Cambridgeshire Autonomous Metro (CAM) & Cambridgeshire Light Rail (CLR) Metro
Qualitative Comparison

CAM

CLR

01 October 2019 (v1)

Cambridgeshire Autonomous Metro (CAM) & Cambridgeshire Light Rail (CLR) Metro Qualitative Comparison

Prepared by:

Brown, I., Brown, M., Cushing, P., Hanson, J.,

Harris, C.M., Moore, D., Uddin, M. & Wakefield, P.

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Executive summary

Cambridge has undergone startling growth over the past 20 years and this is forecast to continue. As noted in the Cambridgeshire and Peterborough Independent Economic Review (CPIER) (2018), this rate of growth is highly dependent upon the region's infrastructure being able to accommodate additional traffic, and there are concerns about impacts on quality of life. Moreover, sustainable growth will also depend on investor confidence in the ability of the region to cater for more people, jobs and visitors.

An order of magnitude improvement in public transport is required to meet these demands. This must both improve performance and capacity for passengers and generate investor confidence in the vision for the region. A technically advanced transport system provides investors with that confidence, and the assurance that a city's plans are permanent, robust and serious. It also plays a critical role in defining the image of the region, and it is imperative that the global reputation of Cambridge – renowned for excellence in research, science and technology – is not placed at risk by its adopted transport system.

The Cambridgeshire Autonomous Metro (CAM) was originally justified on the basis that it could be delivered for "one third of the capital cost of regional Light Rail Transit network" (Steer 2018). It is now clear from Steer (2019) this conclusion was wrong, and the estimated costs for CAM have already tripled from £1.5 bn to ~£4.5 bn. This starkly illustrates the very high level of uncertainty that surrounds the nascent CAM scheme and its costings. It is now clear that Cambridgeshire Light Rail (CLR) can be delivered for comparable cost, and, in whole-life terms, perhaps less.

- CAM is technically undeliverable in the non-guided, autonomous mode and would fail to achieve regulatory or licensing approval in the UK.
- Steer (2019) recognises that CAM must be both guided and driven, at least for the foreseeable future. CAM thus has all the disadvantages of a bus (poor brand, higher emissions, lower energy-efficiency) with none of the advantages. That is, CAM would be an expensive and inflexible bus.
- If CAM is to be driven without guidance, it will require relatively wide lanes, with greater land-take. Tunnelling costs could also significantly escalate if wider lanes are required.
- If CAM is to be guided, but with a driver, it will require a signalling system if high frequencies are to be achieved and regulatory approval obtained. In both cases, significant costs will be incurred.
- Light rail, involving a fixed steel track with modern power, control and asset management systems, is proven to provide an order-of-magnitude improvement for passengers, resulting in growth in usage through both modal shift and the generation of new trips.
- Light rail has even greater benefits by attraction of investment to the region. Improved access to commercial, educational, and cultural assets and services, along with the positive impact on the image, has been repeatedly shown to generate major economic, social and employment benefits.

Given the long-term implications of the metro scheme for the Cambridgeshire economy and environment, and for use of public money, it is both responsible and necessary to undertake a detailed comparison between the two schemes – CAM and CLR – to determine which is more beneficial. This requires an assessment across a broader range of criteria than has so far been the case. To illustrate some of the important differentiating factors between CAM and CLR, we have undertaken a comparison of the two schemes using a qualitative appraisal methodology, the main conclusions summarised in the Executive Summary table overleaf. We recognise the need for more quantitative assessment across the range of criteria, although this work is beyond our current scope.

EXECUTIVE SUMMARY

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)
Network	• If fully segregated, similar to CLR. • If not fully segregated, on roads with other traffic CAM exposed to congestion, with impact on speed and service reliability, reputation and ability to generate modal shift.	5 2	5	• Segregated operation minimises collision risks. • Highly accessible, although potentially higher cost for one additional underground station. • Interfaces well with feeder services, Park & Ride, & heavy rail network.
Technologies: Rubber vs Rails	• CAM is "Bespoke and uncertain" – SDG Report 2018. • CAM vehicle legality uncertain, extending delivery time. • Approval not a given (e.g. tunnels), casting doubt on viability. • Road damage high by heavy vehicles at metro frequency.	1	5	• Standard technology, proven, highly sophisticated. • Billions invested in Light Rail Vehicle development. • Rails specifically address infrastructure wear problem.
Tunnelling	• Tunnel length doubles costs. • Uncertain whether CAM vehicle would be approved for operation within tunnels, placing delivery at risk. • Wider tunnels may be needed for unguided, driven vehicles.	1	5	• Tunnel length minimised to essential needs. • Light rail proven deliverable for tunnel operations. • Tunnels comply with legal, safety and practical requirements.
Safety	• Optical guidance system failure in tunnel could be catastrophic and could impact whole system viability. • Busway safety lower than light rail systems. • Unproven.	1	5	• Very safe technology, proven over billions of miles. • Best safety record possible. Rails provide part of that safety in physical guidance.
Environment & Human Health	• Less energy efficient, more power needed, less sustainable. • Particulate pollution higher. Ecosystem / human health risks. • High volumes of waste tyres.	1	5	• Most energy efficient, less power needed, highly sustainable. • Particulate pollution lowest possible. • Superior technical solution for environment / health.
Costs	• Lower capex to install segregated roadway. • Higher opex and maintenance of roadway / vehicles. • Higher risk – costs less predictable using new technologies. • Procurement from few providers; potentially held to ransom.	2	4	• Higher capex for permanent rails. • Lower whole-life costs. • Low risk - costs predictable using proven technology. • Competitive, cost-effective marketplace.
Financeability	• Low investor confidence profile. • Bespoke and risky solution less attractive to investors who need confidence in dependable and predictable returns. • Lack of permanence on open roads without infrastructure, the same as bus services, creates uncertainty. • Investor confidence likely to be low for Land Value Uplift in areas without permanent investment in infrastructure.	2	4	• High investor confidence profile. • Proven and deliverable solution that provides investors with confidence. • Permanent infrastructure provides investors with confidence in long-term commitments. • Investor confidence essential to raise funds and to generate revenue from Land Value Uplift.
Delivery Risk	• Higher risk, many aspects not proven - costs unpredictable. • Industry support not yet well established with few providers. • Special legal / planning provisions may be required depending on degree of segregation and tunnel operation. • Likely to fail at feasibility or design stage.	1	5	• Vehicles known to meet legal & safety requirements. • Supported by well-established industry. • Proven technology, known deliverable today. • Deliverable via Transport & Works Order procedures. • Unlikely to fail at feasibility or design stage.

1 Background

In January 2018 the Combined Authority for Cambridgeshire & Peterborough (Combined Authority) and the Greater Cambridge Partnership (GCP) jointly published the *Greater Cambridge Mass Transit Options Assessment Report* (Steer 2018). This report compared mass transit options for the Cambridgeshire region, including the Cambridgeshire Light Rail (CLR) model proposed by Cambridge Connect, the Affordable Very Rapid Transit (AVRT) proposal by Prof John Miles, and the Cambridgeshire Autonomous Metro (CAM) proposal put forward by Steer. AVRT was rejected on technical and deliverability grounds.

The Steer (2018) report concluded that a regional light rail network with inner city tunnels, such as proposed by Cambridge Connect, would cost ~£4.5 bn. The report also concluded that the alternative CAM as proposed by Steer, which also has tunnels and a similar network, would cost ~£1.5 bn. Consequently, Steer (2018) concluded:

> *"In comparative terms, CAM represents the best value for money of any option, delivering comparable transport benefits to Light Rail Transit (LRT) at a substantially lower cost (around a third of the capital costs of a regional LRT network)." (Steer 2018: p.x)*

On this basis it was recommended that light rail should be rejected from further consideration because of Value for Money (VfM) and affordability concerns, and that CAM should be taken forward. It was recognised that light rail was strong on technical and network grounds, and in some respects was noted as superior (e.g. ride quality). Based on the Steer (2018) advice, the Combined Authority and GCP decided to progress CAM to Strategic Outline Business Case stage.

