# NETWORK MODELLING SOFTWARE REVIEW

A report to National Grid

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# TABLE OF CONTENTS

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# EXECUTIVE SUMMARY

Pöyry Energy Consulting has been engaged by National Grid Gas plc (NGG) to undertake an independent review of their proposed replacement for the Graphical Falcon (GF) network analysis software, as used for off-line long-term network analysis of the national transmission system (NTS). The replacement software, Simone, has been selected following a rigorous procurement process.

Network analysis is a mathematically complex subject, requiring significant computation. Simone is a network analysis tool that is in widespread use throughout Europe (with deployment by GdF Suez, E.On, VNG, and Gazprom, amongst others) and with an increasing presence worldwide (including Asia and the US). Whilst GF is based on ageing and unsupported technologies, Simone is based on current and supported technologies.

Pöyry Energy Consulting has undertaken an audit-style review of the network modelling software. Following a review of the requirements of offline, long-term network analysis (as laid out in the NTS Transmission Planning Code and IGE/GL/2[1]); Pöyry Energy Consulting wrote a series of observations it thought would be necessary to establish that the software was fit-for-purpose. In addition to these observations, Pöyry Energy Consulting has been furbished with the relevant user guides and product documentation which have provided useful reference material and were afforded unfettered access to the software and various network models (including the NTS).

Pöyry Energy Consulting has also been provided with a full set of results from a joint Simone/GF network validation exercise carried out by NGG during its selection process. In modelling the NTS network, Simone compares very favourably with GF, producing pressure/flow results which are at least as accurate as GF. The mathematical simulation undertaken in Simone appears to behave significantly better than GF, with fewer tendencies to result in mathematical infeasibility and report spurious results. Both the Simone interface and data management procedures also offer some improvements to GF.

After undertaking a review of the requirements for offline long-term network analysis, observing the various tests, and briefly reviewing the mathematical implementation, we conclude that Simone is fit for the purposes of network analysis, as set out in the Transmission Planning Code.

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[1] Institute of Gas Engineers, Planning of Transmission and Storage Systems Operating at Pressures Exceeding 7 bar. Communication number 1627.

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# 1. INTRODUCTION

## 1.1 Software review

Pöyry Energy Consulting has been engaged by NGG to undertake a review of its proposed replacement for the Graphical Falcon (GF) network analysis software, as used for off-line long-term network analysis of the NTS. The replacement software, Simone, has been selected following a rigorous procurement process.

The 2007 Price Control Review of NGG NTS[2] (NGGNTS) introduced the obligation to produce a Transmission Planning Code (the Code), and the obligation to maintain network models as required by the Code. The obligation to maintain the model requires independent verification that the model is fit for purpose.

NGGNTS has historically used the GF software, which was developed by British Gas (prior to privatisation), and successor companies (BG Technology, Advantica). The predecessor to GF, Falcon (now known as Text Falcon), used a remote command line interface, and ran on a central shared server (initially a mainframe computer). A single analysis of the NTS typically took a number of hours. The development of a graphical interface enabled much easier training of network analysts, which, coupled with advancements in computing, facilitated growth in the amount of analysis that could be undertaken. Further developments changed GF from a centrally served system to a Microsoft Windows client based system. Analysis of the NTS now typically takes a number of seconds.

GF is reliant on unsupported technology and will not be developed by its owner. It must therefore be replaced. Simone is a network analysis tool that is in widespread use throughout Europe (with deployment by GdF Suez, E.On, VNG, and Gazprom, amongst others) and with an increasing presence worldwide (including Asia and the US).

This note sets out Pöyry Energy Consulting's findings from the review.

## 1.2 About Pöyry Energy Consulting

Pöyry Energy Consulting is Europe's leading energy consultancy providing strategic, commercial, regulatory and policy advice to Europe's energy markets. Part of Pöyry Plc, the global engineering and consulting firm, Pöyry Energy Consulting merges the expertise of ILEX Energy Consulting, ECON and Convergence Utility Consultants with the management consulting arms of Electrowatt-Ekono and Verbundplan. Our team of 250 energy specialists, located across 15 European offices in 12 countries, offers unparalleled expertise in the rapidly changing energy sector.

