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DELIVERING NATIONAL SCALE NOISE CALCULATIONS WITH CNOSSOS-EU THROUGH CLOUD COMPUTING AND SOFTWARE OPTIMISATION

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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 discusses the challenges and solutions as part of Defra's NMS project to enable CNOSSOS-EU calculations to be delivered on 10 metres grids and at the facades of all residential buildings in England, Scotland and Wales.

Keywords: *noise mapping, cloud calculation, Defra noise modelling system (NMS)*

1. INTRODUCTION

The UK Department for Environment, Food and Rural Affairs (Defra) commissioned the design and build of an environmental noise modelling system (NMS) in 2021. The NMS has been developed to support Defra in preparing its environmental noise evidence base by preparing national road and railway noise models. Defra's model has been produced 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]. This has required the model to incorporate all public road and railway noise sources and provide national coverage with respect to calculated noise maps and exposure statistics. The noise models have been 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].

The NMS has been designed to connect a series of components secured behind a web application firewall. The design of the NMS has taken a 'decoupled' approach which utilizes existing commercial products with 'ground up' development in areas such as its database design and Extract Transform Load (ETL) tools [7].

At the heart of the NMS is a Postgres geospatial database served on Azure CosmosDB. The database has been designed to store noise model and noise exposure datasets alongside each other. In support of Defra's requirements, the NMS has been designed to deliver automated processes whereby selected input datasets are transformed into noise model datasets using Feature Manipulation Engine (FME) software.

The models are stored in a manner which conforms to its system's open data standards which have been developed in parallel to the NMS.

Noise calculations are delivered using a calculation engine which utilizes LimA [8] software modules including noise calculation cores. The calculation engine utilizes a range of components including Azure Cycle Cloud which provides flexibility by allowing calculations to scale up and down by deploying additional virtual machines to the calculation task.

The NMS and the calculation of Defra's model using CNOSSOS-EU has introduced unprecedented computation challenges with a need to balance scale with efficiency and accuracy demands. This paper discusses the key challenges and solutions to delivering CNOSSOS-EU calculations within the NMS at a national level.

2. KEY REQUIREMENTS

Defra set several requirements for its NMS and its noise model which have a direct impact on the approach and requirements for noise calculation. These are summarised as follows:

1) The NMS must be cloud based and scalable
2) Defra's noise model must be developed through automated processes, where practically possible, using authoritative datasets and stored centrally within geospatial database
3) The spatial quality of the noise model must be suitable for localised, detail applications as well as strategic use for national mapping exercises – this means that model simplification is not an option while setting up the geospatial database
4) The noise model must be stored in open standards independent of any noise modelling or calculation solution removing the ability to optimise the noise model itself for a particular calculation solution
5) The noise model must comprise of all public road and railway noise sources and not just those defined under the relevant Regulations
6) The NMS must be capable of delivering noise calculations down to 40 dB L_{den} and 35 dB L_{night} introducing the need for much larger calculation radius and introducing new efficiency techniques applicable to low noise level environments
7) Calculations must be capable of being run for England in 35 days
8) Any techniques adopted to increase computational efficiency should not result in a calculated uncertainty of more than ± 2dB for 90% of receiver point levels.

In combination, these requirements introduce an unprecedented calculation load with firm requirement with respect to the quality of the calculations.

3. RESPONDING TO REQUIREMENTS

During the development phase, focus on efficient, agile and scalable calculation was considered in three areas:

1) Calculation efficiency – Balancing accuracy and compliance with performance requirements at component level i.e. calculation at a single calculation core
2) Distributive Techniques – how to best distribute calculations within a single multi-core machine and across multiple machines
3) Calculation Management – bringing together calculation efficiency and distributive techniques in a managed way.

All three areas were subject to research and development, and associated testing as part of the NMS project.

4. CALCULATION STRATEGY

4.1 Technical challenges

The NMS project is ambitious with respect to extent of project area, detail of model and accuracy demands in calculation. Maximum calculation effort is required when applying CNOSSOS propagation logic.

4.1.1 CNOSSOS calculation method

Compared to CRTN which was previously adopted by Defra to deliver strategic noise maps, CNOSSOS requires working in octaves instead of main frequency and 8-fold propagation paths analysis for a single source-receiver constellation.

4.1.2 Highly detailed model data

NMS has been designed to provide noise modelling data ready for nationwide as well as localised assessment. The resolution of the model therefore needs to be high, as shown in Figure 1.

