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OVERVIEW OF RESEARCH SUPPORTING DEVELOPMENT OF A NATIONAL NOISE MODELLING SYSTEM FOR ENGLAND

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ABSTRACT

The United Kingdom Department for Environment, Food and Rural Affairs (Defra) commissioned the design and build of an environmental noise modelling system (NMS). The NMS has been developed to support Defra in preparing its environmental noise evidence base by preparing national road and railway noise models. This paper provides an overview of the fourteen research projects undertaken to support the implementation of CNOSSOS-EU in England, and the development of the NMS. This includes sensitivity testing of the road and railway source emission models, developing localised input data for road traffic flows, road surfaces & road junctions; railway and light rail vehicles; ground cover, meteorology and calculation settings for propagation modelling. It highlights the NMS system design, and the open data standards developed to support both internal data process workflows, and interaction with third party systems.

Keywords: *environmental noise, noise mapping, big data, noise modelling, GIS*

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1. INTRODUCTION

The UK Department for Environment, Food and Rural Affairs (Defra) commissioned the design and build of an environmental noise modelling system (NMS). A functional requirement for the NMS is to support Defra in meeting its regulatory requirements to produce strategic noise models and maps for relevant road and railway sources in England, along with preparing analysis to fulfil the requirements of the Environmental Noise (England) Regulations 2006 (as amended) (the 'Regulations') [1], the Defra 25-year Environment Plan (25YEP) [2], and the Public Health Outcomes Framework (PHOF) [3]. These requirements are being delivered by producing a national environmental noise model with associated coverage, beyond the extents required by the Regulations. The noise models are being delivered in line with the requirements of the adapted assessment methods based on the Calculation of Road Traffic Noise (CRTN) [4] and Calculation of Railway Noise (CRN) [5], and CNOSSOS-EU [6].
While Defra had previously undertaken national coverage noise modelling in line with the Regulations during R1, R2 and R3 [7-10], the expansion of the coverage to include all roads and railways in England, and the first large scale implementation of the CNOSSOS-EU methodology in the UK, introduced a number of challenges and opportunities which Defra wished to investigate prior to the NMS system being implemented.
The aim of the research was to support the automated and reproducible modelling and calculations to be undertaken within by the NMS. The main objective developed out of

this aim was to support development of a national coverage noise calculation model, and in turn address queries including:

- What input data is required?
- Where does the model require high quality data?
- Who can supply the input data?
- How can the modelled reflect the UK situation?
- When could the calculations be completed?
- How could such a model be implemented?

2. RESEARCH PROJECTS

To address these queries and support the development of the NMS, and the implementation of CNOSSOS-EU in England, Defra commissioned 14 research studies projects investigating the following topics:

- CNOSSOS-EU Road Source:
  - Unknown traffic flows
  - Junction and roundabout flows
  - Junction and roundabout corrections
  - Road Surfaces
- CNOSSOS-EU Railway Source:
  - Heavy Rail Emissions
  - Light Rail Emissions
- CNOSSOS-EU Propagation:
  - Ground cover modelling
  - Meteo corrections
  - Calculation benchmark testing
- Noise Modelling System:
  - Input Data
  - Data Standards
  - System Design

The final reports for each of these projects are due to be published, and this paper provides a brief overview of the projects and highlights key findings.

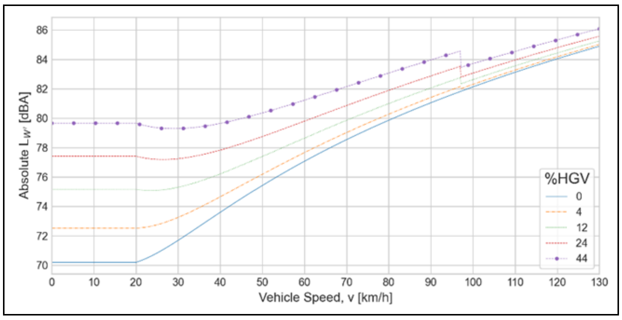

Figure 1. Vehicle speed sensitivity sweeps with composite flows: %HGV, showing discontinuity at 97 km/h.

3. ROAD SOURCE

The investigation of the CNOSSOS-EU road traffic source model aimed to gain an understanding of the effect of input data quality on the uncertainty of the resultant sound power emission levels.