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[2] NGG acting as the licence holder in respect of the NTS, as distinct from NGG Distribution Networks, which operate under a different gas transporters licence.

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# 2. REQUIREMENTS FOR NETWORK MODELLING

This section examines the underlying theoretical concepts and the drivers of network modelling to discuss its purpose within the context of the scope of this document. There are both very specific, definitive requirements for network modelling, but also more exploratory and less formal uses. Due to the nature of some of the underlying concepts of pipeline modelling, network analysis can never be absolutely accurate.

## 2.1 Network analysis theory

Network analysis is (in simple terms and as used within the natural gas industry) the activity of simulating gas flows around, and pressures within, a natural gas network. This is mathematically complicated for a number of reasons:

- the relationship between flow and pressure is not linear;
- accurate modelling of the relationship between flow and pressure requires the use of several other variables;
- many of these variables (including flow) cannot be accurately known or measured; and
- a mathematical model requires complex iterative computation.

The computation element of network analysis requires that (when the system is in a steady state) total out-flow from the network (demand) must equal total in-flow into the network (supplies).

The relationship between flow and pressure is usually encapsulated in a ‘flow equation’. The other parameters used within flow equations include obvious candidates like the length and diameter of the pipeline system (which have a very strong relationship to the capital costs of a gas transporter), but also include less obvious parameters, for example:

- internal roughness and/or efficiency of the pipeline (which may need to implicitly include consideration of pipe-bends, etc.);
- temperature of the gas;
- compressibility of the gas;
- altitude of the pipeline system;
- burial depth of the pipeline; and
- thermal properties of the burial material.

Several of these elements cannot be reasonably and/or accurately known. For example, the thermal properties of the burial material might rely on knowing the sand content and water content of the soil: the former of these can vary greatly over a very short distance, and the latter may need correction for seasonal variation.

This means that all flow equations must be derived empirically. This leads to three important observations:

- any particular flow equation will be accurate only within a specific context (e.g. a range of pressures);

- that different parameters or approximations of parameters might be used in different flow equations; and
- that there is overlap between different equations.

The accuracy of a flow equation is therefore dependent on the network model within which it is being used, and where more than one equation is capable of modelling a particular network within a specified tolerance, the choice of flow equation may not be obvious and may therefore be influenced by the availability of data parameters.

## 2.2 Engineering requirements for network analysis – IGE/GL/2

The Institute of Gas Engineers and Managers is the independent professional membership entity that, in effect, provides authority on gas engineering matters. It communicates this authority through a series of documents covering the different requirements of the engineering and management of gas transportation networks. Network analysis is covered specifically in the document IGE/GL/2, and other requirements of network analysis stem from IGE/TD/1[3], IGE/TD/13[4]. NGGNTS has adopted IGE/GL/2 as network analysis policy.

A key element of IGE/GL/2 is the specification of the tolerance that should be achieved in network analysis. IGE/GL/2 considers that a model of the network would be considered as valid where the broad pattern of flows and pressures computed is within 5% of measured flows/pressures, over the majority of the network. Any network model where all flows and pressures are within 5% of measured observations is therefore considered valid by the IGE, regardless of the flow equation used.

As well as setting out a high-level network planning process, IGE/GL/2 considers that the following parameters should be considered:

- gas physical properties including specific gravity, Joule-Kelvin coefficient, calorific value (CV), Wobbe number, compressibility and viscosity;
- temperatures including ground temperature and gas temperature; and
- efficiency factors (i.e. flow friction factors).

IGE/GL/2 requires that the selected flow formula should be suitable, but does not specify the equation. IGE/GL/2 considers that the following transmission system components should be considered:

- pipe data (e.g. length, diameter, internal diameter);
- pressure reduction stations;
- compressors; and
- demands (including consideration of demand profiles and diurnal storage).

IGE/GL/2 also discusses the requirements for time series ('transient') analysis, and the consideration necessary to identify reinforcement within the network.

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[3] Institute of Gas Engineers, Steel Pipelines for High Pressure Gas Transmission.

[4] Institute of Gas Engineers, Pressure Regulating Installations for Transmission and Distribution Systems.