Noise emissions of sources are pre-calculated within Defra's model and stored in the central database. This avoids interpretations of emissions calculations by different

software tools which may introduce their own adaptation and same time allows for instant inqueries.
The central database delivers model data in a neutral, open format and enables its use by various software products.

The inclusion of all public road and rail sources results in a significant number of emission sources, beyond what would usually be considered in a conventional noise model. This is evidenced by the residential streets in Figure 1.

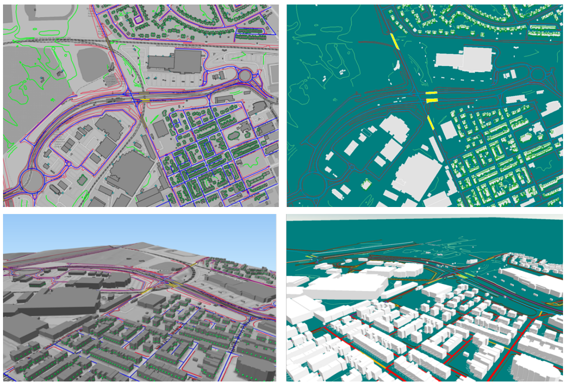

Figure 1. View of Defra's model in open standards (left) and in LimA (right)

4.1.3 Noise Apportionment

The NMS has been designed to support the estimate of noise exposure levels at calculated receiver positions in case of change in emission levels, based on noise apportionment data. For up to 30 most influential sources receptor level contribution per octave as well as the residual noise component need to be stored during the noise calculation. Data is delivered from the LimA calculation cores in a standardised CSV file format which is then ingested back into the central database. This increases calculation overhead by having to write additional information at the end of each calculations. It also requires extensions to LimA's handing of identifier strings to ensure are passed directly from the model into calculation and retained when reporting apportioned noise levels.

4.1.4 Low noise level requirement

To calculate noise at lower levels means that not only major and significant sources of emission are to be considered but rather all roads and rails need to be considered in the calculation. With respect to desired receiver levels in the range of 30 dB, the fetching radius for sources must be set to 3000 m in order to avoid discontinuities in noise grids due to distant high emission sources.

4.2 Calculation parameters and further settings

The immense calculation task does require a careful choice of calculation parameters and extra settings. Though long-standing experience in noise mapping e.g. already showed that small fetching radii for reflector search are reasonable, research was carried out for new parameters and to evidence selected choices in calculation parameters with respect to calculation efficiency (time) and introduce uncertainty (dB).

4.2.1 General calculation parameters

The values chosen for well-established calculation parameters were set to:

3000 m	Fetching radius for road sources
2000 m	Fetching radius for rail sources
25 m	Fetching radius for reflectors
30 dB	Min. relevant receptor levels at night
3 dB	Dynamic error margin (as extreme value)
No	Source segmentation due to ground cover

4.2.2 LimA's established efficiency tools

LimA offers a range of tuning settings to reduce calculation time and 2 key ones are mentioned here as examples. Both of them were introduced into the market by LimA more than 30 years ago.

Most renowned calculation speed tuning feature is the dynamic error margin, whereby a user limits the underestimation of calculated receiver levels, caused by neglection of less relevant sources. It represents a total effect. In many projects this has proven to be a very efficient way to speed up calculation and Figure 2 shows the effect on result and calculation time for a small example with 3 categories of road traffic emission intensity.

However, the need to report noise exposure for all and for major sources hampers the dynamic error concept, as even next to a highway the calculation core might still have to consider minor local roads at distance.

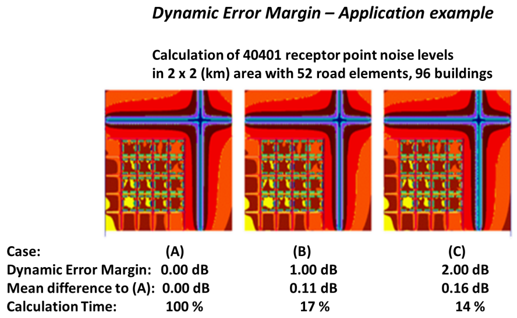

Figure 2. Dynamic Error Margin effects

Another tuning aspect deals with line source segmentation. LimA applies the 'method of projection' where sources are segmented with respect to segmentation of obstacles (e.g. each façade segment of a building) encountered between source and receiver in full 3D geometry analysis. This achieves best continuity for direct and reflected noise contributions.