In February 2019 the Combined Authority and GCP published the *Cambridgeshire Autonomous Metro Strategic Outline Business Case* (Steer 2019). Having undertaken more detailed analysis of CAM, this report assessed the full CAM scheme would cost approximately £3.7 to £4.5 bn, or around three times the original estimate. This report clearly demonstrates that the earlier claim that CAM could be delivered for "a third of the capital cost" of light rail was wrong and therefore was an unsound basis on which to reach decisions on the type of metro system appropriate for the region.

Steer (2019) noted the higher cost of CAM still had a Benefit to Cost Ratio (BCR) of between 3 to 4 (i.e. 'High' to 'Very High' by the Department of Transport (Steer 2018)), which represents 'Value for Money' and therefore the Strategic and Economic case for CAM was "compelling".

2 Introduction

It now clear from Steer (2019) that the projected cost of Cambridgeshire Autonomous Metro (CAM) is likely to be comparable to light rail (~£3.5 to £4.5 bn). This means the two alternative schemes are likely to perform at least comparably on BCR and on Value for Money (VfM) grounds, and the Strategic and Economic cases for both should therefore be similarly strong. Potentially, the greater benefits offered by light rail could improve the BCR further. Light rail therefore remains a strong and realistic option for delivery of a mass transit scheme for the Cambridge region, and should not be rejected at the optioneering stage on the grounds so far used.

Normally, a change in cost of the magnitude determined for CAM should trigger a “Gateway” review to take stock of whether the scheme remains the right option for the required level of investment. In particular, a Gateway review should consider whether the earlier rejection of light rail on cost grounds remains valid now that we know the revised costings for CAM are comparable. This is especially important because CAM is “bespoke and uncertain” (Steer 2018) and thus subject to high levels of uncertainty and risk, unlike light rail which is well-tested and proven in hundreds of cities worldwide.

Given the major escalation in the projected cost of CAM, there is now an urgent need for this type of robust Gateway review to appraise light rail as an alternative to CAM on a like-for-like basis. There is a need for a fully robust and transparent analysis on which to base decisions over which of these two options are most suitable for a Cambridge metro.

For example, on a wide range of other important criteria (such as risk profile, financeability, environment and modal shift etc.) there are key differences between the modes, and these have not yet been properly assessed. Given the long-term implications of the metro scheme for the Cambridgeshire economy, for people’s lives more generally, and for use of public money, it is both responsible and necessary to undertake the detailed comparison between the two schemes to determine which is more beneficial.

This requires a detailed assessment across a broader range of criteria than has so far been the case. In the first instance, and to illustrate some of the important differentiating factors between CAM and CLR, we have undertaken a comparison of the two schemes across a range of criteria using a qualitative appraisal methodology. We fully recognise the need for more quantitative assessment across the range of criteria, although this work is beyond our current scope.

3 Objectives

The objective of this report is to make a qualitative appraisal of CAM and CLR across a range of differentiating criteria to demonstrate the relative strengths and weaknesses of the two models.

Our goal is to present the case that there remains a need to undertake a detailed, ‘like for like’, quantitative comparison of CAM and CLR across a full range of relevant criteria in order that the underpinning evidence for the preferred mode of mass transit appropriate for the region can be properly examined. When complete, this analysis should inform decisions on which metro options to take forward.

4 Authorship

Cambridge Connect has partnered with experts to examine critically the relative merits of CAM and CLR. These experts and companies have extensive experience in the field of design and delivery of mass transit, both in the UK and internationally. The experts are leaders in the field, and have backgrounds of successful delivery of mass transit services over many decades. They are concerned that a robust appraisal of options is undertaken in the Cambridgeshire context in order to provide decision-makers with full and balanced information on which to make mass transit choices, and to give any scheme selected the best chance of success. The companies involved and contributor profiles are provided at the end of this report.

5 Scope

The scope of the appraisal in this report is necessarily qualitative, and the detailed quantitative analysis that is required is beyond current resources. However, the value of this expert qualitative analysis is to highlight areas where the relative performance of each scheme option is in need of more detailed appraisal.

The range of criteria selected for qualitative assessment at this stage represents differentiating factors between the two mass transit options that are likely to have important influences on the outcomes and success of the chosen scheme. For example, factors such as maturity of technology, risk, investment profiles, deliverability and environmental considerations.

We have not covered factors such land take and ecology at this stage, as these factors are unlikely to be key discriminators between the two schemes, unless large parts of CAM were to be unsegregated, which does not appear to be intended. Moreover, it would be too early in the process to undertake a detailed assessment of environmental impacts from scheme delivery.

6 Methodology

6.1 General approach

A relatively detailed analytical framework was developed to maximise use of existing knowledge and to identify key issues that may have been omitted from previous risk identification exercises. This involved development of differentiating criteria to identify opportunities and risks arising from the metro scheme, which in turn strongly influence its implementation and outcomes. These criteria relate to the technical aspects of the alternative network models and modes, risks to cost and programme (in particular ability to raise finance and deliverability), regulatory compliance including safety, environmental and health considerations and reputational implications. These were assessed for both CAM and CLR to provide a comparison. The criteria were grouped under the following six sub-topics:

1. Network
2. Technologies: Rubber vs Rail
3. Tunnelling
4. Environment, Safety and Human Health
5. Costs
6. Financeability and Deliverability

A general summary assessment of the sub-topics is then made in conclusion.

In view of the number of potential issues to be addressed, a formal quantitative risk ranking that allocates numerical scores to impacts and consequences for project delivery, and combines these with the frequency of their occurrence, was considered too complex to undertake within the scope of the present report.

6.2 Appraisal Scale

A qualitative appraisal scheme that takes account of probability of an impact or consequence occurring and its magnitude was developed to assess CAM and CLR across a range of criteria. The appraisal is based on both the expert knowledge of the project team and on the supporting references identified as the evidence base for the appraisal.

A five-level appraisal scale has been adopted in the assessment (Table 1 – see over). The scale ranges from Very Strong / Excellent (5) through to Very Weak / Very Risky (1), with each topic being considered for its performance against the appraisal criteria for both CAM and CLR.

The scale is not suitable for quantitative analysis, for example by adding and averaging scores. This is because the nature and weights of the criteria vary across the topics, and therefore adding and dividing scores could be simplistic and misleading. For example, it would be misleading to attempt to average scores for 'Stop accessibility', 'Power requirement', 'Maintenance', 'Safety', etc., since the topics are very different by nature, and would require different metrics and weights applied if the analysis was to be made quantitatively. It would therefore be inappropriate to average scores over any given topic area (e.g. 'Network', Technologies', 'Tunnelling' etc.) and use these in the Executive Summary.

In summary, the scores given are based on expert appraisal of the relative merits of CAM and CLR for each topic in turn. The Executive Summary has been informed by performance across the range of criteria, and is made by the experts as an overall qualitative judgement, and is not made by averaging scores from within each sub-topic.

Our aim is to highlight areas of potential concern which, in our opinion, warrant more detailed examination including by quantitative assessment. The qualitative assessment draws attention to the need for this type of more detailed and robust analysis by highlighting significant potential performance discrepancies between the two options.

