BEEMCAR - THE INNOVATIVE 'PLASTIC' PRT SOLUTION

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INTRODUCTION

PRT is at its best in an urban environment, and for any PRT system, the primary objective has got to be to entice drivers out of their cosy cars and into pods, therefore, reducing congestion and making a significant contribution to the global reduction in Greenhouse Gases (GHG). BeemCar provides a viable and attractive option for car users. It is an evolutionary conceptual design for a suspended PRT system based on proven technology and lightweight composite construction, including the beam, which was the subject of a separate technical paper and peer review last year. The innovation is in the way the technology has been brought together for this application.

This paper will show how the design of BeemCar was derived from what could be considered to be the 'ideal' requirements for any PRT system, and it will discuss BeemCar's unique design features. In addition, this paper will put into context the perceived high cost and suitability of composites for a PRT application. Equally, the standard advantages of PRT, such as being available on-demand 24/7, will apply to BeemCar.

DESIGN REQUIREMENTS

Consider the 'ideal' requirements of any PRT system to operate in busy, congested urban town and city centres:

- Minimum geographic route constraints
- Minimal infrastructure and no conflict with other transport infrastructure
- Low visual intrusion
- All weather operations
- High carrying capacity
- Easy to remove breakdowns
- High wind capability
- Good performance
- Able to cater for those with any form of disability, cyclists and pushchairs
- Seating for 4-6 passengers, with good visibility and easy access
- Space for luggage
- Easy boarding and alighting
- Good passenger safety and security
- Potentially compatible with GTS (Ground Transportation System)

DESIGN PHILOSOPHY

BeemCar comprises 4 key elements; the pod, drive unit, beam and infrastructure, and control system. Its design is based on simplicity and minimum weight, achieved by not moving unnecessary mass around on the pod or drive unit, which significantly reduces energy consumption, whilst providing a fail safe system that is secure, environmentally friendly and low cost. Importantly, the pod interior has to be comfortable enough to attract drivers out of their cars, and for the system to perform in most weather conditions. Simplicity means a minimum parts count and ease of dismantling, with minimal maintenance and low operating costs, energy consumption and CO_2 emissions. Design for Manufacture is intrinsic in BeemCar's design, as is the use of COTS (Commercial off-the-shelf) parts to minimise cost. Also, BeemCar's performance is limited to fit in with available and proven technology - Technology Readiness Level 8/9 for those familiar with the aerospace and defence industries. In addition, the design philosophy has to be 'green', with minimal energy consumption, zero emissions, low maintenance, longevity, recyclable materials, and where possible, use of renewable energy.

SUPPORTED OR SUSPENDED?

When considering the design requirements, a suspended system offers significant advantages over a system that is supported on guideways, especially as the narrower and lighter beams of BeemCar will be less visually intrusive; a major factor when it comes to community acceptance. Moreover, a suspended beam can more safely carry power and more easily be routed over or around obstacles, and it has the ability to tackle steep inclines greater than 30º, compared to 10º for supported systems, which enables BeemCar to swoop down to stations at street level and exchange passengers, in a relatively short space.

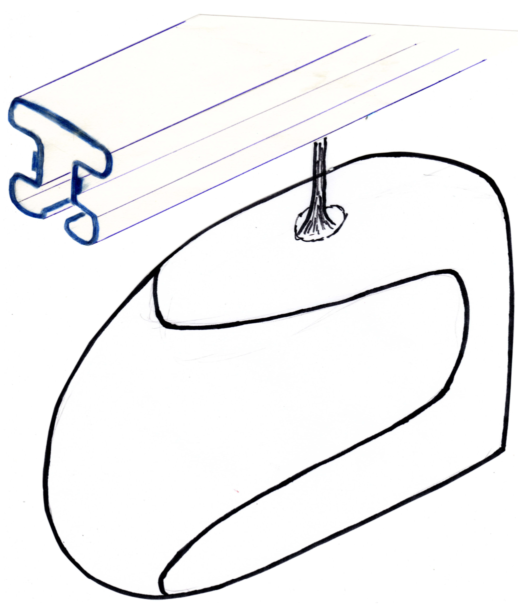

Figure 1 - Sketch of Pod and Beam

Importantly, suspended PRT operations never need to come into conflict with existing transport systems; their ground footprint is little bigger than that which already exists for street lights and operate at a height where the risk of collision is negligible. Consequently, BeemCar pods can be much lighter as they do not need to be collision proof. In its 110th year of operation, the Wuppertal monorail is a testament to the durability and longevity of suspended systems, with an unbeatable safety record for a public transport system.

