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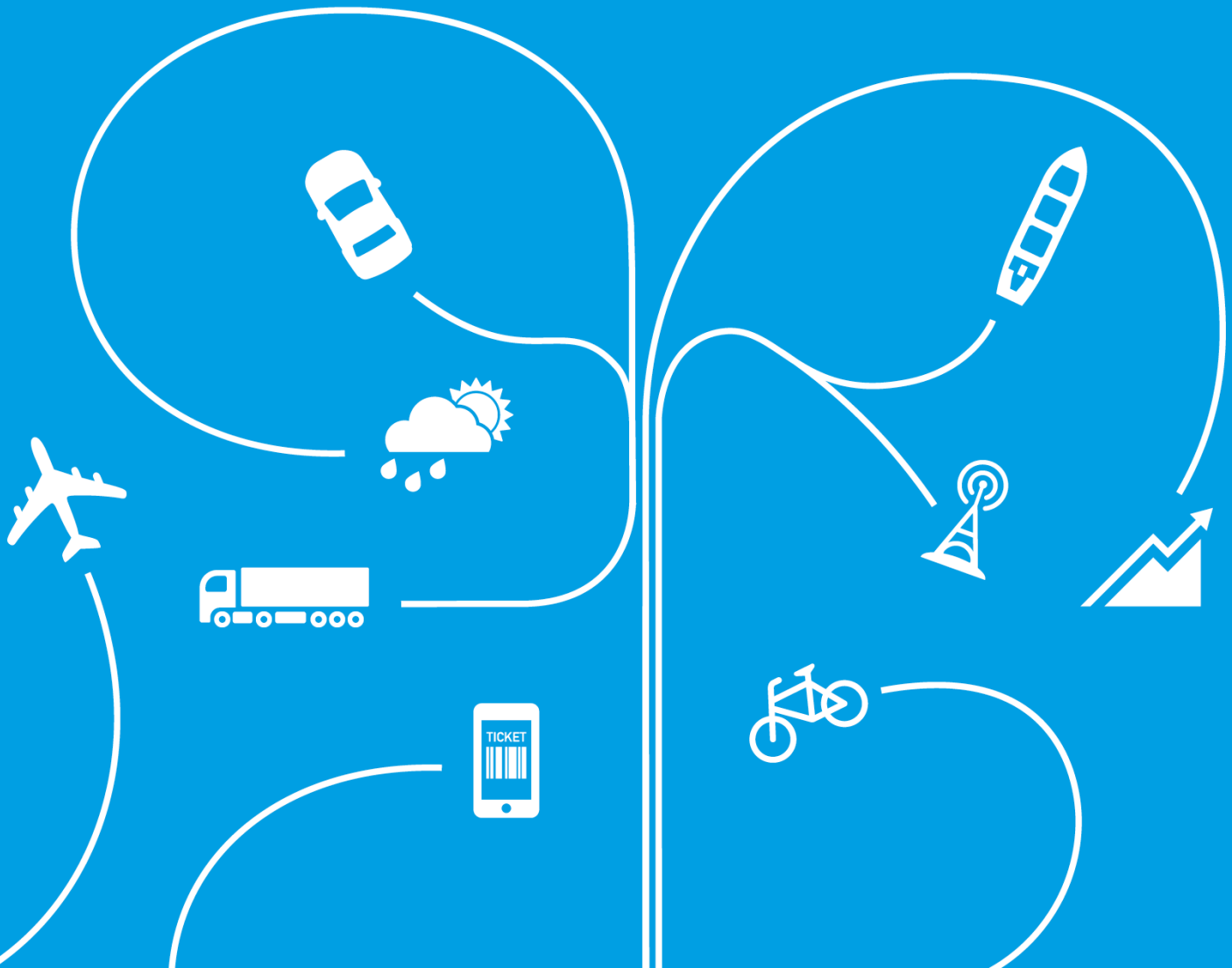
Utilising Mobile Network Data for Transport Modelling

Recommendations Paper



Utilising Mobile Network Data for Transport Modelling

Title: Recommendations Paper

Release: Final Issue

Date: 19/04/2016

Author: Tobias Hemmings, Carl Goves

Owner: Robin North

Client: Department for Transport

Document Ref: MV7/RPT001

Version No: D14

Document Control

Document Background and Location

This report provides recommendations on the use of mobile network data for transport modelling. It is intended to provide a foundation which the Department for Transport can use to formulate guidance in this field as part of a new WebTAG unit.

This document is only valid on the day it was printed.

Revision History

Date of this revision: 19/04/2016

VERSION	STATUS	DATE	AUTHOR	REVIEWER
D14	Final Issue	19-Apr-2016	Carl Goves Tobias Hemmings	Robin North

Approvals

This document requires the following approvals.

Signed approval forms are in the project filing system.

Name: Robin North	**Sign Off Statement**
Date: 19/04/2016	I confirm that • the content of the attached Recommendations Paper is correct and fit for purpose given the current stage of the project.
Signature: APPROVED	
Title: Lead Technologist – Modelling and Visualisation	I approve • the attached Recommendations Paper for release.

Distribution (This Version)

This document has been distributed to:

Name	Date of Issue
Alan Feeney	14/03/2016

Executive summary

Overview

This paper provides recommendations and background information relating to the use of mobile network data (MND) in transport modelling, in the context of building origin / destination matrices. It provides these recommendations and information related to five topic areas which were initially identified through engagement with the supply chain: MND pre-processing; MND data request / specification; benchmarking; MND to model matrix; and legal and ethical considerations.

The recommendations have been made with expert input from a range of technical authors who currently practice in the use of MND in transport modelling and thus should reflect current best practice. It is recognised that the use of MND in transport modelling is still an emerging technology and as the supply chain matures, the approaches employed will evolve. The evolving nature of this practice has resulted in misunderstanding across industry on what MND represents and what data can be legally obtained for use in transport models. So in addition to making recommendations, this paper also includes background information for each of the topic areas which can be used to help educate the industry on what can realistically be obtained and achieved with MND. Ultimately, the information in this paper should allow the Department for Transport (DfT) to fill a gap in WebTAG by providing recommendations, which can be used as a basis to draft guidance in this area whilst recognising the evolving nature of this practice. A summary of the recommendations for each topic area is provided below.

MND pre-processing

This concerns the processing undertaken by mobile network operators (MNOs) to transform event data (i.e. the communication of mobile phones with the mobile network) into a matrix of trips. Extensive background information is provided along with recommendations which encourage dialogue between model developers and MNOs to impart understanding on a variety of issues including:

a. range and type of event data collected;
b. networks that are being probed and where they are being probed;
c. typical sample or events per day from users of different network generation handsets;
d. data availability (i.e. if historical data are available);
e. typical biases in the data (a non-exhaustive list is provided in this Paper); and
f. impact of any data privacy restrictions.

Additional key considerations when collecting MND include:

a. As a minimum, ten days of event data is required, although a full month is preferable. If weekend matrices are needed, this may require a longer data collection period;
b. If round trips need to be split, or mode specific legs need to be identified, this should be discussed with the MNO on a project by project basis;
c. Matrices representing a minimum of hourly intervals are normally requested. Shorter intervals may be feasible, however privacy rules may limit their application;

d. Matrices of inter-zonal trips at middle super output area (MSOA) zoning resolution are achievable. In some areas a finer resolution maybe achieved, especially when the data are combined with data from other sources;
e. Intra-zonal trip estimates will be less accurate than inter-zonal trips as not all short distance trips can be detected;
f. Trip purpose is normally inferred by detecting the home and work end of trips to derive five OD purposes. If a more detailed purpose split would be advantageous this should be discussed with MNOs;
g. Expansion of MND is normally carried out at a user level by the MNO prior to aggregation. How the expansion carried out may vary by project so any specific project requests should be raised with the MNO;
h. A technical note normally accompanies MND on hand over to model developers, typical topic areas are identified in this Paper; and
i. MNOs do not normally correct MND for biases. For some projects model developers may however wish to work with MNOs to account for these biases at the pre-processing level.

MND data request / specification

This topic addresses how an MND request is specified to an MNO. Generally, model developers are encouraged to work in collaboration with MNOs in order to optimise the data specification. Key considerations when making an MND request include:

a. The time period which is to be studied which may be over number of months or days or a specific day of a special event;
b. The type of day to be studied (e.g. average weekday);
c. The spatial region which is to be studied;
d. Which movements are required (e.g. intra-zonal and inter-zonal trips);
e. Where intersection of an internal study area is agreed, the definition of time must also be agreed; with the start time either the true start time of a trip, or the time at which the trip intersected the study area; and
f. The matrix segmentation required (e.g. mode, purpose, time of day).

To gain an understanding of MND from MNOs, model developers are encouraged to ask the following questions:

a. What mobile events (data sources) are studied by the supplier?
b. What non-MNO data sources have been used (if any) in the creation of the dataset? This is to ensure any validation of supplied data is performed in a fair context.
c. What expansion or validation methods have been applied to the data?
d. What are the license restrictions around the use of the data product for a particular purpose?
e. What methods have been used for expansion?
f. Has the event data already been collected or does it need to be collected for the study?
g. What is the potential to re-use data for other purposes, or use cases?
h. Will a suitably detailed method statement be provided?

MND Data is typically delivered in a format such as a .csv, alongside a project overview report.

Benchmarking

Benchmarking recommendations have been largely informed from practitioner experience from a specific case study, namely the use of MND to build Regional Traffic Models for Highways England. As such the emphasis is on the use of road based MND although many of the recommendations could be generalised to be applicable for multimodal studies which use MND.

Sixteen tests are presented[1] which are designed to inform modellers on the robustness of data through comparison with external data sources as well as checks for internal consistency. Through discussions between technical authors on this project, five of these tests have been prioritised which check for fundamental trends in the data. For all these primary tests, as well as a selection of the remaining secondary tests, recommendations are made for threshold values of the R^2 statistic which can be used by modellers ascertain whether the data is acceptable or not.

It is recognised that the use of MND in transport modelling is still maturing and that any guidance on benchmarking criteria would benefit from feedback on whether threshold values are appropriate when applied on projects which use MND. Generally, modellers are advised to substantiate the use of MND by undertaking checks which are appropriate to the project in hand.

MND to model matrix

This concerns the conversion of MND to model matrices. The development of model matrices is a complex one. At the time of producing this Paper, the Department for Transport (DfT) had a separate study commissioned which focussed on making recommendations on matrix building to allow the Department to draft a new WebTAG unit for this topic area. Recommendations made here will inevitably overlap with some of those from this parallel study although the focus here is on incorporating MND into model matrices rather than general building of a model matrix.

The recommendations focus on any adjustments practitioners may need to make to MND following the completion of benchmarking activities. Such adjustments include, but are not limited to: replacement of short distance trips with synthetic estimates or observations; corrections to consistent over / under-expansion; segmenting matrices by vehicle type and trip purpose; and trip length distribution corrections. In addition, potential external data sources are identified to help calibrate such adjustments although it is highlighted that practitioners should liaise with MNOs to understand if any of these data sources have already been used in deriving MND to ensure as far as possible that adjustments are informed from independent data.

Legal and ethical considerations

The legal framework that governs the use of MND is identified and highlights that due to the Data Protection Act 1998, MND cannot be provided with any personal information or be provided in a format where personal information can be identified if merged with complimentary data sets. Whilst MNOs follow published codes of practice in this area, it transpires that many of the processes adopted by MNOs related to privacy concerns are to mitigate against potential reputational risk from perceived concerns from the public rather than solely the material risk of releasing personal information.

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[1] The tests are based on work undertaken by the Technical Consistency Group within the Regional Traffic Models for Highways England. Though the work was a group effort, it was led by AECOM.

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1. Scope and Objectives

1.1 Background

1.1.1 Transport modelling has until now used more established methods to gather data on people's movements. These have typically involved directly asking people about their travel patterns through conducting intercept surveys such as roadside interviews or through the use of household surveys. Despite limitations on survey scale and sample biases, these methods are accepted as the state of practice. However, these methods are becoming increasingly expensive and time consuming to conduct and to authorise; e.g. road-side surveys require permission from the police and their presence at the time of the surveys. Sample rates are very low: typically, around 1-2% for household surveys and around 10% for roadside interviews, and then only for a small number of cordons and screenlines with some routes, e.g. the strategic road network, being difficult or impossible to survey.

1.1.2 There is huge potential to reduce these costs (both monetary and time) through the use of MND to record the movements of travellers. The feasibility of the use of the data has already been demonstrated with several transport consultancies having used MND to generate matrices of travel demand movements for use in transport models. However, the level of scrutiny of the use of this data in some early studies has been limited and there is as yet no consensus on the most appropriate or technically accurate way to utilise the data or elucidate the biases within the data, let alone correct for these. These are important pieces of information for transport modelling and which must be attached to or inferred from the data in some form. Privacy and anonymisation is also a key factor in the use of MND and there does not appear to be an understanding across the industry of whether, and how, legal restrictions limit the level of detail MND can be provided in.

1.2 Project Scope

1.2.1 The purpose of this research is to examine the use of mobile network data (MND) within transport models; more specifically, the use of MND to create matrices of traveller's movements from their trip origins to their destinations, one of the fundamental inputs into transport models.