Table 1. Qualitative Assessment Criteria

	VERY STRONG / EXCELLENT • Very high potential contribution to GVA • Highly secure income source • Very strong alignment with / supported by stakeholders • Relatively straightforward to implement • Technically superior and proven • Very cost-effective • Likely to be deliverable on time / within budget • Known / predictable compliance with regulatory requirements / standards • Objections to scheme unlikely to be upheld / can be addressed.	**5**
	STRONG / GOOD • High potential contribution to GVA • Secure income source • Strong alignment with / supported by stakeholders • Practicable to implement • Technically sound and proven • Cost-effective • Usually deliverable on time / within budget • Low risk of failure to comply with regulatory requirements / standards • Objections to scheme unlikely to be upheld / can be addressed.	**4**
	REASONABLE • Reasonable potential contribution to GVA • Generally stable income source • Reasonable alignment with stakeholders with reservations • Technically adequate although (non-critical) aspects of technology unknown • Some risk to cost-effectiveness • Some challenges to implementation • Some risk of failure to comply with regulatory (non-critical) requirements / standards • Some risks to delivery on time / within budget	**3**
	WEAK / RISKY • Low potential contribution to GVA • Unpredictable income source and / or exposure to market fluctuations • Weak alignment with / unappealing to stakeholders • Difficult to implement / limited track record / relatively untested • Technically inferior / some key aspects of technology unknown • Weak / poorly known cost-effectiveness • Moderate risk whether deliverable on time / within budget • Moderate risk of failure to comply with regulatory requirements / standards • Moderate risk of objections being upheld, with impacts on cost, programme or deliverability.	**2**
	VERY WEAK / VERY RISKY • Very low potential contribution to GVA • Very unpredictable income and significant exposure to market fluctuations • Very weak alignment with / unacceptable to stakeholders • Very difficult to implement and/or untried or untested • Technically poor / critical aspects of technology unknown • Very poor / unknown cost-effectiveness • Unlikely to be deliverable on time / within budget • Significant risk of pollution / environmental damage • Significant risk of failure to comply with regulatory requirements / standards • Significant risk of issues that affect funding delivery or investment confidence • Significant risk of objections being upheld, with impacts on cost, programme or deliverability • Issues likely to result in excessive costs / time to address, making scheme non-viable.	**1**

7 Scheme Profiles

CAM

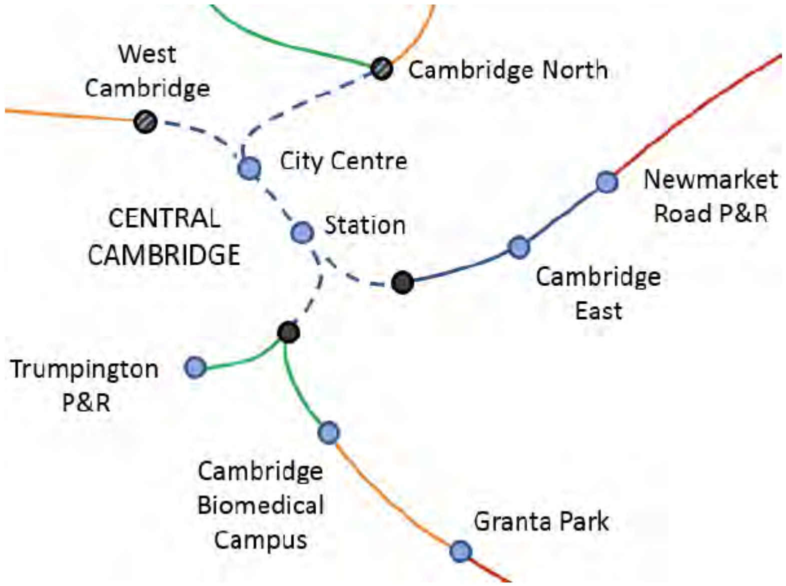
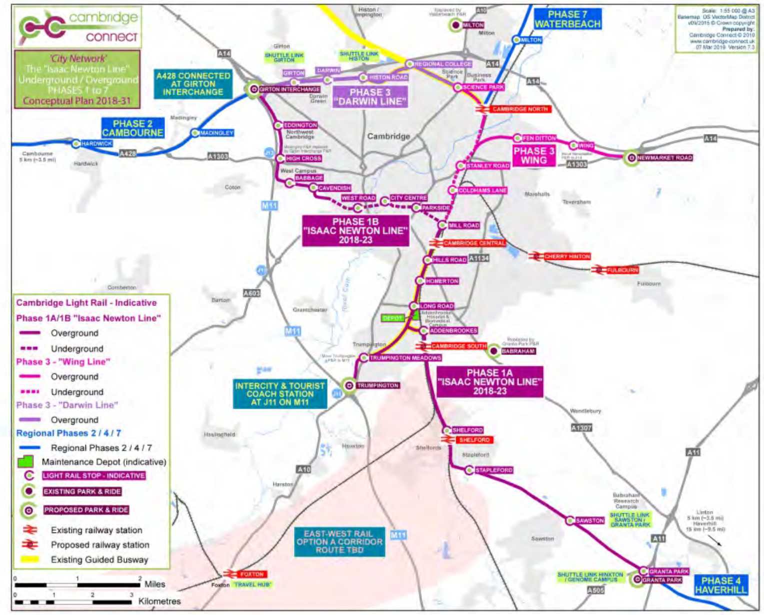
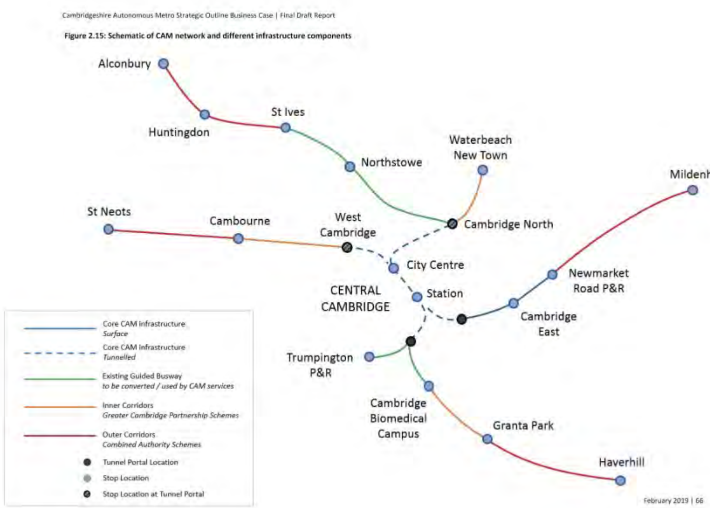
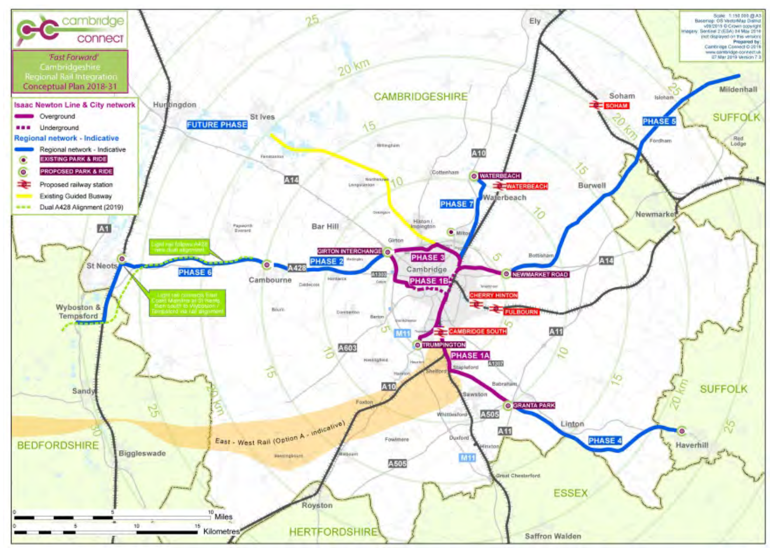
CLR

