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The Mobility as a Service Maturity Index: Preparing Cities for the Mobility as a Service Era

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Abstract: Mobility as a Service (MaaS) is the use of a "digital interface to source and manage the provision of transport related services" which meet people's mobility requirements. The implementation of a MaaS based transport system is dependent on a city possessing a number of characteristics. Before planning for MaaS it is important for decision makers to understand how close a city is to fulfilling these characteristics. Therefore, the aim of this study is to develop the 'MaaS Maturity Index'. This measures a cit's readiness for MaaS implementation based on characteristics across five dimensions: 1. Transport operators data sharing and openness, 2. Citizen familiarity and willingness, 3. Policy, regulation and legislation, 4. ICT infrastructure, and 5. Transport services and infrastructure. The index is applied to four metropolitan areas in Europe; London, Birmingham, Greater Manchester, and Copenhagen. The results indicate that London is slightly more ready for MaaS, but that all cities have lots of room for improvement.

Keywords: *Mobility as a Service; MaaS; Index; API; Data; Openness; Cities*

1. Introduction

In its most general sense Mobility as a Service (MaaS) can be defined as "*Mobility as a Service is a user-centric, intelligent mobility distribution model in which all mobility service providers' offerings are aggregated by a sole mobility provider, the MaaS provider, and supplied to users through a single digital platform*" (Kamargianni and Maas, 2017). This means that consumers can in fact plan and book 'door to door' travel using one electronic platform (i.e. app) with a single payment. 'Door to door' travel is achieved by using multiple modes of transport from conventional scheduled public transport such as buses, to demand responsive services such as taxi. The optimal means of making the journey will be determined by the app, based on real time information, the constraints, preferences and travel history of the customer (Kamargianni et al., 2015). This makes MaaS extremely user-centric and personalised and offers a viable alternative to the private car. But how ready are cities for such as dramatic change in the way we travel? To answer this question, the objective of this work is to construct the 'MaaS maturity index', which will assess the readiness of a city for the implementation of mobility as a service. This paper begins with a review of MaaS and related literature to determine the elements required for the implementation of MaaS in a city (Sections 2 and 3. Existing indexes related to MaaS are then assessed to understand what has been measured in the past and what else needs to be done to measure MaaS readiness (Section 4). Section 5 outlines the methodology used to construct the MaaS Maturity index. The results of the index are then presented for four metropolitan areas in Europe; London, Birmingham, Greater Manchester, and Copenhagen.

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2. Review of the elements required for the implementation of MaaS in a city

The integration of a wide range of modes of transport into a seamless system involves the physical linking of multiple modes and routes, and the calibration of schedules. Li and Voege (2017) state that a wide range of transport modes is a basic condition for MaaS to be able to develop and operate. More specifically MaaS cannot be successful with only public transport. One reason for this is that the appeal of MaaS is its ability to offer 'door to door' travel. Therefore other 'demand responsive' modes such as bike sharing, ride sharing, car sharing, taxi and ride hailing are needed to provide 'last mile' solutions (i.e. to connect people with public transport stations/stops and their final destination) (Lund, Date unknown). Offering a wide variety of transport modes gives MaaS providers greater choice meaning they are more likely to be able to meet the needs and preferences of their customers. The physical integration of multiple modes is also very important. For example, providing parking and bike rental points at stations enables multi-modal journeys. Route integration is achieved by creating transfer points at strategic locations to ensure sufficient coverage of the network whilst preventing duplication of routes (Chowdhury and Ceder, 2016). The quality of these transfers is also important to users. This includes factors such as walking time between services, safety, amenities (toilets, seating, shelter) and disabled access (Chowdury and Cedar, 2016). Schedule integration is the harmonisation of the schedules of all modes of public transport so that connections in multi-vehicle/multi-modal services can be made on time but with minimal waiting time (SPUTNIC, Date unknown). This needs to be done in real time to adjust for delays ensuring convenience and reliability.