1.2.2 This research aims to identify the technical issues with the use of MND, to identify what methods have been developed so far to overcome these issues and what particular barriers exist to prevent the widespread utilisation of MND. It also seeks to identify what guidance could be provided and what this guidance would need to address to help organisations exploit the potential huge benefits and time / cost savings associated with the use of MND.

1.2.3 The research aims to achieve these goals through the following steps:

- Engagement with the different elements of the MND supply chain (data providers, service providers, client authorities, and national regulators) to identify and address barriers to the wider adoption of these methods;
- Examine how MND can be benchmarked to gain confidence in using it to develop national, regional and local OD matrices;
- Investigating the priorities for guidance to support the clear and consistent use of MND in Transport Modelling and Appraisal e.g. in terms of outputs, formats, quality metrics and associated data collection requirements.

1.3 Objectives

1.3.1 The outputs of the research will be a set of recommendations of how best to utilise MND in transport models and what methods can be used to derive or infer the required information from the data. These recommendations will be used by the DfT to draft guidance on the use of MND which can be included in the DfT's WebTAG modelling and appraisal guidance framework.

1.3.2 The research is not expected to determine the most statistically accurate or technically reliable means of using MND within transport models nor would such an aspiration be appropriate at this stage of the development of the data source. The use of MND is still a developing technology which utilises an emergent form of big data and which is subject to rapid technological and methodological advancements. Some of this development will be subject to intellectual property rights, and therefore access may be limited.

1.4 Wider Benefits

1.4.1 Current methods used to develop matrices of origin-destination movements for transport modelling are costly to conduct and take a significant amount of time to administer and undertake, dependent on the scale of the model being developed. There is a move to using MND which could have large benefits associated with it due to reduced costs of obtaining the data with no need to undertake expensive and time consuming on-the-ground surveys. But there is hesitancy in exploiting MND due to the uncertainty around the data, including but not limited to a perceived lack of transparency in how MNOs process, aggregate, anonymise and expand the data, and the lack of historical precedent and established technical processes in using it.

1.4.2 As MND may not contain fields required for modelling, *such as personal characteristics*, fusion with other data sources is inevitable.

1.4.3 All transport models which have been developed, from large scale city and regional models to local area models, use data which describe origin – destination movements in some fashion. This includes models developed by the DfT, Highways England, Transport for London (TfL), Metropolitan Authorities, Local Authorities, Passenger Transport Executives (PTE's) and private developers. Each of these organisations would benefit from being able to exploit MND to develop their models, to reduce their development costs as well as reduce the time taken to develop the model. Correspondingly, the larger the scale of the models the greater the potential savings. There is also the added potential benefit in increasing the quality of the models due to the much larger sample sizes of travellers which can be captured using MND in comparison to traditional surveying methods.

1.4.4 Highways England have commissioned a project to build a national dataset of traveller movements from MND. This research would be complementary to that Highways England work (relationships have already been established with Highways England to enable the sharing of the outcomes of both pieces of research) and would help to further remove the obstacles to the use of MND for modelling and appraisal.

1.4.5 Establishing UK methodologies for the utilisation of MND in transport modelling, and preparing the basis for suitable guidance will also provide the MND supply chain, and the transport consultancies in particular, with a competitive edge in the global market.

2. Work Methodology

2.1 Approach

2.1.1 To deliver against the objectives of this project, two main activities have been undertaken:

- Stakeholder engagement with the MND supply chain including MNOs, consultants, local authorities, government departments and academia. This has been facilitated through formal workshops to explore specific issues faced by the profession in the context of using the data to build matrices for transport models as well as ad-hoc meetings with current and historical project teams; and
- Formulation of this recommendations paper through appointment of experts in the field who have first-hand experience of using MND in transport modelling.

2.2 Stakeholder Engagement

2.2.1 Close engagement with the MND supply chain has been undertaken throughout the project. The wider engagement has grown the project email distribution list to over eighty members. This list is provided in Appendix B. Whilst the wider engagement has communicated project events and outputs (such as Workshop reports), a subset of the stakeholders have been actively more engaged through attendance and contribution at the project workshops and have helped shape areas to focus recommendations on.

2.3 Workshops

2.3.1 Four workshops have been undertaken during the course of the project. These three workshops have focussed on:

- Benchmarking requirements;
- Technical approaches;
- Pan-European experience; and
- Best practice (essentially a showcase of content from this recommendations paper).

2.3.2 Technical notes were produced to report on the findings of these workshops, a copy of each can be found in Appendix C.

2.4 Technical Authors

2.4.1 This Recommendations paper has been drafted with significant input from experts within the profession. Technical authors from four organisations were appointed to assist with the drafting of this paper following a procurement exercise which was opened up to organisations who had engaged in the project workshops. The four organisations appointed were:

- Atkins;
- Citilogik;
- Movement Strategies; and
- Telefonica.

2.4.2 The recommendations to be drafted were divided amongst the technical authors depending on their areas of specialism. Whilst individual authors led the drafting of the recommendations for specific topics, all authors reviewed and challenged all topic areas to reduce the risk of biased views from being expressed. This internal review process has been strengthened by review of the paper by the project steering group, as well as the earlier (and first) release of the paper being made available to the DfT for comment.

2.5 Paper Format

2.5.1 This paper has been structured to provide background recommendations pertaining to the use of MND in transport modelling. This is in the context of developing OD matrices for transport models. Whilst it is termed a recommendations paper, it also contains a significant amount of background information as the stakeholder engagement highlighted that specifics parts of the MND lifecycle is not well understood.

2.5.2 The recommendations have been split across several topic areas reflecting the lifecycle of how the data is generated (section 3), requested (section 4), benchmarked (section 5) and the used to build model matrices (section 6). This typical lifecycle was introduced at the second project workshop and is shown graphically in Figure 1. A short section is also included on some of the legal and ethical considerations which are made in supplying the data (section 7) is also included.

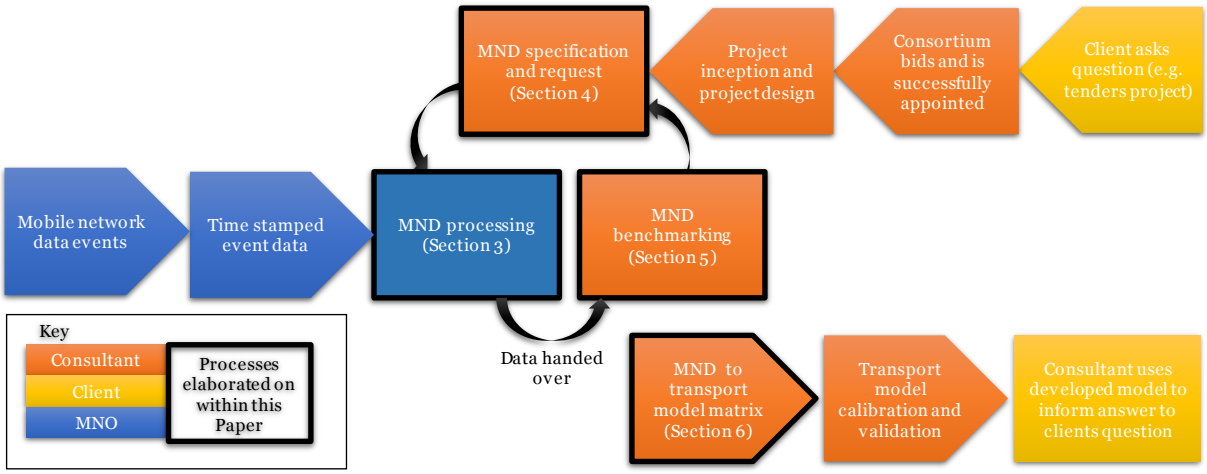


Figure 1 - Typical project transport modelling lifecycle using MND

2.5.3 The recommendations have been drafted in response to a number of questions which were consulted on with the DfT. These questions were formulated in response to discussions with stakeholders and try to elicit information and recommendations pertaining to areas where there is not a common understanding across industry. They form the sub-headings to each of the topic areas identified. Recommendations have been highlighted in **bold red text** to differentiate them from background information. Also in having the document reviewed a number of user perspectives were provided for some technical areas. These have been coloured in grey to provide further context / specific examples to the point being made as well as raising some questions which are worth considering when drafting guidance.

2.6 MND Overview (Storyboard)

2.6.1.1 As part of this project TSC have also produce a storyboard that can be used to produce a video to explain the key principles for the use of MND within transport models. This video would provide an overview, to support the guidance, to practitioners. This video is not intended to provide technical advice or a how-to-guide.

2.6.2 This MND Overview can be found within Appendix D: MND Overview – Storyboard.

3. MND Pre-processing Recommendations

3.1 Overview

3.1.1 This section provides an overview of the pre-processing MNOs undertake to generate MND which is then handed to model developers to incorporate into transport models. Each MNO have different ways of undertaking pre-processing although some features are consistent which are elucidated here where possible. The workshop 2 report, shown in Appendix C, contains some indicative flow charts of some of the typical processes undertaken (inclusive of challenges and discussion points from the workshop attendees).

3.2 What is mobile network data?

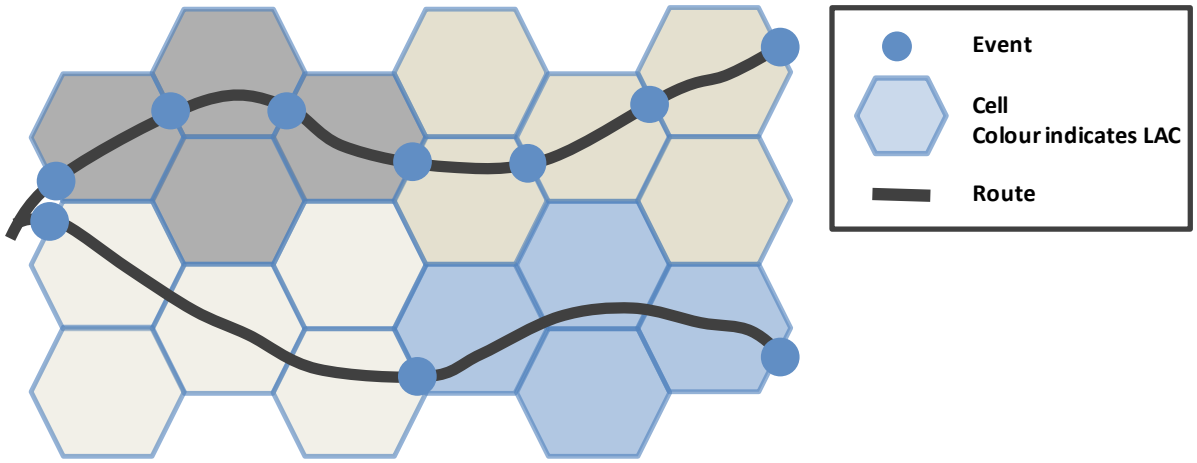
3.2.1 A mobile network is a communication network distributed over land areas called cells, each served by at least one fixed-location transceiver, known as a cell site or base station. This base station provides the cell with the network coverage which can be used for transmission of voice and data information.

3.2.2 As mobile phones are used, they communicate their position with the mobile network for network operation, billing and regulatory purpose. This communication takes the form of single data points, called 'events'. Each event is associated with a distinct, persistent and anonymous user id, a timestamp and a cell identifier. A GSM Cell ID (CID) is a generally unique number used to identify each Base Transceiver Station (BTS) or sector of a BTS within a Location Area Code (LAC) if not within a GSM network. The cell identifier can be used to locate the event within a specific region of the UK by means of a cell map.

3.2.2.1 An anonymous and persistent user id implies that the event data is pseudonymised. This involves changing the user id in each event for a phone to another false id which is always associated with that phone. This allows the movement of the phone to be tracked over time in terms of places visited and the times of those visits.

3.2.3 Although these events are created as a by-product of the operation of the mobile phone network, they have great potential for a wide range of transport planning applications, including the creation of origin-destination (OD) and production-attraction (PA) matrices for transport models.

3.2.4 Events can be divided into two broad categories: active and passive. Passive events occur even if a phone is not being used; they can be subdivided into periodic updates and events that occur when a phone moves from one set of cells (a local area code, or 'LAC') to another. Depending on the way data is collected, these passive events may indicate the first cell that the phone has connected to in the new LAC or they may only identify which LAC the phone has entered. It is important to consider this difference when using the data as it will affect the spatial resolution offered by this type of passive event. Refer to diagram below.



3.2.4.1 It is important to note that cells can vary in size from around 500m in busy urban areas to around 7.5km in remote rural areas. This affects the spatial accuracy of cell id data since it does not reveal precisely where the event occurred within the cell.

3.2.5 The terms 'On call' and 'Off call' have been used as synonyms for 'Active' and 'Passive' events. In this document the terms Active and Passive are used throughout for clarity.

3.2.6 Active events occur when a phone is used, e.g. to make or receive a phone call. Active events may either consist of 'call data records' (CDR) data, which indicate when a call has taken place, or of network probe data, which also indicates the cells used by the user during the phone call.

3.2.6.1 It is important to distinguish these event because CDR only gives you the first event in the call, where as other sets may include many more events as the phone moves.

3.2.7 Events can also be divided into bands, or generations. Depending on the handset and cell coverage, a phone may connect to a 2G, 3G or 4G cell and this will determine the band type of the events generated. Often cells in different bands will overlap and a user will switch between bands as the user moves and as the network adjusts itself to balance the load on each cell.