Relevant to today's changing climatic conditions, suspended PRT systems can be built above flood plains and flood risk areas, and are less affected by snow and ice build up, as the drive unit is inside the beam and protected from the elements. As beams are suspended from the support posts by cantilevers, they can more easily be integrated into buildings, thus providing the possibility of stations in large centres of employment, shopping centres and parcel depots. Also, where space is restricted, beams can be attached to the sides of buildings. From a 'green' perspective, the top surfaces of beams can be covered by photo-voltaic cells, providing renewable energy directly into the power buses in the beam, especially in hot climates. In addition, the installation of small wind turbines with vertical blades, such as Quiet Revolution systems, is worth considering.

POD DESIGN

BeemCar's pod is unique in meeting the design requirements, in that it is the only pod where all seats are forward facing with extremely good visibility, which is what most people prefer. It has 4 individual seats in 2 tiered rows, between which, there is a long, centre flat floor that will accommodate the largest mobility scooter currently on the UK market, wheelchair, pushchair or bicycle. A fifth forward facing seat can be folded out from the rear wall, although with the average occupancy likely to be lower than 2, this is unlikely to get much use.

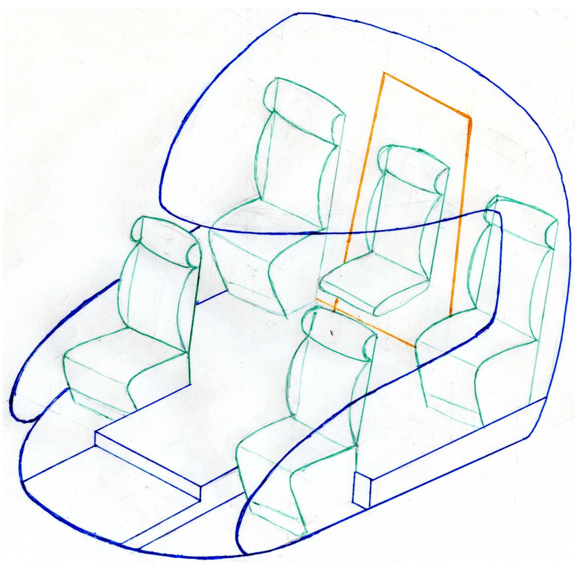

Figure 2 - Isometric Sketch of BeemCar Pod

The rear seats are set slightly higher and further apart to increase the visibility for passengers through the large transparent front end that extends from floor to ceiling, and wraps around most of the sides, similar to a helicopter cockpit, as illustrated below. In contrast to a supported system, all passengers will have an excellent view of the scenery below the pod - passengers will be able to see where they are going, rather than stare at a piece of track.

The pod measures approximately 2.4m long x 2m wide x 1.8m high, and is a lightweight, mechanically simple structure, that does not need the same level of crash protection as a car due to the negligible risk of collision. It is far from utilitarian as it has to provide the same or better level of comfort as a modern day car. For ease of access and simplicity in construction, the door is set in the rear wall, in line and level with the long centre flat floor. Front and side opening doors were considered, but both would require additional structure, making the pod heavier and impair the forward visibility of passengers.

The pod lends itself to composite construction, as do the pods of most PRT systems, but where BeemCar differs is in the type of construction, with fewer mouldings. The strength and simplicity of the construction is in the 'U' shape structure that forms the ceiling, rear wall with inset door, and floor. These parts have all been designed to be flat without openings or transparencies, which enables off-the-shelf sheet materials to be used. These can be machined and bonded together in jigs, significantly reducing manufacturing costs. The front and sides are mouldings of a lower structural integrity, with the majority of the area being transparent. All materials will be high strength, low weight and fire retardant, with inherently good insulation properties.

The door hinges at the top, is wider at the lower end and supported by gas struts, and is electrically operated. In stations, the floor will be level with the platform, to enable ease of access, particularly for wheeled passengers. The floor extends forward at the same height to a point adjacent to the front seats, before it steps down to enable access for front seat passengers, and blends into the large front transparency. In line with the design philosophy, equipment compartments will be integrated into the structure under the rear floor, with external access from the sides; where practical, wiring looms and seats will be integrated into the structure, minimising weight and the parts count.