Scheme profiles – key characteristics

Characteristic	Cambridgeshire Autonomous Metro (CAM)	Cost (£m)	Cambridgeshire Light Rail (CLR)	Cost (£m)
Mode	Bus on tarmac or concrete road		Light rail vehicle on rails	
Power	Electric batteries. Recharging at termini. Charging infrastructure. OLE / ground power supply options not currently available.		Electric Overhead Line Equipment (OLE), or option for Electric ground supply, or batteries with charging infrastructure.	
Guidance	Optical laser / image processing technology (proposed, not currently proven in UK)		Physical steel rails.	
Network length[1]	~142 km (including tunnels and busway to Huntingdon / Alconbury).	4500	~142 km (including tunnels and converting busway to Huntingdon / Alconbury)	4500
Tunnel length[2]	~12 km	1340	~6.5 k	726
Segregation	Core network fully segregated. Regional routes fully segregated (£1610 m), Regional routes not fully segregated (£800 m).	2890 1610 800	Fully segregated >95% of network	
Service frequency	~5 mins at peak within city, not specified beyond city so assumed 15 mins (similar to Nottingham)		~5 mins within city, ~15 mins beyond city.	
Max speed	88 kph (55 mph)		100 kph (60 mph)	
Autonomy	Driver required. Autonomous operation proposed but delivery date unknown.		Autonomous operation available now. Driver optional.	
Number of vehicles	79 (@ ~£1 m ea)	80	34 (@ ~£2.5 m ea) for 5-min city headway; 52 vehicles for 3-min city headway.	85
Vehicle capacity	100 – 300		150 – 300	
Vehicle longevity	15 years (estimated)		20 years (proven)	
Vehicle length / width	12 – 31 m / 2.4 – 2.7 m		18 – 37 m / 2.4 – 2.7 m	
Vehicle weight	18 – 51[3] tonnes		18 – 50 tonnes dependent on length	
City stops	11		31	
Underground stations	x2 (City centre, Cambridge Rail Station)	490	x3 (eg. City Centre, Parkers Piece, West Road)	735
Depots	x1	40	x1	40
Operating costs	£3.30 to £4.00 per vehicle kilometre (estimate)	25 – 30 pa	£5.00 to £6.00 per vehicle kilometre4 (proven)	38 – 50 pa

1. CAM cost from Steer 2019. CLR cost based on estimate of £30 m per km for new line. This is based on average UK scheme costs (excluding DLR; Ref 18) scaled to 2019 prices , multiplied by an optimism bias of 1.4. Half of this cost (£15 m per km) has been estimated for busway conversion since many costs will not be required (eg alignment, moving services, land purchases, etc.).
2. Tunnel costs based on Steer 2019.
3. Based on fully loaded 51 tonnes CRRC vehicle of 31.6 m.
4. Based on Metrolink & other operational lines analysed by P. Cushing 2019. NB: DLR & Metrolink operate at profit, Nottingham NET breaks even. Revenue-earning capacity also needs to be taken into account.

Scheme profiles – network maps

	Cambridgeshire Autonomous Metro (CAM)	Cambridgeshire Light Rail (CLR)
CITY		
REGION		

8 Comparative Analysis

CAM

CLR

NETWORK

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)	Cambridgeshire Light Rail (CLR)	Ref.
Segregation	• If fully segregated similar to CLR.	• Fully or mainly segregated across full network.	
	• Some of network may be unsegregated using normal road network (unproven). Where unsegregated, benefits lost.		
Stop Accessibility	• Network accessibility poor in city • Only one stop in city centre, one at central rail station.	• Accessibility better with greater density of city stops, achieved by more surface level operation • More than 3 underground stations may not be affordable.	
Service Reliability	• If fully segregated similar to CLR, but unproven (eg. road maintenance issues, operation in tunnels).	• Speed and reliability guaranteed and predictable – high reputation. • Maintains high levels of customer satisfaction, which encourages modal shift.	15, 16, 17, 18
	• If unsegregated, exposed to congestion constraints, with impact on speed and service reliability with consequent impact on reputation / capacity for modal shift. • Breakdown recovery by another vehicle on batteries difficult		
Longevity & Permanence	• If fully segregated similar to CLR.	• Permanent track provides long term investor confidence that infrastructure will be enduring. • Locational investment decisions are based on permanence and confidence.	
	• If unsegregated doubts about longevity / continuity of service – services can easily be withdrawn. • Locational investment decisions faced with greater uncertainty		
Network Topology & Flexibility	• If fully segregated, same flexibility as CLR	• Permanent track less flexible than bus, which can use road network.	
	• CAM may be more flexible if vehicle can operate on normal roads, although practicalities are uncertain. • Needs an approved guidance system (especially for tunnels) • CGB evidence shows few routes extend beyond the busway, and routes on rural roads are unlikely to be cost-effective. • Claimed flexibility unlikely to be realised in reality.	• Permanent network backbone provides confidence • Feeder bus services/ Park & Ride links at stops can offer required flexibility in service over a wider area. • Track can be extended where / when needed as future demand becomes manifest (phased).	
Power Requirement	• Higher power requirement to deliver similar service level; greater exposure to risk of power capacity constraints. • Higher costs over scheme lifetime. • Battery option only, and technology still immature.	• Most efficient power usage; lower exposure to risk of power capacity constraints but risk of network-level power failures without back-up technology (eg. battery) • Lower whole scheme lifetime costs. • Options for OLE, ground feed, or battery systems. • Power delivery via OLE more efficient, but visual intrusion.	

TECHNOLOGIES: RUBBER vs RAILS

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)	Ref.
Maintenance	• Road wear: proportional to the fourth power of the axle weight. CAM 18-51 tonnes: wear similar to HGV. • Heavy vehicles at 'Metro' frequencies exacerbate wear. • Repetitive tracking on single path (e.g. optical guideway) will exacerbate wear (e.g. in Caen, problems plagued operation of rubber-tyred trams, with ballooning road maintenance costs and unreliability leading to system replacement by light rail). • Road maintenance costs will be significant; Steer 2019 state "surface infrastructure" maintenance included although unclear whether full road maintenance is included in operating costs. • Cambridge Guided Busway: significant maintenance needed after 8 y, despite theoretical 20 y lifetime. • All maintenance costs need to be accounted for in the whole-life cost appraisal of CAM (and all forms of bus).			• Rail / trackbed transfers vehicle loads using well-understood engineering. • Rail engineering proven to be durable and effective over hundreds of years of experience. • Rails specifically address road wear problem. • Rail maintenance is required but comparatively lower. • Rail maintenance costs are accounted for in budgets and paid out of operational revenues. • Light rail is replacing busways where whole-life costs are taken into account.	1
Autonomous operation	• Autonomous operation uncertain and delivery time unknown.			• Autonomous operation deliverable today.	
Friction / efficiency	• High tyre friction; low energy efficiency. • Higher friction generates additional heat, adding to ventilation costs in tunnels.			• Very low friction; most energy efficient. • Steel wheels on rails have ~15% of the rolling resistance of rubber tyred vehicles.	2
Power requirement	• Significantly more power required to deliver an equivalent service level owing to substantially lower energy efficiency of rubber-tyred vehicles. • Higher power requirements inflates operational costs.			• Light rail requires the lowest possible power to deliver the required service level because of its high efficiency. • significantly less energy will be required to run light rail vehicles than CAM to deliver the same service level.	2
Resuspension of Particulates	• Approx 27% of non-exhaust particulates are derived from resuspension of particles along route. • Large tyre > road contact surface increases particulate resuspension and recycles harmful pollutants into air.			• Lowest possible contact area of wheel to rail (size of 5p piece) – particulate resuspension lower.	13
Passenger experience	• High ride quality claimed but road subject to wear / maintenance over time, leading to deterioration in quality; impact on passenger satisfaction unknown.			• High ride quality proven and consistent over lifetime of rail light rail vehicle with appropriate maintenance.	1, 15, 16, 17, 18