3.2.8 Mobile network operators (MNOs) may use a variety of different types of event when creating OD matrices. **Model Developers are advised to discuss the range and type of event collected with the MNO as this will affect the resolution and bias of the data collected**. For example, not using 2G events could be disadvantageous because, although 2G cells tend to be larger than 3G and 4G cells, many older handsets can only connect to 2G cells and so ignoring these events would cause the output to under-represent users with older handsets. Using subsets of data types may introduce biases in the trip distribution and coverage of particular user types.

3.2.8.1 Using only a subset of bands does have the potential to introduce huge bias and reduce the sample significantly and / or distort trip distribution (i.e. if a 4G enabled handset travels in from a rural area which only has 2G then even though it shows up in an urban area with 4G coverage the initial part of the trip is not incorporated into MND thus shortening the trip)? The caveat to this is that it is probably ok to not always include 4G, since 4G carries only data, any 4G user is ALSO carried on 2G/3G, so is still present.

3.2.8.2 Call Data (Detail) Records are insufficient for purposes of building matrices. It is necessary to have as much data as possible for each phone, including passive data. Passive data is also essential in distinguishing between mode and home based/non-home based trips.

3.2.8.3 One might consider excluding events from 2G handsets rather than excluding events from the 2G network (which may be from 3G or 4G handsets). Whilst there is no evidence to suggest that excluding 2G handsets would introduce bias in the sense that the travel habits of 2G users are any different to 4G users, it is a fact that 2G handsets generate fewer events and their owners are more likely therefore to be excluded on the basis that they have not generated enough events to identify their ODs and mode of travel between those ODs. This is unavoidable, although 2G handsets should be included where there are sufficient events to identify ODs and mode. There is no need to throw away data unnecessarily.

3.2.9 It is certainly important to understand what an MNO is offering. **They should be asked to state which networks are being probed, where they are being probed, what type of events will be received from each network location being probed and whether or not those events will be at cell level. They should also be asked to indicate the Xth percentile number (e.g. the 50th percentile (median)) of events received per day from users of 2G, 3G and 4G handsets.**

3.2.10 Some alternative methods for collecting location data from mobile phones exist, including Wi-Fi and Bluetooth tracking and app-based GPS data collection. These should be considered distinct from MND and the use of these technologies is beyond the scope of these recommendations.

3.3 How can mobile data be collected for the use in transport models?

3.3.1 MNOs are able to collect (or 'probe') event data, storing it in a database for further analysis. The MNOs do not collect data from the handsets, rather they use the information that has already been transmitted at a network level. For transport planning purposes, all data will be anonymised prior to storage to protect the personal data of the users concerned.

3.3.1.1 In consideration to the potential need to attach socio-economic data available to the MNO from the data which they have on their customers - a level of personal data could be provided for specific purposes, subject to the requirement. This data can be provided, but aggregated and presented in a larger set of data. The associated level of noise, from anonymity, can therefore increase.

3.3.1.2 Standard metrics may be available across the industry, with others available to a specific MNO. In all instances the model developer would need to discuss their requirement with the MNO.

3.3.2 Data may either be collected across the whole of the UK, in which case the full end-to-end route of a journey can be observed, or for only a part of the UK, in which case it will be necessary to infer the point of enter and exit of a journey into a study area. **MNOs differ in their approach to the storage of historical data, and model developers are advised to contact MNOs to confirm data availability and coverage at the start of a project.**

3.3.3 As with many data collection techniques, collecting data over a longer time period will generally improve the accuracy and consistency of the data by reducing the impact of day-by-day variations in behaviour. MNOs are also restricted in the resolution of data that they can provide for both cell coverage and data privacy reasons, and by combining data from multiple days the impact of these restrictions is reduced. **As a minimum, it is recommended that ten days of data are collected and combined for creating a matrix, although using a full month (20 weekdays) is preferable. If Saturday or Sunday matrices are required, this may necessitate a longer study period.**

3.3.4 One advantage of MND is the ability to collect data over a longer period and then subsequently remove some unreliable data (e.g. days affected by disruption or special events) prior to constructing the matrix.

3.4 How can mobile network data be used to create trips?

3.4.1 Since the events created by the mobile network are associated with a persistent user id, which is only available to the MNO, a timestamp and a region of space can be used to create a trace, showing the behaviour of a user as they travel around the UK.

3.4.2 Where a succession of events occurs at the same cell or with overlapping coverage this indicates that a user is stationary, and this can be used to create a trip end or 'dwell'. MNOs usually adopt a minimum time threshold (about 30 minutes) for a user to qualify for a dwell. It is sometimes necessary to infer or interpolate a dwell from the time and position of observed events.

3.4.2.1 Dwell time is according to the mobile data received, rather than dwell time for the individual.

3.4.2.2 The problem is that there is no guarantee that someone will generate two or more events in the same location when they are stopped at an OD. They may generate only one event or zero events. They may also be stopped for less than the 30 minute dwell threshold. A more sophisticated approach is required which could specify a dwell threshold based upon the expected travel time across a cell rather than an arbitrary and uniform 30 mins (one approach is to use other data sources to strengthen this eg telematics data for that particular time of day). It will also be necessary to set a threshold for cell to cell travel times so that ODs can be inferred in locations where events have not been generated.

3.4.2.3 School escort trips may involve dwells a lot less than 30min so a universal 30min value may not be appropriate for all studies.

3.4.3 When users travel between two dwells, this indicates a 'trip'. A trip in this context is defined as an end-to-end movement between two periods where a user is stationary, regardless of mode legs, diversions, round trips etc. **Where an alternative definition of a trip is required, *e.g. if round trips should be split, or mode specific legs needs to be identified*, this should be discussed with the MNO on a project by project basis.**

3.5 How can mobile network data be used to determine the route of trips?

3.5.1 The events that are generated while the user is moving (defined as the events between dwells) can be used as via-points, from which the route of the journey may be identified. This is sometimes done with reference to a routing engine, allowing the full route between the origin and destination to be inferred.

3.5.2 **Since privacy constraints preclude release of individual routing information, model developers should consider the option of requesting additional aggregated outputs such as route-based segmentation or select-link type analyses to make best use of this data. The way that the data is collected may also affect what is possible with regard to routing, so any requirements should be discussed with the MNO in advance of the project.**

3.6 What time intervals may be used when segmenting mobile phone trips?

3.6.1 The timestamps of events generated by a user can be used to infer the start time (or mid-point, or end time) of trips, however, privacy restrictions and noise place limits on the smallest time interval that can be used for this purpose.

3.6.1.1 Depending on provider, the time entering the cordon is usually based upon an MNO routing engine to estimate time entering a cordon (not just straight line).

3.6.2 **For most projects, it is recommended that hourly intervals or longer periods (AM peak, Interpeak, PM peak etc.) are used. For some study requirements it may be appropriate to use shorter time periods, however aggregation should be discussed on a project-by-project basis as privacy rules may limit the application.**

3.6.2.1 Refer to section 3.11.3. MNOs can identify long trip lengths and attribute the OD movement to the 'correct' time period, *for example trips >1 hour*, by start time end time or some intermediate point. All trips can be added at the time they enter the cordon, although this may not be available from all MND suppliers.

3.7 To what zonal resolution is MND reliable?

3.7.1 The cell maps used by MNOs to geo-reference an event are commercially sensitive, and in any case a single point in space may be covered by dozens of overlapping cells. It is therefore usual for MNOs to convert OD information into a zone system specified by the client prior to sharing an output.

3.7.2 As mentioned in section 3.2.10, MND does not use GPS technology. As such, the data is most applicable to identifying larger scale movements and not to detecting very short movements. **This limitation also affects the precision with which a handset's location can be inferred, and this should be considered when specifying a zone system for using the data.**

3.7.3 It is important to note that the cell coverage boundaries are not clearly delineated and can be subject to variation as a result of many natural factors that affect radio signal propagation, such as weather, *e.g. fog, rain*, and the amount of leaves on trees.

3.7.4 The spatial resolution of MND improves in urban areas compared to rural areas, and so it is common to use a zone system based on census zones which reduce in size in areas with higher population. **MNOs agree that inter-zonal middle super output area (MSOA) resolution can comfortably be achieved using the data, but for some study requirements it may be possible to achieve a finer resolution, especially when the data is combined with data from other sources. Because the nature of the technology is that shorter trips are more difficult to detect, intra-zonal trips may be less accurate depending on the granularity considered.**

3.7.4.1 Intra-zonal trips may be supplied at MSOA, *but often with a caveat*, where absolute volumes may be less accurate (since short trips are missing). It often depends on the size of the zone.

3.8 How can trip purpose be inferred from mobile network data?

3.8.1 It is possible to infer trip purpose from event data if the data is associated with a user id that persists over multiple days. By analysing the events created by each user during specific times of day it is possible to infer the location of the user's home and workplace. This inference would have to take into consideration variations to expected patterns, *such as night-time work or daytime education*.

3.8.2 **The precise approach adopted by each MNO varies but they generally consist of identifying regular locations visited at night (for home) or during the working day (for work) with additional rules used to refine the inference.** Once a home and workplace have been identified, trips between these locations and other locations can be split into one of five purposes: home to work, work to home, home to other, other to home and non-home based. Non-home based trips are those NOT with neither their origin nor destination at home.

3.8.3 Since these purposes are direction specific, model developers will be able to convert data with this purpose segmentation into a production-attraction matrix if required.

3.8.4 Capabilities with regard to trip purpose across the MNOs are evolving and new functionality may become available, for example with regard to the treatment of other purpose types and shift workers. **If a more detailed purpose split would be advantageous this should be discussed with the MNOs.**

3.8.4.1 Whereas home and work location can be determined in a robust way and hence for these purposes is quite reliable. Caution should be taken for other purposes, such as shopping, leisure, personal business etc.

3.9 How can mode be inferred from mobile network data?

3.9.1 The mode of trips can be inferred from MND based on a combination of factors:

a. The time and location of events along the journey can be used to estimate the speed of travel (this is relevant for very long distance trips in determining rail and non-rail trips although is less applicable to trips with shorter trip lengths)

b. The spatial pattern of events along the journey can be used to identify the route of the journey

c. The clustering pattern of events generated along the journey can be used to identify rail travel (when users on a train move from one cell to another they tend to create a cluster or events, because they all connect to the cell in a short space of time)

3.9.1.1 The use of cluster analysis to identify rail trips is reliant upon random location updates which occur when a large group of phones cross a location or routing area boundary within a short space of time. If the train does not cross such a boundary, there will be no clustering because the phones on the train will only interact with the network by means of active events. Cluster analysis also depends upon the network being configured to return the cell id as well as the LAC as part of the event.

3.9.2 The remaining modes (including car, bus, LGV, HGV, coach) will usually be reported as a single group. In some cases, MNOs can apply more developed techniques to identify shorter rail trips (e.g. Metro or Underground trips), especially in urban areas. It may also be possible to identify HGV trips, based on speed profiles for longer distance trips. In all cases it is easier to detect mode for longer trips since more diverse events will be created, providing more opportunities to analyse the trips.

3.9.2.1 There is a difficulty in differentiating mode for short distance trips. This is more the case in differentiating between slow and motorised road modes (rather than rail) over short distances as (outside London anyway), there are very few rail trips under 5 miles.

3.10 How is raw MND *expanded* to be representative of the UK population?

3.10.1 The three main MNOs in the UK each have a total market share of approximately 30%, although this varies across the UK. It is important to scale up MND to make it representative of the whole UK population. This is achieved by comparing the number of observed home locations in a region to secondary data concerning the population of those regions to calculate a weighting factor for each user, for example by using census data. This process will also reduce any bias caused by variations in the market share in different parts of the UK, because users in areas where an MNO has a higher market share will become associated with correspondingly lower weighting factors. **It is therefore important that this expansion is carried out at a user level by the MNO prior to any additional expansion or estimation that may be carried out by the developers building the model.**

3.10.2 **The details of how expansion is carried out will vary by project in terms of the region used, the secondary population data referenced and the treatment of any demographic bias in the data – any specific project requests should be raised with the MNOs.**

3.10.3 Potential approaches to benchmarking, including whether the expansion process has been representative, are referred to in Section 5.

3.11 How can mobile network data be handed from an MNO to a model developer?

3.11.1 Because of data privacy restrictions, MNOs are not able to provide individual level data to model developers. Instead, MNOs will usually provide data in an OD matrix format, segmented by a variety of factors such as trip start time, trip mode and trip purpose. The more detailed segmentation is applied, the more matrix cells will be produced and this may increase the impact of the data privacy restrictions that MNOs are required to apply.

3.11.2 This could include aggregation, rounding off values or masking smaller values where sample sizes are small. **To avoid this, model developers are advised to combine multiple days of data in the specified output and to consider limiting the complexity of any proposed segmentation. The impact of any data privacy restrictions should be discussed with MNOs prior to specifying the project and any implications taken into account in the expansion.**

3.11.2.1 Whilst MNOs cannot legally provide traces of individual phones which contain information that will allow a user to be identified, there is no legal obstacle if personally identifiable information is removed or pseudonymised. Modellers should ask the MNO for their policy in this regard if they require such information.