## 2.3 Safety and security requirements for network analysis

The three driving requirements for the long-term offline network analysis function in NGGNTS stem from external obligations – the Safety Case, the 1 in 20 security standard and the Ten Year Statement – which we describe below. The overarching obligation placed on NGGNTS from primary legislation (the Gas Act 1986 as amended) is to develop and maintain an economic and efficient network.

NGGNTS is required under Health & Safety legislation to maintain a Safety Case, which sets out in detail its safety management procedures. Changes to the Safety Case must be approved by the Health & Safety Executive. Pöyry Energy Consulting understands that the Safety Case requires that network analysis complies with IGE/GL/2, as well as NGGNTS internal policy documents.

Network security requirements are embodied in the NGGNTS transmission licence. This requires that the network investment is made to ensure that the network can meet the 1 in 20 peak-day demand level (i.e. the highest daily demand that would be expected once in 20 years[5]). The computational requirement of network analysis (that in-flows and out-flows balance), implies that aggregate supplies into the network must be matched to the 1 in 20 peak day demand.

Another transmission licence obligation requires NGGNTS to produce the Ten Year Statement, exploring the potential investments in and developments of the NTS (incorporating consideration of the 1 in 20 condition), for a ten-year, forward-looking horizon.

The transmission licence therefore states what is to be achieved, whereas the Safety Case is directed more towards how safety/security is achieved. As the compliance with 1 in 20 condition can only be established through the application of network analysis techniques, Pöyry Energy Consulting consider that compliance with IGE/GL/2 is the only way to discharge such licence conditions.

## 2.4 Other requirements for network analysis

Other requirements for network analysis establish certain other practices within the sphere of network analysis. These are:

- response to information requests from Ofgem might require the production of capability and/or capacity figures, e.g. for the specification of baselines;
- commercial requirements arising from the capacity and connection regimes, e.g. buy-back of entry capacity;
- procedural requirements arising from the capacity regimes, e.g. entry capacity substitution;
- design and engineering requirements to establish likely or possible operational duties of certain plant, etc.; and
- as might be driven other bespoke analysis, as required.

A fuller explanation of these requirements is given in the NTS Transmission Planning Code.

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[5] For a more specific definition, please refer to the relevant Standard Licence Condition 16 of the NTS Licence, currently available at http://epr.ofgem.gov.uk/index.php?pk=folder132658

Each of these practices enables some degree of interpretation of the results which, in practice, is usually driven more by assumptions of network in-flows and out-flows than it is of the low-level model parameters required in network analysis.

A common requirement is to maximise the flow at specific entry or exit points on the network. Unfortunately, due to the computation element of network analysis, this cannot be achieved whilst maintaining all other things as equal – where a particular in-flow is increased, either other in-flows will need to be reduced, or out-flows (specifically or generally) will need to be increased.

Problems of this sort are sometimes handled through scenario analysis; however it is usually the case that some form of analysis or consideration, external to network analysis and more commercial in nature is required to enable the purpose of any study to be met. An obvious example is the setting of baselines in the NTS licence, where externalities such as the risks and returns of buy-back incentives will require a more holistic consideration.

## 2.5 Network model obligation & NTS Transmission Planning Code

The transmission licence further requires that NGGNTS prepares and maintains the NTS Transmission Planning Code, where changes can only be approved by the Gas and Electricity Markets Authority (GEMA).

The licence also requires that NGGNTS maintains a computer simulation model of the NTS (the ‘network model obligation’), to:

- facilitate compliance with the Gas Act (‘to develop and maintain an efficient and economical pipe-line system for the conveyance of gas’);
- be consistent with the NTS Transmission Planning Code; and
- demonstrate that the model is consistent with the above objectives.

Pöyry Energy Consulting would note that the establishment of a computer simulation/model of the NTS is an implicit requirement of the Gas Act, such that the above obligations are discharged through consistency with the NTS Transmission Planning Code.

## 2.6 Conclusion

As the NTS Transmission Planning Code incorporates the requirements of IGE/GL/2 and wider requirements for offline long-term network analysis, Pöyry Energy Consulting consider that the purpose of network analysis within the context of this study is therefore adequately described by the NTS Transmission Planning Code.

