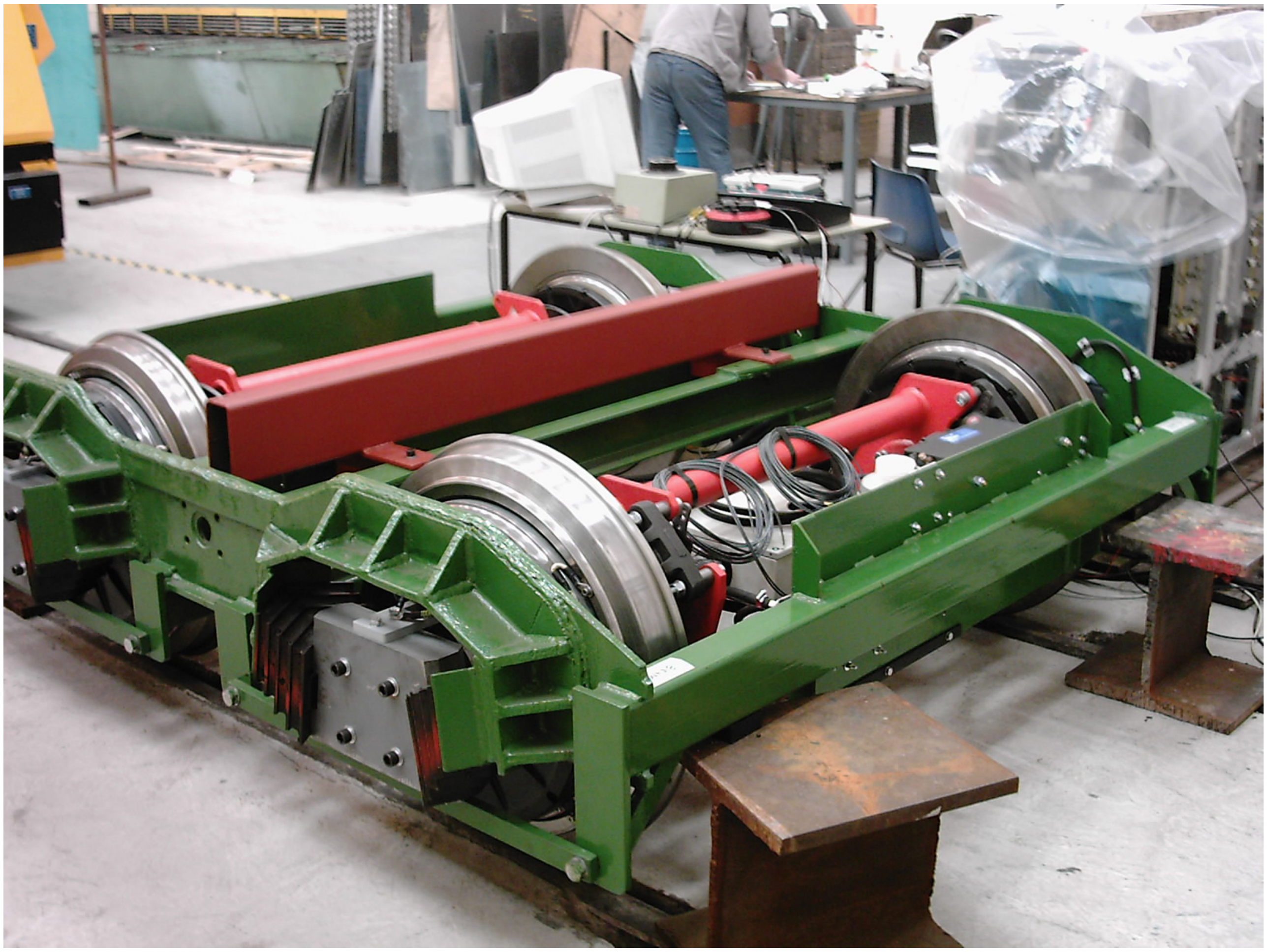
The use of lightweight, low track force vehicles and energy storage will give a considerable reduction in infrastructure cost. The track bed can be downsized, and rather than diverting utilities, temporary track can be used round road works, energy storage will help here, as short distances can be travelled without external power supply.