The spatial coverage of the transport network is also very important for MaaS. There is no point in having an extremely dense transport network in the city centre if residential sub-urban areas are left unserved. This is frequently a problem for car sharing which is often located in the inner city but is needed in sub-urban areas for local journeys or traveling further out of the city (Kamargianni et al., 2015; Sochor et al., 2015). Temporal coverage is also important as in order to compete with the private car MaaS needs to a 24 hour service. This may be provided by many demand responsive modes but night time public transport services may be lacking. In summary high levels of transport provision and integration allows MaaS to offer the same level of convenience as the private car.

As described above the sharing of data is vital for MaaS. Specifically transport operators need to grant data/MaaS providers access to their data (Kamargianni and Matyas, 2016). This data is likely to be made available via API (Application Programing Interface) - a set of procedures and tools for building software applications that interact with the features or data of another application or operating system (TSC, 2016). APIs allow third parties such as MaaS providers to communicate with the 'back office' systems of transport operators giving access to their data and systems. For example, access to the booking API of a transport operator allows MaaS providers to use that transport operators availability data and booking systems in their application. Therefore sharing of APIs allows MaaS providers to offer customers a single digital interface for planning, booking, paying for and using transport. In summary, for MaaS to be implemented it is vital that transport APIs are made available to MaaS providers.

Travelspirit (2017) states that MaaS implementation would benefit not only from the sharing of APIs with MaaS providers but also making these APIs 'open' (freely available for anyone to use, alter and redistribute (Open definition)). This would allow multiple developers and MaaS providers to make use of transport operators data and back office systems. For example, Transport for London do not have their own travel app but instead provide its APIs to thousands of developers allowing them to use their data and software (Delloite, 2017). An even greater step than this would be for transport operators to make APIs 'open source'; which primarily means access to the source code used to create the APIs is provide (Other criteria outlined by Open Source initiative, 2007). This, along with access to transport operators' raw data, would allow developers to create new MaaS applications. Making APIs 'open' and 'open source', as well as sharing raw data, would also encourage innovation and competition creating the best possible MaaS marketplace.

With the need for data sharing and openness comes the need for data security, especially when it comes to customer data. The International Transport Forum (2016) outlines a number of factors which contribute to transport data security:

- Data minimization: Collect the minimum amount of data required and dispose it when it is no longer relevant.
- De-identification/Anonymization: Remove personal details associated with data. Can be achieved through aggregation.
- Encryption: Encode information so that only authorised parties can access it.
- Clarity in "terms of use": Make it clearer to people what they are consenting to being shared. Give people choice and flexibility with regard to what data they share.

Strong data security policy and practices build trust in the system meaning people and organisations are more likely to adapt new technologies and data sharing practices (Smart Cities Council, 2015).

Data security is reliant on national legislation and citywide policy and regulations. For example, EU countries are subject to the Data protection directive, which is put into National law. In 2018 this will be replaced with the General Data protection regulation, which will be directly applicable to EU countries. This outlines the rights of citizens such as the right to consent, erasure and data portability (Allen and Overy, 2017). Data portability is the right for customers to transfer their data from one data system to another and is extremely important for MaaS. This means that customers can switch MaaS providers encouraging a competitive market which supports innovation, quality assurance and the delivery of value for money (Transport Systems Catapult, 2017). The EU General Data protection regulation also outlines the responsibilities of data holders such as the responsibilities to encrypt and anonymise data, report data breaches, and record processing activities (Allen and Overy, 2017). The Smart cities Council (2015) suggests that cities should also put in place and publish specific regulations to ensure data security and privacy.

A number of other policies and regulations would also be helpful for the implementation of MaaS. Firstly, third parties must be allowed to sell tickets on behalf of transport operators (Li and Voege, 2017). In many countries and industries this is not the case meaning integrated ticketing may not be possible (Li and Voege, 2017). Secondly, Finger et al. (2015) suggest that the authorities have a role to play in the standardisation of data exchange formats and that they should have recommended citywide open data formats. However, he also argues that standardisation can hamper innovation if there is not enough flexibility to incorporate new design standards. Thirdly, the prevalence of employer/school schemes to support sustainable modes of travel is likely to be a factor which influences the viability of MaaS (Chowdhury and Ceder, 2016). Fourthly, the presence of stringent passenger rights (e.g. to refunds for cancelled services) is important to ensure that both transport operators but especially MaaS providers are accountable for their actions (Kamargianni and Matyas, 2017). Finally, the presence of stringent anti-monopoly legislation is vital to ensure a fair and competitive MaaS market, which encourages high levels of innovation, value for money and service quality.