Using an approach first used by the project team when investigating CRTN and NMPB'96 Interim Methods [11,12], a Python implementation of the CNOSSOS-EU road traffic source model was developed to enable parametric sensitivity analysis to be performed for each of the model input parameters. The output results were analysed to quantify accuracy implications & uncertainty, and identify parameters with the greatest influence on road SWL emissions.

The results indicated the input data sensitivity could be characterised as follows:

- **Vehicle speed:** Max uncertainty of ±11 km/h is recommended for traffic volumes typically dominated by cars
- **Surface type:** Deriving surface correction coefficients should be considered for each use case. Uncertainty is lowest where speeds are <30 km/h
- **Surface gradient:** Significant at low speeds for light vehicles (downhill), and at high speeds for medium/heavy emissions
- **Traffic flow:** Changing flow by a factor of 1.6 changes emissions by ±2 dBA. Sensitivity is greatest on lower trafficked roads
- **Flow composition:** Assumptions regarding the %HGVs is more important on lower speed roads
- **Air temperature:** Road traffic noise emissions are relatively insensitive to air temperature

More detail may be found in the 2022 paper [13], and the final report published by Defra.

4. ROAD SOURCE – UNKNOWN TRAFFIC FLOWS

The NMS includes all roads in England; however, traffic count and model data does not include all roads. The project aimed to develop a toolkit to convert 12-hour traffic flow data to annual average day, evening and night data required for strategic noise modelling with CNOSSOS-EU, and to identify approaches to fill gaps in road traffic flow data.

Scale factors were developed for three vehicle categories, and for three road classes, for situations where some road traffic count data was available, Figures 2. Where it was unavailable, and could not be derived based on adjacent links in the network, a range of default traffic flows by road class were proposed, Figure 3.

	All Vehicle Types	Cars	LGVs	HGVs
Day (0700-1900)	0.806	0.808	0.820	0.740
Evening (1900-2300)	0.116	0.122	0.097	0.082
Night (2300-0700)	0.078	0.070	0.083	0.178

	A Road	B Road	Unclassified Road
Day (0700-1900)	0.834	0.835	0.903
Evening (1900-2300)	0.103	0.086	0.080
Night (2300-0700)	0.064	0.079	0.017

Figure 2. 12-hour Traffic Flow Expansion Factors derived from a sample of traffic counts, and proportion of 24-hour Traffic in other time periods based on a sample of traffic counts.

Category	24hr AADT flow	Source
B Road	3,000	DfT count database
C Road	1,000	DfT count database
Unclassified Road	400	DfT count database
Service Road	400	As Unclassified Road (DfT count database)
Dead end road	200	Breakpoint in DfT traffic estimates and approx. 3dB lower than 400 vehicles option for Service Road roads

Figure 3. Recommended Default values for different road types (24-hour AADT).

5. ROAD SOURCE – JUNCTION & ROUNDABOUT TRAFFIC FLOWS

The NMS includes all roads in England; however, traffic count and model data does not include slip roads and roundabout segments. The project aimed to develop a junction and roundabout traffic flow rulebook suitable for automation within the NMS input data transformation process. Based on a literature review, and analysis of National Highways Webtris data [14], 14 rulebook examples were developed, Figure 4.

6. ROAD SOURCE – JUNCTION & ROUNDABOUT CORRECTIONS

The CNOSSOS-EU road traffic source methodology includes corrections to account for accelerating and

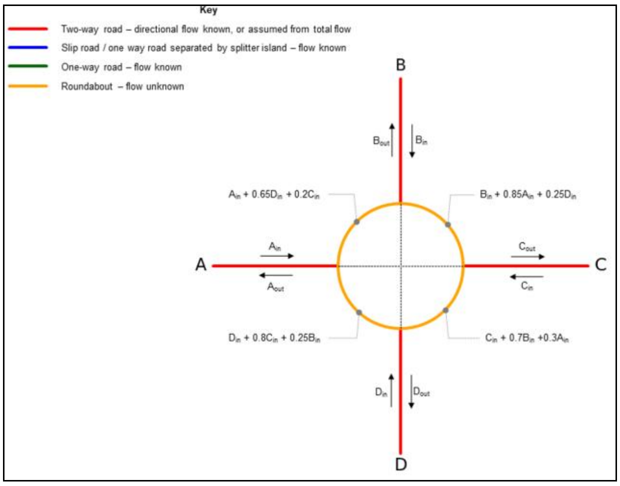

Figure 4. Example of a roundabout rulebook.

