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Ped-elec: Development of a New Value Chain Approach to the Provision of an Urban Mobility Solution

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Summary

Velomobiles currently form a niche product when viewed in the context of the market for mobility. However, they have a number of distinct advantages over other forms of mobility when considering the need to reduce transport emissions, tackle congestion in urban settings and support the move towards energy independence. How to transition from a niche product to the mainstream is the focus of this research activity. The ped-elec project will provide a demonstration platform that integrates innovation in the product with new approaches to manufacture and retail, therefore realising a transition for velomobiles from niche product to mainstream mobility solution.

Keywords: business model; car-sharing; consumers; infrastructure; light vehicles; market development; mobility concepts; policy; user behaviour

1 Introduction

Green House Gas (GHG) emissions, urban pollution and congestion, and a dependency on fossil fuels are key problems associated with our current mobility choices. These choices are, in turn, associated with the established practices of a given system. Hence, to change our mobility choices requires system change.

A given mobility system, or regime, depends on the inter-relationship between political, economic, societal, technological, environmental and legal conditions or the PESTEL framework [1]. For example, the way that government, regional or national, intervenes in the transport sector (political) relates to tax and spend requirements (economic), which in turn relates to consumption in terms of journey frequency, distance travelled and mobility choice (societal) and so on. However, as opposed to creating a dynamic system, whereby change at component level can reorganise the system, these inter-relationships have the opposite effect and create resistance to change.

The development of alternative mobility system requires that this resistance to change or lock-in is overcome. Through an understanding of the relationship between component changes and interdependencies, concurrent changes can be introduced that can overcome this lock-in and can lead to a reorganisation of the system. This is the focus of this paper, to introduce system change through a combination of changes at component level that work with, and not against, the interdependencies that exist within the system. The proposed combination of component level changes include: a mobility concept (ped-elec); a design approach (factor four); a propulsion system (human/electric hybrid); and a manufacturing / retail model (micro-factory retailing).

2 Background

New mobility choices are required to meet the demands of lower emissions, a reduction in congestion and a move to energy independence.

- In terms of emissions, the transport sector is coming under increasing scrutiny. The ‘Paris Agreement’ of 2015 aims to limit the global temperature rise to 1.5°C through reduction in GHG emissions and transport [2], as the source of nearly a quarter of all Europe’s GHG emissions, has become one of the focal points. When looking at air quality, there are concerns over the ability of cities to meet legal targets as a result of transport related emissions. As an example, for London in the 12 months to August 2015, NO2 concentrations at Oxford Street were almost 4 times the legal limit (150 µg/m3)[3].

- In terms of congestion, as demand for mobility continues to grow, there is going to be an increasing strain on our transport infrastructure. This is going to be felt most acutely in our urban centres, the intensity of transport use being higher in urban areas and the population affected by transport is larger given the significantly higher densities. As an example, London’s population is expected to grow 20% to 10.5M by 2041 with the number of trips made on existing transport infrastructure expected to rise from 26.7M in 2015 to 32.2M per day by 2041[4], putting pressure on an already strained transport system. In fact by the end of 2015 London traffic had slowed back to pre-congestion charge speeds, moving at 8.3mph on average, with journey times in Central London rising 12% annually between 2012 -2015 [5] (fig.1.).

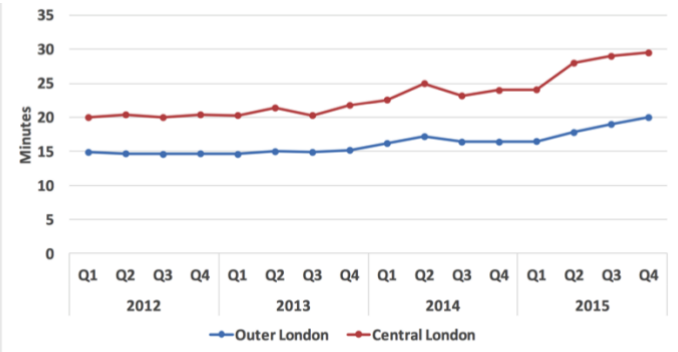

Fig.1. Average Travel times for a 5-mile trip during daylight hours (6am - 9pm), 2012 to 2015 [5]

- In terms of energy independence, the sustainability of our transport system is also under increasing scrutiny. Increasing demand for mobility is being primarily met through extension of existing mobility choices, primarily fossil fuel based. As transport accounts for two-thirds of the EU’s final demand for oil and petroleum products, this poses a particular issue and places a constraint on the longer term viability of the transport system. Further to this, a change to alternative energy sources also poses problems [6], as there is expected to be an energy gap between generation and supply particularly in the renewables sector [7].

Public transport has long been viewed as the solution to urban transport problems [8]. However, the validity is now open to question. In London, where population growth is expected to lead to a growth mobility demand from 26.7M to 32.2M trips over the period 2015 to 2014, only a 3% rise in public transport use is predicted for that timeframe [3]. To plug this mobility gap (the difference between growth in mobility demand and growth in mobility provision that would otherwise be filled by conventional passenger cars), one viable solution is to increase engagement with alternative forms of mobility.