TUNNELLING

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)	Ref.
Tunnel Configuration	• Tunnel configuration: one central tunnel that splits in two at both ends, with 4 portals. • Tunnel length ~ 12 km. • Similar tunnel diameter assumed, although uncertain. • Twin bore tunnel design.			• CLR & CAM tunnel configurations can potentially be similar • Current CLR tunnel configuration: two tunnels that join at one end, with 3 portals • Current CLR tunnel length ~ 6.5 km. • Tunnels of a size that are legal and safe. Prelim indicative size is 4.8 – 5.2 m in diameter.	8, 9
Capacity	• Tunnel capacity future-proofed.			• Tunnel capacity future-proofed.	
Safety	• CAM safety: autonomous, driverless, optical / laser guided – unproven and risks unknown. • Extremely high risk to network viability if CAM guidance systems fail in tunnel (e.g. crash) at speed with lack of physical guidance. • Lack of physical vehicle guidance may necessitate wider tunnel to meet safety tolerance requirements. • In-tunnel 800 mm wide along-track accessway assumed required, influencing tunnel diameter requirements.			• Safety case well proven (e.g. DLR), including with autonomous operation. • Very low risk – rails provide physical guidance, proven safe over millions of miles. • Light rail one of the safest forms of public transport. Fifteen times safer than buses, and 24 times safer than cars. • In-tunnel 800 mm wide along-track accessway assumed required, influencing tunnel diameter requirements.	
Tunnel operations	• Particulate pollution exacerbated in confined tunnel spaces – likely to exceed Health & Safety regulations without significant mitigation. • Additional costs for ventilation / filtration systems need to be built into capital and operational cost projections. • Dispersal / disposal of contaminated air at surface also needs to be addressed. • Need for escape routes.			• Low particulate emissions and zero engine emissions make light rail better suited to use inside confined space of tunnels. • Twin bore tunnel design would have cross passage linkages and comply with legal, safety and practical requirements. • Need for escape routes, but assumes shorter tunnel length.	

ENVIRONMENT, SAFETY & HUMAN HEALTH

1	2	3	4	5
● (red)	● (amber)	● (grey)	● (light green)	● (green)

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)	Ref.
Energy Efficiency	• Double to triple energy requirements (assumed equivalent of articulated bus). • Regenerative braking transfers energy back to power plant. • Battery will wear out/lose capacity over time.	2	5	• Energy consumption accounts for large proportion of operational costs, so low energy requirement is a significant on-going cost saving. • Regenerative braking transfers energy back to power plant. • Rail is most energy efficient form of mass transit.	2
Emissions & Particulate Pollution	• Zero electric motor emissions at point of operation. • Higher particulate pollution from tyre, road & brake wear. • Particulates elevated by heavy vehicles and tyre footprint. • Fine particulates harmful to human health at least as important as tail pipe emissions but often ignored. • Microplastics from tyres discharged into ecosystems.	1	5	• Zero electric motor emissions at point of operation. • Generates particulate pollution from rail / wheel / brake wear. • Lower levels of fine particulates. • Better option for human health.	3, 4, 5, 6, 7, 13
Waste & sustainability	• Thousands of waste tyres, which may be recycled into other uses, including burning for fuel, though energy inefficient. • Battery waste disposal may be significant environmental issue. • Raw materials for batteries come from non-renewable sources.	1	5	• Low waste. Durable. Steel recyclable. • If OLE catenary used, no waste batteries, and power can be obtained from sustainable, renewable sources. • Vehicles have a longer life, more sustainable use of materials / embodied energy.	
Noise	• Electric vehicles low noise, although rubber tyre roar at speed • Improvement on diesel buses	4	4	• Electric vehicles low noise, although rail screech in some places if not well-maintained • Improvement on diesel buses	
Carbon Footprint	• If segregated, works and guideways may result in more construction carbon. • Tunnel length ~ doubles tunnel construction carbon.	2	3	• Rails may elevate construction carbon cf roadway structures.	12
	• Modal shift offsets construction carbon and carbon from energy consumed. Modal shift less certain than CLR. • Higher operational carbon emissions owing to lower energy efficiency, depending on power sources.	4	5	• Modal shift offsets construction carbon and carbon from energy consumed. Modal shift more certain than CAM. • Lower operational carbon owing to higher energy efficiency, depending on power sources.	
Collision Risk	• If fully segregated similar to CLR, although busway safety has been lower than light rail systems.	4	5	• Segregated operation minimises collision risks • Risks of injury / death extremely low – one of the safest forms of transport that exists. • Operational speed, reliability, revenue and reputation all maintained at high levels. • Potential collision costs minimised using segregated routes.	10
	• Collision risk elevated on shared roads. *“Collisions in shared road space are a significant operational cost.”* • Elevated risks of injury / death • impact on operational speed, reliability, revenue & reputation.	1			
Visual Impact	• Concrete / tarmac roadway including cuttings, and potential structures for guidance, signs etc.	3	3	• OLE catenaries, if used, and tracks including cuttings. • Catenary not required if ground feed or battery operation adopted (hybrid approach could minimise visual intrusion in sensitive areas).	

COSTS

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)	Ref.
Overall cost & risk	• £3.7 bn for partially segregated network. • 4.5 bn for fully segregated network. • Relatively uncertain technology. • Elevated technical risks. • Elevated cost overrun risks. • Fewer benefits for similar investment.	2	5	• £3.5 – 4.5 bn for full network. • Proven deliverable, lower financial risk. • Greater benefits for similar investment.	9, 15, 16, 17, 18
Tunnel cost & risk	• £1.34 bn for 12 km of tunnels & 4 portals. • If wider tunnel required for vehicle with no physical guidance, tunnel costs could rise significantly.	1	5	• £726 m for 6.5 km of tunnels & 3 or 4 portals (estimate based on Ref. 9) • Tunnel length minimised to reduce costs. • Tunnel size and costs more predictable / lower risk	9
Underground station cost	• £245 m per station (estimate from Ref. 9) • 2 stations proposed.	3	3	• £245 m per station. • 3 stations proposed to improve network accessibility.	9
Segregated way costs	• Capital investment lower if operating on normal roads.	4	3	• Initial capital investment in steel track higher. • Whole life costs more favourable (see below).	
	• Capital investment significant for segregated roads.	3			
Vehicle costs	• £1 m per vehicle, although this cost uncertain for fully articulated version with rail-type bogies. • Shorter quoted vehicle life.	2	4	• ~£2.5 m per vehicle (Metrolink purchase cost, 2017) • Proven long vehicle life.	9
Operational costs	• Uncertain as few systems in operation. • Operational road maintenance costs may be high. • More power needed to deliver service, escalating operational costs. • Replacement tyres elevate operational costs. • Higher ventilation costs in tunnels to dissipate heat and particulates from rubber tyres. • Autonomous operation not currently deliverable, necessitating drivers and increased staff costs.	2	4	• Lower operational costs (eg. lower power requirements, no waste tyres, high durability of permanent way, lower ventilation costs in tunnels). • Autonomous operation currently deliverable, which could reduce need for drivers and staff costs.	