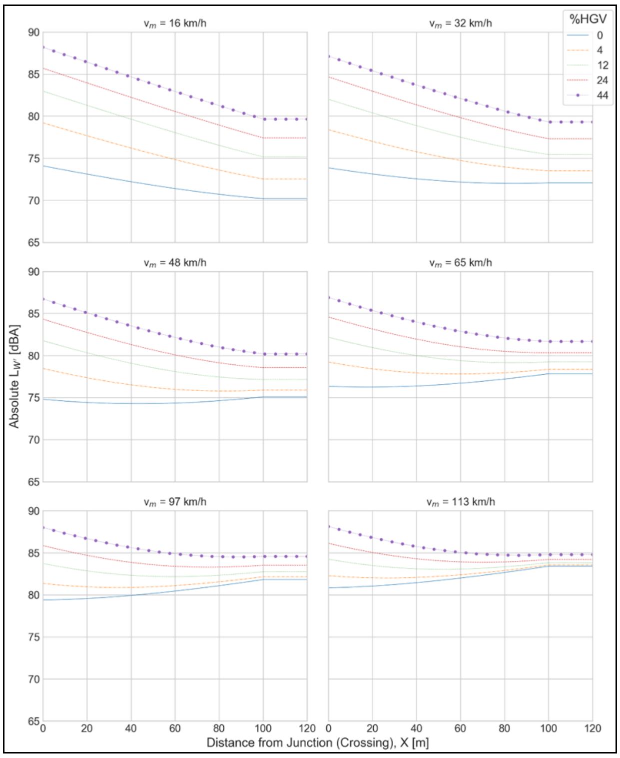

Figure 5. Distance to junction (crossing) with composite traffic flows and range of % HGV.

decelerating traffic within 100m of traffic light-controlled junctions and roundabouts. The project aimed to quantity the change in calculated road traffic source emission near junctions and roundabouts, and identify how the model could be constructed to implement the corrections.

Parametric analysis was undertaken for each junction type, for each vehicle class, and for a range of composite traffic flows. It was identified that the corrections have larger effects near junctions, at low speeds, for high proportions of HGVs; up to about 7 dBA for composite traffic flows near junctions, and 5 dBA near roundabouts, Figure 5.

The report recommended to include the corrections, with road segments split into 25m lengths (or less) within 100m of the junctions.

7. ROAD SOURCE – ROAD SURFACES

The CNOSSOS-EU methodology includes a table of 17 road surface types in Appendix F Table F-1, these are based on pavement constructions typical within The Netherlands. The project aimed to develop road traffic source emission parameters, and road surface corrections, to represent the English road traffic fleet, and common UK road surfaces.

Based on literature review, existing CPX measurement data, and National Highways pavement management data (HAPMS) [15], source emissions parameters and road surface corrections were developed for UK values for CNOSSOS-EU database.

Category	Coefficient	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
1	A_R	80.22	86.32	84.82	90.22	97.22	93.82	83.92	73.32
	B_R	24.21	35.71	33.11	19.91	26.71	31.41	33.21	34.21
	A_P	95.19	89.79	87.99	84.49	81.99	85.29	81.69	74.39
	B_P	-4.12	4.38	4.88	5.18	5.18	5.18	5.18	5.18
2	A_R	88.23	92.73	95.23	100.43	101.23	94.63	87.33	83.13
	B_R	27.42	33.22	30.02	21.22	27.52	33.62	35.72	37.52
	A_P	105.10	99.80	100.10	98.30	100.60	97.40	90.80	84.60
	B_P	-3.19	3.41	5.11	5.21	5.21	5.21	5.21	5.21
3	A_R	91.23	95.73	97.73	104.43	104.63	98.03	90.63	85.13
	B_R	27.42	30.92	28.72	22.82	29.22	34.52	36.02	38.02
	A_P	108.40	103.80	103.10	102.50	102.20	98.10	93.40	87.10
	B_P	-1.29	1.71	3.31	3.71	3.71	3.71	3.71	3.71
4a	A_R	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B_R	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A_P	93.00	93.00	93.50	95.30	97.20	100.40	95.80	90.90
	B_P	4.20	7.40	9.80	11.60	15.70	18.90	20.30	20.60
4b	A_R	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	B_R	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	A_P	99.90	101.90	96.70	94.40	95.20	94.70	92.10	88.60
	B_P	3.20	5.90	11.90	11.60	11.50	12.60	11.10	12.00

