Systems Engineering Approach to Mobility as a Service

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AUTOMOTIVE ELECTRONICS INNOVATION

CONTENTS

FIGURES

This paper is produced by AESIN Systems Engineering workgroup.

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1 INTRODUCTION

This paper explores challenges to future mobility at a high level and the benefits from viewing future mobility as integrated yet independent system of systems. The authors' intention is to outline the challenges, explain a future mobility "system of systems", and introduce potential desired "properties".

This paper does not explore possible development approaches to future mobility system of systems. Engineering future mobility to have desired "properties" for users, manufacturers, and legislators will be the subject of future papers.

2 WHAT IS THIS ABOUT?

"Mobility-as-a-Service (MaaS)" has come to prominence as a leading strand to the future mobility needs of an expanding world, based upon fleets of connected, highly automated vehicles.

MaaS systems already exist that integrate the current communication, data, and location aware services of conventional, multimodal transport systems. Figure 1 illustrates a framework for the possible evolution from today's multimodal transport systems to future mobility MaaS.

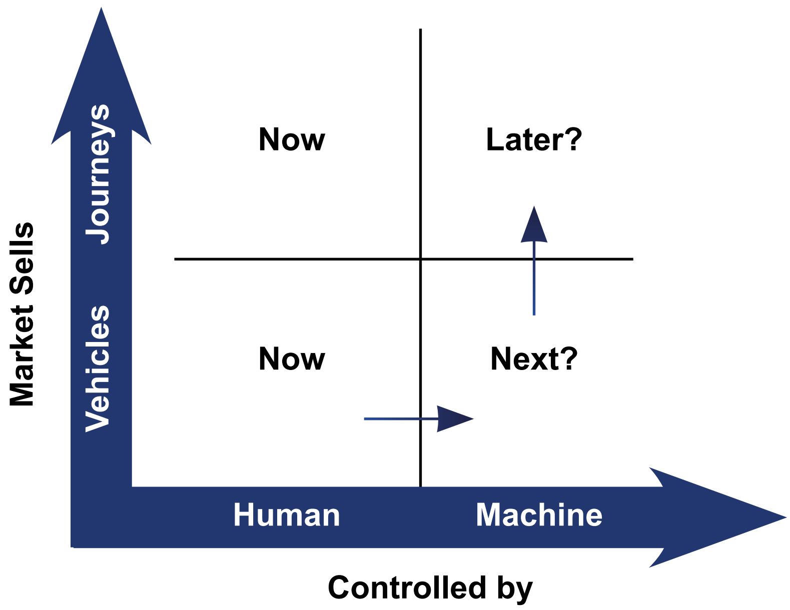


Figure 1: Potential evolution towards future mobility MaaS

Many roadmaps predict the automotive sector incrementally evolving from a product market, selling human-operated vehicles, into a service market, selling journeys delivered by machine-operated vehicles. Successful, rapid evolution tends to be disruptive, so rather than focusing on the pathway, a series of epochs are identified according to changes in the underlying architectures.

• Epoch 1 (now) – Today, automotive companies sell vehicles that are operated by their owners or leased/shared to others to operate.

• Epoch 2 (next) – Highly automated vehicle technologies are in development to enhance future automotive products. These will provide owners with machine-operation, freeing up owners' time for other tasks.