The 'method of projection' was introduced into the market by LimA and by now is available in most noise mapping products and is described in ISO9613-2024 [8]. However, this only focusses on diffracting barriers.
In distinct model situations the propagation influence of ground cover may become important and an extra segmentation of line sources will be feasible. Therefor LimA does support an optional extra segmentation due to ground cover shapes. With respect to the highly detailed/scattered ground cover data and the fact that CNOSSOS does not deal with this issue, it was decided not to activate this feature.

But with source-receiver distances up to 3 km, and with buildings in urban areas, source segmentation needed further streamlining. Source line segmentation took full details of buildings at a maximum distance of the maximum of 8-fold maximum ground extent or at least 300 m from source or receiver. Source segmentation by further objects at larger distances were only considered with their individual total aperture angle. This technique was found to further rationalise the calculation load.

4.2.3 Efficiency tools developed alongside the project

To further enhance calculation performance it was accepted that under certain circumstances the dynamic error margin logic needed to be subject to 'pre-filtering' of certain sources. This was found to be the case where the calculations were subjected to significant densities of emitter with very similar noise emission levels due to the use of default values. Testing identified that
road and/or rail line sources with an emission level (SPL per m) below 75 dB could be filtered prior to the dynamic error margin when they are at a distance beyond 750 m whilst meeting calculation uncertainty requirement. This logic in effect introduced two calculation radii linked to the importance and influence of different types of sources i.e. high quantity low emission, and low quantity high emission.

Efforts in reflection calculation are reduced by limiting the number of reflecting surfaces next to receivers. Here a minimum aperture angle of 10 degree is used, with adjacent façade segments in same plain especially cared for.

4.2.4 Quality assessment

All strategies are subject to a specific study to ensure calculation accuracy remained within agreed tolerance. Recommended calculation settings result in calculation times of less than 0.4% of benchmark in urban areas, and less than 0.15% in rural areas, with mean difference of about 1.0 dB in urban areas, and 0.5 dB in rural areas, and 95% CI of 2.7 dB in urban areas, and 1.0 dB in rural areas.

4.3 Distribution Techniques

The model is stored in the central database in line with the Ordnance Survey tiling structure. This stores model data in 5 x 5 (km) project areas defined by their OS tile reference. A single CPU takes over a noise calculation task for a 1 x 1 (km) region. With 3 km buffer zone this already results in 49 km² model area to deal with per calculation run.

The NMS was designed to host a central controller node VM which manages a project processing queue and allocates individual projects by their OS tile reference to available VMs, known as the 'worker nodes'. Along with the project details it sends all model data required from central database. All this is organized by PowerShell scripts with the scaling of available worker node VMs managed by Azure Cycle Cloud. This logic is presented in Figure 3.

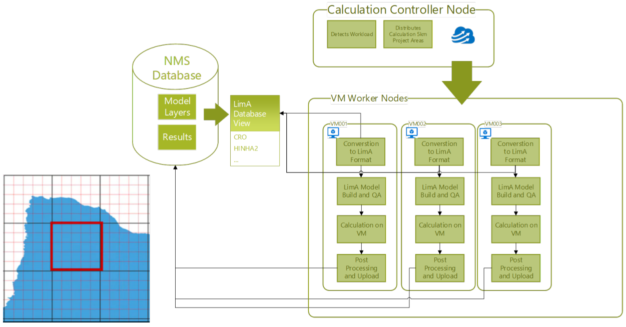

Figure 3. Calculation Distribution Logic

4.4 Calculation Management

Calculation management has to deal with model data transfer, initiating calculation jobs and collecting result files. The demand for apportionment results in massive size result data sets, which can run into several hundred MB per 1 x 1 (km) tile.

4.4.1 Calculation task description

Calculation requirements for project processing are written into Project Management File (*.PRM). This is the only initial user exercise and it is set up in a semi-automated process.