Figure 6. CNOSSOS-UK proposed road noise emission parameters.

The project developed CNOSSOS-EU rolling & propulsion noise coefficients for UK fleet, Figure 6. Road surface corrections for six common pavement types in England were added to the CNOSSOS-EU database, Figure 7, and a lookup table was produced which aligned 162 road surface types from HAPMS to 23 surface types in the extended CNOSSOS-EU database.

ID	description	cat	α_m 63 Hz	α_m 125 Hz	α_m 250 Hz	α_m 500 Hz	α_m 1 kHz	α_m 2 kHz	α_m 4 kHz	α_m 8 kHz	β_m
CRTN01	Pervious macadam	1	6.2	-1.8	-1.8	-0.9	-5.5	-7.6	-5.4	-3.8	-1.8
		2	13.2	4.8	3.3	-1.0	-2.4	-2.7	-1.3	-0.8	0.5
		3	13.5	5.5	3.5	-1.0	-2.4	-2.7	-1.3	-0.8	0.3
CRTN02	Impervious macadam	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRTN03	Concrete	1	8.3	-0.4	5.1	2.5	1.5	2.9	1.8	-0.3	7.6
		2	0.5	8.9	7.4	3.5	3.9	3.4	1.0	0.4	3.2
		3	0.4	10.1	7.7	3.5	3.4	2.7	0.7	0.3	2.0
LA11101	LA111 Hot Rolled Asphalt	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA11102	LA111 Brushed Concrete	1	9.2	0.5	6.0	3.4	2.4	3.8	2.7	0.6	7.6
		2	1.4	9.8	8.3	4.4	4.8	4.3	1.9	1.3	3.2
		3	1.3	11.0	8.6	4.4	4.3	3.6	1.6	1.2	2.0
LA11103	LA111 Thin Surfacing	1	9.8	0.1	-1.2	-1.8	-3.6	-5.4	-4.0	-2.0	-2.9
		2	13.2	4.8	3.3	-1.0	-2.4	-2.7	-1.3	-0.8	0.5
		3	13.5	5.5	3.5	-1.0	-2.4	-2.7	-1.3	-0.8	0.3

Figure 7. CNOSSOS-UK road surface correction factors.

8. RAILWAY SOURCE

The investigation of the CNOSSOS-EU railway traffic source model aimed to gain an understanding of the effect of input data quality on the uncertainty of the resultant sound power emission levels.

Using an approach previously used by the project team when investigating CRN and RMR 1996 Interim Method [16,17], a Python implementation of the CNOSSOS-EU railway traffic source model was developed to enable parametric sensitivity analysis to be performed for each of the model input parameters. The output results were analysed to quantify accuracy implications & uncertainty, and identify parameters with the greatest influence on road SWL emissions.

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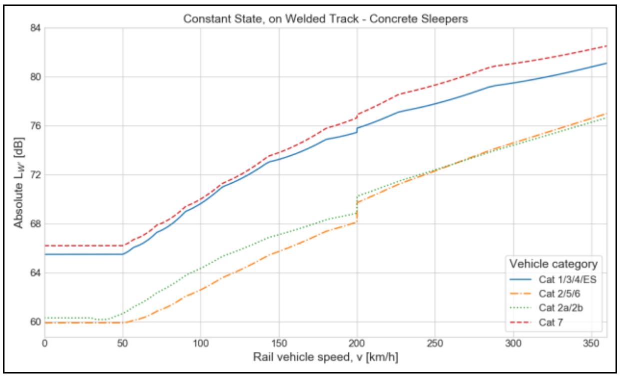

Figure 8. CNOSSOS-UK railway vehicle emission SWL with speed.