FINANCEABILITY & DELIVERABILITY

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)		Cambridgeshire Light Rail (CLR)		Ref.
Investor confidence	• Bespoke, uncertain, higher risk. • Lower investor confidence.	2	5	• Proven modern technology & systems = lower risk. • Higher investor confidence.	
Operational Revenue	• There is likely to be modal shift from other modes as well as additional trip generation • Risk CAM may be extracting from other bus services	4	5	• Likely to generate more farebox revenues than CAM as a light rail scheme is likely to generate greater modal shift toward it than a guided bus solution. • Similar to modal shift, a rail solution is likely to have a greater trip generative effect than a guided bus solution.	15, 16, 17, 18
3rd Party Revenue Potential	• Lower potential revenue with bus-based brand	2	5	• Higher potential revenue opportunities (vehicle advertising / station naming rights) from higher quality image.	
Land Value Capture	• Fewer stops but will improve connectivity of labour and buyers of goods and services to the Cambridge CBD driving up land prices and property values. • Appeal relatively uncertain, so land value uplift less predictable.	4	5	• More stops - theory suggests that competition between house buyers will create a pattern of a gradient in land values close to each transit access point. • Permanence of CLR will attract housebuilders, investors and buyers alike.	11, 19
Legal Approvals	• If fully segregated similar to CLR, EXCEPT in tunnels where safety case uncertain and yet to be proven.	2	5	• Light rail network deliverable via standard, well established Transport & Works Order procedures. • Tunnel operation likely to be straightforward in terms of legal / safety approvals as already proven (e.g. DLR).	
	• If unsegregated, CAM legally similar to articulated bus on public highways. • If approved, practical / successful operation on the Cambridgeshire road network is unknown.	1			
Deliverability	• Unproven technology and unsubstantiated assumptions regarding permanent way; power supply; relative attraction to passengers; ability to secure consents, licensing and approvals; • Likely to fail at feasibility or design stage	1	5	• Proven technology; many recent precedents; clear process for consents; proven passenger attraction; etc. • Unlikely to fail at feasibility or design stage.	

OVERALL SUMMARY

1 2 3 4 5

CONSIDERATION	Cambridgeshire Autonomous Metro (CAM)			Cambridgeshire Light Rail (CLR)
Network	• If fully segregated, similar to CLR. • If not fully segregated, on roads with other traffic CAM exposed to congestion, with impact on speed and service reliability, reputation and ability to generate modal shift.			• Segregated operation minimises collision risks. • Highly accessible, although higher cost for one additional underground station. • Interfaces well with feeder services, Park & Ride, & heavy rail network.
Technologies: Rubber vs Rails	• CAM is "Bespoke and uncertain" – SDG Report 2018. • CAM vehicle legality uncertain, extending delivery time. • Approval not a given (e.g. tunnels), casting doubt on viability. • Road damage high by heavy vehicles at metro frequency.			• Standard technology, proven, highly sophisticated. • Billions invested in Light Rail Vehicle development. • Rails specifically address infrastructure wear problem.
Tunnelling	• Tunnel length doubles costs. • Uncertain whether CAM vehicle would be approved for operation within tunnels, placing delivery at risk. • Wider tunnels may be needed for unguided, driven vehicles			• Tunnel length minimised to essential needs. • Light rail proven deliverable for tunnel operations. • Tunnels comply with legal, safety and practical requirements.
Safety	• Optical guidance system failure in tunnel could be catastrophic and could impact whole system viability. • Unproven.			• Very safe technology, proven over billions of miles. • Best safety record possible. Rails provide part of that safety in physical guidance.
Environment & Human Health	• Less energy efficient, more power needed, less sustainable. • Particulate pollution higher. Ecosystem / human health risks. • High volumes of waste tyres.			• Most energy efficient, less power needed, highly sustainable. • Particulate pollution lowest possible. • Superior technical solution for environment / health.
Costs	• Lower capex to install segregated roadway. • Higher opex and maintenance of roadway / vehicles. • Higher risk – costs less predictable using new technologies. • Procurement from few providers; potentially held to ransom.			• Higher capex for permanent rails. • Lower whole-life costs. • Low risk - costs predictable using proven technology. • Competitive, cost-effective marketplace.
Financeability	• Low investor confidence profile. • Bespoke and risky solution less attractive to investors who need confidence in dependable and predictable returns. • Lack of permanence on open roads without infrastructure, the same as bus services, creates uncertainty. • Investor confidence likely to be low for Land Value Uplift in areas without permanent investment in infrastructure.			• High investor confidence profile. • Proven and deliverable solution that provides investors with confidence. • Permanent infrastructure provides investors with confidence in long-term commitments. • Investor confidence essential to raise funds and to generate revenue from Land Value Uplift.
Delivery Risk	• Higher risk, many aspects not proven - costs unpredictable. • Industry support not yet well established with few providers. • Special legal / planning provisions may be required depending on degree of segregation and tunnel operation. • Likely to fail at feasibility or design stage.			• Vehicles known to meet legal & safety requirements. • Supported by well-established industry. • Proven technology, deliverable today. • Deliverable via Transport & Works Order procedures. • Unlikely to fail at feasibility or design stage.

9 Conclusions

Cambridge has undergone startling growth over the past 20 years and this is forecast to continue. As noted in the Cambridgeshire and Peterborough Independent Economic Review (CPIER) (2018), this rate of growth is highly dependent upon the region's infrastructure being able to accommodate the additional traffic movements. Moreover, sustainable growth will also depend on investor confidence in the ability of the city to absorb and cater for more people, jobs and visitors.

An order of magnitude improvement in public transport is required in Cambridge to meet these demands. This must both improve performance and capacity for passengers and generate investor confidence in the vision and plans of the city. A first-class, technically advanced transport system provides investors with the confidence and assurance that a city's plans are permanent, robust and serious. It also plays a critical role in defining the image and 'brand' of the region, and it is imperative that the global reputation of Cambridge – renowned for excellence in research, science and technology – is not placed at risk by its adopted transport system.

CAM was originally justified on the basis that it could be delivered for "one third of the capital cost of regional Light Rail Transit network" (Steer 2018). It is now clear from Steer (2019) this conclusion was wrong, and that light rail can be delivered for comparable cost, and, in whole-life terms, perhaps less.

Rubber-tyred trams have been adopted in very few metros worldwide, and then mostly where there was a particular need to operate on relatively steep gradients, which are not found in Cambridgeshire. Problems plagued operation of rubber-tyred trams in Caen, with ballooning road maintenance costs and unreliability leading to the decision to replace the system by light rail (King *et al.* 2015). Rubber-tyred trams initially promised cost savings and greater network flexibility, but a host of operational and technical problems led Bombardier, one of only a few developers of the technology, to stop offering the system. We might also recall that structural and maintenance problems have plagued the Cambridgeshire Guided Busway, leading to major unforeseen and disputed costs.

Light rail has been proven to generate major economic benefits to support both public and private sector investment in numerous cities around the world. Modern light rail systems provide fast, reliable transport to millions of passengers worldwide. These benefits result from both more efficient transport for users of the system and wider employment and quality of life impacts. Buses do not have these wider benefits and tend to fulfil narrower mobility aims alone. We suggest that Cambridgeshire needs the wider benefits that light rail can bring, which will further attract investment that will itself help fund a phased development of the system. We also suggest, based on available evidence, that modern yet proven technology represented by light rail has numerous advantages over unproven, speculative and highly risky bus-based systems such as CAM.

9.1 Principles for an effective transit system in Cambridgeshire

- Cambridgeshire needs a transit system that gives confidence to developers, corporations and others to invest in the city. Evidence shows that fixed track light rail systems have the permanence, performance and brand appeal to provide investors with such confidence.
- The transit system must be proven as deliverable and capable of securing the necessary regulatory and licensing consents. Technology that is unproven or that has significant technical flaws, exaggerations and hidden costs, carry a high risk that they will not be deliverable and that they will eventually fail at one of the development hurdles.