Table 1. Extract of PRM file defining calculation task

runID	nmsRailCNOSSOS_2021_Area8_SE47SE
userID	nmsAdmin
runDate	28.11.2023 16:20
calcDate	28.01.2023
runName	PRJ_320
runDescription	2021 Railway Noise Calculation - CNOSSOS-UK
runType	optimalNoiseMapping
processNodes	100
calcMethod	CNOSSOS-EU
calcSource	Rail
calcReceivers	Grid
gridSpacing	10
modelViews	CMTNMS CRA GBO GELCONT GELSPTH WGB HINHA3R HINHA3A LCMTOP HINHA7
calcRegion	nmsRailCNOSSOS_2021_Area8_PRJ_SE47SE_RLGD__calcRegion.lst
calcReflections	1
calcMargin	3
calcRadius	2000
calcTemplate	L_07M_CF_NMS.STD
calcOptions	BEW LDEN PEGMIN 30 GROUND 0.0001 L_DISLEV 750 75 RGEMI 1900 GEBNZ 4 SEG-TOP- DOPHIN
dbView	defra

4.4.2 Orchestrate the noise calculation

Once all data has been sent to a worker node, a LimA macro developed for the NMS takes over, defining jobs for LimA modules. The actions comprise:

1) Retrieving model data from the central database and converting the data into LimA format without simplification
2) Creating separate job files per 1 x 1 (km) calculation tile
   For each job the calculation input file is generated with respect to the information in the *.PRM file.
3) Job-files are stored in a central spool directory and are dispatched by LimA's DSERVER.EXE to any available out of 7 parallel processing queues. (One CPU is spared to support OS) with each worker node configured as an 8-core VM
4) When all jobs are finished data is zipped and handed over to separate processes for upload into the database.
5) Finaly the VM either takes over a next project or is powered down.

4.5 Hardware

Chosen hardware in the Azure cloud HPC environment is the result of efficiency tests, i.e. costs vs. calculation speed comparison. This testing demonstrated that the optimum configuration was an 8 core VMs with 32 GB RAM. Potential deployment of tasks on up to 150 VMs was ensured for the actual noise calculation as well as all other processes related to the project. Most of actual costs are linked to active processing and data communication across the network.

5. ACHIEVEMENTS

The NMS has been used to deliver noise calculations at national scale in England, Wales and Scotland. For grid calculations alone, the following number of calculation points have been generated:

- England, 1.329 billion
- Scotland, 803 million
- Wales, 212 million

The typical calculation times have been in the region of 0.2 seconds per calculation point. For England alone, national scale road traffic noise calculations on the NMS have a theoretical calculation time of around 2 days plus data transfer overheads across the NMS's 150 worker node VMs as opposed to 384 days on a single worker node VM. The Azure pricing logic means that the total calculation costs will be equal irrespective of the number of identical VMs involved.

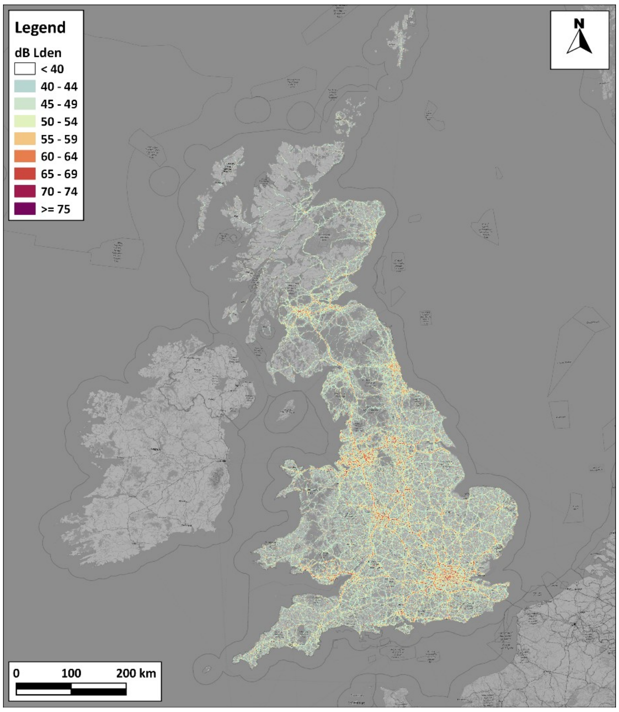

Figure 4. L_{den} road traffic noise map for England, Scotland and Wales

6. CONCLUSIONS

The NMS project demonstrates that detailed large area noise calculations delivered to much lower levels than previously considered are deliverable and achievable through a combination of traditional and optimised efficiency techniques and by utilising modern cloud solutions to create calculation environments.

7. REFERENCES

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