The results indicated the most important data collection considerations are to identify:

- Sections of track with impact sources such as joints, and joint density
- The mean speed per vehicle type
- Bridge types which incur a correction and where track is directly fastened to the bridge
- Braking systems
- Curved track, measures against squeal, and curved track known to not squeal, and calculate track curvature
- Rail flow per vehicle
- The number of axles per vehicle
- Wheel diameter for vehicles with cast iron tread brakes

9. RAILWAY SOURCE – HEAVY RAIL

The CNOSSOS-EU rail vehicle database, in Appendix G Table G-5, contains only five example vehicles. The project aimed to develop railway source terms to represent a range of English rail vehicles, on a range of English tracks, in order to improve the quality of the output from the railway source terms model.

Following a literature review, data from previous measurement campaigns and new trackside measurements, extended CNOSSOS-EU railway database tables were developed.

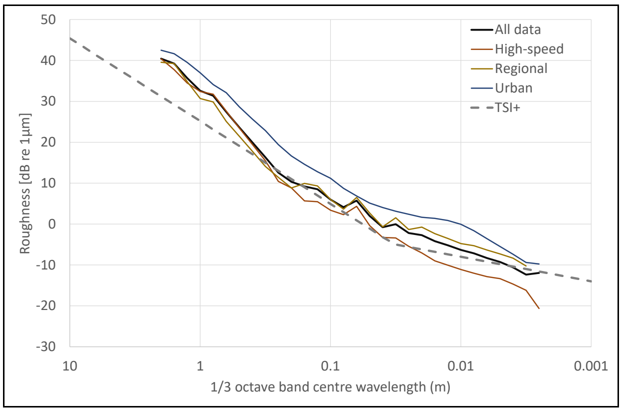

Figure 9. Average (mean) spectra for different track types. Compared to the average spectra across all track forms and the extrapolated TSI limit spectra.

The extended railway database covers:

- 47 CRN rail vehicles to aid model migration, and
- 16 additional CNOSSOS-EU rail vehicle types

The extended database tables also include:

- 4 additional wheel roughness spectra; cast iron tread, composite, disc, and metal sintered brakes
- 3 additional rail roughness spectra; high speed, regional, and urban lines, Figure 9

It was also identified that additional data on rail roughness, and rail fastener stiffness would help further improve the model.

10. RAILWAY SOURCE – LIGHT RAIL

The CNOSSOS-EU rail vehicle database does not contain any specific light rail or tram data. The project aimed to develop light rail source terms to represent a range of English light rail vehicles, on a range of light rail tracks, in order to improve the quality of the output from the railway source terms model.

Following extensive liaison with each of the light rail operators in England and Scotland, literature review and data from previous measurement campaigns, extended CNOSSOS-EU railway database tables were developed.

The extended database covers:

- 12 additional CNOSSOS-EU light rail vehicle types, one per light rail network

Extended database tables also include:

- 1 additional rail roughness spectra, for light rail network
- 1 additional track transfer function, for embedded track

It was also identified that additional data on rail roughness and rail fastener stiffness, and measurement of resilient wheels and traction noise of light rail vehicles, would help further improve the model.

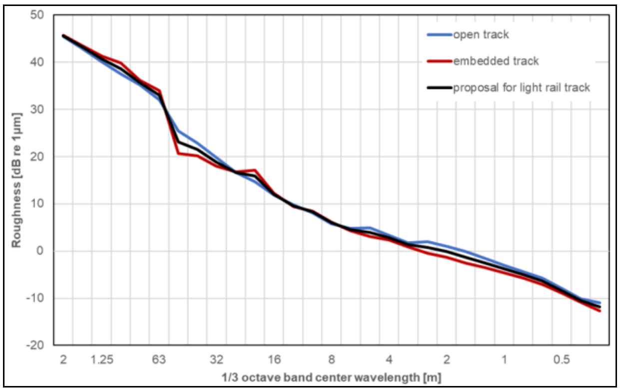

Figure 10. Proposed roughness spectrum for light rail track.