3.11.2.2 The model developer should not over-specify the granularity of the data required as this may have a negative impact on the level of noise introduced in order to protect personal data in matrix cells with small sample sizes.

3.11.2.3 The minimum value per cell will vary per MNO.

3.11.3 For some projects, only trips that penetrate a specific model cordon will be included in the matrix. **In this case, the route of trips that start and end outside the cordon will need to be calculated and assessed to check if it penetrates the cordon.** The time at which each trip enters the cordon may also be inferred based on the events generated during the trip. In many cases there may be a need for full ODs.

3.11.3.1 Routes are generated from the location of cell events during the journey. Cells cover areas which are large enough to contain many roads - especially in urban areas. The number of cell events per trip is also variable and routing engines use free flow or typical speeds in order to select the fastest route.

3.11.3.2 The route selected by the routing engine could easily therefore be incorrect. In that regard it may be advisable for modellers to define an outer cordon around the model area and to exclude only external to external trips which do not cross this cordon. The modeller should then use the model and local knowledge to inform their own judgements as to which of the remaining external to external movements should be included or excluded from the matrix.

3.11.4 **The data provided to model developers by the MNO should be accompanied by a technical note summarising:**

- **a. What event types have been collected and used to create the output**
- **b. The spatial coverage and date period of data collection, and details of any days that have been excluded from the analysis**
- **c. What definition of a trip has been used?**
- **d. What zone system trips have been allocated to**
- **e. If the trips have been included based on a cordon**
- **f. Whether trips have been routed and how**
- **g. What mode segments have been identified and how**
- **h. What purpose segments have been identified and how**
- **i. How trips have been allocated to time bands**
- **j. How trips have been expanded and what secondary data has been used**
- **k. Details of any other segmentation provided – for example affluence, frequency of travel or employment status**
- **l. Details of any further manipulation that has been carried out on the data**

3.12 What are the typical biases in mobile network data?

3.12.1 MNOs provide details of observed trips based on mobile phone movements. **Those using the data should be aware of the potential bias in the data, which include**:

- **a. Shorter distance trips are less likely to be detected using mobile data. The definition of a short trip will depend on the cell resolution in the area concerned**
- **b. Trip mode for short trips may be less well identified.**
- **c. Trips made to places where the user spends a short amount of time, for example school drop offs, may not be represented in the data or may be subsumed into a longer trip.**
- **d. Trips made by younger (<18) and older (>70) users may be under-represented in MND, since these individuals are less likely to carry a phone.**
- **e. Trips to areas where an MNO has very poor mobile network coverage (for example in rural areas) may be misrepresented in MND.**
- **f. Trips made by international visitors to the UK may not be represented, or may be represented in a different way, depending on the approach of the MNO.**

3.12.1.1 The largest bias is bias towards those users who generate the most events. This depends upon the habits of the user as well as the type of handset, with the newer generations producing more events. Whether this bias is significant or not in terms of deriving representative travel patterns of the population is another matter.

3.12.1.2 If bias in age group is identifiable and quantifiable it can be dealt with by applying age group specific expansion factors if the MNO is prepared to utilise this information. Otherwise, it is best left to modellers.

3.12.2 **Usual practice is to provide model developers with the data without correcting for these biases, but in some project-specific cases the model developers may wish to work with the MNOs to account for these biases as access to additional data types may assist in bias correction.**

3.12.2.1 An MNO is in a better position to account for these biases as they can examine the raw data behind the firewall pre-aggregation.

3.13 How is the approach to mobile data evolving?

3.13.1 The technology context and analytical approaches relating to MND are constantly evolving. For example:

a. The 4G network coverage is growing, and more users are switching to 4G enabled handsets. The resultant increase in data 'events' is increasing the granularity of the data. Privacy issues will remain as a limiting factor for the granularity at which the data can be reported.

3.13.1.1 Future considerations are that the impacts of generational changes (5G etc.) will also need to be understood as this may affect MND detail and provision.

b. Big data storage and processing capabilities are improving, enabling more sophisticated ways to derive data from the large volume of events collected by the MNOs

c. As MNOs gain more experience they are developing more elaborate processes for analysing event data to derive travel patterns;

d. Development of smartphones is increasing communication between handsets and cell masts, even if the phone is not in 'active' use.

e. Storage of historic MND will allow faster turn-around times. Also, it will enable before and after studies.

3.13.2 Because of these continuous changes, all of the processes and conventions described in this report should be considered subject to change. **An ongoing dialogue between model developers and the MNOs will be required to continue to take advantage of developments.**

3.14 How else might mobile network data be used in the transport modelling and appraisal process?

3.14.1 Although this note is primarily concerned with the creation of OD matrices from MND, it is important to consider other ways that MND could be applied to the transport modelling process. Note that this list represents includes possible innovations in MND and do not necessarily reflect current practice. As such not all of these items have been proven or have methodologies identified to deliver them,

a. Currently, trips are assigned to a highway or PT matrix based on assignment models. Trips collected by MND will already include an element of route information, and this could be used to inform or validate the assignment process, at least for the base year model.

b. Using route information, select link analyses could be used to derive turning ratios and volumes on key junctions at a suitable spatial granularity (e.g. at a motorway junction).

c. Delay factors for roads are usually derived theoretically or based on standard approaches, MND could be used to more accurately determine the delay factors for a particular road based on estimates of journey time and journey time reliability.

d. Transport models usually accommodate variations in trip making behaviour based on various segmentations including age, gender, car ownership and income. MND could be used to create trip patterns with these segmentations, and to test assumptions about how trip making varies for each group.

e. It will usually be necessary to forecast growth in trip making in the study area to create a future year model. Growth rates will usually be based on theoretical methods as well as land use planning forecasts. As MNOs store more historical data there is potential to assess year-on-year trends on travel in an area, and use these to refine the growth forecasts.

f. By continuing to collect data in the study area, it may be possible to update the model more frequently than usual, and to measure the impact of any schemes to test the validity of model forecasts.

g. Transport models are usually based on an 'average' weekday during a 'neutral' month, but networks often have to accommodate unusual conditions such as disruption events, special events or seasonal travel variation. The business case for some schemes might be significantly improved if their impact during these events could be appropriately measured. MND could be used to assess the frequency and severity of such events, and to understand travel behaviour when they occur.

h. MND may also be collected in real time and used to inform the operational management of a network.

4. MND Data Request / Specification Recommendations

4.1 How should model developers *specify* a MND request? (i.e. what criteria should they use to specify a request?)

4.1.1 **Generally, model developers are encouraged to work in collaboration with MNOs in order to optimise the data specification. Model developers should also ask MNOs the likely trade-offs associated with requesting different resolutions (e.g. number of demand segments, temporal resolution or geographical resolution) of data as a result of the aggregation techniques which are applied.**

4.1.2 **When making such a request, the model developer should specify the following criteria:**

- **a. The time period which is to be studied for example:**
  - **'1 month of data between the dates x and y representing a neutral month'**
  - **'3 months of data between the dates x and y representing season z'**
  - **'2 separate months of data, representing time periods before and after a policy implementation'**
  - **'multiple study periods' spanning a wide time period (such as years) to explore trends and changes in behaviour**
- **b. Specific days upon which events occurred.**
- **c. The type of day to be studied, for example:**
  - **Data should represent an average weekday**
  - **Data should represent an average weekend**
  - **Data should represent an average day**
- **d. The spatial region which is to be studied, specifically agreeing:**
  - **A zonal structure (for example, MSOA), including any aggregations of that structure (for example, a study of southern county may aggregate or wholly ignore movements at the opposite end of the country)**
  - **The definition and format of that zonal structure (i.e. shapefiles)**
- **e. Which movements are required, such as:**
  - **Intra-zonal movements**
  - **Movements intersecting the internal study area only (requiring routing by the MNO), or all movements (requiring far larger data volumes).**

f. **Where intersection of internal study area is agreed, definition of time must be agreed; with the start time either the true start time of a trip, or the time at which the trip intersected the study area.**

g. **Any attributes by which the matrix should be disaggregated such as:**
   - **Mode of transport (road, rail, air, combinations etc.)**
   - **Trip purpose (PA only, HBW, HBO, NHB, etc.)**
   - **Time aggregations (hour of day, period of day etc.)**
   - **Additional MNO offerings such as by age, gender, frequency, or other user subsets.**

4.1.2.1 The choices for mode are usually air, motorised road or rail (or perhaps motorised road and rail combined). Practitioners could also ask for 'slow' road, but most of these are short distance trips and will not have been identified. Note also that there will inevitably be some cycle trips included in the motorised road category because it is impossible to isolate them (especially for trips under 5 miles or so in urban areas - the typical location and range of cycling trips). The same is true of walk trips - normally under 1.5 miles.

4.1.2.2 The home location of a phone is readily identifiable from mobile data. Segmentation by HB/NHB is therefore possible. Segmenting HB trips into HBW and HBO can also be inferred by MNOs. This inference is likely to be less accurate in areas which have a high concentration of workplaces which operate night shifts (such as airports and factories).

4.2 What are the typical *values* / range of values for the criteria used to specify MND?

4.2.1 Of the request specifications above, criteria vary depending on study requirement and commercial constraint. However typical criteria that has been used with positive outcomes have included:

a. In time, a study period of 1 month is frequently used (as recommended in section 3.3.3), with smaller durations containing noisier outputs.
b. For day type, for example output representing an 'average/typical weekday'.

4.2.1.1 These values would normally be determined by the transport planner, however an average day is typical for anonymity reasons and the mobile network industry focuses on weekday. The MNO can of course provide whatever is required by that use case. An average of 'bank holidays' is just as achievable.

c. Spatial structure varies by model, however a zoning system of similar granularity to MSOA is commonly used, increasing in scale away from the study area (as recommended in section 3.7.4).

d. For most studies, only movements intersecting the study area are required. An MNO however must study the entire nation to accurately calculate aspects such as home location and expansion factors.

e. Depending on the experience and expertise of the model developer, either 'all mode' matrices are typically requested, or road/rail split.

f. Commonly trip purposes are requested in full, but may be aggregated where such requests cause the distributed sample sizes to fall too low.

4.2.1.2 Distinguishing trip purposes, such as HBW, HBO, NHB etc. depends on the MNO. An MNO for example may also identify are areas, *such as education*. It should be expected that this level of sophistication will evolve.

g. Depending on the survey period, typically matrices are requested at 'day part' granularity to reduce the impact of anonymity procedures, meaning; hour-by-hour, night, AM peak (period or hour), interpeak, and PM peak.

4.3 What ***questions*** should model developers ask when requesting MND?

4.3.1 **Any user of MND should explore with potential suppliers the following questions:**

a. What mobile events (data sources) are studied by the supplier?
- **2G/3G/4G?**
- **Probed events, or Call Data Records only?**
- **Active and Passive events?**
- **Granularity of passive events (cell, area ID only)?**

b. What non MNO data sources have been used (if any) in the creation of the dataset? This is to ensure any validation of supplied data is performed in fair context.

c. What expansion or validation methods have been applied to the data (overview)?

d. What are the license restrictions around the use of the data product for a particular purpose? What is the potential to re-use of data for other purposes, user cases (contractual issues)?

e. What methods have been used for expansion and the range of expansion values?

f. Is the data already collected or new data specifically collected for the study?

g. Will a suitably detailed method statement be provided? (potential contents of such a method statement is provided in section 3.11.4)

h. What is the timescale for delivery of MND?

4.3.2 Also, a feedback loop between practitioner and MNO is standard practice to ensure the data is fit for purpose. There is a commercial impact associated to this process however. This Paper could specify a deep number of requirements, but MNO's would accordingly increase fees for this (where as today, those variables depend upon customer needs).

4.3.2.1 Anybody considering purchasing mobile data should ensure that the MNO fully explains how they process event data into trip records i.e. the trip processing methodology. In particular, the identification of ODs, home location, mode, allocation of ODs to zones and routing. A checklist of these things needs to be included. Also, it should be noted that there is scope for the modeller to specify their own trip processing methodology.

4.3.2.2 The methods applied to the data (c.) are open as they are dependent on the use case.

4.3.2.3 The Modeller could ask the MNO "What methods have been applied to assure privacy?' however the value of the MNO detailing their processes is questionable. Each MNO has to ensure privacy and data anonymity, which is regulated, and outlined within their published Privacy Statement.

4.4 To what temporal detail can MND be handed over in (i.e. over an hourly period etc.)?

4.4.1 Commonly, MNO's process data to the most granular temporal accuracy possible, however the importance of privacy and anonymisation requirements often lead to aggregation of such data. While an MNO may be able to provide data at greater temporal precision, it is rare that data is required at granularity less than hour, and indeed more commonly day part (peak, interpeak etc.) is most suitable.

4.4.1.1 Currently an MNO would advise part-day or hourly granularity, but not smaller.

4.4.1.2 Where greater granularity in time is required by a study requirement, reductions in spatial accuracy or other attributes or increase in survey period are often required to maintain sufficient sample size and anonymity.

4.4.1.3 It is possible to produce matrices for any temporal segmentation. However, the smaller the time period, the smaller will be the values in the matrix cells. This could be an issue if the MNO operates a policy on minimum cell value and so increase the number of matrix cells which are adjusted to alleviate privacy concerns.

4.5 How is the data delivered? What does it look like?

4.5.1 With a request completed and commercially aligned, MNO's will begin a given project. Timescales and delivery method vary depending on MNO capability (with some recording and processing data after project agreement, and others processing data continuously ready for extract).