Smaller and lightweight vehicles, together with cycling and walking can contribute to removal conventional transport modes from city centres improving air quality and increasing system capacity. Indeed, promotion of alternative forms of mobility is one that is already finding credence in a number of cities. Since 2017 London has invested £770 million in cycling infrastructure, equaling that of ‘leaders’ the Netherlands and

Denmark [9], and the £2.1billion ‘Healthy Streets Portfolio’ aims to create more pedestrian and cycling friendly environments [9] in order to get 80% of Londoners walking, cycling and taking public transport by 2041[10]. Similar large-scale initiatives can be seen in Hamburg’s ‘Green cycling network’ which will cover 40% of the city [11], Paris’ doubling of cycling routes [11], and similar initiatives de-prioritising conventional transport modes in Germany[11], Madrid[12], San Francisco and Vancouver [11]. The impact is clear. In London, for example a TfL report stated 70% of London Cycle hire users feel the scheme has encouraged them to cycle more [13]. A further potential benefit is to be found in health. The ‘Transport and Health in London’ report suggests the 3% increase in cycling expected by 2031 could deliver health benefits of between 3,800 and 6,800 years of healthy life for the population of London. This is equivalent to nearly £250 million in monetary terms [14].

The alternatives that are being promoted by cities respond to the concerns about emissions, congestion and energy independence, with benefits also expected in terms of health from more active lifestyles. However, they do not necessarily provide the same overall set of benefits to the consumer. There are a number of limitations associated with moving from a passenger car to cycling or walking. The reduced capability in terms of distance that can be covered, the safety perception, the protection from the weather, and facilities, including provision of dedicated infrastructure, are all issues that would dissuade consumers from switching from conventional transport modes. In the UK, as an example, 55% of Londoners stated ‘fear of being in a collision’ as a deterrent to take up cycling in TfL’s ‘Attitudes to Cycling’ report in 2016 [13], with 49%, 32% and 26% citing traffic, lack of confidence and poor roads conditions respectively as three other key deterrents to take up cycling. The requirement is for a solution that retains some of the benefits associated with the passenger car, whilst realising the lower emissions, reduced congestion and energy independence.

User safety and protection are key issues limiting cycling engagement, with.

A proposed solution would be a velomobile. The velomobile is a human powered vehicle (HPV) with three or four wheels and external body to provide weather protection and also an aerodynamic advantage. Whilst the velomobile would overcome some of the limitations associated with cycling or walking there are still a number of issues that would need to be overcome if it was to find greater acceptance as an alternative to the passenger car and over a wider range of mobility requirements. To improve the mobility offer, improvements proposed include, but not necessarily limited to:

- Creating a new vehicle concept through technology improvement by combining the HPV with electric propulsion would widen the scope of the velomobile in terms of its capability and accessibility – achieving greater distances, able to cope with greater loads and requiring less energy requirement from the user. To achieve system change, in addition to technology improvement, consideration would also need to be given to the cost and achieving a price point that is acceptable to the consumer.

- Enhancing the safety perception would require appropriate mitigation measures that would come from technology improvement, but also from policy and legislative measures. To achieve system change would require that technology provides an acceptable benefit to cost ratio (BCR) to balance the economic and societal concerns. Whilst the legislative and policy measures would need to respond to consumer concerns, for example by providing a safe operational environment, but not create additional barrier to entry or create situations that are less safe for other users within the mobility system. For example, as a mobility concept, extending the environment in which velomobiles may be used to include cycle infrastructure may reduce risk for the user of the velomobile by removing conflict with larger vehicles, but would increase risk for existing users of that infrastructure.

- Development of an alternative mobility concept that would support the transition from the niche to mainstream would require a wider appreciation of how the system behaves. As an example, moving from an ownership model to a pay-as-you-go model would provide opportunity for a higher price point that would be an enabler for technology innovation, but this would need to be balanced with a requirement for a new manufacturing and retail model (business model) to align with the lower volumes that result (cf. passenger cars). Education would support the promotion of the velomobile to society, leading to acceptance of alternative mobility solutions as opposed to compelling them pursue an alternative.

It is clear that there is a requirement to consider changes at component level, whether a vehicle concept, a mobility concept or a business model as part of a wider PESTEL system if transformation is to be achieve and emissions reduction, congestion improvement and energy independence achieved.

3 System Transformation

It is the inter-relationships between the different parts of the mobility system that can create resistance to change. It is understanding and managing these relationships, or how component changes impact upon them, that is key to transformation of the mobility system. For an innovation to move from niche to mainstream acceptance will require concurrent changes in different parts of the system. This is not well understood or tested, but key examples exist that can support our learning.

3.1 Mobility Concept

Within urban areas an observation has been the gradual shift to both mass public transport solutions and also to alternative personal mobility solutions based around the concept of "Mobility as a service" or MaaS [15]. These developments are changing the traditional model of car ownership (and the related value chain) with an objective of meeting consumer mobility needs in the most efficient way. Alternative mobility concepts will mean that getting from Point A to Point B can be done in a multitude of ways and may mean using a privately owned vehicle for only part of the journey or not owning a car at all (especially in dense urban areas).