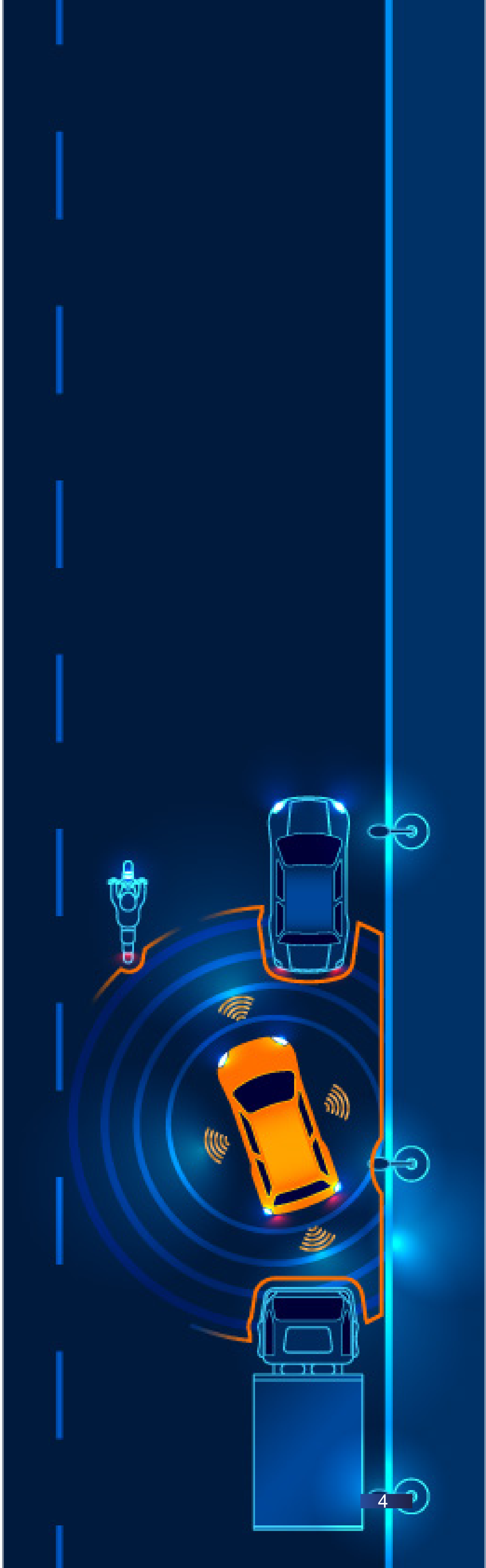
• Epoch 3 (later) – Service providers sell journeys, delivered by machine-operation, freeing up owners' capital investment and negating operating concerns.

The use of epochs rather than a pathway allows us to explore our needs from future mobility. The evolutionary process is driven by "pressure", in this case market needs bounded by regulation, with clear future states. This approach helps us to identify and focus on actions needed now to create the desired future state.

3 WHY IS THIS IMPORTANT?

3.1 BACKGROUND

Automotive companies develop products that respond to a range of societal pressures. Significant recent focus has been placed on enhancing in-vehicle systems; replacing carbon-based propulsion with lower carbon alternatives, increasing vehicle intelligence to improve occupant safety and comfort. Further challenges are emerging that require reference to a wider ecosystem. *How best to move people and goods in a way that protects privacy, allows personal choice, and is supportable and sustainable?* Such questions cannot be answered by automotive companies alone.



3.2 ECONOMIC AND SOCIAL PRESSURES

The growth of convenient ride hailing services has eroded the traditional model of car ownership and displaced the need for car ownership in many large cities. Many young people do not learn to drive, with 20% reduction of 17-25 year olds in UK gaining driving licences in the last 10 years. The idea of investing substantial capital in an asset, which will be unused most of the time, and into skill development to operate that asset occasionally, is seen by many as inefficient. Even where ride hailing services are yet to be established, vehicle ownership has declined in favour of leasing. In the UK, over 75% of new car "sales" include some element of leasing. Modern consumers seem content to pay-as-you-go for mobility, freeing up capital. The societal benefits also include a freeing up of urban real estate with a reduced need for car parking.

The market transition from vehicle purchases to journey purchases is not limited to passenger mobility but is also witnessed in new freight transport models. New service providers are piloting door to door delivery business models. This trend brings some potential downsides, such as a loss of privacy or loss of self-expression through ownership, along with potential new security concerns. However, these negatives could be addressed by socio-technical considerations and by service differentiation.

3.3 TECHNOLOGICAL AND ENVIRONMENT PRESSURES

Modern automotive products are connected as part of the wider Internet of Things. This allows for vehicle tracking and ongoing condition monitoring, which can provide real time assessment of the asset book value. However, this connectivity also exposes vehicles to an increased risk of cyber-attack and the potential for unfunded liabilities. For example, one recent attack through a firmware update risked rendering an entire vehicle fleet unusable, potentially resulting in thousands of insurance claims.

The energy use by transport, and associated impact on climate change, is well understood, and highlighted in the energy balance sheet example for UK citizens shown in Figure 2 [1].