4.5.2 **Data is typically delivered in a format such a .csv file, alongside a project overview report (the detail of which varies by project requirement and commercial agreement).**

4.5.3 The content of the supplied matrix (.csv file) is often a variation of the following:

zone_from	zone_to	time_period	mode_id	Person-trips
X	Y	T	Car	Z

4.5.3.1 Person trips are always expanded. The assumptions used for this and associated vehicle occupancy are to be explored by the Modeller with the MNO.

4.6 What are the common outputs that can be requested by model developers?

4.6.1 Most commonly an OD matrix and/or PA matrix is requested of an MNO. However, this complex 'big data' set can be used to fulfill other study requirements. Additional outputs commonly requested include:

a. Select link analysis – examining volumes of users, and catchment for specified links within the road network of suitable scale.
b. Routing analysis – consideration of routes taken by users between sets of zones, and study of this variability in time/when incidents occur etc.
c. MNO's may offer additional consultative analysis of underlying datasets to create visualisation/reporting depending on the study requirement.

4.7 What quality metrics should be requested of MND?

4.7.1 Mobile data has been shown to be valuable in a number of projects, however it is important that a model developer understands the underlying quality of any supplied dataset and its inherent biases. **Any quality metrics may vary depending on project scale and agreement with the chosen supplier however should encompass metrics such as:**

a. Matrix consistency
- **Variability by day within the period**
- **Examination of matrix consistency (inbound/outbound journey comparison)**
- **Impact of anonymity procedures, detailing the overall sample pre and post anonymistion.**

4.7.1.1 What may also be requested is the criteria by which users are included or excluded from the sample. In other words, what constitutes a 'valid' user. Typically, it is necessary to exclude 'roamers' because they are not residents and therefore incapable of expansion using population (mainly an issue in London where there are large numbers of tourists). MNOs will also apply criteria based upon the frequency with which they receive events from users. For instance, users who only generate events on a few days during the study period are not useful if you intend to expand based upon the ratio of population to number of users observed in the study period i.e. because not all of the trips made by such users will be observed.

b. Comparison against external sources, including:
- **Handset home population vs census**

4.7.1.2 Any MNO can only provide a sample of people in any geographic area - there will not be a 1 to 1 correspondence with census. The sample size will also vary from one geographic area to another and hence the expansion is undertaken separately for each area.

- **Trip length distribution**
- **Trip rates**

c. Distinguish tests that only the MNO can make and those that the model developers can make.

4.7.1.3	The Modeller should consider whether these tests are the same as the verification data. The MNO should explain tests which could be compared and, if possible, acceptability criteria.
4.7.2	Any supplier should confirm which external sources (if any) have been used in the creation of a modelled output, to ensure potential verifications/quality metrics are not self-fulfilling.
4.7.2.1	It would be extremely valuable to model developers if MNOs inform on what has been thrown away, such as unusable records, users out of scope, short distance trips, so that developers can get a feel for what proportion of all data has been useful (and perhaps can bring it back into the analysis).

5. Benchmarking Recommendations

5.1 Overview

5.1.1 The following benchmarking recommendations have been largely informed from practitioner experience from a specific case study, namely the use of MND to build Regional Traffic Models for Highways England. As such the emphasis is on the use of road based MND although many of the recommendations could be generalised to be applicable for multimodal studies which use MND.

5.1.2 It should be recognised that in any guidance derived from these recommendations that the benchmarking criteria (shown in Table 1) have been derived from expert discussion and project experience to date so tests against stated criteria would benefit from feedback from practitioners on whether the stated thresholds are appropriate when applied on future projects which use MND.

5.2 What checks should be undertaken to investigate the robustness of MND once handed over?

5.2.1 The provision of an 'all modes' matrix is a standard output. Methods can then be applied to split out trips by mode. The basis for this is usually to successively remove trips identified robustly as 'road', 'rail' or 'air'. Short distance trips (e.g. typical active modes) are typically difficult to distinguish robustly.

5.2.1.1 With regard to short distance trips, It is not possible to detect intra-cellular trips. However, cell sizes vary from as little as 500m in urban areas to 7.5km in remote rural areas. Hence, the detection ability is lower in rural areas. On the other hand, there are likely to be fewer short distance trips in rural areas. It is also the duration of a trip as well as its distance which affects the ability to detect a trip: the lower the duration, the lower the likelihood that events will be generated at the either the origin or destination.

5.2.1.2 In urban areas therefore, it is quite possible to detect short inter-cellular trips of much less than 2km provided that the duration spent at the origin or destination is long enough for events to be generated. The same is true in rural areas, but only if a handset is generating active events when crossing a cell boundary. In summary, for any given amount of time spent travelling to/from and stationary at an origin or destination, it is more likely that an inter-cellular trip will be detected in an urban area than a rural area.

5.2.1.3 The greater the distance travelled (particularly above 7.5km maximum cell size), the more equal becomes the probability of detection.

5.2.2 The first check is to test whether or not rail trips have been misallocated as part of the data provided. This will be especially critical if there is considerable rail commuting associated with the study area, or if rail lines are passing close to main roads in the study area.

5.2.3 Several checks are needed, as shown in Table 1. The table is heavily based on work undertaken by the Technical Consistency Group within the Regional Traffic Models for Highways England. Though the work was a group effort, it was led by AECOM.

5.2.4 The checks shown in Table 1 have been segmented into two groups:

1. Primary – these are coloured green in the table and reflect those tests which are deemed to be the most important in benchmarking MND and should routinely be undertaken and reported on;
2. Secondary – these are coloured yellow in the table and reflect other tests which could be carried out to gain confidence in MND.

5.2.5 In all these tests, it is noted that MND is unlikely to contain short trips and this should be borne in mind when the benchmarking is done. The definition of 'short trips', *such as 2 kilometres*, will depend on the topology of the LACs, environment and cell density.

5.2.5.1 The issue of short trips not being able to be detected is one that appears many times. Guidance should reflect upon this and future iterations of the guidance should seek to provide more information based on evolving practice.

5.2.6 The tests are carried out for trips where one or both legs are in the study area. Finally, in all these comparisons, the statistical reliability of the data needs to be considered for the various datasets as much as possible.

5.2.7 Whilst the initial tests have been informed from the Highways England work, practitioners should consider developing other tests to suit the application of MND in their study. For example, there could be value in conducting some benchmarking tests which compare average dwell time per purpose against available household interview data, or the number of simple and complex tours compared to the national travel survey.

5.3 What metrics should be used to undertake the checks?

5.3.1 The metric used depends on the test being undertaken – refer to Table 1 (below). It is noteworthy that some of these comparator datasets have their own errors and biases. For example, NTS is based on reported data, and there is the potential that some trips are not reported by respondents. It is important to caveat these tests and the associated statistical criteria, *such as* R^2.

5.3.2 The use of a category analysis may prove effective, in this case, for example:

a. R^2 above x is good,
b. R^2 above y is accepted, but try to investigate and report any reason for this level; and
c. R^2 below y is not acceptable, prompting practitioners to re-engage with MNOs or for practitioners to make documented adjustments to the data.

The values of x and y will vary depending on the test undertaken. Indicative values are provided in Table 1 where appropriate.

5.3.2.1 Much discussion has been generated on the use of R^2. These discussions considered the strengths and weaknesses and the use of R^2 in existing modelling practices and concerns over the biases and errors which can be present on comparator datasets. It was concluded that R^2 can provide a useful indication of the robustness of MND and that RAG (red, amber, green) bandings could be used to indicate if corrective action is required. The banding, however, should not be constant and differ by test to reflect the uncertainty associated with comparator datasets. Generally, it was agreed that for tests which involve comparing MND with itself (i.e. such as a trip symmetry test),

expected R^2 values should be higher than those where MND are compared to other datasets. This is reflected in Table 1.

5.3.2.2 Benchmarking may benefit from multiple regression analysis to consider factors such as: population, car ownership, income or environment. This analysis could be conducted for: trip ends, trip rates, trip length distribution and sector to sector trip movements. However, further checks against measured count data should be undertaken once the matrix has been assigned to the network.

5.3.3 The coincidence Ratio (CR) of the distribution curves, calculated using the following formula, should be used to assess the correlation between observed and modelled trip length distributions. Correlation strengthens as the CR value approaches unity.

$$CR = \left\{\frac{\sum_T[\min(PM_T, PO_T)]}{\sum_T[\max(PM_T, PO_T)]}\right\}$$

CR is Coincidence Ratio, PM_T and PO_T is proportion of modelled and observed distribution respectively in interval (distance band) T.

5.3.4 For tests, such as Test 16, the Root Mean Square Error could be calculated to give an indication of the goodness of fit of flows across long screenline. The smaller the value of RMSE, the smaller the error and hence better the fit. It has the following formulation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}[(Count_i - Model_i)^2]}{N}}$$

and

$$\%RMSE = \frac{RMSE}{\left(\frac{\sum_{i=1}^{N} Count_i}{N}\right)} \times 100$$

5.3.5 The use of other statistical metrics should be considered by practitioners to help understand the relative strengths and weaknesses of MND although recognise as mentioned in 5.3.1 that comparator datasets have their own errors and biases which must be recognised.

5.4 What level of aggregation should be undertaken in the course of benchmarking?

5.4.1 The level of aggregation is indicated in the table below and is key to the robustness of the analysis. The spatial detail or 'granularity' at which the tests are carried out will be a function of:

- the MND provided; and
- how strategic the study area is.

5.4.2 On point a. above, usually MND will be supplied at MSOA or LSOA level. It is best to start at the level of granularity provided by the MNO, and check, using the tests in the table, if the data is reliable at that level. If not, then move to more aggregated levels (e.g. from LSOA to MSOA and then to District), until the data is reliable, and satisfies the statistical tests proposed in the table. It might be found that greater aggregation is required by some tests than others. An example of this is that it may be found that trips in rural areas are underestimated to a greater degree than those in urban areas.

5.4.2.1 On point b. above, one perspective is that it is extremely likely that MND will prove much more useful for national and regional studies than the more local studies, where the Cell ID's may cover multiple model zones. In such cases, it may be found that the MND is only useful at a strategic level providing target flows for large sector pair movements.

5.4.2.2 A competing perspective is that MND will be useful at the local level particularly if other data are used to disaggregate spatially. It could be misleading to suggest in guidance that MND can only be used at the national and regional level.

5.5 What data sources can be used when benchmarking?

5.5.1 Ideally, the datasets need to be independent from those used by the MNO to produce the data, to act as separate validation, but that is not always possible. Practitioners should request from MNOs the datasets used to derive MND in order to gauge whether benchmarking checks represents a true validation exercise or one that confirms that characteristics of calibration datasets remain in the final MND handed over. Example datasets which could be used for benchmarking include:

a. Census residential population and Journey to Work data;
b. National Travel Survey (NTS) – the latest 3 years available;
c. Recent roadside interview (RSI) data in the model area (optional);
d. Local household survey data (if available); and
e. Various traffic count data within the study area.

5.5.2 Furthermore, key demand producers / attractors within the study area, such as ports and airports, and large residential and employment areas should be checked against independent data. For airports this can be sourced from DfT and CAA statistics.

5.6 What information should be included in project reports with regard to benchmarking?

5.6.1 **The list below is not exhaustive but provides an idea of the type of material that needs to be presented.**

a. Scatter plots, graphics and statistics of all the tests in the table, for all modes and purposes combined and separately;

5.6.1.1 It may also be useful to indicate minimum and maximum values and outliers on the scatter graphs.

b. GIS plots of the zoning system adopted for MND and the model;
c. GIS plots of zonal trip rates to detect any zonal misallocation, or disparity between urban-rural;

d. Matrix values before and after adjustments for trip ends, matrix totals and inter sector trip movements. These metrics could be disaggregated by trip purpose, trip length and time period (daily values as well as model time period if different); and

e. Justifications of any adjustments made to MND.

5.7 What type of adjustments are needed if benchmarking shows problems?

5.7.1 **There are some preliminary adjustments that are required, such as:**

a. Infilling for short distance trips, using some synthesis. See section 6.2.7.6

b. If tests 1 and 2 in the table indicates that the MND contains misallocation of rail trips within the supposedly road based matrices provided by the MNO, it might be best to ask the MNO for the rail trips as well. These are added to the road based MND, and the modal processing will then include the removal of bus and rail trips together. See section 6.2.2.1.

5.7.2 Besides corrections for short trips and public transport, the various tests applied as in the table above are bound to reveal disparities and require adjustments. The main purpose of the benchmarking is to identify outliers, which can then be examined in greater detail, to assess the cause for the disparity and attempt to find a means of correcting them.

5.7.3 Some of these adjustments might be iterative, for example correcting for trip ends could well impact on the test for distribution or trip length. For these reasons, it is not straightforward to specify the adjustments that are likely to be needed.

5.7.3.1 Does the MNO complete these tasks alone or in collaboration with the model developer? If these are global or local, how should these be reported?