- There must be high confidence that the selected scheme is capable of delivering on its objectives. In the case of Cambridgeshire (indeed globally in the context of climate change), there is an urgent need to drive substantial modal shift and to reduce the current dependence on private cars. The potential success of CAM in delivering modal shift remains speculative compared to light rail. Experience has shown that schemes based around buses struggle to achieve the scale of modal shift that is needed in Cambridgeshire. Light rail has been demonstrated to have that capability in numerous practical, operational examples worldwide.

- The system must be fundable. There must be confidence that revenues will cover operating costs; and that public and private sector financiers will have sufficient confidence in the operability and deliverability of the system itself to support capital costs.

9.2 Key conclusions

- CAM is technically undeliverable in the non-guided, autonomous mode and would fail to achieve regulatory or licensing approval in the UK. The length and weight of the vehicles together with the untested guidance system render the technology unsafe and unusable on the open highway network.
- The latest Steer (2019) report recognises that the system must be both guided and driven. They propose that the vehicle could be configured as up to a triple-articulated, 51 tonne driven bus, on a fully segregated track. This has all the disadvantages of a bus (lower speeds, poor passenger brand, higher emissions, lower energy-efficiency) with none of the advantages. That is, CAM would be an expensive and inflexible bus.
- Some CAM costs still appear to have been excluded, such as the cost of providing high voltage rapid charging facilities to key points on the network, and the cost of maintaining an asphalt or concrete pavement capable of accommodating vehicles up to 50 tonnes in weight. Moreover, significant additional costs may be hidden until detailed engineering requirements to operate the vehicle within tunnels have been determined.
- If CAM is to be driven without guidance, it will require relatively wide lanes, involving significantly greater land-take. Tunnelling costs could also be significantly increased by a requirement for wider lanes. If it is to be guided, but with a driver, it will require some form of signalling system if high frequencies are to be achieved and regulatory approval obtained. In both cases, significant costs will be incurred.
- Light rail, involving a fixed steel track with modern power, control and asset management systems, are proven to provide an order-of-magnitude improvement for passengers, resulting in growth in traffic through both modal shift and the generation of new trips. This improvement which attracts new trips is a function of shorter journey times, more reliable performance (punctuality), enhanced capacity, a more comfortable travel environment and improved public perception and understanding of routes and networks.
- Light rail has even greater benefits by attraction of investment to the region. Improved access to commercial, educational, and cultural assets and services, along with the positive impact on the image, has been repeatedly shown to generate major economic, social and employment benefits. Buses do not have this effect.

In just one year, between the decision taken to progress CAM in 2018 and the publication of the Strategic Outline Business Case in February 2019, the estimated costs for CAM tripled from £1.5 bn up to £4.5 bn. This starkly illustrates the very high level of uncertainty that surrounds the nascent CAM scheme and its costings, and we consider it likely that the costs will escalate further if work on CAM proceeds to more detailed engineering design. Current estimated costs for CAM are now comparable to, and perhaps more than, those projected for light rail, although given light rail schemes are well-proven, with many operational schemes across the world, these costs are inherently more predictable.

Now that we know that the original justification of CAM, namely that it could be delivered for one-third of the cost of light rail, was exaggerated and misleading, the question arises:

> *Why commit resources on this major scale to a public transport scheme that is unproven, risky and in many respects inferior, when a proven, reliable and more predictable, cutting edge solution already exists and can be delivered today?*

Light rail needs to be reappraised as a metro solution for Cambridgeshire. It is the only proven, reliable, low-risk, cost-effective, affordable and deliverable solution suited to the meet the public transport needs at the scale required, and that takes into account the unique constraints and opportunities of both Cambridge city and of the Cambridgeshire context. Failure to deliver the world-class system that the region deserves would result in poor transport performance and a massive waste in public funds.

The interest in proving autonomous bus technology is legitimate and should be progressed. However we believe this should not be undertaken on an experimental basis involving very substantial investment in a Cambridge metro where tunnels comprise an important element in the scheme. It should be undertaken as a development project either at a test facility, or on a more modest scale in an area where the technology can be proven as successful, and it can be demonstrated that the risks can be mitigated.

The stakes are high: the continued success of the Cambridge economy to 2030 and beyond depends on successful delivery of measures to address the challenges of growth, as warned by the CPIER (2018) report. A weakly performing, or failed, public transport scheme on this scale would place at risk the sustained success of the Cambridge economy, and there needs to be more adequate appraisal of the risks and their implications for the Cambridge economy, society and environment in the longer term. Appropriate cost weightings should be applied to recognise elevated risks where they exist.

This appraisal should inform choices of the public transport system for Cambridge, and investment made where the risks are lowest and the benefits are greatest. Relatively minor differences in capital costs at construction stage between light rail and CAM will be considered insignificant should CAM ultimately fail to deliver the transport benefits currently claimed without practical experience or proof (e.g. modal shift, reliability, operation in tunnels, autonomous operation), or indeed to attract the level of financing needed to make the scheme a reality.

Cambridge is inspirational: it is at the cutting edge and a global leader in science and technology, it has exceptional historic, heritage and architectural values, and it is a vibrant economic power-house for the United Kingdom. The public transport system selected for Cambridge must be equal to that, but must be carefully planned based on evidence and proof, must be enduring and sustainable, and must not place at risk the city's outstanding heritage, environment, and quality-of-life attributes, nor its reputation for excellence which has been established over hundreds of years.

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11 Company profiles

Ankura

Ankura is a full management advisory and expert services firm of over 1,500 professionals with offices in more than 30 major cities worldwide. Expertise and experience in project feasibility and in scheme delivery includes financial and commercial modelling, as well as construction, contractual and commercial advisory services. Ankura has undertaken independent project reviews in the UK rail sector, and its professionals regularly provide expert services and testimony on transport projects globally.

Amey

Amey design, build, maintain, operate and invest in infrastructure, including engineering, facilities management, utilities, transport, environmental services, defence and justice. Amey has a turnover of £2.2bn and employs 19,000 people internationally with a focus on the UK. Amey is one of the largest light rail operators in the UK, and runs both Metrolink and the DLR in partnership with Keolis. Amey's partnership ethos enables it to serve successfully more than 15 UK local authorities and clients such as Highways England, BAA, United Utilities, Network Rail, Ministry of Defence (MOD), and the Metropolitan Transport Authority in New York.

CMS Cameron McKenna Nabarro Olswang LLP

CMS is the largest law firm in the UK, with particular expertise in transport and planning law. CMS has been recognised by InfraDeals 2017 as "*the No 1 overall team in the UK and Europe for infrastructure and transport*". CMS is ranked as a Top 10 Global Law Firm, and operates in 41 countries.

Cambridge Connect

Cambridge Connect Transit Ltd was established in 2015 to promote and help to deliver a world-class, integrated and economically, socially and environmentally sustainable metro network for the Cambridge region, in particular using light rail with an underground component in the historic city core as part of an integrated and multi-modal strategy. Cambridge Connect has developed partnerships with expert companies and organisations with the aim of securing scheme delivery.

Railfuture

Railfuture is the UK's leading independent organisation campaigning for better rail services for passengers and freight. It is a voluntary group representing rail users, with ~20,000 members, and is not funded by train companies, political parties or trade unions. Railfuture promotes rail as a cost effective and environmentally sound means of transport to connect communities and support economic growth.

UK Tram

UK Tram was established in 2004 to coordinate, promote and represent the light rail and tram industry in the UK. The members include network operators, infrastructure and rolling stock maintenance organisations, passenger transport executives, local transport authorities, local government, concessionaires, manufacturers and equipment suppliers, industry advisors and expert consultants. UK Tram plays a leading role in developing technical and safety standards to improve industry best practice.

12 Author Profiles

James Hanson – Ankura

James manages the EMEA Construction Advisory team. He is a Civil Engineer with over 20 years industry experience in managing large and complex capital projects. James specialises in advising and assisting clients in project development, risk strategy, project controls and in the selection of project team and contracting organisations.