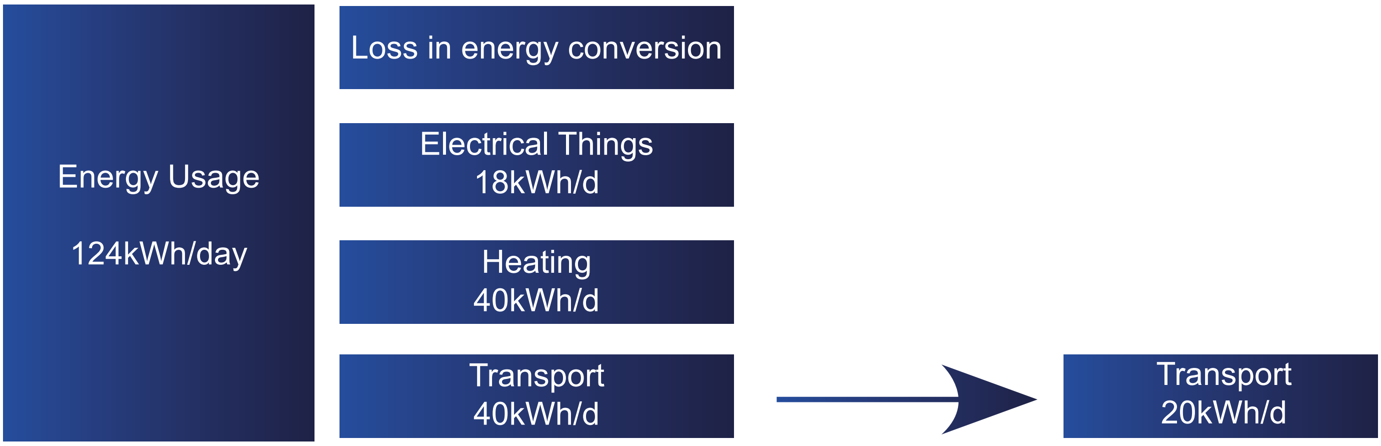


Figure 2 : Energy Consumption per person UK [1]

While transport moves away carbon-based propulsion, the total energy usage is as much a relevant concern as the energy source. Energy efficiency, in terms of energy per journey, is a focus.

1. Sir David MacKay, "Sustainable energy without the hot air", 2008

3.4 LEGISLATIVE AND REGULATORY PRESSURES

The UK government has committed to reducing carbon emissions and banned the sale of internal combustion passenger cars, pushing the vehicle market towards an all-electric passenger fleet. Solutions for freight movement will emerge in the coming years with government support. However, in terms of addressing the overall energy efficiency of an integrated mobility system, the expectation is that market forces will foster solutions and service providers will take commercial advantage of the opportunities.

4 WHAT IS THIS FUTURE STATE?

Our specific question then is what does a future state look like? Is it an extrapolation of the existing vehicle and mobility architecture? Is this essentially an incremental evolution from the horse and cart? Or are there radical new architectures, where control, energy, or even motive power, are distributed?

The systems engineering contribution to addressing these complex questions is often overlooked. This architecting activity searches for the optimal balance between technology, societal needs, processes, and regulation, to deliver the desired outcome. The systems engineering contribution in largescale IT, defence, or aerospace, is more visible, where stakeholders and governing authorities comprise a closer ecosystem. However, in transport, the platforms and infrastructure are more loosely connected.

The 20th century's largest revolution was the dawn of the information economy, the fusion of telecommunications and information technology, to deliver information 24/7 to our fingertips. But was this created by a holistic vision, with an internet considering security, provenance, and data ownership? Unfortunately, not. The early internet protocols had to be retrofitted with these properties at great expense.

Future mobility offers an opportunity for radical thought, to promote attributes which may not be achieved through market forces alone. Otherwise, the outcome may comprise singular solutions delivered by the largest or cheapest providers, or most innovative business models. Attention must be given now to the desired properties of future mobility.

4.1 WHAT DO WE WANT FROM THIS FUTURE STATE?

What are the desired properties of the future mobility state, epoch 3? A linked, integrated, on-demand, multimodal mobility system solution is enthusiastically promoted as a means of:

• Reducing environmental impact by more efficient energy usage and the eventual replacement of carbon-based propulsion,

• Optimising utilisation of physical infrastructure, roads, car parks, freight channels,

• Improving safety by reducing collisions and the effects of collisions (fatalities, emotional distress, business costs, emergency services costs, etc.) through reducing the impact of human error, and moving towards highly automated systems,

• Creation of new business models to aggregate user experience, developing choice and convenience through a stratification of services,

• Creation of new business models building on the generation and exploitation of mobility data,

• Societal benefits, addressing demographic shifts and increasing independence.