11. PROPAGATION – GROUND COVER MODELLING

The CNOSSOS-EU methodology includes Table 2.5a with G values and flow resistivity for eight different types of ground cover. The project aimed to investigate options available to describe the ground cover in England, and whether the resolution of the ground cover dataset affected the calculated time and the results generated.
Three options, offering broadly low (CLC) [19], medium (CEH LCM) [20], and high (OSMM Topo) [21] resolution description of ground cover areas were identified and tested.
The results of indicated that complexity could double the calculation time, but also appeared to improve the quality of the results. The recommendations were to use CEH LCM 2019 for national mapping, and that it may be preferable to use OSMM Topo data for smaller localised assessments.

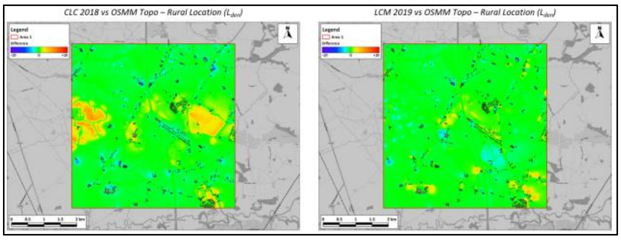

Figure 11. Calculated results difference grids for CLC (left) and LCM (right) compared to OSMM Topo.

12. PROPAGATION – METEO CORRECTIONS

The CNOSSOS-EU calculates propagation twice:

- Straight rays for homogeneous conditions; and
- Curved rays for conditions favourable to propagation from source to receiver

The long-term average sound level is derived using the percentage of favourable propagation (%FP), at the receiver point, based on the source location, for 20-degree increments, for day, evening and night periods, however it is not described how to prepare information of %FP based on long term weather data.
A literature review identified two methods used for NMPB2008 [22] and NORD2000 [23]. The NORD2000 method was fully documented, and all the required input data was available in the UK, namely: average wind speed; wind direction; cloud cover; and air temperature. The %FP was calculated across 131 meteo stations in England, and interpolated to 1 km raster for use within the NMS [24].

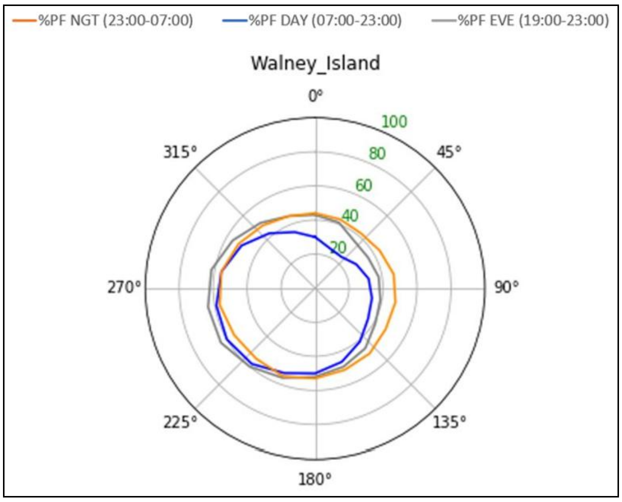

Figure 12. Example of %FP data prepared.

13. CALCULATION BENCHMARKING

The CNOSSOS-EU is a recent methodology, in 2021 when the project commenced there was very little experience in large area noise mapping using the new method.

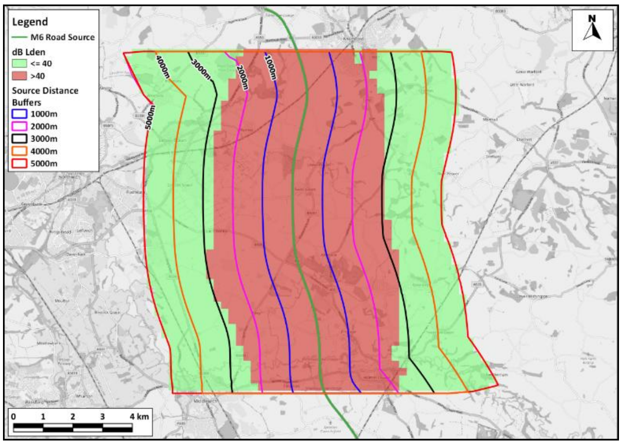

Figure 13. Propagation Distance Test – L_{den} Results.