The pod is suspended from its flat ceiling by the linkage from the drive unit that is supported inside the Beam. At the lower end of the linkage is a damping mechanism, which will prevent longitudinal swinging when the angle of the pod to the beam changes very quickly, and will absorb side loads from the wind, ensuring pod stability during bad weather. This damping mechanism is covered by an external non-structural moulded fairing that blends into the rear wall. Given the rear access, there are 2 options for embarking and disembarking passengers; reverse the pod into a parking bay, so after exchanging passengers, it pulls out forwards; or to twist the pod as it comes into the station, similar to some fairground rides.

There is also the problem of stabilising the pod when it is 'berthed' while loading and unloading takes place. Parking bays complicate the pod's operation and could cause a backlog at busy times, and stations will need to be bigger to accommodate the extra movements. BeemCar has been designed with a small, lateral dorsal fin that will enable the pod to twist through 90° as it approaches the station, and when the rear end of the pod has come to rest against the platform edge and level with the pod floor, the dorsal fin will be clamped, such that the pod is held firmly in place against the platform edge.

Importantly, to make BeemCar attractive to car users, the pods have to be built to a high specification, and maintained as such. A climate control system will ensure passenger comfort, and the pods will be as well equipped as the best cars on the market, with screens built into the front seats for the rear seat passengers, power points, fold down tables, drinks holders, and other enhanced features that may be relevant at the time of build. Moreover, aids will be provided in all pods to ensure accessibility to all; not only the physically disabled, but also those with a sight or hearing impairment.

The pod has a payload of 500kgs, which is sufficient for 5 large passengers or one passenger and the heaviest mobility scooter on the market, with a gross weight of 360kgs. The large flat floor will enable parcels to be carried without any pod conversion. However, if there is a demand, then a dedicated parcel pod could easily be produced, with no seats, a completely flat floor, a large composite moulding to replace the transparency, and a more secure door. Also, if there is the capacity, then individualised pods could be produced for the elite, at a price.

DRIVE UNIT

The drive unit is the heart of any suspended monorail or PRT system, running either inside or outside of the beam. It carries the propulsion motors and braking systems, and other systems necessary for safe operations.

SAFEGE was a 1960s experimental French monorail with an internally running drive unit, which illustrates the basic principle used by BeemCar. The bogies (drive units), were taken directly from the Paris Metro and enclosed inside the concrete box beam, where they were completely protected from the weather.

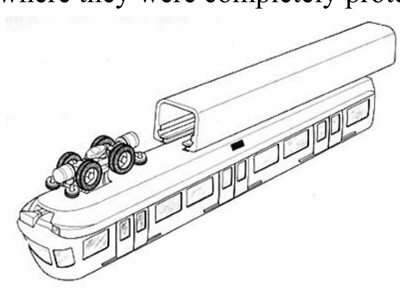

Figure 3 - SAFEGE with Internal Drive

More importantly, a drive unit running inside a beam needs no track switching at junctions, removing the need for moving parts, especially points, which are a major cause of railway accidents. Operation of SAFEGE was electric from a third rail enclosed in the box beam, which reduced the risk of accidental electrocution - another significant advantage of this arrangement. SAFEGE used rotary motors driving traditional pneumatic wheels, which provided a high friction contact with the tracks in the beam, for forward propulsion and a traditional braking system.

Although rotary motors can be more efficient than Linear Induction Motors (LIMs), the LIMs offer the advantage of providing forward propulsion and braking without any physical contact, which removes the need for a braking system. This makes the drive unit more energy efficient in 2 ways; firstly, by doing away with the need for a high friction contact between beam and drive unit, and secondly, by significantly reducing the mass that has to be carried around on the drive unit. Consequently, wheels for BeemCar need only be of sufficient size and strength to support the combined mass of the drive unit and pod, and can be low cost and have a very low coefficient of friction, for example, Nylon wheels on a PTFE track. This arrangement is inherently safer.