Pöyry Energy Consulting has therefore undertaken to review the proposed new network analysis software, Simone, against the requirements outlined in the NTS Transmission Planning Code. As a benchmark, we have assumed that the current network analysis software, GF, is consistent with the requirements of the NTS Transmission Planning Code, and therefore draw comparisons where appropriate.

# 3. OBSERVATIONS AND VALIDATION

This section of the document sets out the individual observations that Pöyry Energy Consulting witnessed, and provides short commentaries on the network model validation exercises undertaken by NGGNTS.

## 3.1 Observations

### *3.1.1 Foreword*

NGGNTS granted Pöyry Energy Consulting unfettered access to the network analysis models used to establish Simone's capability of modelling the NTS. This included granting access to equivalent GF networks.

The blue italic text included in sections 3.1.2 to 3.1.14 represents a series of scripted tests that Pöyry Energy Consulting scripted to establish the fitness of Simone for NTS network analysis. The observations and findings for each test have been included in black text.

Throughout the observations, we were particularly impressed with the speed and stability of analysis undertaken using Simone.

### *3.1.2 Basic network analysis functionality*

*Check basic functionality*

Basic network modelling functionality was examined, to check that pipeline lengths and diameters, supply pressures and/or flows, and demand pressures and/or flows could be specified, pursuant to the relevant and applicable mathematical modelling techniques used in the model.

Basic functionality appears to work as required. We note that pipeline objects have placeholders for several different characteristics/variables; however these are greyed out depending on the flow equation in use within the model.

*Check that appropriate results can be obtained.*

We specifically observed that compressor inlet temperature was an available result. Other basic results, e.g. pressures and flows, were also apparent.

*Check that appropriate warnings/alarms can be specified and are reported as appropriate.*

We specifically observed that a minimum pressure alarm could be set at a node, and that the software appropriately reported against this alarm, and in a manner that made it apparent that alarm had occurred.

### *3.1.3 Supply flows*

*Check that supply flows can be set and that they are held in analysis.*

We specifically set supply flows at Easington and St. Fergus, observing appropriate rebalancing at the set pressure (balancing) nodes.

*Check that set pressures can be set, and are held in analysis.*

Pressures can be set at supply nodes. Where pressures are set, the required change to the flow from the supply is calculated and reported by the software.

A supply node therefore has two potential flow values: the specified flow and the set pressure flow. The flow in the connected pipeline(s) correctly sums to the net inflow at the supply node.

*Check that other properties of supply flows (e.g. gas quality) can be appropriately specified.*

We specifically reset the calorific value of the gas entering at a set pressure supply node. The resultant set pressure flows were adjusted accordingly, suggesting that recalculations are appropriate.

*Check transient dimensions (profiles) as appropriate.*

We specifically observed that the specification of a supply of gas into the network resulted in an appropriate profile of the flow of gas in an immediately connected pipeline. We are therefore satisfied that profiles can be modelled appropriately.

### 3.1.4 Demand flows

*Check that demand flows can be set and that they are held in analysis.*

We specifically set demand flows at various locations within the model, observing appropriate rebalancing at the set pressure (balancing) nodes.

*Check transient dimensions (profiles) as appropriate.*

We specifically observed that the specification of a profiled offtake in the network resulted in an appropriate profile of the flow of gas in an immediately connected pipeline. We are therefore satisfied that profiles can be modelled appropriately.

### 3.1.5 Entry flow maximisation (capacity)

*Check that a process can be followed which enables the discovery of maximum flow at entry point(s).*

We note that the interface used in Simone for the setting of flows at entry points is sufficiently similar to that used in GF to enable a process to be adopted with Simone which will be very similar to the current GF-based process. We therefore conclude that it should be feasible to undertake this.

### 3.1.6 Energy/volumetric conversion

*Check that there is appropriate consideration of calorific value in any conversion between energy and volume dimensions.*

As noted in section 3.1.3 above, this appears to be correctly considered.

*Check that reference conditions can be specified, or are correctly available.*

Simone has functionality to change units and reference conditions, and that there are a range of suitable options.