Some of these desired properties are in conflict and will result in trade-offs, which is a common generic feature of complex system of systems.

While future mobility should be safe, affordable, and convenient, other possible properties are listed in Figure 3.

Figure 3: Candidate properties of the System

All possible properties listed in Figure 3, and further unlisted desired properties, require collective rigorous validation by all stakeholders. The inclusion of the ethical property indicates the realisation that future mobility is a socio-technical system. How these properties are addressed will ultimately define the future mobility system of systems architecture, such as sensing, communication, infrastructure, etc. It is recognised that vehicles and infrastructure cannot follow independent designs.

4.2 WHO WILL NEED TO BE INVOLVED IN THE DEVELOPMENT?

Figure 4 illustrates a minimal list of stakeholders forming a future mobility eco-system.

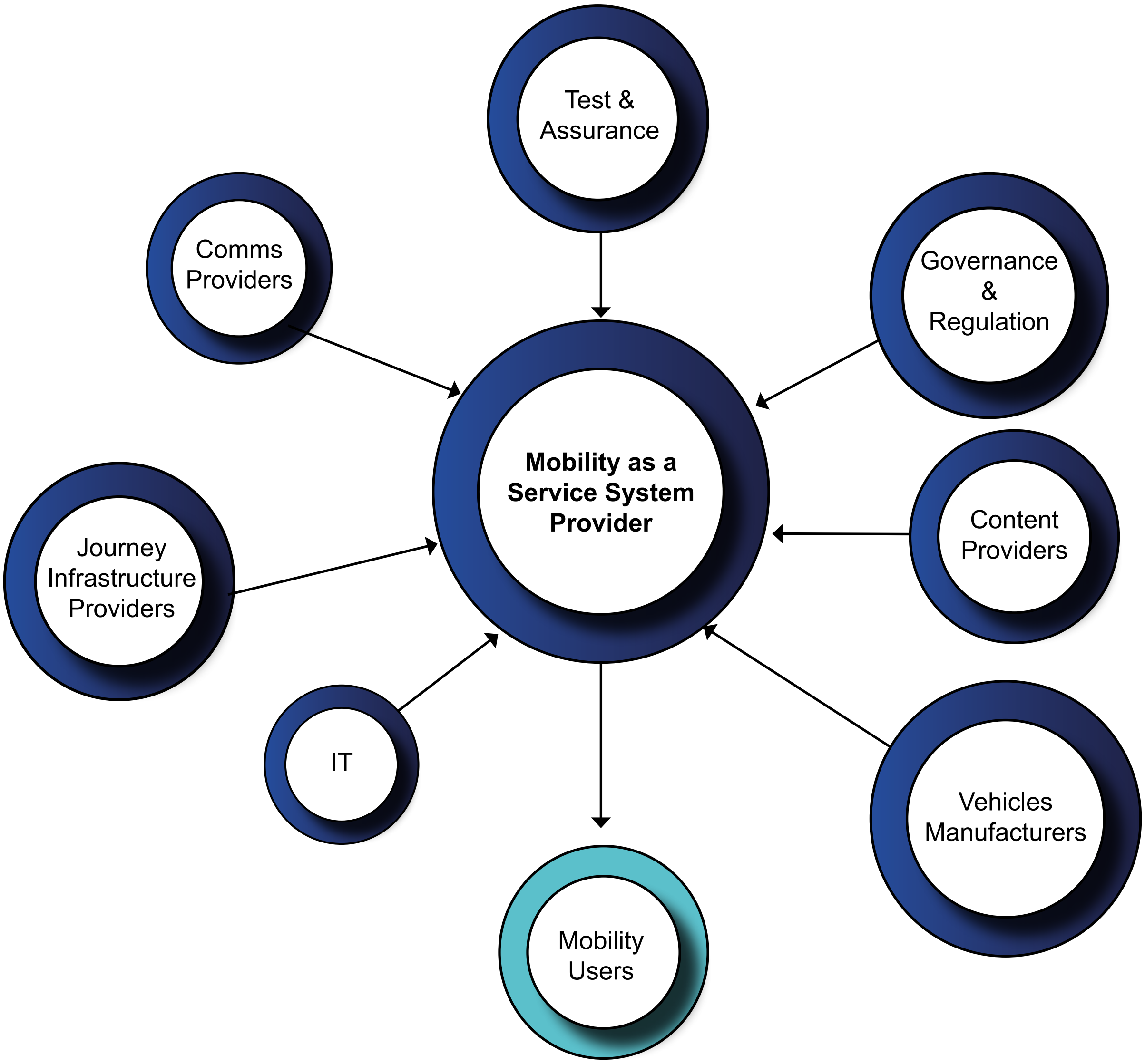


Figure 4: Mobility as a Service eco-systems

Current developments towards future mobility lack cohesion, with several parties in competition to become a Systems Operator, focused on specific services according to existing narrow viewpoints. There have been moves by some OEMs to start repositioning themselves as mobility service providers rather than automotive product manufacturers/ retailers. The risk conscious to many OEMs is of becoming commodity manufacturers, while product differentiation may belong to alternative mobility service providers.

The role of aggregators may become a further disruption to value capture. Some travel services have attracted secondary (or even tertiary aggregators, such as Kayak searching Expedia, Booking.com, etc.) offering intermediary services between end users and service providers.

4.3 WHO DEVELOPS AND OPERATES THIS SYSTEM?

The challenges to be faced now are definition of the future mobility system of systems' desired properties, and the design approach to ensuring their delivery. Approaches to system of systems design, employed in other sectors, may provide inspiration for this. But selection of the possible design approach will require a critical decision on the need for a system owner/operator and the potential candidate identification. Place-based infrastructure providers, holding a natural monopoly, may also provide a potential governance role in this approach. With these decisions made, the systems lifecycle process will become clearer.

Figure 5 lists a popular classification of system of systems based on the degree of control, from the US Department of Defense.

Directed	The SoS is created and managed to fulfil specific purposes and the constituent systems are subordinated to the SoS. The component systems maintain an ability to operate independently; however, their normal operational mode is subordinated to the central managed purpose