A recent example of a MaaS is the Autolib project in the Ill de France region [16]. The starting point was two-fold; Paris needed to meet EU air quality standards, while also wanting to reduce urban congestion. A first attempt was Vélib, a joint operation between Paris and advertising space promoter J C Decaux, first pioneered in Lyon. At the same time, private firm Groupe Bolloré was trying to promote its new traction battery technology, which fell on deaf ears with car manufacturers. It therefore decided to develop its own car using the technology, in conjunction with Italian partners CeComp and Pininfarina. In addition to being able to supply the right vehicle, Bolloré also has the capability to run the remainder of the Autolib project through in- house resources, including chargers, customer interface systems and the call centre. As a mobility concept, the success of the Autolib project was based on the service provider, Groupe Bolloré, controlling most of the value chain, including supply of core powertrain components, notably the battery, they control design and development of the vehicle and control distribution of the vehicle via Autolib and a personal contract hire scheme. In addition, they manage all aspects of Autolib from vehicle repair and maintenance through providing and running chargers and charging stations, to managing the customer interface via hardware, software and a call centre. Autolib has recently got into financial difficulty for a number of reasons and the contract with Paris has been terminated, but it is unclear whether this will be Bolloré's only downfall as the company has an interest in similar schemes in other cities.

Fig. 2: Autolib Paris-based EV sharing scheme

The learning is that an innovative mobility concept can be successful if it considers the wide social-technical, political-economic and innovation-environmental factors that drive the system response.

3.2 Vehicle Concept

The call is for new personal mobility concepts that are energy/space efficient, clean and safe. The dichotomy is that mobility concepts used in urban areas are, at present, extensions of those used outside of the urban environment. They are inherently less efficient [17] (based on energy used per unit mass moved), they pose safety concerns (due to the mismatch between vehicle size and those road users that are most vulnerable) and they often rely on drivetrain technology that is ill suited to closed urban spaces (emissions from vehicle exhausts in terms of particulates and GHG). Furthermore, there is potential to remove the required segregation between traditional transport modes (cars) and more vulnerable modes of transport (cycling). Reducing the amount of different transport infrastructure, with some arguing that new cycling infrastructure is increasing congestion for road traffic in London [18].

Electric vehicles (EVs) are not a new concept, with electric tricycles appearing in the late 19th Century [19]. However, there is increasing pressure to reduce carbon emissions as outlined by the Europe 2020 vision [20] and, as such, electric vehicles are one of the possible solutions [21]. Several of the major automotive manufacturers have launched mass production EVs such as the Nissan Leaf and Renault Zoe. These vehicles are primarily a modification of an existing mobility concept (four seat passenger car of varying size). The problem, therefore, is competition in the market place. Even though these vehicles often attract a government subsidy to offset a portion of the initial purchase price, they still remain prohibitively expensive for the average motorist. There are also the problems of limited range and extended recharging times. A further limitation of an electric drivetrain is the size and weight of the energy storage system. The additional mass and size of the energy storage system, relative to traditional internal combustion engine or ICE, results in a virtuous circle as a higher mass requires additional energy input and hence a larger energy storage requirement. Therefore, electric vehicles often have a greater emphasis on lightweight technologies, which increases costs. Reducing the number of batteries, which are also expensive, may offset some of this cost but this will reduce the vehicle's range.

The alternative is to focus on the advantages of EV (low running costs, low emissions and ease of use) and create a design and business concept where these advantages can be exploited. The focus is, therefore, on a lightweight urban electric vehicle or LEV. There has been significant interest and increase in the number of electrically assisted 2-wheelers used in urban settings due to the advantages demonstrated by such a concept (less congestion, more efficient energy use, no pollution, etc.) and the LEV can be viewed as a logical extension of this. This is not a new sector and there is a growing body of research and development focused on LEV designed to take one or two passengers and are often classified as quadricycles. Examples include the REVA G-Wiz and Th!nk City. There are other vehicles that have been proposed previously, some of which offer new concepts. These include the Hiriko project, which was a Spanish consortium developing a folding city car based on a concept developed by MIT [22], the Danish Eco Move Qbeak, which offers flexibility of design and upgrade options [23], and GEVCO, which offers a partnership model to production, with envisaged pooling of resource and supply chain [24]. However, none of these can be considered as a mainstream mobility solution. Despite the advantages there is a lack of public engagement in velomobiles. Issues relating to practicality and parking present themselves, as well as potential emotional considerations regarding the unfamiliar design, form and user experience of some types of velomobile

The introduction of light electric vehicles (LEVs) does provide new opportunities. However, due to the limited driving range of electric vehicles, people may have to adapt their travel behaviour or choose between different mobility modes based on their needs. Human behaviour is an important driver for the success of these introductions. It is important to know how people react to driving electric vehicles and how people will integrate the electric vehicle and the e- mobility concepts into their daily lives. Further to this, the promotion of alternative transport is often constrained by the requirement to share road space with existing transport and transport infrastructure. The penetration of alternative forms of transport is significantly weakened as a result. Hence, many of Europe's urban areas are struggling to address the transport-related challenges they are facing. New technologies and innovative measures are emerging, but they are not taken up at a scale that is necessary to meet impending targets.