### 3.1.7 Gas qualities

*Check that there is appropriate tracking and blending of various gas qualities, and check that constituent properties can be appropriately considered.*

We specifically observed that calorific values appear to properly co-mingle and that flow weighted average calorific values appear to be calculated.

Testing of individual component tracking and the derivation of calorific values, and Wobbe numbers, etc., from such component level data has not been observed.

We note that the Simone documentation contemplates the ability to calculate gas properties from gas components, and that it has the ability to track and blend gas components. We also understand that Simone is used for the calculation of CV in a billing context in France, and has achieved metrology standards specified by OIML (the Organisation Internationale de Métrologie Légale). We have not encountered any evidence to suggest that the Simone does not function as per the documentation, and we are therefore satisfied that Simone is capable in this regard.

### 3.1.8 Compressor modelling

#### 3.1.8.1 General

*Check that compressors can be modelled sufficiently for the purposes of replicating flows and pressures through the network model.*

Simple compressor functions can be modelled adequately.

*Ascertain that where specified, further detailed compressor modelling appropriately interacts with the overall network model (e.g. compressor efficiencies are appropriately calculated, used to calculate fuel usage, and that fuel usage is appropriately considered within the wide network model).*

We have specifically examined the detailed unit-level compressor model, and observed that compressor envelopes, including efficiency values, can be specified and appear to be used to recompute motive power requirements.

#### 3.1.8.2 Station-level considerations

*Check that a variety of logical configurations can be modelled (i.e. parallel, series, etc.)*

Different configurations can be set up as required. Parallel or series configuration results in a combined operating envelope.

*Check that appropriate station-level considerations can be included in the model (e.g. site pressure losses).*

Maximum site outlet pressure can be set separately to a compressor control pressure. The lower of the two is used as the constraining factor.

*Check that environmental considerations can be applied (e.g. ambient temperature).*

We observed that environmental considerations could be applied.

#### *3.1.8.3 Unit-level considerations*

*Check that compressor units can be modelled to reflect known or specified compressor performance, including:*

- power;
- speed;
- choke;
- surge;
- efficiencies;
- fuel utilisation; and
- emissions.

*Check that appropriate controls (e.g. surge, minimum speed) can be specified and utilised.*

We note that the compressor modelling within Simone is different to the compressor modelling used within GF. The advantages of the approach used in Simone:

- it facilitates network optimisation functionality, including compressor configuration optimisation (not tested);
- it avoids the potential for loop flow which can make the network mathematics less stable (discussed in section 3.1.10 below);
- minimises the risk of incorrect interpretation of compressor performance and efficiency characteristics (not tested, although we understand that curves are specified, which is different to the interpolation approach used in GF);
- it can hold or relax adhesion to the surge control line (which has been tested and observed);
- the compressor model is distinct from the motive power model; and
- power can be modelled (correctly) as a function of ambient temperature (which has been observed).

At present, Simone is not capable of modelling a dual series/parallel configuration within its compressor station model(i.e. one unit in parallel with two units in series). We understand however that this particular configuration is rarely used with the NTS, a workaround is available and that development work to facilitate this is envisaged in the near future.

We have observed an erroneous use of a default compressor inlet temperature, in specific circumstances, which we discuss below in section 3.1.10.

We consider the implementation of compressor station/unit modelling in Simone to be more powerful than the implementation in GF.

### 3.1.9 Resistor/regulator modelling

*Check basic controls can be applied and are held in results (e.g. outlet pressure).*

We specifically observed that flow constraints and pressure constraints could be set and held.

*Check that characteristic curves can be applied.*

The Simone documentation describes definitions for Mokveld and Argus characteristic curves. No investigation has yet been undertaken by NGGNTS to check this functionality in the NTS or other test network models (primarily as NGGNTS currently only has incompatible Fisher curves available). The functionality to model characteristic curves also exists in GF, however NGGNTS has not required to use it within GF NTS models.

We therefore consider that this requirement can be disregarded.