5.7.4 Below is a preview of issues to consider and the type of adjustments that might be applied:

a. Test 3 is quite a coarse test given that trips are not only a function of population but socio-economic attributes such as car ownership, household structure, income, and the % of trips by active modes, which are not included in the MND. Nevertheless, it will help identify outliers that need to be examined further;

b. If low correlation in Tests 3 to 10 is detected, it might be due to trips misallocated to a neighbouring zone, in which case a GIS plot can be useful to explore trends. As a result, advice may be to carry out the analysis at a more aggregated level and consider using MND to control model movements at a more aggregated level or for developers to reengage with MNOs in order to correct any potential misallocation;

c. If the R^2 is acceptable but the slope of the scatter plots in tests 4-7, and 9 is not close to unity, this could indicate that the expansion of the MNO data was not accurate. A global factor can be applied to the MND to bring the slope closer to unity;

5.7.4.1 More detail on the 'factor' should be reported as well as other factoring methods being considered

d. When undertaking tests 12 and 13, it may be necessary to apply adjustment factors by distance bin (discrete intervals of distance) to the MND so that it is in line with the comparator dataset;

e. For test 14 to be carried out properly, the MNO needs to clarify whether or not escort trips to education are included in the HBW matrices. If the purpose split in the MND is materially different to the comparator dataset, then global factors might need to apply to the MND;

5.7.4.2 Escort trips should not be mistaken for work trips, where the phone stays relatively immobile for 8 hours. The impact of part-time workers should also be considered.

f. The outcome of test 16 will identify overall deficiencies in the matrix derived from MND. Any material discrepancies need to be explored to identify the reasons. It is hoped that assignment errors will be minimised through the use of long screenlines. Correction factors might need to be applied to the MND at sector pair level to bring the model and observed flows closer to parity. Such factors would need to be justified when reporting to indicate why they are credible

5.7.4.3 Is this expansion in a different manner, and therefore should one go back to expansion first at the pre-processing stage?

Table 1 – Benchmarking Metrics

No.	MATRIX ELEMENT	BENCHMARKING	ANALYSIS	SPATIAL GRANULARITY	TEMPORAL LEVEL	STATISTICAL INVESTIGATIONS	RAG CRITERIA	TEST OBJECTIVE / COMMENTS
1	Removal of Rail Trips	HBW from home origins vs. Census JTW 'home' locations. JTW data with and without rail trips 4	Regression / scatter plots	LA Districts / MSOA / Model Zones /	Daily	Assess R^2, look for outliers	R^2>0.7 – Green R^2>0.5 – Amber R^2<0.5 - Red	Verify that rail trips are not in MND for road assignment modelling
2		HBW to work destinations vs. Census JTW 'work' locations. JTW data with and without rail trips	Regression / scatter plots	LA Districts / MSOA / Model Zones /	Daily	Assess R^2, look for outliers	R^2>0.7 – Green R^2>0.5 – Amber R^2<0.5 - Red	
3	Trip-ends, Trip rates	From-home origins and to-home destinations vs. Census population	Regression / scatter plots	LA Districts / MSOA / Model Zones /	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.95 – Green R^2>0.9 – Amber R^2<0.9 - Red	Verify level of spatial granularity at which the data is suitable. If even at District level serious disparities are found, the suitability of the MND should be reviewed
4		HBW from-home origins and to-home destinations vs. Census JTW 'home' locations	Regression / scatter plots	LA Districts / MSOA / Model Zones /	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R2>0.7 – Green R2>0.5 – Amber R2<0.5 - Red	
5		HBW from-home destinations and to-home origins vs. Census JTW 'work' locations	Regression / scatter plots	LA Districts / MSOA / Model Zones /	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.7 – Green R^2>0.5 – Amber R^2<0.5 - Red	
6		Trip origins and destinations vs. NTEM trip-ends, separately for HBW, HBO, and NHB.	Regression analysis / scatter plots	Model Zones	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.7 – Green R^2>0.5 – Amber R^2<0.5 - Red	

No.	MATRIX ELEMENT	BENCHMARKING	ANALYSIS	SPATIAL GRANULARITY	TEMPORAL LEVEL	STATISTICAL INVESTIGATIONS	RAG CRITERIA	TEST OBJECTIVE / COMMENTS
7		From-home trip rates vs. NTS. (3 years for better sample and road based modes only).	Average trip rates. Verify expansion of data	County & level at which data is reliable. Carry out analysis by urban-rural	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.7 – Green R^2>0.5 – Amber R^2<0.5 - Red	
8	Symmetry	From-home vs. to-home trip ends all purposes -2	Regression analysis / scatter plots	MSOA	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.9 – Green R^2>0.8 – Amber R^2<0.8 - Red	Confirm symmetry in data – i.e. correlation between inbound and outbound trips
9		From-home vs. to-home trip ends HBW	Regression analysis / scatter plots	MSOA	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.9 – Green R^2>0.8 – Amber R^2<0.8 - Red	
10		Sector pair trip totals vs their transpose	Regression analysis / scatter plots	Model sectors	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	R^2>0.9 – Green R^2>0.8 – Amber R^2<0.8 - Red	
11	Trip Distribution	HBW from-home vs. census	Regression analysis / scatter plots	MND Sectors or District	Daily	Assess R^2, look for outliers Slope close to unity and small intercept	No Criteria	Confirm HBW distribution aligns with census JTW
12	Trip Length Distribution	HBW from-home vs. JTW data	Frequency histograms	Crow fly distance bands	Daily	Compare mean and standard deviation. CR ≥ 0.70	N/A	Comparison for trips > 2 km as MND unlikely to have short distance trips
13		All purposes vs. NTS data	Frequency histograms	Crow fly distance bands	Daily	Compare mean and standard deviation. CR ≥ 0.70	N/A	

No.	MATRIX ELEMENT	BENCHMARKING	ANALYSIS	SPATIAL GRANULARITY	TEMPORAL LEVEL	STATISTICAL INVESTIGATIONS	RAG CRITERIA	TEST OBJECTIVE / COMMENTS
14	Trip Purpose	HBW/HBO/NHB split vs. NTS	Compare proportions	Region & County	Daily	Look for significant differences & outliers	N/A	Investigate inclusion of HBE in HBW matrices
15	Daily Profile	Daily profile of trips (05:00 – 20:00, all purposes, from-home) vs. NTS	Compare profiles visually	Region	Hourly	No Criteria	No Criteria	Compare trip start time profile NTS is only 24 Hour.
16	Vehicle flows	Assigned flows vs. counts across long screenlines	Compare traffic volume / person volume	Screenline	Daily	Absolute, relative and GEH differences, RMSE	Differences ≤ 10% of observed flows	Use long screenlines to minimise model routing errors. An average occupancy is required to convert people to vehicles. It is recommended that screenlines are defined away from town centres to minimise the inconsistency due to the inclusion of buses in the MND. This applies to vehicle flows

6. MND to model matrix recommendations

6.1 Overview

6.1.1 The development of model matrices is a complex one. At the time of producing this Paper, the DfT had a separate study, led by Arup, which focussed on making recommendations on matrix building to allow the Department to draft a new WebTAG unit for this topic area. This section of the Paper will inevitably overlap with some of those recommendations although the focus here is on incorporating MND into model matrices rather than the general building of a model matrix which the other study focuses on. Also, at the second workshop for this project, attendees discussed and challenged a set of flow charts which could depict the incorporation of MND into model matrices. These flowcharts can be found appended to the workshop 2 report in Appendix C which may be useful in visualising some of the typical processes model developers go through when using MND.

6.1.2 This section has been written trying to combine experiences gained through various projects. Some of the approaches listed here have been influenced by a paper entitled 'Regional Model Matrix Development: Consistent Approach Towards using Provisional Data'[2] produced by Hyder/Ch2M/Atkins/AECOM for Highways England, who kindly accepted that outputs are used as part of these recommendations.

6.1.3 Typically, the process of converting MND data into prior matrices includes a number of steps. **The process includes three main stages: verification, adjustment and segmentation of the data.** The verification process is used to assess usability of data and address identified limitations and biases within the data.

6.1.4 The segmentation and disaggregation process is used to split data by mode, vehicle type and trip purpose, and convert it from mobile data zoning into model zoning depending on the way the data is provided and the study requirement. Ultimately, these three stages may be iterated until confidence is gained that the prior matrices developed are sufficiently robust for use in model calibration and validation.

[2] Regional Model Matrix Development: Consistent Approach Towards using Provisional Data, Highways England, Issue 5 (Main Authors: Reza Tolouei (AECOM) and Siamak Khorgami (AECOM))

6.2 What steps can be taken to create model matrices from MND?

6.2.1 Initial Verifications and Adjustments

6.2.1.1 MND data tends to be provided already expanded to person trips using the following segmentation (may possibly be further enhanced), and provided for an average day or sum of all the days considered during the survey period:

a. Mode
   - Slow modes (pedestrians and some cyclists);
   - Rail trips
   - Road based trips (car, LGV, HGV, bus, coaches)
   - Some MNOs may also be able to provide a matrix for HGV movements.

b. Purpose
   - Home based Work (HBW, including commuting trips and home based employers' business trips)
   - Home Based Other (HBO)
   - Non Home Based (NHB)

c. Trip directionally for Home Based trips
   - From home
   - To home

d. Time
   - Time periods agreed between MNO and model developers, including timing location (start of trip, entry into study area for cordoned models…)
   - Day of the week: weekend/weekday

6.2.1.2 A number of processes have been applied by MNOs to the MND in order to arrive to person-trips (origin-destination), typically split into several segments (such as mode and purpose). **These processes as well as inherent biases and limitations of MND may lead to the MND being unsuitable for direct use as prior matrices.** After converting the MND to an average day, verifications undertaken as part of the benchmarking may have identified issues such as:

a. Incorrect mode allocation;
b. Unsuitability of the data at the granularity at which MND was provided;

6.2.1.3 Recommendation should be to 'seek to ensure that data is received at the appropriate granular level, not at a level that subsequently needs aggregation'.

c. Under representation of short trips; or
d. Expansion issues such as overall under or over estimation of the demand.

6.2.1.4 **These need to be corrected using other data sources and possibly synthetic demand issued from gravity models.** A number of issues are expected to have been identified which need to be addressed before developing the prior matrices.

6.2.2 *Separating Unidentified Rail Trips from Road Based Trips*

6.2.2.1 Past experience suggests the possibility that MND data matrices may include some rail trips due to limitations in identifying travel mode of trips reliably, especially for shorter trips. **This might be corrected using external data sources including census, other surveys or existing model information.**

6.2.2.2 There is actually less probability of confusing rail and road for trips under 5 miles since according to NTS only 0.24% of trips (nationally) under 5 miles are by rail. That proportion is higher in London because of the underground system and identifying rail trips using the deep level tubes where there is no mobile signal is a problem.

6.2.2.3 One possible resolution to the loss of signal across the deep level tube network maybe to focusing on trips that disappear from MND at stations.

6.2.3 *Appropriate Spatial Resolution*

6.2.3.1 Reflecting on the outcome of the initial benchmarking tests, a decision should be made on the suitability of the spatial resolution where the mobile phone OD data should be used. **If the analysis suggests that there are large trip allocation errors at model zone level, aggregating the data into 'mobile sectors' where the trip allocation errors are reasonably small should be considered.**

6.2.3.2 Should aggregation be done by the MNO? Also, other data such as TrafficMaster can be used to refine zonal allocation

6.2.4 *Infilling Short Trips*

6.2.4.1 **If the outcome of the initial benchmarking tests shows that the derivation of short trips in the MND data is unreliable, this should be corrected by replacing short trips with other sources (observations or synthetic) so that trip length profiles from adjusted data matches those based on independent data.**

6.2.5 *Expansion Issues*

6.2.5.1 Some of the benchmarking tests could provide insights into any issues with MND expansion. For various reasons, the total number of trips made from an area might be higher or lower than expected as suggested by independent data. Any expansion issue might be global (affecting the whole matrix) or local (affecting a specific area).

6.2.5.2 **If all the above data consistently suggest an over-expansion or under-expansion of the MND matrices and if no underlying structural matrix problems can be found, adjustment factors should be estimated by comparing trip rates and total vehicle flows with independent data. For road based trips, it is recommended that due to the inclusion of buses, LGVs, and HGVs in the matrices at this stage, any adjustment be made with caution and only at a geographically aggregate level.**

6.2.5.3 Could the MNO pre-process better and explain the values of the adjustment factor?

6.2.5.4 **Once these adjustments have been undertaken, the following key steps need to be completed in order to process the adjusted MND data into final prior matrices:**

- **a. Build separate aggregate matrices for each model time period (i.e. AM, Inter-peak, and PM);**
- **b. Split the OD matrix by vehicle type and trip purpose (if required);**
- **c. Disaggregate the matrices from mobile data sectors into model zones, if required;**
- **d. Convert matrices from OD level to PA level (i.e. combine home to work and work to home OD matrices to a HBW PA matrix), if required; and**
- **e. Convert matrices from people to vehicles (if required).**

6.2.5.5 It could be advantageous to seek further advice on the conversion from people to vehicles.

6.2.5.6 Whilst the use of synthetic matrices may be recommended, separately by vehicle type and trip purpose, to support matrix build process in various stages this is not compulsory. **These may however be used to infill short distance trips, as well as segmenting MND matrices by vehicle type and journey purpose.**

6.2.5.7 The quality of the resulting matrix is directly dependent on the quality of the synthetic matrix. It is assumed every company does this differently leading to very variable quality. At the moment there isn't a enough guidance on in WebTAG, but this should be built into the revised guidance for release in 2016.