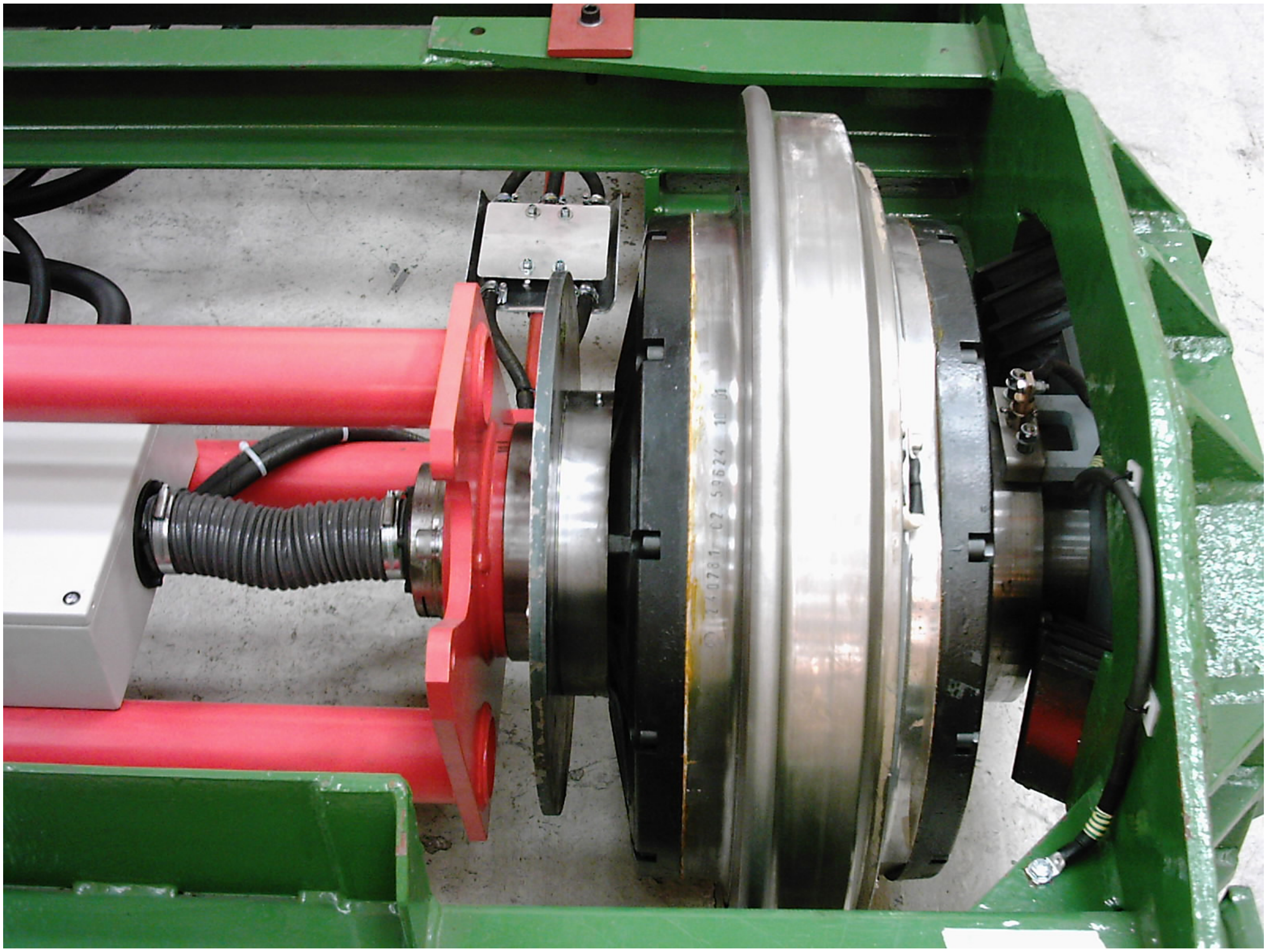
The vehicles would have minimal amount of roof mounted equipment, electrical equipment can be distributed round the vehicle. This reduces the body shell cost; vehicle height, reducing the cost of underpasses; and reduces the centre of gravity, giving better stability.