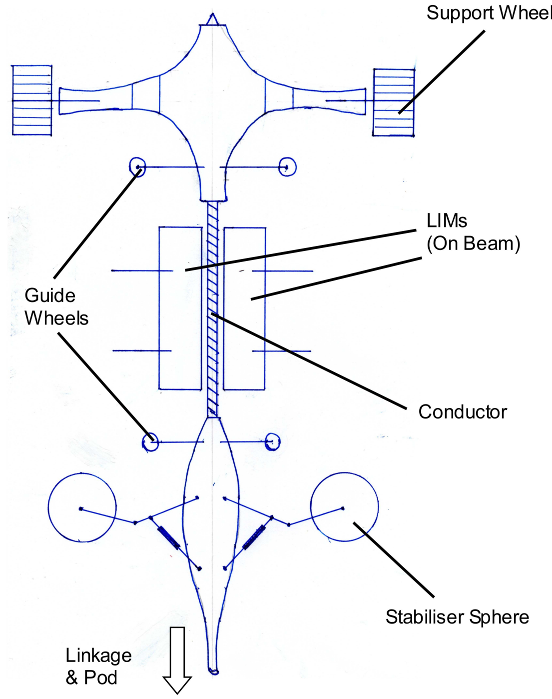

Figure 4 - End View of Skeletal Drive Unit

In line with the design philosophy, further simplifications can be made to reduce energy consumption by fitting the LIMs to the beam instead of the moving drive unit. Forward propulsion is produced by the lightweight, flexible conductor on the drive unit that travels between 2 sets of LIMs, one set fitted to each side of the beam. This reduces the mass even more, as the drive unit, no longer needs components to transfer large amounts of power that would have been needed to drive the motors, if they were on the drive unit.

With the LIMs fitted to the beam, power is direct from the busbars; only a relatively small amount of power is needed to be transferred from the beam to the drive unit for powering the on-board equipment in the pod.

The flexible conductor is the core of the drive unit, from which all forces are resolved, thus creating a balanced system. The mass of the pod is suspended from the conductor, which is supported by 3 sets of low-friction wheels that run on tracks in the top of the beam. Propulsion and braking come from the centre of the conductor as it passes between the LIMs attached to the beams. The 3 sets of spring loaded spheres running in tracks at the bottom of the beam provide maximum stability by absorbing the side loads and providing damping.

Small interim guide wheels are fitted to the conductor to assist it around the corners, as the distance between the conductor and LIMs is critical and has to be maintained. The wheels, spheres and conductor are connected by 3 frames, with each having an additional function; the front frame has a mechanism to bias the direction of travel of the drive unit when it comes to a junction. As the drive unit approaches the junction, it passes a sensor on the beam that alerts the control system that the pod needs to take the next left fork, (for example). Either a magnetic switch or mechanical latch will pull the the drive unit to the left hand wall, such that it takes the left turn and passes another sensor to notify the control system of its new position.

At the top of the centre frame is an inductive pick-up for the relatively small amount of power needed to drive the on-board equipment. The rear frame is fitted with an emergency braking system, based on the use of hydraulic accumulators and high friction metal wheels that, in an emergency, would act against a high friction track on the inside of the beam.

Lastly, to meet the requirement of being easy to remove during breakdowns and the design philosophy for ease of dismantling, the drive unit will be skeletal and held together by close tolerance shear pins, as used in the aircraft industry. In the event of a breakdown, this will enable the pod to be lowered and the drive unit dismantled in-situ, through the gap created when the LIMs are removed.

BEAM AND INFRASTRUCTURE

The key property of the beam is stiffness, to reduce sagging and enable greater distances between supports. For maximum stiffness, an 'I' shape is far better than the traditional rectangular steel beams, as evidenced by the use of RSJ beams in the construction industry. A hollow steel 'I' beam would be expensive to manufacture, whereas composite materials can be moulded to virtually any shape and the wall thickness and composition altered quite easily. Moreover, stiffness of composite structures can be enhanced by using fairly simple techniques, such as moulding simple sandwich constructions with a foam or honeycomb core. Indeed, there is a balance to be struck between adding extra reinforcement on the beam to provide increased stiffness, and the distance between support posts, for example, when crossing waterways or deep cuttings.

A composite beam will be much lighter than its equivalent, in steel, which means that the supporting infrastructure needs to be less substantial and itself, can be made from composite materials that will not corrode or rot in the ground.

Composite poles are being used extensively in the USA for telegraph and power cables and can be produced with sufficient strength and in sufficient numbers for supporting a lightweight composite beam.