3.3 Value Chain

Velomobiles haven't yet been brought to the market in the right capacity, limiting their effectiveness as a functional and accessible tool, limiting public engagement, and subsequently minimizing the societal benefits of the product. It is this low scale manufacturing associated with alternative mobility, mean that currently velomobiles have a high price point, which limits the accessibility of such vehicles. For instance the Elf Solo retails at a minimum of £6822. There are basic functional capabilities of a car that no velomobile can provide due to limitations in size, weight and capacity, suggesting that a key reason for the limited uptake is this disparity between traditional expectations of vehicle ownership and high costs compared to even a small conventional passenger car.

Despite the ubiquity of automobiles across the world, with around a billion such vehicles currently on the road, the car industry is a barely profitable business. As a result, the automotive industry is devoting considerable resources into improving the performance of existing distribution channels. Great effort has gone into the reduction of customer order lead times, reduced stock levels and greater flexibility of response. Such improvements are seen as necessary to market survival both in terms of meeting customer needs and in terms of driving down per-unit costs in order to achieve profitability. However, the current system has at its heart an irreconcilable difference between the fluctuating demands of the market and the inflexibility of a production system that requires continuous high-volume production.

A modern integrated high-volume car plant is a huge undertaking, and requires very large investments. Moreover, each new vehicle model requires dedicated investments and considerable development costs. Much of the high investment cost is associated with the all-steel body. In the manufacturing plant the all-steel body requires a press-shop, body-framing (welding) lines, and paint-shop, which together account for about 75% of the total investment in vehicle manufacturing. In terms of the model to be produced, the major investments are in the dies and fixtures used to first press the panels required and then weld them together. High volumes of output are needed to amortise these costs. An all-new contemporary car can require Euro 700 million to Euro 1 billion to develop, with perhaps half this cost accounted for by the steel body. In addition, within Europe, the automotive industry in aggregate is balanced on a knife-edge of profitability. The decision to build a new plant or introduce a new model is a major one, a very risky decision with uncertain outcomes. The high cost of model-specific investment tends to result in conservative 'evolutions' of core models in an attempt to minimise risk. The result is minimal change to the status quo. Building electrical vehicles on the same basic concept as for conventional automobiles creates numerous drawbacks: cost of the battery makes electric cars only available for a few people; volume and weight of the battery may reduce space for passengers and payload; compromise between performance and range of EVs remains unsatisfied; and if the electricity comes from carbon intensive sources, then the emissions savings may not be realised [25].

The quest for sustainable and efficient manufacturing techniques is gaining great momentum across the European Union [26]. It will not be sufficient to swap internal combustion engines to an electric drive line, whilst retaining a traditional passenger car and related manufacturing process. The requirement is for innovative vehicle concepts and technology coupled with new approaches to manufacturing. From a lifecycle analysis perspective there is also a need to revaluate the business model to further enhance this manufacturing system to allow for re-manufacturing, while significantly extending product life and thus giving a much longer in-use phase over which to spread the original energy cost of manufacture; a key issue, as with EVs the manufacturing impact can represent more than half the lifecycle impact in CO2 terms. An example is micro factory retailing.

Micro Factory Retailing or MFR is a manufacturing system that sacrifices some advantages of greater scale (such as increased automation) in order to allow a business model in which the entire product service system can be offered in a single location that will provide service, maintenance, repair, upgrades, customisation and end-of-life vehicle treatment while enhancing both local employment and job content. The model allows incremental expansion (and therefore reduced investment and employment risk) in both volume and geographic terms, while the business captures a higher proportion of the total lifetime earnings generated by the vehicles. The manufacturer may also retain ownership of the vehicles and in effect offer a ‘product service system’ on a per-km basis to users. The model in effect provides the business concept to deliver genuine product stewardship and corporate social responsibility, with the ancillary benefit of allowing the economic benefits (jobs, wealth creation) also to be distributed. The business model in turn allows several different strategies to be pursued: The advantages of MFR are multiple. These included greater localisation leading to local employment opportunities; greater flexibility in production volumes leading to closer alignment to market requirements and a higher value product. These advantages cannot be realised fully through traditional design and manufacturing approaches. Therefore the design and manufacture needs to be approached in a way that will maximise the advantages of MFR.

4 Ped-elec

4.1 What are we looking to achieve?

It is clear that the use of smaller, lighter and more specialised road passenger vehicles must be encouraged if we are to improve the air quality situation, reduce greenhouse gas emission and respond to congestion problems. However, there are several obstacles that limit the market penetration of these vehicle types [27]. Policy measures that support the transition from combustion engines to clean forms of propulsion exclude the smaller, lighter and more specialised vehicles. It is also difficult to achieve economies of scale, which when combined with the exclusion from policy measures removes many of the financial incentives leading to higher unit costs. These higher costs, together with uncertainty their legal status (when and where they can be used and the level of safety they are required to provide), in turn, lead to consumer disengagement and remove the incentive for the industry to invest.