### 3.1.10 Error handling and analysis

*Where possible, observe failure of a model and follow the process for correcting failures, including mathematical infeasibility, erroneous configuration, and partial failures.*

#### 3.1.10.1 Infeasibility

Generally, Simone appears to be far more stable than Falcon. In attempting to create specific failures within Simone, we encountered far less instability which made the task much harder. One example of this was the specific failure (an infeasible problem) created in Falcon at an extreme demand (20 mcmd) in middle of the network, which was not observed in Simone until much higher levels (50 mcmd).

#### 3.1.10.2 Erroneous configuration

We also specifically constructed a short compressor loop model in both GF and Simone (where a compressor inlet and outlet are connected by a relatively short pipe loop, and the compressor is on and recycling gas around the loop). In Simone, this resulted in the use of a default inlet node temperature definition (10 °C), without alerting the user. This has the effect of incorrectly calculating gas temperatures within the model and therefore, in an analysis where quality and temperature effects are being used in the flow and pressure calculations, this will result in incorrect flow and pressure results. GF also failed to analyse correctly and used inappropriate temperatures in calculations, however, it does report a mathematical failure and that results may be erroneous. It should also be noted that the parameters used to generate the scenario were extreme.

We would comment, however, that the likelihood of this error occurring in network analysis of the NTS is probably small due to the small number of potential short compressor loops that exist in practice and the extreme test scenario that exhibited the problem. **We therefore find that the unreported use of a default temperature term is of minor concern.** We would recommend that this is handled through an appropriately diligent analysis management process (which we understand already exists to handle the numerous peculiarities of GF). NGGNTS might wish to consider a development of Simone which enables this to be specifically reported.

#### *3.1.10.3 Partial failure*

We also specifically created a partial failure (lack of pressure definition). Simone maintains the analysis with undefined pressures (-1 barg) reported in the undefined section. We replicated the failure mode in GF and observed that it maintains the analysis with spurious numbers. It is not clear whether the spurious numbers in GF affect the correctly specified section of the network model. However, the results in both Simone and GF for the correctly specified section of the network do not appear to alter when correct specification is restored.

### 3.1.11 Multijunctions

*Check that multijunction configurations can be appropriately modelled.*

We specifically observed that pipeline configurations at Aberdeen could be changed and successfully reanalysed. We also note that the detailed valve arrangements at Hatton appear to be fully replicated in the NTS network model used in Simone.

### 3.1.12 Network reinforcement

*Check that network analyses can be undertaken with and without specific physical elements, and that appropriate comparisons can be made.*

We specifically followed the process of adding in a new section of pipeline to the network and observed the resultant changes to flows and pressures in the model. Comparison of results before and after the addition of physical assets is not as easy as GF, but it is possible to compare results. We understand that NGGNTS is considering commissioning developments that would improve the ease of directly comparing project alternatives.

We have also observed that constraining factors (e.g. outlet pressure, motive power) at compressor stations can be modified and that analysis adheres to reset constraints (where appropriate).

### 3.1.13 Minor functionality

*Examine any areas of additional functionality that can otherwise be handled externally (e.g. cost tracking, seasonal demand specification).*

The model appears to handle cost tracking, where costs of gas can be specified.

The additional functionality of an Application Programmers Interface (API) is of significant note. This should allow the embedding of network analysis into spreadsheets. A possible application could be to allow the creation of a series of scenarios (e.g. supply/demand scenarios), defined in a spreadsheet, which are analysed in Simone. A predefined set of results would then be extracted from Simone back into the spreadsheet.

Typical uses may involve creating a batch of analyses to be run overnight. This may have applications in discovering maximum capacities under certain conditions, capacity substitution and transfer calculations, and estimating buy-back/interruption risks. It may also enable the direct observation of network analysis scenario specifications and the relative results by third parties, e.g. Ofgem, without requiring knowledge of how to use the Simone software or a detailed knowledge of network analysis theory (although untested change to input parameters may need expert checking).

### *3.1.14 Management*

*Examine model management techniques and/or processes (e.g. naming conventions, routes for auditing and checking procedures).*

We specifically observed the process of creating a network and applying a scenario to the network model. We note that the use of a physical network model that is distinct from a scenario (where the various variables are specified, e.g. demand), is fundamentally different from the approaches used in GF, and therefore care will need to be taken to ensure users are fully aware of the loading/saving process and any naming conventions required. However, there are greater benefits to the Simone approach, arising from better data control, security, archiving and auditing practices that can be adopted.