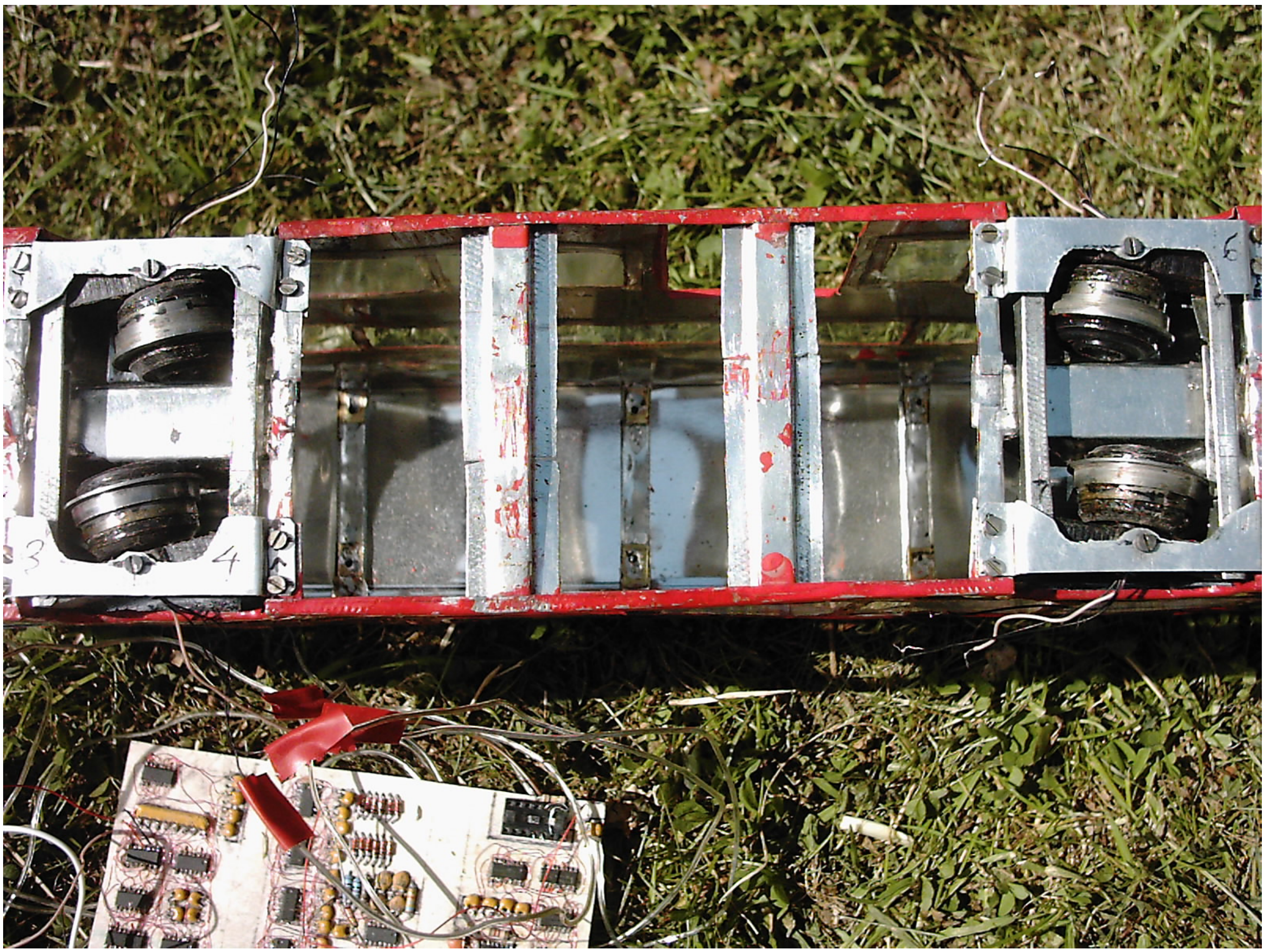
The sceptics will come up with all sorts of spurious reasons of why this can't be done. One is unsprung weight. The whole assembly of two wheel-motors, frame assembly and chevron suspension units fitted in the Blackpool trials comes to 1 Tonne. I very much doubt that the total weight of conventional wheelsets, axles, bearings and some part of a transmission is less than this. I have done a new design, not yet built, that should reduce wheel-motor weight to about 300Kg. The total weight is much less than a conventional installation, as only about half the number of wheels are used. Again, it will be said that the wheel load is higher, but as the total vehicle weight is about half, it will not be. As there are half the number of wheels, and they steer, overall track wear will be very much lower. It will be said that the system will be unstable, and not meet safety cases. A study into the stability of the system was undertaken by Loughborough University my a team led by Professor Roger Goodall under the "mechatronic train" banner, and came to the conclusion that the system will be stable if the correct algorithms are used in the control system, indeed, software can replace mechanical dampers! It should be noted that by having two opposite wheel-motors operating at the same frequency, the effect is the same as if they were coupled by a solid axle with some torsion, and conicity can be used for control for straight track. In the Blackpool trials, the wheel-motors on one side were disabled, and the tram negotiated the sharp turning circle at Starr Gate without problem. This was of course without steering, but I have tried a test rig on my model tramway with a locked wheel, and it did not derail. It will be said that over 60% return of traction energy by regeneration is not attainable. The wheel-motors are designed with low losses. Many modern traction motors are not very efficient. They may attain about 90% efficiency under some conditions, but during acceleration and braking they do not, and this is where efficiency is most required! For instance, the motors of the Nottingham "Incentros" have a loss each of 12KW during full acceleration. In the existing wheel-motor this is only about 4KW. In my new design this should reduce to about 2.5KW. These losses are important for regeneration, as they happen twice, both during acceleration and braking. Some motors also use "field weakening", which means that full torque at high speed is not possible, which makes full braking torque at high speed not possible. In the wheel-motor, full torque is available at all speeds.