For any new concept, the requirement is that it finds alignment with policy; it is economically viable; that is has accepted by society; that industry has the incentive to invest; that it is in step with the environment into which it is deployed; and that ambiguity over its legal status is addressed. Concepts that promote a new technology, but fail to consider the economics or the legal status within the market fail to achieve that system transformation. Concepts that promote a new business model, but fail to provide the technology to support that business model or do not engage with the consumer fail to achieve that system transformation. Concepts that promote new approaches to manufacture, but fail to consider the wider role of policy in promoting and sustaining existing approaches fail to achieve that transformation. However, the introduction of concurrent concepts that maintain or strengthen inter-dependencies between the PESTEL factors can lead to a system transformation. Taking a new vehicle concept and changing the retail environment to account for the different unit cost can succeed. Taking a new mobility concept and changing the regulatory environment can engage with the consumer and succeed.

4.2 The Ped-elec concept

Fig. 3. The Ped-elec design

To drive system transformation and extend mobility choice, a new approach is proposed. Ped-elec is based on concurrent changes to vehicle concept, mobility concept and business model. The combination of new design, dedicated supporting infrastructure, supplied through new approach to the value chain, enabling development and technological advancement to the vehicle. Combined these elements can create a comprehensive product, and effectively create a genuine travel alternative to the car in urban environments.

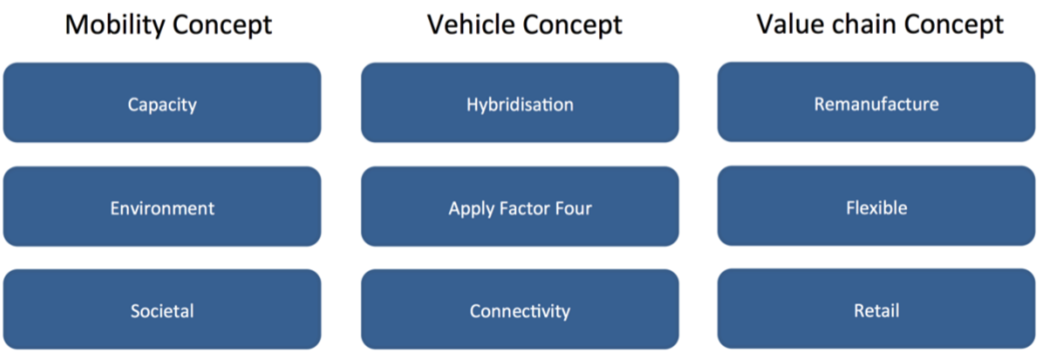

Fig. 3. Ped-elec Mobility, Vehicle and Value chain concepts.

Mobility Concept

- Increase system capacity by including a new mobility option

The advantage of a velomobile as a base for the ne mobility concept is the reduction in the vehicle footprint cf. existing conventional mobility options (passenger cars). However, this advantage can only be fully realised if the operational environment is also adapts. The proposal is to include the velomobile into existing road transport infrastructures that at present accommodate passenger vehicles, but also those infrastructures that are set aside for cycling and for pedestrians. Appropriate policies and legislation would be developed as part of the Ped-elec project to ensure that existing approaches to transport segregation do not present barriers and that appropriate control measures mitigate any potential dis-benefits, primarily safety.

- Improve environment by removing pollutants from transport.

The move to electric propulsion removes the opportunity for pollutants to enter the system where they would create the most harm (where the vehicle is used). However, there may still be cause for pollutants to enter the system at other points, for example energy generation or vehicle manufacture/disposal. Ped-elec as a mobility concept considers these aspects by reducing the overall energy and material consumption. The shared mobility system, when managed appropriately can remove unnecessary vehicle miles and reduce the overall number of vehicles required to meet mobility demand.

- Create societal impact through accessible, clean and healthy transport.

Ped-elec operates as a 'floating'/dockless' vehicle as part of a shared usage program/system, that is demand responsive and integrated with larger public transport systems (via smart cards as a key feature). This access to existing transport infrastructure such as road and parking magnifies the benefit of Ped-elec's dockless parking, which enables the user to stop a journey anywhere that parking is possible and start it again from a new location/vehicle. Furthermore, the application of Ped-elec in a MaaS system, removes the high cost factor, which has effected existing velomobiles success. Ped-elec could be part of an integrated transport plan, a leg in a work commute. Located near railway stations and users can travel in, cycle to busy work places, park and start at their work. The perceived safety benefits and road position, while maintaining eco-values and health benefits for those wishing to incorporate activity into their commute/journey. The overall provision of Ped-elec in more accessible form and system may encourage increased public engagement in 'clean' mobility, and subsequent societal impact of the product.

Vehicle Concept

- Develop and trial innovative control strategy for Human / Electric drivetrain for efficient energy usage.

The advantage of a human/electric drivetrain is the use of human power to complement that of the battery to increase range and decrease vehicle mass. The system proposed is not a parallel hybrid drive (where the human provides direct drive to the wheels), but a series type hybrid drive with novel control algorithms that will optimise the energy flows and hence the energy efficiency and range of the vehicle when used in urban environments. More precisely it uses the concept of a Range Extender, as already used by electric vehicles such as the BMWi3 car (which has a 25kW ICE generator and a 120kW electrical motor) that is proposed. Basically it allows the vehicle to have a greater range, without increasing the quantity of energy stored in battery. In the traditional range extended vehicle, the ICE generator provides extra energy into the battery to allow the vehicle to travel further; it does not directly drive the wheels. The Ped-elec concept uses a pedal powered generator, operated by the vehicle's passengers to achieve the same result. The human factor as a source of energy will be considered and the concept of range will be studied in depth considering a kind of possible "human plug-in".