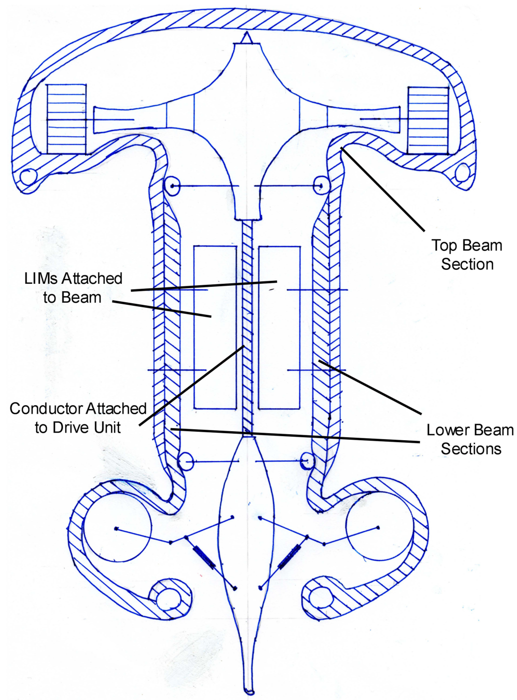

Figure 5- BeemCar Beam & Drive Unit

Each support post for BeemCar will have 2 cantilever arms, each supporting a beam, one for each direction of travel. Stations (some no more than simple stopping points) are simply loops off the main beam brought down (or taken up) to a level suitable for passengers to board and alight without the need for stairs or lifts. Larger stations would have more than one loop to enable more pods to stop, to cater for higher passenger demand. The result of a much lighter infrastructure is a significant reduction in the cost of transportation and construction.

Extra power needed for going into and out of stations, and to tackle steep inclines, will be provided by double-banking the LIMs. This will enable BeemCar to tackle routes with inclines of more than 30º, through areas that would not be suitable for other forms of transport. Where there are challenging routes, the number of support posts can be balanced against the wall thickness of a composite beam, to provide the most safe and cost effective solution.

Over the last 20 years, the construction industry has started to see the advantages and endorse composites, which substantiates the concept of a composite beam.

For example, the Aberfeldy Bridge in Scotland (1992), the Worlds first FRP (Fibre Reinforced Plastic) footbridge; the River Leri and Halgover Bridges, and more recently, deck structures and primary structures for road bridges, such as the Standen Hey Bridge. Quoting from the National Group for Composites in Construction:

"FRP offers bridge designers key advantages:

- Reduced mass leading to easier, faster and more economic installation
- Superior durability, in particular to atmospheric degradation, de-icing salts etc, leading to reduced maintenance requirements
- Ability to form prefabricated complex shapes
- Good electrical and thermal properties

The benefits of FRPs have been demonstrated in short-to-medium span bridge applications but these will be even more significant in larger span bridges. This will open a new era of bridge design, allowing innovative, dramatic and more efficient structural forms to be conceived and constructed."

CONTROL SYSTEM

BeemCar will use a synchronous control system, which is much safer as all pods act as one. The system operation is based on a few simple 'rules of the road'; all traffic on the main beam has priority and travels in the same direction at a constant 50kph (30 mph), controlled by the synchronous operation of the LIMs. Pods joining from stations are timed to fit into gaps on the main beams and are individually programmed to travel direct from 'A' to 'B', by the shortest route, without stopping.

Upon entry to a station, the pod is automatically braked, twisted to bring it into line with the platform, and stabilised so that it doesn't move while passengers alight and board.

Once the pod has stopped, the door opens automatically for passengers to alight. The door will remain open until passengers have boarded and the 'Close Door' manually activated, when the door will close under power assistance, after route selection and payment has been made. The system automatically accelerates the pod up to speed, timed to fit with a gap in the main beam traffic.

Because all of the pods on the network operate synchronously, as if one vehicle, control of the overall system is simple, with the pods stopping only when in stations, or when there is a power failure. This makes for much safer operation and makes it possible for shorter headways of less than one second, with the consequential uplift in system capacity. In an emergency, power can be turned off on sections of the network, without affecting other parts. Pods will automatically follow the selected route, slotting into 'free' slots as they travel through junctions from one main beam to another, using positional information from sensors located before and after junctions. Maintenance staff will be able to isolate pods physically and electrically from the network.

The simple synchronous control system will only power up LIMs as required, prior to the arrival of a pod and while it is passing, thus minimising energy consumption. BeemCar is not designed to break any speed records but to provide a safe, secure and reliable system of transport, travelling at a constant speed of 50kph, faster than the congested traffic over which pods would pass, which probably includes many electric and hybrid cars that will have little or no impact on reducing congestion.

CONCLUSION

BeemCar's success will be judged against the primary objectives for PRT; assuming a realistic and modest replacement of car journeys of 10-15%, it is estimated at today's energy prices and using the Government's figures for fuel consumption, BeemCar would produce energy savings in the order of 2 million tonnes Oil Equivalent, with a potential cost saving of £2bn; and reductions in GHGs in the order of 10 $MtCO_2$ (million tonnes of CO_2). It will also be a testament for the use of composite materials in challenging areas where they would normally have not even be considered.