6.2.6 Time Period

6.2.6.1 The time periods at which the MND is available need to be agreed between MNO and model developers, including timing location (start of trip, entry into study area for cordoned models etc.). This may have some implications on the later use of the data in conjunction with gravity model synthetic demand. This may also have an impact depending on how the resultant prior matrices are used (assignment model or demand model) and need to be accounted for.

6.2.7 Mode / Vehicle Type / Purpose Split and Spatial Disaggregation

6.2.7.1 The adjusted MND matrices need to be segmented by mode, vehicle type and trip purpose. There are two key criteria to be met:

- a. The segmentation should ensure that purpose split at each origin / destination reflects the diversity in the land-use, trip rates, public transport accessibility and planning data; and
- b. The segmented matrices should reflect the differences in trip length distribution by vehicle type and trip purpose, as derived from independent data.

6.2.7.2 **In order to meet both these criteria, segmentation factors are required which not only reflect purpose splits at trip-ends, but also vary by distance to reflect differences in trip length distributions by vehicle type and trip purpose.** For example, from total number of trips originating from a given zone, business trips tend to travel longer distances compared to other trip purposes.

6.2.7.3 The mode definition obtained from the adjusted MND is generally not sufficient for the purpose of transport modelling. Typically, what is expected is:

a. Public transport;
b. Car;
c. LGV; and
d. HGV.

6.2.7.4 Whilst Rail trips are *generally* provided as part of the mode breakdown within the MND, adjustments made to the data at earlier stages need to be taken into consideration to produce a matrix representing all public transport trips. MND slow mode matrices may be added in order to develop and complete a set of public transport matrices, but the lack of short trips and the implications this may have need to be checked and understood. **It should however be noted that currently limitations in identifying bus trips need to be accepted and MND may not be directly used for public transport matrices without significant checks and adjustments.**

6.2.7.5 When considering problems with bus and slow modes, explicit advice on how to deal with this using local or national data would be beneficial.

6.2.7.6 Remaining road based trips are required to be split between car, LGV and HGV. To date the most practical approach is to derive LGV and HGV matrices through other means (observations or synthetic demand estimates from gravity models or other model estimates[3]) and to subtract these from the adjusted MND **being mindful about the Person to Vehicle Conversions.**

6.2.7.7 Subtracting may lead to false negative numbers so use of proportions rather than absolutes values may want to be considered.

6.2.7.8 An alternative would be to estimate a split car/LGV/HGV at zonal or OD level and apply this to the MND or prior matrix.

6.2.7.9 Some MNOs may be able to provide a matrix of HGVs movements, although it may be necessary to validate and/or scale this matrix against other data sources prior to use in the model.

6.2.7.10 Some HGVs can be positively identified if they travel long distances over roads with traffic conditions and speed limits which allow a speed differential to be established. In most cases however, there will be a lot of estimation involved. **Detailed discussions with MNOs are advised if there is the intention of deriving HGV movements from MND.**

[3] For example HGV may be derived from BYFM and LGV from TrafficMaster

6.2.7.11 Where Spatial Disaggregation of the adjusted MND, provided at sector level, to a finer zoning system is required or if further purpose segmentation to the one provided by MND (including Employers' Business) is required, the use of synthetic demand at zonal level is recommended. The developed synthetic matrices can then be used to disaggregate the adjusted MND sectors to model zones. The outcome of this process will be segmented matrices in model zones controlled to total trips from MND data in mobile data sectors. Therefore, whilst the resultant trip length distribution will be different for each segment, the overall trip length distribution from the adjusted MND data for the aggregate matrix of all segments will be retained.

6.2.7.12 The segmentation and disaggregation process described above ensures that the overall trip pattern from the adjusted MND data, having verified as being suitable, is retained at the sector levels identified where trip allocation errors are minimal.

6.2.8 Production-Attraction and Person to Vehicle Conversions

6.2.8.1 For the purpose of the demand model, the matrices may need to be in the form of production-attraction, and for the purpose of highway assignment models, they need to be converted to vehicle or PCU (Passenger Car Units) trips.

6.2.8.2 The process described above can be applied with a further segmentation by trip directionally (from home/to home) for home based trips. This provides flexibility to convert matrices to origin-destination or production-attraction format.

6.2.8.3 Typically, MND is provided as person trips. Average occupancy factors are required to convert person matrices into vehicle matrices for road based trips, these factors could be applied by purpose, time period, and distance and obtained from external sources.

6.2.8.4 An alternative would be to estimate a split car/LGV/HGV at zonal or OD level and apply this to the MND or prior matrix.

6.2.9 Comparisons with Counts and Further Refinements

6.2.9.1 At the end of the process above a set of prior matrices, by time period, mode and purpose based on MND data is produced. Once combined with other trip matrices used to build the transport model, the prior matrix needs to be validated. This may include benchmarking tests described previously in these recommendations and existing WebTAG recommendations for prior matrices.

6.2.9.2 Depending on the outcome of the checks described above, refinements to the segmentation methodology may be needed. Any adjustments made to the MND need to be justified following the verification tests, and based on statistical methods and available evidence.

6.3 What other datasets can be used in deriving or enhancing model matrices from MND?

6.3.1 Primary datasets are listed in WebTAG Unit M1.2 "Data Sources and Surveys". Most of these are used as part of the benchmarking tests. **The datasets used for benchmarking can also be used to enhance the model matrices produced using MND, however these are to be used only in stages subsequent to those in which they have been used for benchmarking.** This is critical in ensuring that the MND benchmarking and verification test are using independent data.

6.3.2 **A non-exhaustive list of these datasets and their potential uses is given below:**

- **a. Census Journey-to-Work (JTW) for mode share and trip length distributions[4];**
- **b. National Travel Survey (NTS)[5] for trip rates, trip length distributions and mode shares and occupancy factors;**
- **c. DfT NTEM (National Trip End Model) [6]for trip ends and time period splits.**

6.3.3 **Local study specific surveys such as Roadside Interviews (RSIs) or Local Household Travel Surveys may also be used to replace national values.**

6.4 What data is / could be used to expand MND to be representative of total population, and for mode and purpose allocation (i.e. census, NTS, local information, etc.)?

6.4.1 The expansion of MND to full population is undertaken by the MNO. **The MNO should provide detailed information on the expansion process including data sources used as part of their reporting (as detailed in the MND pre-processing section).**

6.4.2 Again, primary datasets are listed in WebTAG Unit M1.2 "Data Sources and Surveys".

6.4.3 However, recognizing the weaknesses in the MND with regards to mode split for road based trips, it is suggested that other sources are used to generate bus, HGV and LGV demand to help with separating car form other modes. These could include:

- DfT TrafficMaster data for LGVs

6.4.3.1 DfT Trafficmaster data only contains around 30,000 LGVs which is a very small proportion (around 1%) of those registered in the UK. There is a risk a lot of the cells in a matrix would end up being zero just because of the small sample size.

[4] http://www.ons.gov.uk/ons/ons/publications/re-reference-tables.html?edition=tcm%3A77-295663
[5] https://www.gov.uk/government/statistics/national-travel-survey-2014
[6] https://www.gov.uk/government/collections/tempro

6.4.3.2 An experience from London using highway assignment model (HAM) zoning system (700,000 zone pairs) and 1 year's worth of data, was that the LGV matrix had values in for approx. 20% of the cells. Using the LTS zoning system (8,000 zone pairs) approx. 80% of cells with at least 1 trip was filled.

- DfT Base Year Freight Model (BYFM) for HGVs

6.4.3.3 Whilst it is recognised that the BYFM data is out-of-date (2006 base) there are very little options for an alternative source. TrafficMaster for HGV is not good as it is a very small sample. LGV is better and car mode is good.

6.4.4 It should be noted however that these may not be fully applicable for smaller study areas, and other local study specific surveys may be required.

6.4.5 For public transport and to separate bus (and potentially unidentified rail) trips from road based trip sources supplementary data such as rail ticketing information or bus ticketing data can be used.

6.5 What information should be included in project reports with regard to accounting for MND in building a model matrix?

6.5.1 **Information regarding MND collection should be presented in the traffic survey report accompanying the model development report. Typical sections found in survey reports should be included, however owing to the specific nature of the survey, a number of additional sections should be included:**

a. Statement on privacy;
b. Explanation of the technology including the type of events surveyed;
c. Flowchart of the methodology used by MNOs to derive trips, mode and purpose from MND, with associated commentary;
d. Details on the expansion methodology;
e. All checks and verifications undertaken and initial adjustments which may have been necessary.

6.5.2 **It is recommended that any survey documentation provided by the MNO is appended to the report, with a report on:**

a. adjustments made;
b. ranges and outliers; and
c. a presentation of tabular and graphical comparisons.

7. Legal and Ethical Considerations

7.1 Why can't individual traces be provided to model developers?

7.1.1 Traces of individual mobile phone records cannot be provided to transport model developers. This is principally due to law, specifically the Data Protection Act 1998 (DPA), which prevents 'personal data' (i.e. data which can be used to identify living individuals either in isolation or in combination with other datasets) from being disclosed.

7.1.1.1 The Data Protection Act (DPA) of 1998 was made by parliament in response to the EU Data Protection Directive of 1995. According to both, the principles of data protection do not apply to data rendered anonymous in such a way that the data subject is no longer identifiable. There are various anonymisation techniques. One of these is to pseudonymise data relating to specific individuals. Another is to aggregate data for a number of individuals within, for example, a trip matrix. These and other techniques are discussed in the ICO published document entitled 'Anonymization: managing data protection risk code of practice'. There is a link to this document in Para 7.2.2.

7.1.1.2 In addition to the DPA, there are The Privacy and Electronic Communications (EC Directive) Regulations 2003 (PECR). These sit alongside the DPA and contain some extra rules for electronic communications. Cell id or event data is covered by Regulation 14 as location data. This states that location data may be used without the consent of the user provided that the user cannot be identified from the data (which is consistent with the principles of the DPA). In these circumstances, the data may be used by third parties under the authority of the MNO.

7.2 What data can legally be provided to model developers?

7.2.1 Data which is anonymised (i.e. data which when used in isolation or combined with other available datasets cannot identify living individuals) can be provided to model developers. As such, the MND, which is provided to model developers, would have undergone processing by the MNO to ensure it is anonymised.

7.2.2 Anonymised data is not considered to be personal data and as such is not bound by the DPA. However, the way in which anonymization is conducted is guided by codes of practice. As of 2015, the code of practice used to guide MNOs in anonymising MND is owned by the Information Commissioner's Office (ICO) and entitled: *Anonymization: managing data protection risk code of practice* which is available here from the ICO's website.

7.2.3 The way in which anonymization is implemented may differ by MNO. Therefore, practitioners should request from the MNO the key processes, which have been applied, and the likely consequences / biases, which result from the anonymization process.

7.2.4 Typical anonymization processes used by MNOs include:

a. applying a minimum origin destination value (i.e. if there are less than *x* movements for a single OD pair then a lower cap of *x* is applied) and/or;
b. aggregating the underlying zonal system to reduce the number of OD pairs which need to have a minimum cap applied; and/or
c. aggregation of multiple days of data together, rounding results to lower resolution values.

7.2.4.1 How the minimum "x" value applies across the different time periods, segmentation, etc. depends on the MNO. There is not a legal requirement for this and the MNO will make a policy and process based more on perception, than compliance.

7.2.4.2 This is important as for a modeller it might be desirable to know the value of x; and to agree a process of aggregation (over time or space or modes or purposes) that will ensure that this threshold is always exceeded, avoiding downstream biases.

7.2.4.3 Legally, traces of individual phone movements can be supplied to and used by third parties provided there is no personal information contained in the data. According to the European Commission, this includes data containing a pseudonymised user id provided that the person to whom the data is supplied does not have access to the data encryption key or the personal data to which it is linked.

7.2.4.4 That said, there is no reason why any modeller would need the pseudonymised user id and any MNO could remove it before supplying the data in order to be doubly sure - effectively making it anonymous. There is also no prospect of being able to identify a user from the places visited given the spatial resolution which is achievable with the data - it is not GPS data which is accurate to 5 or 10 metres. MNOs may choose not to supply this information, though due to the reputational risk of being perceived to provide personal data.

7.2.4.5 An interesting point which has not been considered is where a client uses data from a MNO subject to certain conditions regarding that usage. Those conditions arguably represent the 'authority' referred to in the PECR. If therefore a condition was that the data could only be used by that client for a single purpose or type of purpose, then the client could be in breach of the PECR if they fail to comply with the conditions (not to mention being sued by the MNO for loss of business).

7.2.4.6 For example, data may be provided to a client for use on a certain project or type of projects (eg HE or DfT projects). If the data is then used (say by a consultant) on different projects (say for another highway authority), then that could be a breach of the PECR. It might be wise therefore for the MNO and client to be clear as to the purposes for which the data can be used - ideally through a written contract.

8. Summary

8.1.1 This paper provides recommendations and background information related to the use of MND in transport modelling, in the context of building OD matrices. It provides these recommendations and information related to five topic areas which were initially identified through engagement with the supply chain:

a. MND pre-processing;
b. MND data request / specification;
c. Benchmarking;
d. MND to model matrix; and
e. Legal and Ethical Considerations.