- Optimise vehicle architecture using the 'Factor Four System' for lower energy consumption.

Factor four is about being more efficient. Present vehicle design approaches focus on the optimisation of the individual elements. By considering the vehicle as an integrated system the efficiency can be optimised. The lighter the car becomes, the more components become not only smaller but also unnecessary (as individual functionality is combined); this "compounding" of weight savings is even faster with hybrid drive. The objective is to design the vehicle keeping everything simple (not simpler). Using ultra-strong yet crashworthy materials will make the car lighter whilst reduction in component size will enable better design and improvements aerodynamically. Since advanced materials greatly reduce the weight and the power needed to propel it, electric powertrains will become much smaller, hence economically viable. Such autos have the potential to reduce U.S. auto fuel consumption by 95 percent by 2050 - roughly one-third - by needing less energy to move them, the rest by substituting electricity (which can be more efficiently used) for fossil based liquid fuels.

➢ Integrate the on-board control strategy with external transport support systems for a new mobility concept.

To optimise the on-board energy flows requires effective integration with the road transport support infrastructure. Present urban centres rely on road transport support infrastructure to manage traffic. The energy flow control algorithms developed for the Ped-elec will be integrated with existing transport support systems (RFID, Car to Car, etc.). The project will demonstrate how such integration will lead to further improvement in energy efficiencies.

Value Chain Concept

➢ Integrated manufacturing/retailing model

The Ped-elec project adopts an integrated manufacturing/retailing model along the lines of Micro Factory Retailing (MFR). The advantages of MFR are multiple. These included greater localisation leading to local employment opportunities; greater flexibility in production volumes leading to closer alignment to market requirements and a higher value product. These advantages cannot be realised fully through traditional design and manufacturing approaches.

➢ Greater flexibility in production volumes leading to closer alignment to market requirements and a higher value product

Ped-elec adopts a different manufacturing strategy to provide flexibility and responsiveness to respond to variation in market demands. The manufacturing system will be modelled around the vehicle design and architecture, and the decisions taken with respect to materials and forming processes. The key aspects of the manufacturing system will be determined by the multiple small scale (MSS) strategy to obtain sufficient economies of scale in manufacturing while allowing an innovative product service system business model that allows decentralised market penetration.

➢ Greater localisation leading to local employment opportunities

In addition to proving to be highly scalable, Ped-elec will adopt a manufacturing strategy that will enable a high degree of localisation in the manufacture. Whilst scalability enables an expansion strategy whereby growth in the market can be exploited, localisation shortens the route to market enabling greater responsiveness to changing market demands thus realising a higher product value.

4.3 What does the Ped-elec concept deliver

The vehicle concept of Ped-elec is to be a comfortable lightweight quadricycle with a low energy demand and a small footprint, well-integrated into existing urban infrastructure and with a range of use that should enable a wide number of people to engage with it. Ped-elec as a concept combines an number of innovations and ideas in order to deliver system change and hence provide greater mobility choice. As a shared/rentable system it provides an alternative to traditional mobility solutions at a price point acceptable to the consumer, through innovation in the manufacture and retailing it provide an alternative to traditional mobility solutions that are attractive to industry, through innovation in the vehicle design it provides benefits to society in terms or reduced emissions, energy independence and lower congestion, etc.

The Ped-elec vehicle developed as part of this project has the following technical specifications

- Vmax 105 - 130km/h: the peak speed is intended to be reached only during short durations (<15 min)
- Consumption C= 1,5 to 2,5 kWh/100km with average speed in the range from 40 to 60 km/h
- Range > 200 km
- Charge performance depends on the charger option that will be chosen by the customer:
    - with three-phase charger (with grid/ 400 V – 32 A): >12 km/min

- with single-phase charger (with grid/ 230 V – 16A): >2 km/min

Vmax: the choice of the maximum speed impacts the necessary power of the energy chain because of the increase of the mechanical losses is not linear with speed, as it is for the losses in the electrical machine. The increase of losses in the electrical machine leads to limit because of thermal constraints the duration of moving at the peak speed. Sensitivity of the mass to the choice of the peak speed will be analysed in the project.

Consumption: if supposing perfect energy recuperation of kinetic energy during braking, the consumption during a cycle is directly linked to the losses that depend on the speed, the mass and the efficiency of each component of the energy chain. The practical efficiency during the braking is linked to the power density of each component and especially of the storage component (battery) whose power density (kW/kg) is the lowest one in comparison with power converter and efficient electrical machine. With data from previous projects and improvements of the global efficiency obtained by a global optimization, reasonable consumption values have been estimated in the range of speeds of an urban vehicle.

Charge performance: the proposed values have been calculated with a pessimistic value of 2,5 kWh/100km and are intended to highlight the difference depending on the kind of grids available for the customer.