Acknowledged	The SoS has recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system
Collaborative	The component systems interact more or less voluntarily to fulfil agreed upon central purposes. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards
Virtual	The SoS lacks a central management authority and a centrally agreed upon purpose for the SoS. Largescale behaviour emerges (and may be desirable) but this type of SoS must rely on relatively invisible mechanisms to maintain it

Figure 5 : Taxonomy of System of Systems

On the current evolutionary pathway, future mobility will be delivered as a virtual system of systems with the only desired properties being those emerging from market forces or incremental regulation. The cooperative need is beginning to be recognised, but the stakeholder community will need coherent consensus on the desired properties to ensure selection and definition of an appropriate engineering design approach. However, it cannot be assumed that all stakeholders can agree on the same set of desired outcomes or the architectural principles that will deliver on these. This community action may also need to bring to bear best practices, tools, methodologies, and techniques from adjacent markets to deliver a shared vision.

The risks posed by not addressing both the desired properties and the design approach are significant. Future mobility will involve and depend upon greater levels of autonomy than ever before, which will result in a safety critical system not previously seen. Individual vehicle design must be replaced by coordinated system solutions to ensure the specific property of safety is achieved.

2. However it cannot be assumed that all stakeholders can agree on the same set of desired outcomes or the architectural principles that will deliver on these

The convergence of the automotive industry, assurance, ICT, ITS, transport planning, and behavioural science, to bring about this revolution in safety and other desired properties, cannot be guaranteed without action. The future mobility systems of systems, built on interdependent yet independently controlled complex constituent systems, requires a multi-disciplinary endeavour transcending traditional competence areas.

5 CONCLUSIONS

This paper has posited future transport as a complex system of systems, which must be defined and then developed in an integrated, holistic approach. The vision for the future state, and its desired properties, must be identified and agreed by all stakeholders, and be engineered into the future mobility system architecture.

The activities by which these goals might be achieved, and possible reference architectures, will be the subject of future papers, and the authors welcome broad stakeholders' input.
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