8.1.2 The recommendations and background information have been made with expert input from a range of technical authors who currently practice in the use of MND in transport modelling and thus should reflect current best practice. It is recognised that the use of MND in transport modelling is still an emerging technology and as the supply chain matures, the approaches employed will evolve. However, the information in this paper should allow the DfT to fill a gap in WebTAG by providing recommendations which can be used as a basis to draft guidance in this area whilst recognising the evolving nature of the industry.

Appendix A

Glossary

Term	Meaning
2G, 3G, 4G	G refers to the generation of mobile telecommunications technology
BTS	Base Transceiver Station
BYFM	Base Year Freight Model
CDR	Call Data Records
CID	Cell Identifier
DfT	Department for Transport
GSM	Global Systems for Mobile communications
HA	The Highways Agency, currently known as Highways England
HBO	Home Based Other
HBW	Home Based Work
HE	Highways England, formally known as the Highways Agency
JTW	Journey to Work
LAC	Local Area Code
LSOA	Lower-layer Super Output Area (SOA)
MNO	Mobile Network Operator
MSOA	Middle-layer Super Output Area (SOA)
NHB	Non-home Based
NTEM	National Trip End Model
NTS	National Travel Surveys
OD	Origin-Destination
PA	Production-Attraction
PCU	Passenger Car Unit
PTE	Passenger Transport Executive
SOA	Super Output Area

TfL	Transport for London
WebTAG	Web-based Transport Analysis Guidance

Appendix B

Stakeholder List

FULL NAME	ORGANISATION
Alan Feeney	Department for Transport
Aled Davies	TfL
Aliasgar Inayathusein	TfL
Alistair Crossling	EE
Allos Anan	Atkins Global
Andrew Bagnall	Peter Brett Associates
Andrew Merrall	Atkins
Andrew Stoneman	WSP PB
Andy Emmonds	TfL
Ben Lethbridge	EE
Bill Oates	ONS
Bryan Whittaker	Arup
Carl Goves	Transport Systems Catapult
Charisma Choudhury	University of Leeds
Charles Pangrazi	Vodafone
Chris Pringle	Elsevier
Chris Roe	Movement Strategies
Daniel Steinberg	Vodafone
Dave Ladbrook	ITO World
Dave Sweeney	Telefonica
David Connolly	Systra
David McArthur	Univeristy of Glasgow
Devrim Kafa	PTV Group
Eddie Wilson	Bristol University
Erik de Romph	Delft University of Technology
Fiona Docherty	Transport Scotland
Gavin Hawkins	Telefonica
Geoff Smith	Jacobs
Gordon Finne	Canton AARGAU
Hugh Neffendorf	Katalysis
Ian Palmer	TfGM
James Cockerton	TfL
James Hobbins	Mouchel
Johannes Schlaich	PTV Group
John Allan	Systra
John Burns	
John Polak	Imperial College
John Preston	Southampton Uni
John Rands	Citi Logik
Jonathan Turner	TfL

FULL NAME	ORGANISATION
Jordy van Kuijk	Red Ninja
Julia Gerlach	Tu Dresden
Katarzyna Sila-Nowicka	University of Glasgow
Kevin Lumsden	Peter Brett Associates
Kostas Goulias	Uni. of California S.B.
Lora Mihova	Telefonica
Lyndsay Kennedy	Transport Systems Catapult
Marcus Chick	WSP PB
Maria Diet Gutierre	NTNU
Mark Birkin	Leeds University
Marlon Sharland	Scisys
Martin Thust	DBFV
Matthias Heinrichs	DLR
Mayara Monteire	UFPE – Brazil
Nadia Lyubimova	WSP PB
Nick Bromley	Citi Logik
Nick Corby	Highways England
Pablo Aloaez	AECOM
Pawel Kucharski	Department for Transport
Peter Davidson	Peter Davidson Consultancy
Peter Jones	UCL
Phil Richards	Atkins
Philippe Perret	Citi Logik
Rajesh Krishnan	ITS P&E / Imperial College
Rehan Mien	Mouchel
Reza Toluei	AECOM
Richard Bradley	Atkins
Robin Cambery	DfT TASM
Robin North	Transport Systems Catapult
Roger Himlin	Highways England
Rui Moncelino	Uni. Hospital Southampton
Shaleen Srivastava	PTV Group
Siamak Khorgami	AECOM
Stephen Cragg	Transport Scotland
Stephen Wood	Department of Regional Development - Northern Ireland
Stig N. Andersen	NDRA
Susan Grant-Muller	ITS Leeds
Susan Williams	Office of National Statistics
Tim Day-Pollard	Mott Macdonald

FULL NAME	ORGANISATION
Timothy McHugh	O2
Tom Metcalfe	WSP Parsons Brinckerhoff
Tom van Vuren	Mott Macdonald / ITS Leeds
Tony Dichev	TfL
Tony Morris	TfGM
Vanua Thakuriah	University of Glasgow
Wimvander Hoeven	Mezuro

Appendix C

Workshop Reports

Workshop 1: Benchmarking requirements	Workshop 2: Technical Approaches
MV7_TECH001_Wor kshop 1 Technical N	MV7_TECH003_Wor kshop 2 Technical N
Workshop 3: Pan-European Experience	**Workshop 4: Best Practice**
MV7_TECH005_Wor kshop 3 Technical N	MV7_TECH006_Wor kshop 4 Technical N

Appendix D

MND Overview – Storyboard

MND Storyboard for short animation/film (Duration=2mins:40s)

Slide 1: Image/animations

Duration: 20 Secs

Sequence: Word cloud with words relating to MND appears. The following words "why, for who and purpose" become more prominent as the rest of the word cloud becomes more opaque and fades into the background.

Slide 2: Setting the context

Duration: 5 Secs

Sequence: 3D animation of a city with people, cars, bicycles, trains....?

Do we want a more national perspective including Motorways/long distance travel?

Slide 3: Traditional methods for data collection

Duration: 20 Secs

Sequence: Show images and display the following:

- 2D Model of a city / A strategic plan view
- Data used in a strategic model is:
- * Roadside interviews - only one day of a year
- * Automatic counting
- * Manual counting
- * House hold Surveys
- * Census Data
- * ANPR

Slide 4: Dispelling the myths and providing an up to date status of MND in the UK.

Duration: 10 Secs

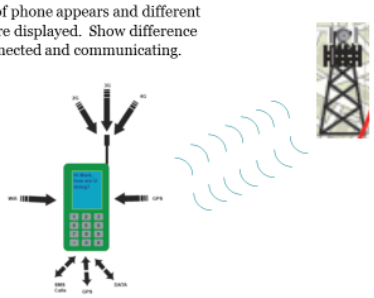
Sequence: starts with image of mobile phone data as a chest with golden light coming out of it, inferring treasure. Zoom into chest, chest opens and padlock with a key hole in the shape of a £ sign falls to the ground. The camera moves to a position to look inside where a vault made of gold is reviled this is covered with smaller combination locks or digital code keypads.

MND is the saviour!!!.....
...or is it????

Slide 5: Image/animations

Duration: 10 Secs

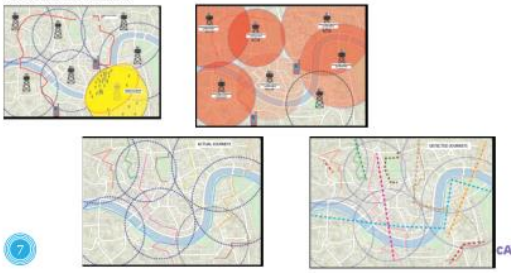
- Sequence: Image of phone appears and different means of comms are displayed. Show difference in pinging and connected and communicating.



Slide 6: Technical description of how phones communicate with Cells and variables....

Duration: 30 Secs

Sequence: Show cell tower layout, then show cell zones and their overlaps. Show graphic of a single phone movement within a city. Show pinging /connection to the different cells throughout a journey and time stamp of establish contact time and handover/engagement with the next cell. Show zone adaption due to demand, show actual movement vs. detected movements.



7

Slide 7: Legal information/situation

Duration: 20 Secs

Sequence: Images of privacy cases/protests. Tabloid headlines..... Then show bullet points

Legal

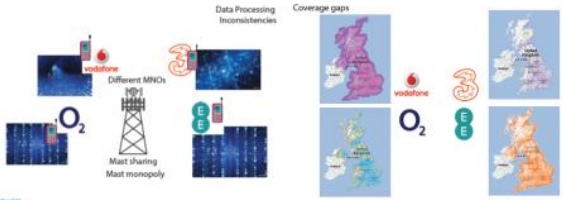
- Aggregation/privacy
- State of affairs?
- Legal cases
- Public cases
- Public enquiry
- other.....

8

Slide 8: Image/animations

Duration: 10 Secs

Sequence: Show the difference operators, show how they can sometimes share masts in busy densely populated areas, describe how they don't share elsewhere to maintain a competitive advantage. Show overall coverage. Zoom in to show variance within an more focused area to demonstrate how a single MP data supplier could have holes in the important data/possible areas of interest (will buyers know this before they buy the data?)



9

Slide 9: Conclusions

Duration: 30 Secs

Sequence: Show top level bullet points..

- What can MND provide?
  - Show sub level bullet points (TBC)
- What can MND not provide?
  - Show sub level bullet points (TBC)
- What could MND provide if combined with other data?
  - Show sub level bullet points (TBC)

10

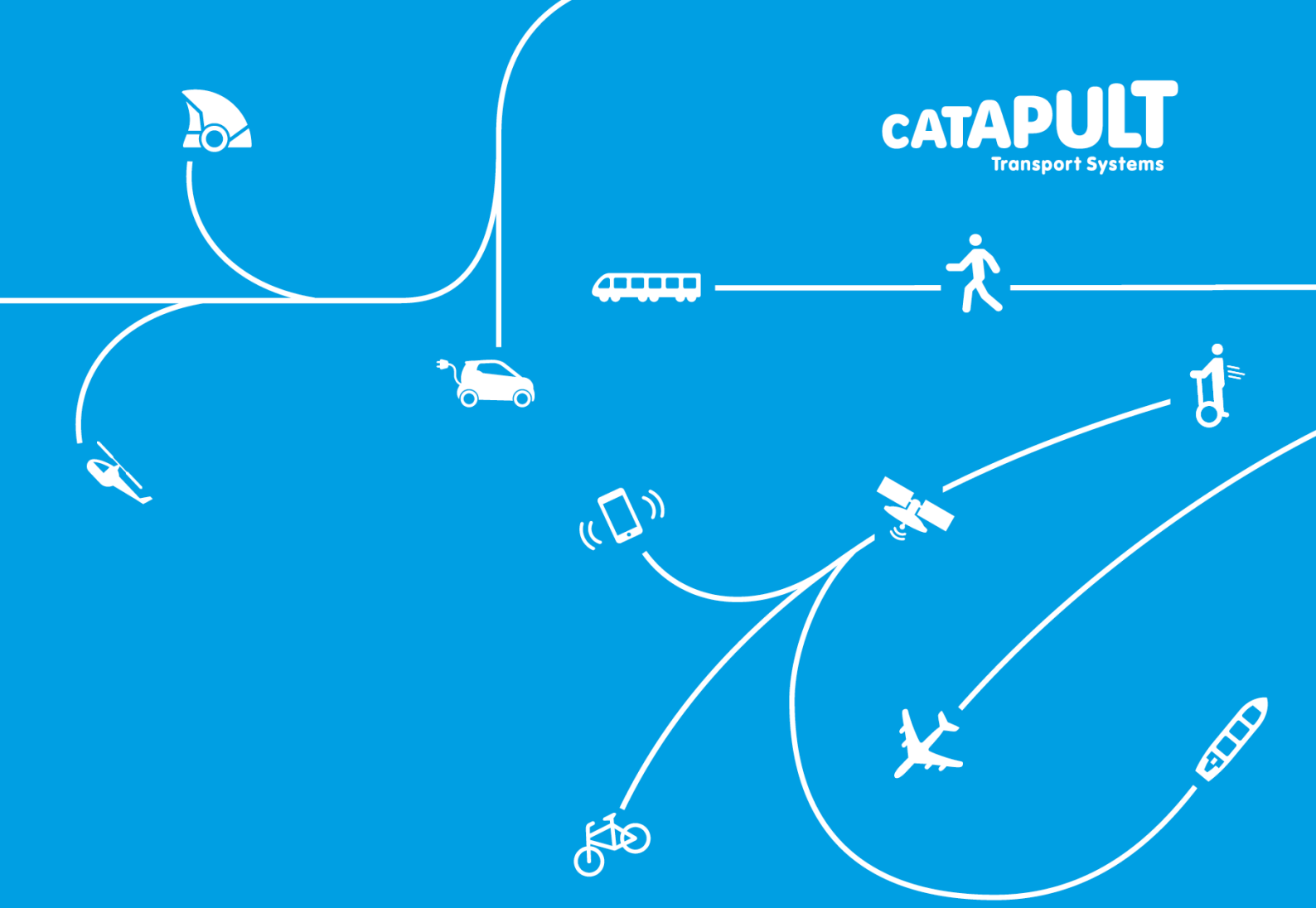
Slide 10: Credits

Duration: 5 Secs

- Show TSC and DfT logos and information of M&V BU that created the animation.

11

CATAPULT
Transport Systems



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