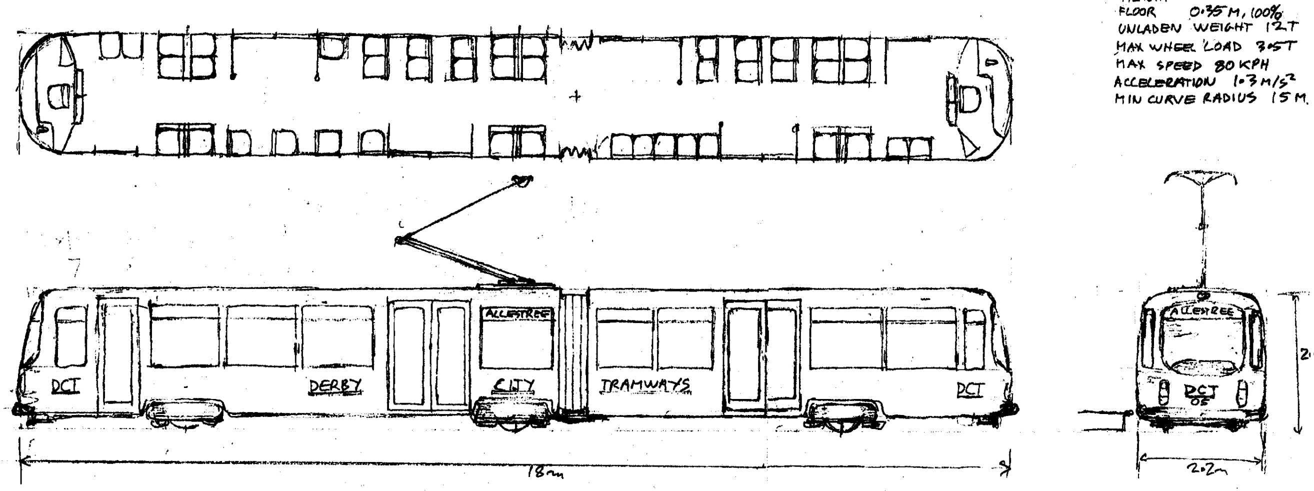
I attach pictures of the wheel-motors fitted into the Blackpool bogie, steering wheel-motors fitted to my model tram, and a prospective design of tram.

David Gibson. 23 August 2010.









LENGTH 18 M
WIDTH 2.2 M
HEIGHT 2.5 M
FLOOR 0.35 M, 100%
UNLADEN WEIGHT 12 T
MAX WHEEL LOAD 3.5 T
MAX SPEED 80 KPH
ACCELERATION 1.3 M/S²
MIN CURVE RADIUS 15 M.

44 SEATS
9 TIP-UP SEATS
57 STANDEES AT 4/M²

DJ. 13/1/05