This project aimed to support decision making on noise calculation parameters, and how this would affect calculation resources, and quality of noise mapping results:

- What source to receiver distance is required for calculated levels of 40 dB L_{den} and 35 dB L_{night} due to road and rail sources?
- What may be considered an optimum set of calculation settings, balancing calculation speed

with results uncertainty, having regard for the CNOSSOS-EU:2020 ±2.0 dB(A) quality criteria?

Using test models covering rural and urban areas, Figure 13, multiple calculation settings were tested one at a time, and in combination. Recommended calculation settings were proposed for delivery of national coverage noise mapping calculations.

14.NMS – INPUT DATA

Strategic noise mapping at national coverage requires a wide range of input datasets, many of which need to be spatially referenced, and come from a range of data suppliers and stakeholders. This project aimed to identify input data requirements, review options for required input data, and identify requirements for input data validation and pre-processing, including QA & QC processes.

Input parameters and results output requirements were identified for CNOSSOS-EU, CRTN, CRN, 25YEP, and PHOF, and reviewed against published literature. Almost 100 datasets were identified and screened, of which 39 underwent detailed review, and 37 were proposed as inputs for the NMS.

Recommended datasets were supplied by OS, EA, CEH, Met Office, NH, DfT, OpenStreetMap, OpenRailMap, RTT, Network Rail, ONS.

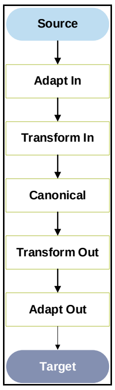

Figure 14. Seven-layer data architecture.

15.NMS – OPEN DATA STANDARDS

There are currently no open data standards for noise models which met all the requirements of the NMS. Open data standards help manage the flow of data through the NMS, and support interoperability with third party GIS and noise mapping software.

Existing spatial data, input data and output data standards, policy & regulatory requirements, government policy on open standards, Defra data principles, and published noise mapping data schemas, were reviewed including:

- INSPIRE, GEMINI, ISO 19100 series, ISO 196500 series, ISO 17534, ISO 15836, COVADIS and EEA Reportnet 3 noise reporting templates
- CadnaA, dBmap.net, eNoise City GML, DIN 45687, IMMI, LimA, MithraSIG, noise3D.net, NoiseMap, NoiseModelling, ODEN, Predictor/iNoise, SoundPlan

Conceptual and logical data models were developed for data flowing in and out of the NMS. The content and format of open data standards were proposed for a range of data layers supporting CNOSSOS-EU, CRTN and CRN, alongside proposals for metadata.

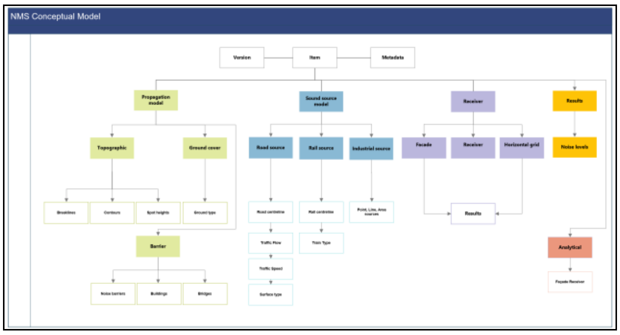

Figure 15. NMS conceptual model.

16.NMS – SYSTEM DESIGN

Off-the-shelf software components within the NMS conceptual design had not previously been combined. This project aimed to develop a mapping prototype of the NMS combining all key components within MS Azure cloud hosting:

- Web application firewall- security
- MS Azure Database for PostgreSQL – Hyperscale (Citus)
- Safe Software FME server – data integration and processing
- Oden – web-based environmental modelling tool
- Azure CycleCloud – HPC orchestrator
- LimA – propagation calculations

The prototype NMS was developed and included a test model area around Manchester [25], and subsequently scaled to full national coverage.

17.CONCLUSIONS

Fourteen research projects were undertaken to support the implementation of CNOSSOS-EU in England, and the development of the NMS. The findings and outputs for the projects were all used during delivery of the strategic noise mapping of roads and railways in England.

18.ACKNOWLEDGMENTS

We gratefully acknowledge Defra for commissioning the research studies in support of the NMS.

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