James has extensive experience in the transport sector with expert knowledge of the financial, contractual and supply chain risks involved in delivery of railway projects. He has advised on major contractual, commercial and technical risks associated with capital delivery, operation and maintenance of railway projects, and advised on time and budget management. He has undertaken risk management reviews of vendor construction contracts, pre and post signature.

Prior to Ankura, James was Managing Director of Navigant's Global Construction Advisory practice which was acquired by Ankura in 2018. Previously James was a Partner at PwC and worked for both its UK and Middle East Capital Project & Infrastructure practices.

Misbah Uddin – Ankura

Misbah is a Managing Director at Ankura specialising in transport and infrastructure project and finance advisory with over 17 years of experience. He is a government advisory and PPP specialist with particular knowledge and experience of the transport sector and infrastructure finance. His global experience and expertise includes business case development and review, cost/financial modelling, benchmarking, project due diligence, and project structuring advice to procuring authorities as well as bid-side advice to investors and contractors.

Notable past clients in the rail sector include the DfT, TfL, National Express, Etihad Rail, Oman Rail, Qatar Rail, Abu Dhabi DoT, Dubai Roads & Transport Authority, Russian Railways, Banedanmark, RATP and various other private transport sector investors and operators. Prior to Ankura, Misbah was a Director in Navigant's disputes, forensics & legal technology segment, which was acquired by Ankura in 2018. Misbah previously worked for PwC in both its UK and Middle East Corporate Finance and Capital Project & Infrastructure practices. Prior to that, he worked for Booz Allen Hamilton advising clients on a wide range of UK and international transport projects.

Dr Mark Brown – Amey

Mark is Development Director of Amey's Consulting and Rail business where he leads strategic planning and work winning. He was previously Group Development Director at Halcrow. Mark is an economist with 30 years' experience in the transportation sector. He has worked on a wide variety of highway, rail and development projects in over 20 countries and is widely published in project economics, rail planning and asset management. Mark is a director of the Wales and Borders Train Operating Company that is responsible for train operations throughout Wales, on behalf of Transport for Wales.

Peter Cushing – Chair, UK Light Rail Safety & Standards Board, UK Tram

Peter Cushing was until recently Director of Manchester Metrolink, with responsibility for the day to day operation and delivery of a £1.8bn capital programme, retiring in 2017. He has extensive operating experience at board level, underpinned by business development and commercial expertise gained throughout a successful and progressive career within the logistics, rail and consultancy / interim management sectors. Peter has significant experience working with senior local and central government bodies delivering major capital programmes in the UK and overseas in addition to holding full P&L

responsibility whilst leading the evolution and development of effective change in a variety of large, complex operational environments.

Peter has provided leadership in migration / transition planning, merger planning and organisation design in a variety of Light Rail Transit and Metro assignments in the UK and abroad. He has been a senior figure in other consultancy projects including operations and commercial analysis roles for DfT, and several major rail bids. Peter is Chief Executive of the newly-established UK Light Rail Safety Standards Board, which is tasked by government to review and set safety standards for tramways and light rail in the UK.

Dr Colin Harris PIEMA – Cambridge Connect

Dr Colin Harris is Director of the environmental planning consultancy Environmental Research & Assessment, based in Cambridge, and is Director of Cambridge Connect. Dr Harris was educated at the University of Otago (BA Hons, First), the University of Western Ontario (MA), and gained his PhD from the University of Cambridge, specialising in environmental management and spatial planning. He has worked in this field for 25 years and is a Practitioner in the Institute of Environmental Management and Assessment. His principal professional focus is on environment, sustainability and strategic spatial planning.

Colin established *Cambridge Connect Transit Ltd* in 2015 to promote an evidence-led strategy to address Cambridge transport challenges. Light rail with an underground component in the historic city core is supported by evidence as a strong and deliverable solution. Colin designed a segregated light rail network delivery strategy, and has published and presented widely on the subject.

David Moore – CMS

David Moore is a Partner in the Infrastructure & Projects Team at the law firm CMS Cameron McKenna Nabarro Olswang LLP. David read engineering at the University of Cambridge and gained professional qualifications at the Chester College of Law. David specialises in the development and operation of transport infrastructure and is a specialist in the rail sector. He has over 20 years' experience advising on the development and operation of rail infrastructure (including as a PPP), rail franchises (both bidding and during operations), rolling stock procurement (including maintenance arrangements), operational issues, rail regulation and industry arrangements. He also has extensive experience developing and operating other transport infrastructure and acts for both private sector and public sector clients in the UK and internationally. He has been recognised by the legal directories as "*a judicious and intellectually astute transport projects lawyer*" and "*brilliant*".

Ian Brown CBE FCILT – UK Tram

In a career spanning over 40 years, Ian Brown has made an outstanding contribution to public transport and the rail industry in the UK and internationally. His extensive achievements include playing a leading role in establishment of the Docklands Light Railway and the London Overground, the major extension of the East London Line, the integration of Croydon Tramlink into TfL and the expansion of Oyster 'pay as you go' to all National Rail stations in Greater London. Highlights of Ian's career include the British Rail Policy Unit, Managing Director of Railfreight Distribution, policy adviser to SNCF, and Chief Passenger Manager at the London Midland region.

Ian retired as Managing Director of TfL's London Rail in 2011 after 10 years in the role, and was honoured with a CBE in 2011 for services to the railway industry. Ian is a Vice President of Railfuture, and is on National Board of Directors. As Director of Policy, Ian has been instrumental in determining Railfuture's policies at a strategic level and has written several of its submissions to the Department for Transport. Ian is also a Board Member of UK Tram and leads its Centre of Excellence programme.

Peter Wakefield – Railfuture

Peter Wakefield was chair of Railfuture East Anglia until 2017, a role he held for over 20 years. In this role he advocated for public transport improvements, recognising the crucial link between a quality railway and sustainable economic development. For example, Peter pioneered the Railfuture campaign to restore East – West links between Cambridge and Oxford, an effort which is now close to practical delivery. Peter was closely involved in the successful campaign to establish a new station at Cambridge North.

Peter has detailed knowledge of the rail industry, as well as of the UK rail network and operations. Peter is interested in helping decision makers to make prudent forward-looking plans for the rail network and public transport services. Peter has played an key role on the Rail Freight Committee of Railfuture, has contributed to numerous submissions to government and consultations, and has been a spokesperson on topical issues. Peter has played the lead role in the Cambridge Connect initiative for Railfuture.

13 Declarations of interest

Ankura, Amey and CMS

These companies are agnostic in terms of specific transport modes and are involved in a wide range of public transit delivery schemes, including both bus and rail. They are interested in helping to deliver a successful metro scheme in the Cambridgeshire region on a commercial basis. None have vested interests in any specific metro solution for Cambridgeshire, rail-based or otherwise, and have freely offered their knowledge and expertise in order to help deliver an evidence-led solution with the best chance of success.

Cambridge Connect

Cambridge Connect was founded on the principle of helping to design, develop and deliver the best public transport scheme for Cambridgeshire based on evidence, and is agnostic in terms of specific transport modes provided they meet quality and deliverability criteria. Evidence reviewed led to the conclusion that light rail offers the most promising technology for delivery of a successful mass transit backbone in Cambridgeshire, and this would need to integrate with all other modes. Conceptual design work has therefore focussed on light rail as the core of the mass transit scheme. Work has been undertaken on both a cost-recovery and / or voluntary basis, and in future Cambridge Connect aims to continue this work on a commercial basis.

Railfuture and UK Tram

These non-commercial groups aim to promote and support the public interest in rail-based transit in the United Kingdom in general. They have no commercial interests in the metro outcome for Cambridgeshire. These groups formed natural partners in the project because they possess substantial expertise in the field.