Another interesting issue arises from the extent to which public transport is government funded. Finger et al. (2015) argue that in countries, which heavily subsidise public transport, MaaS may not be feasible as providers would struggle to make profit on public transport journeys without charging the customer more than the normal price. On the other hand, Heikkilä (2014) argues that MaaS could benefit from the extension of subsidies to non-public modes of transport in order to make all modes affordable. However this is only likely to be the case if the government subsidised MaaS instead of individual modes of transport, as MaaS providers could make a profit whilst still providing customers with discounted mobility.

The extent to which citizens are familiar with and willing to use MaaS related elements of a transport system is also an important pre-requisite. Firstly, MaaS may require customers to pay in advance for a mobility package. Therefore, the willingness of people to pay for services in advance may be necessary for its success (Sochor et al., 2015). Secondly, the willingness to change from private car ownership to MaaS is likely to be dependent on age (Matyas and Kamargianni, 2017). Younger generations tend to favour access to services over ownership and often embrace the 'sharing economy'. On the other hand, older generations often favour ownership (Lund, Date unknown). Therefore, the younger the demographic of a city the more likely it is to embrace MaaS. These facts are highlighted in many cities across the world where driving license and car ownership are decreasing (Finger et al., 2015). This trend is also clearly beneficial for the potential implementation of MaaS. Thirdly, given that technologies such as smartphones are required for the use of MaaS, it is important that citizens are willing and able to use them. Finally, the extent to which people currently use public transport, an important part of MaaS, is also an important factor.

Many elements of MaaS are reliant on the use of technology (Kamargianni and Matyas, 2017; Jittrapirom et al., 2017). Data sharing relies on data collection, which requires sufficient coverage of sensors and measurement devices. For example, GPS is required on vehicles in order to collect real time vehicle location information. Mobile devices also have the ability to collect data such as vehicle speeds, locations, routes etc. (International Transport Forum, 2016) and well as customer data. Mobile devices and reliable internet access are required for customers to be able to access digital platforms for planning, booking and paying for journeys, as well as for sharing data. Finally ticketing/payment technologies such as NFC terminals, Wi-fi and SMS allow customers to use their mobile device to pay and as a ticket meaning all elements of making at trip can be achieved through one digital platform.

3. Data required to enable MaaS

For MaaS to be successful a wide range of transport data is required. Table 1 below outlines the different types of data required, according to whom, and gives a justification for its requirement. It would be beneficial for all of this data to be dynamic (real time) so that MaaS providers can update optimal routes for customers in real time to provide a seamless and convenient travel experience (i.e. little waiting time etc.). Sometimes real time data is not required (marked with a star in Table 1) and static data may be sufficient for the requirement of MaaS.

Table 1. Data requirements

Type of Data	Source	Justification
Available Routes	TSC (2016), Kamargianni and Matyas (2016)	MaaS providers need to know the routes which vehicles will take in order to plan routes for customers according to their needs and preferences
Data on where customers can access and egress transport	TSC (2016), Kamargianni and Matyas (2016)	Customers can obviously not access the transport at every point along the route
Real time asset/vehicle position	Transport Systems Catapult (2016), Kamargianni and Matyas (2016)	Allows MaaS providers to determine how far away vehicles are from customers and thus estimate what time they will arrive (when combined with speed data)
Speed	Transport Systems Catapult (2016)	Allows MaaS providers to estimate how long journeys will take and how long vehicles will take to reach customers (when combined with vehicle position data)
Asset characteristics e.g. Disabled access, toilets, space for luggage, Wi-fi*	Transport Systems Catapult (2016); Giesecke et al.(2016)	Allows MaaS providers to accommodate for users needs, preferences and specific requests allowing. Allows for a more convenient and conformatable journey
Transfer time i.e. Platform to platform times	Finger, Bert and Kupfer (2015)	Allows MaaS providers to take transfer times into account when planning journeys
Asset usage by customers (demand)	TSC (2016)	This allows MaaS providers to determine the availability of transport services (i.e. seats, bikes e.t.c.) meaning they can plan routes for customers accordingly
Environmental Impact	Jittrapirom et al. (2017)	Some MaaS providers use such data to promote sustainability and give customers the choice to travel in the most environmentally friendly way. Some even offer rewards for doing so.
Ticketing (Pricing)	Kamargianni and Matyas (2016), TravelSpirit (2017)	Pricing data is required so that MaaS providers can set appropriate prices for its services