The following benefits of Ped-elec are envisaged

System Capacity

Questions remain regarding the suitability of existing transport modes to obtain the most from existing transport networks in the future, and their ability to facilitate an increase in demand. Due to the small footprint of velomobiles, the impact on the capacity of urban roads is positive. They are able to obtain the most from existing transport networks, with some single occupant designs being under 1m in width, allowing 4 or 5 vehicles to be parked in a single car parking bay.

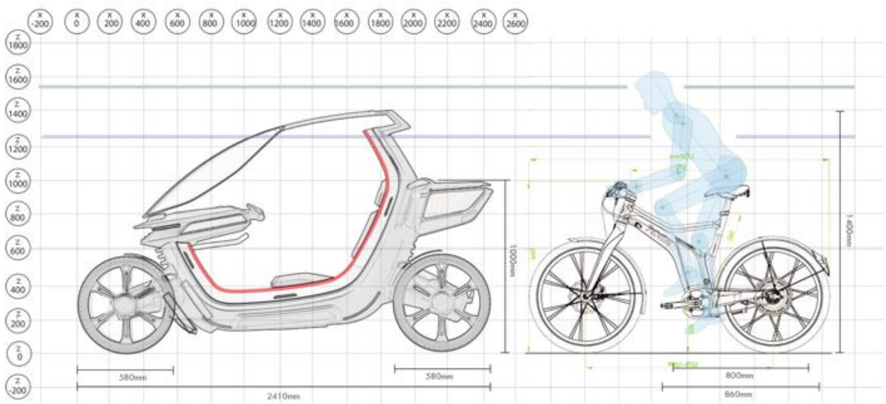

Fig. 4. Ped-elec Side orthographic view, in comparison with standard E-bike.

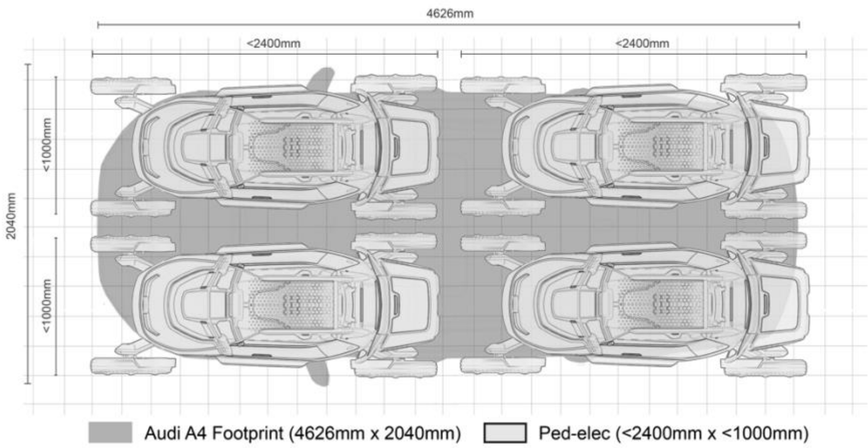

Fig. 5 Ped-elec footprint

The road impact of Ped-elec would be minimal, with the current iterations length being 600mm more than a bicycle 1800mm (fig. 2), with the intention of reducing this gap further. This means that Ped-elec could use cycling infrastructure. The benefits of this ability to integrate between different transport infrastructures is enhanced due to the small footprint of the vehicle. With the width between 800mm – 1000mm, and length of ≤2400mm meaning that 4 Ped-elecs could fit comfortably in a conventional parking bay in the UK (4800mm x 2400mm).

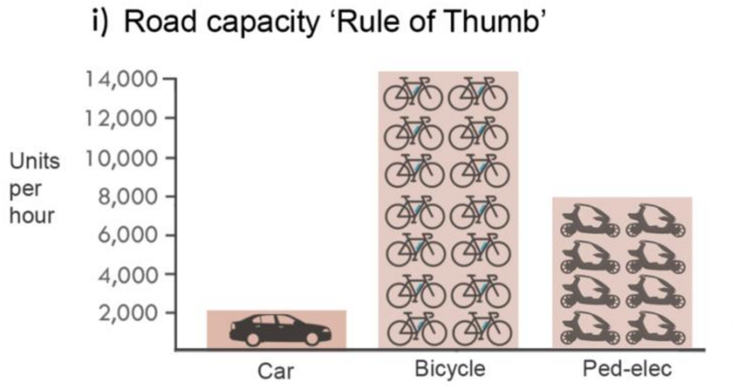

Fig. 6 Road capacity rule of thumb,

The difference in space efficiency usage between cars and velomobiles is highlighted if you consider the road capacity 'rule of thumb' where cars and bicycles flow at 2000 and 14,000 units/hour respectively [28] (fig. 6). With Ped-elec under 1000m in width, you can fit 4 in the equivalent footprint of 1 saloon car. It's possible to theorise a potential velomobile road capacity of 8000 units/hour. This is a 200% increase in space efficiency (fig. 5).