4. Methodology

4.1 Index Construction

The most authoritative and complete work on index's, otherwise known as composite indicators is the OECD and JRC (2008) 'Handbook on Constructing Composite indicators'. This gives a detailed outline of the methodology to be used, as well as guides on how to perform specific techniques. It is targeted to measuring country performance in specific areas such as innovation however most of the steps are also applicable to citywide analysis. This methodology was roughly followed to construct the MaaS Maturity Index. This methodological framework is outlined in Table 2. Where other sources of information are used these are cited in the text.

Table 2. Methodological framework

Step	Description
1. Theoretical framework	• Definition of the concept to be measured • Design of a theoretical framework which shows each dimension/sub-dimension of the concept and how they are related. To ensure dimensions are appropriate this step involves expert elicitation.
2. Indicator selection	• Selection of the indicators which represent each of the dimensions. • To ensure indicators are appropriate this step involves expert elicitation.

3. Data collection	• This is done through a series of oral questionnaires with transport operators and transport authorities, and the use of internet /secondary data. Data collected from:
	  • Transport authorities
	  • Transport operators: Largest operators (by market share) from each mode of transport available in the city. For the purposes of this study transport integrators are treated as transport operators.
	  • Internet sources are used when data is not available from interviewees.

4. Normalisation	• The conversion of multiple variables into quantities with the same units (or unit less quantities). This not only makes aggregation possible but also prevents the index being biased towards indicators with its range of values at a high magnitude (Centre for the Study of Living Standards, 2003). • A 'linear scaling' normalisation method was used
5. Weighting	• Weighting involves explicitly giving dimensions, sub-dimensions and indicators certain levels of importance relative to one another. The objective of weighting in this case is to take into account the fact that not all dimensions, sub-dimensions and indicators are equally important for the implementation and success of mobility as a service. Therefore a 'participatory weighting' method involving expert elicitation known as 'budget allocation' is used.
6.Aggregation	• The combination of all weighted indicators and dimensions into an overall value. • A simple and 'compensatory' (deficiency in one indicator/sub-dimension/dimension can be made up by higher scores in another) aggregation method is used (Mazziota and Pareto, 2013). The normalised and weighted values of each indicator in a sub-dimension is first summed. The same is then done for each sub-dimension in a dimension. Finally this is done for each dimension making up the overall index.

7. Uncertainty and Sensitivity analysis	• To assess the impact of the weighting scheme equal weighting is used for all dimensions, sub-dimensions and indicators as oppose to weightings based on the 'budget allocation'. The effect of the maximum values used in normalisation is also assessed. • Sensitivity analysis is presented as a scatter plot. • These are then used to perform an 'internal coherence assessment' i.e to assess whether the index is dominated by a small number of indicators and which indicators just add noise (COIN, 2017). • Returned to step 1 and go through the process again removing any unnecessary indicators and re-weighting dominating indicators.
8. Index Deconstruction	• Breaking down index to identify the contributions of individual dimensions and sub-dimensions.

4.1 The MaaS Maturity Index

The index measures a metropolitan area's readiness for MaaS before it has been implemented. The index takes into account pre-requites for the implementation of MaaS as well factors that will effect the 'likelihood' of it success. It could be said that the index measures the extent to which the 'raw ingredients' required for MaaS are in place. It is important to note that the index does not take into account how many of the elements of MaaS have already been integrated into the transport system but the potential for each of these elements to be put in place. Furthermore, the index is not applicable to intercity transport or rural areas. Finally the index assumes a MaaS model in which the MaaS provider is a private company in line with the Transport Systems Catapult's (2016) 'reference architecture'. Figure 1 (below) shows the theoretical framework of the index. Based on the literature review and expert elicitation 5 key dimensions of MaaS maturity were identified:

1. Transport operators openness and data sharing: The extent to which transport operators share data and make API's available to third parties. This includes whether data and API's are made 'open' (i.e. freely available to use, redistribute and alter).
2. Citizen familiarity and willingness: The extent to which citizens lifestyles and behaviour aligns with a MaaS model of transport provision. This includes travel behaviour and use of MaaS related technologies.
3. Policy, regulation and legislation: The extent to which key policies, regulations and laws which support MaaS are in place. These may be at a city level or a national level.
4. Transport services and infrastructure: Looks at how ready the current transport system is for MaaS. This includes the variety of modes available, the density of services, the frequency of services and the integration of services.
5. ICT infrastructure: Looks at the penetration of MaaS enabling technologies. This includes internet access and smart ticketing infrastructure.

As you can see in Figure 1 each dimension is made up a series of sub-dimension. Some dimensions also have secondary sub-dimensions. These were chosen based on the literature review, expert elicitation and review of existing indexes in the field of transport and open data.

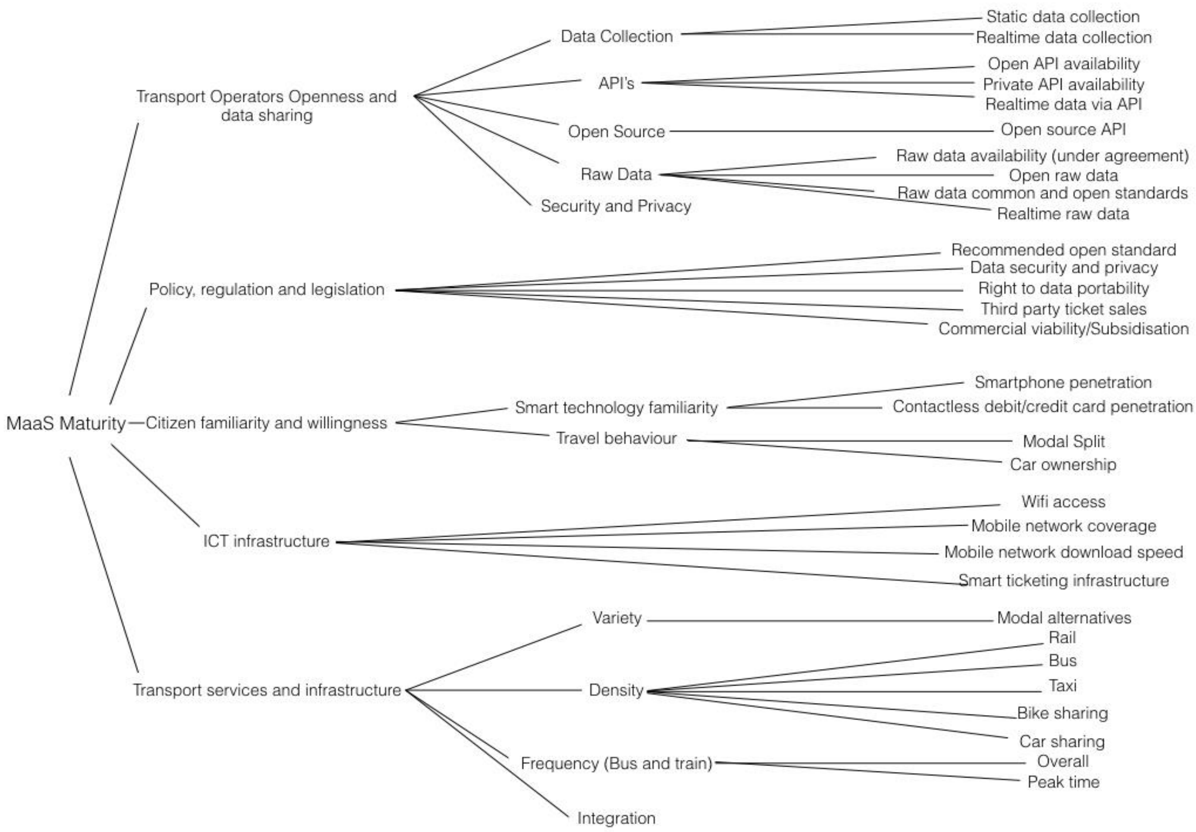

Fig 1. Index nested structure

6. Application of the MaaS Maturity Index

6.1 The selected cities: London and the West Midlands

Two UK cities were chosen to which the index is applied. London is chosen as it is the largest city in the UK, it has an extensive transport network including underground and overground rail, and it is known for its open data advocacy. Therefore it is thought that London could provide a benchmark as a city with high levels of 'MaaS Maturity'. For the same reasons London is the most likely city to implement MaaS meaning the results of the index will be useful to decision makers. It is also a unique case study as all public transport in London is operated by Transport for London (TfL) meaning many openness and data sharing practices are common across multiple modes of public transport. This provides a test of the adaptability of the 'MaaS Maturity Index'.