Environmental Improvement

Ped-elec is designed to be as efficient as possible, both in how it is powered and how it is constructed - designed to minimise unnecessary weight and manufacturing costs. The reduced frontal area enhances aerodynamic performance compared to that of conventional mobility choices.

Using a Human-Electric hybrid powertrain in a series hybrid system, propulsion is only from electric source. The user pedals an electrical generator with electronically controlled resistance and speed, which is fed with power from a generator and from a battery, removing the requirement for heavy gears and chains. With the user also able to chose the level of required physical exertion. The Electric assist comes from 2 hub motors, enabling a simpler packaging and construction compared to mid mounted motors. This comes with the added benefits of reduced costs in manufacturing the part itself and the engineering required to house it. As the energy generated by the user runs directly to the power storage system, this enables use of low cost mass-produced motors. This too provides packaging benefits, enabling an uncluttered platform chassis and easier adjustment of the pedal positions relative to the cyclist.

A further key societal benefit is that as a human/electric hybrid, Ped-elec produces no emissions at the point of use, a substantial improvement on any ICE vehicle with a typical passenger vehicle creating 404 grams of C02 per mile [29]. The reduced mass of a Ped-elec means results in the use of this energy being far more efficient, consider the additional energy required to move the mass of a conventional passenger vehicle. It is recognised that the benefit of EVs over ICE, however EVs still produce some particulate matter emissions, due to tire, brake and road wear. The effect of this emission would be reduced when using a velomobile, as a result of a lightweight/smaller form and subsequent reduced wear/effort/put of said parts. Ped-elecs target weight of <125kg is just 7.9% of a 1,580kg Nissan Leaf.

User Benefits

Due to the weather protection, Ped-elec offers the user the ability to arrive at their destination presentable in appearance without specialist outer clothing or a change of clothes, a key feature of its potential appeal to those who use cars as their main mode of transport for reasons of comfort and ease. Being able to travel without necessary physical exertion, with addition of weather protection opens the possibility of attracting a wider scope of potential users to 'clean' mobility, increasing the potential demographic range.

Further considerations are made towards user emotions and perceived lack of safety from cycling and existing velomobiles. The structure and side profile creates a 'cocoon' effect around the user, creating a visual and functional ring/mass around the occupant. Furthermore this open side acts as the entry point of the vehicle, with angled edges (away from the user) to ease user egress and ingress as indicated as the red line in fig. 4.

Societal Benefits

Ped-elec provides the benefit of incorporating activity into peoples daily lives or commutes. If everyone in London walked or cycled for 20 minutes every day, it would reduce their individual health risks significantly. As predicted in the 'Transport and Health in London' report the potential impact of C02 reductions from increased 'clean' transport and cycling engagement can lead to further benefits such as economic gains, improved public health and productivity.

Economic Benefits

Transition (from niche to mainstream) requires high investment and this will be accompanied by a high economic risk as the classic business models for original equipment manufacturers (OEMs) have to be modified or developed from scratch. The position of Ped-elec as a new mobility option, and one that is based upon principles of MFR, will be provide opportunity for small and medium enterprises (SMEs) to drive system change, as opposed to the OEMs. SMEs are very significant for the economic growth. There are more than 20 million SMEs representing 99% of businesses in the EU. SMEs are the "back-bone" of the European economy and a significant driver for economic growth, employment and social integration in addition to their crucial role in innovation and research and development (R&D). Thus, the European Commission aims growth by promoting successful entrepreneurship and improving the business environment for SMEs with policies designed for assisting SMEs at all stages of development.

Fig. 7. Ped-elec 1/4 scale model

5 Summary

Within urban areas, the call is for new personal mobility concepts that are energy/space efficient, clean and safe. The dichotomy is that mobility concepts used in urban areas are extensions of those used outside of the urban environment. They are inherently less efficient (based on energy used per unit mass moved), they pose safety concerns (due to the mismatch between vehicle size and those road users that are most vulnerable) and they often rely on drivetrain technology that is ill suited to closed urban spaces (emissions from vehicle exhausts in terms of particulates and GHG). Velomobiles provide a solution, but struggle to transition from niche to mainstream. It is a virtuous circle. For the consumer, velomobiles are not competitive with other mobility choices, for the industry the lack of consumer engagement is a disincentive to invest, and the limited interest means they are overlooked by policy makers leading to issues with promotion, but also a failure to deal with the barriers preventing greater acceptance.

Ped-elec is a proposal for a system wide approach to changing mobility in urban areas. Though the targeting of concurrent changes that leverage inter-dependencies (as opposed to working against them) the intention is to provide a mobility choice that, as opposed to compelling users to make a choice, is attractive in its own right. That this approach requires concurrent movement from industry, consumer and policy maker is one of the difficulties, but the proposal put forward in this paper demonstrates that this is possible. Providing the framework for these vehicles to operate within, promoting these as alternatives, responding to consumer concerns, providing the incentive for industry to invest are all activities that when promoted in isolation fail to illicit system change, but when combined would reorganise that system and achieve the goals that we have set ourselves for improving the transport system.

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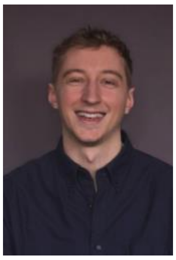

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