The West Midlands is chosen primarily, as TravelSpirit's (Unpublished) index has been applied to this metropolitan area meaning comparisons could be made between the two index values and especially the 'Transport operators openness and data sharing dimension'. Furthermore, the city has recently launched a MaaS demonstration (Whim, 2016) and therefore has a clear objective of implementing MaaS in the city. Again the results of the index could be useful to decision makers. Secondly, the city's transport system is different from that of London, in that it does not have an underground or an extensive overground rail network. The city is also behind London in terms of its openness and data sharing. The West Midlands therefore provides a good test of the adaptability of the index.

6.2 Scores of the selected cities

London's 'MaaS Maturity Index' score is 0.64 (2.d.p). Given this is the first application of the index, it is unknown whether this score is indicative that a city is ready for MaaS. More research is needed to determine the threshold value for each indicator that is required to successfully implement MaaS. The 'MaaS Maturity Index' score of the West Midlands is 0.59 (2.d.p). It is not surprising that London's score is slightly higher than the West Midlands given the characteristics of the two metropolitan areas described above. Figure 2 breaks down the index score, for both cities, into its constituent dimensions (unweighted scores for each dimension). It can be seen that both cities excel in the 'Policy, regulation and legislation dimension'. This is not surprising given TfL's advocacy of openness and data sharing and Birmingham's pursuit of MaaS. Furthermore two out of five indicators in this dimension are based on national legislation meaning no cities in the UK will have a score of below 0.2.

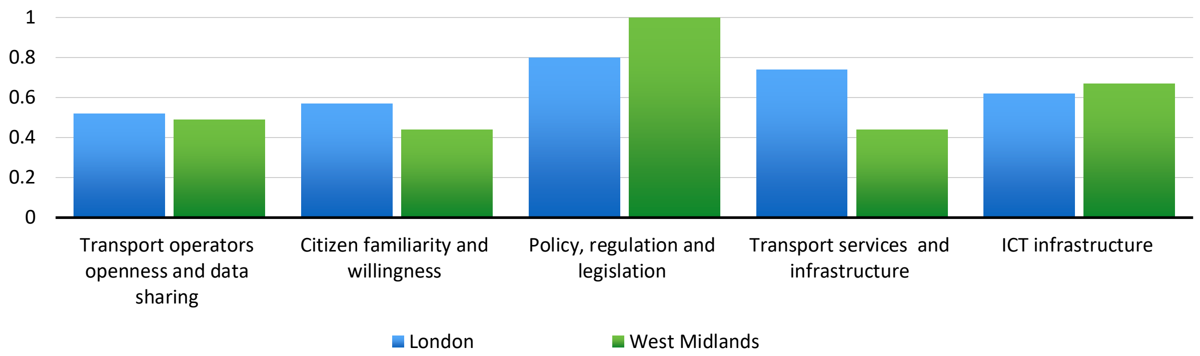

Fig 2. Breakdown of index into constituent dimensions (Unweighted)

Surprisingly London's lowest score is the 'Transport operators openness and data sharing dimension'. This is also the dimension with the highest weighting meaning it should be targeted as an area for improvement by transport authorities. The West Midlands scores similarly to London in this dimension, partly because car rental and car sharing are represented by Enterprise in both cities. Unfortunately bus and road network operators were not able to answer the questionnaire in the West Midlands which may paint a false picture of the similarity of the two cities.

Figure 3 breaks down this dimension into the five elements of openness. It can be seen that both cities perform highly in 'data collection' and 'security and privacy'. On the other hand both cities clearly need to encourage transport operators to make the software that powers APIs open source. API and raw data sharing is at intermediate levels in both cities. However API sharing is slightly greater in London ,perhaps due to the use of their unified API. Raw data sharing is slightly higher in The West Midlands which could be due to the fact that London has focused on sharing through APIs.

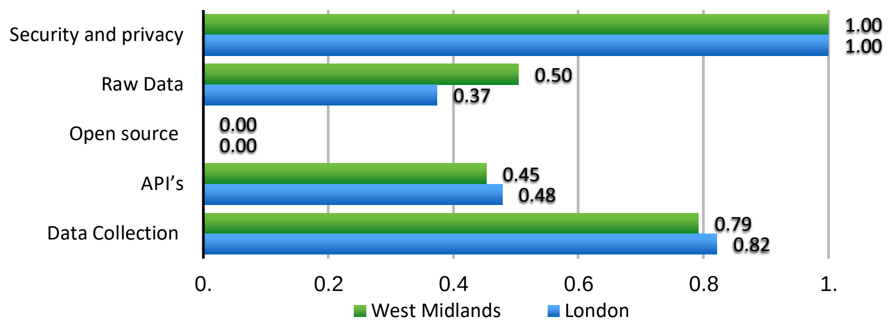

Fig 3. Breakdown of 'Transport operators and openness' dimension into elements of openness (Unweighted)

It is also very important to know which data categories score the highest in the 'transport operators openness and data sharing' dimension. Figure 4 breaks down the transport operators dimension by data category. Openness and data sharing could be improved dramatically in both cities for most data categories. London certainly needs to focus on making 'booking' API's available, open and open source. On the other hand it performs well in the 'routes' and 'schedules' data categories. This is not surprising as these categories are only relevant to scheduled transport, which is operated by TfL, who have strong open data policies especially for these types of data. The West Midlands should focus especially on the collection and sharing of vehicle location data from all of its operators. However they do out perform London in the 'demand', 'booking', 'environmental impact' and 'station/vehicle characteristics and facilities' data categories which should be commended.

ICT infrastructure scores and its constituent indicators are similar in both cities. In both cities W-fi access on buses (and other public transport) needs to be improved whereas smart ticketing services are well established. Mobile network coverage and download speed could be improved to be in line with the most advanced cities in the world however they are relatively high.

'Citizen familiarity and willingness' is moderate for both cities but slightly higher for London. This is mainly due to the fact that its modal split value is over double that of the West Midlands (2 out of 4 indicators are national and so same for both cities). This is the weakest dimension for the West Midlands: clearly to increase 'MaaS Maturity' the city needs to tackle high levels of car ownership and persuade more people to use public transport.

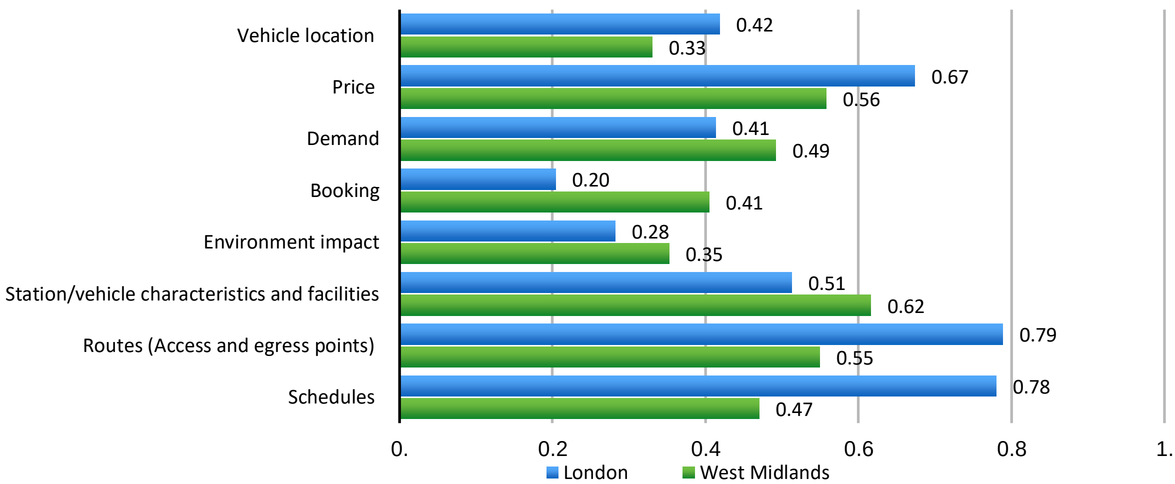

Fig 4. Average 'Transport operators openness and data sharing' score by data category

‘Transport services and infrastructure' is the dimension in which the two cities most widely diverge. The breakdown of this dimension into its constituent elements is shown in Figure 5 (the elements are unweighted but the indicators within each element are weighted). London is leading heavily in every element but especially density and frequency. If the West midlands are going to catch up with London they need to increase the density and frequency of public transport, especially rail based (see rail density and frequencies in appendix). ‘Integration’ is only based on ticketing integration as this was the only indicator available, however it is clear that both cities could include more modes of transport in their integrated ticketing schemes.

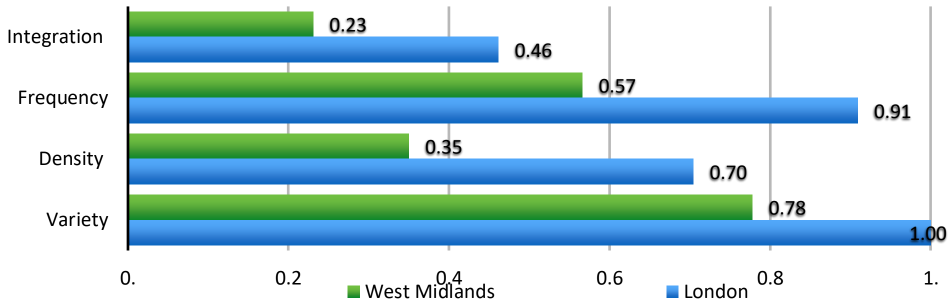

Fig 5. Transport services and infrastructure breakdown (Unweighted)

7. Conclusion

The factors which determine a cities readiness for MaaS have been determined through a review of literature and existing indexes related to MaaS, transport and open data. Five key dimensions of readiness have been identified; ‘Transport operators openness and data sharing’, ‘Citizens familiarity and willingness’, ‘Policy, regulation and legislation’, Transport services and infrastructure’ and ‘ICT infrastructure’. These have are made up of multiple sub-dimensions which represent different elements of the overall dimension.

These factors were ‘measured’ through the assignment of indicators to each sub-dimension. The indicators represent, either directly or by proxy, the level of readiness in each sub-dimension. The indicator values were normalised using maximum and minimum benchmark values. It was shown through uncertainty analysis that the choice of maximum had significant effects on the results of the index. Further work is therefore required to determine appropriate maximum benchmark values. The indicators were assigned weightings based on their level of importance by experts in the field of MaaS. However the uncertainty analysis based on the UK case study results suggests that these weightings were not significant in determining the results of the index. Therefore other weighting methods such as equal weighting may also be viable. Furthermore sensitivity analysis revealed that the indicator may be dominated by a small number of indicators meaning weightings should be revisited. The indicators were aggregated simply by summing the weighted indicator values. This is appropriate as it is a ‘compensatory’ aggregation method which means deficiencies in one area of the index can be made up in other areas whilst also allowing cities to identify areas for improvement. It is also ‘simple’ and therefore allows non-expert stakeholders to apply the index.

As expected the ‘MaaS Maturity’ of London (0.64) is greater than that of the West Midlands (0.59). London out-performs the West Midlands in the ‘transport operators openness and data sharing’ and the ‘citizen familiarity and willingness’ dimensions. London also performs significantly better in the ‘transport services and infrastructure' dimension which is the main reason for its higher overall index score. However the West Midlands does better than London in terms of 'Policy, regulation and legislation' and 'ICT infrastructure'. A key area for improvement in both cities is open source API availability. London should focus particularly on the sharing of raw data, and improving openness in the 'booking' and 'environmental impact data categories. The West Midlands need to improve their 'transport services and infrastructure', and focus on changing citizens familiarity with and willingness to use public transport as oppose to private vehicles. They should also aim to increase the sharing of APIs and raw data.

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