## 3.2 Validation

Network validation is an exercise undertaken by NGGNTS on an annual basis, in accordance with IGE/GL/2, which attempts to recreate a specific period of actual operation within a network model. Flow measurements are used as the primary input to the model and pressure results are compared to pressure measurements.

The latest validation data that has been used to validate the current GF model of the NTS has also been used to validate the Simone model. Pöyry Energy Consulting took the opportunity to confirm that the network validation results presented to it were actually present in network analysis models held in the relevant systems.

The Simone validation compares favourably with the GF validation. Summary errors within each model are comparable, however Simone appears to more closely follow changes in the rate of change of pressure than GF. Assuming absolute error can be removed through fine-tuning, we would therefore expect Simone to be capable of more accurate historical modelling than has currently been discovered.

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# 4. SIMONE DOCUMENTATION AND MATHEMATICS

Pöyry Energy Consulting has been provided with product documentation. This section provides high-level summary and commentary of these documents. In particular, we have examined the underlying mathematics and confirmed that the underlying mathematics appears to be reasonable.

Pöyry Energy Consulting has found no evidence that the documentation describes functionality that does not exist in the product tested.

## 4.1 Documentation

The documentation provided includes:

- the main user guide, which covers the main interface description;
- the supplement to the main user guide, covering file descriptions and parameter specification/references;
- the user manual for the enhanced compressor station modelling;
- the manual describing all the underlying mathematics and computational considerations; and
- manuals for optional modules, comprising:
  - the long-term optimization manual;
  - the manual for the capacity calculation tool; and
  - the specification of the Simone API (a tool that allows the network analysis to be run through an external application, e.g. Microsoft Excel).

The documentation appears to be thorough, especially the API and mathematical documentation.

Much of the documentation describes functionality that is not available in GF, for example long-term optimization. Whilst we have not ascertained how NGGNTS proposes to make use of this functionality, it affords every opportunity to introduce additional benefits to the network modelling undertaken by NGGNTS.

## 4.2 Mathematics

Pöyry Energy Consulting countenances that no weight be placed on a microscopic examination of the underlying mathematics. Pursuant to IGE/GL/2, legal obligations will be discharged via the empirical testing of the network analysis software and mathematics, using the validation exercise mentioned at paragraph 3.2.

However, the manual containing all the underlying mathematics has been briefly examined by Pöyry Energy Consulting, in order to confirm that the equations used by the software are reasonable and/or consistent with academic approaches.

The documentation includes descriptions of:

- the flow characteristic equations;
- the equations of state;
- gas quality tracking equations;

- the equations for heat dynamics;
- thermodynamic and other equations for compressor stations; and
- the equations to describe control valves and other restrictions.

We discuss the approach used in the software in each of these areas, below. In addition the documentation also describes other features of network analysis which, as they are of little concern to long-term offline analysis, are not reviewed here.

At a high level, the two major differences between Simone and GF is the treatment of the conservation of momentum, and the solution algorithms. Simone has a more sophisticated approach to implementing the laws of thermodynamics, which should enable models to be better tuned to actual observation, especially with regards to analysis where the temporal dimension is important. Text Falcon was designed to consider bulk transportation problems and therefore neglected terms in the momentum equation that are required to model very fast pressure fluctuations in the network, in order to simplify implementation and increase computational speed on the mainframe computers that existed at the time. The development of GF did not change the implementation of the original Text Falcon mathematics, and so GF does not model fast transient effects on the network.

Simone also uses a different algorithm for solving the analysis. GF uses explicit numerical integration techniques which can be mathematically unstable under certain conditions, whereas Simone uses a different approach based on a mathematically more stable implicit method described in Kralik et al[6]. The Simone approach appears to be mathematically more stable in practice which is consistent with the research described in this paper.

### 4.2.1 Flow characteristics

Simone makes use of partial differential equations to describe both continuity and momentum. The equations contain terms that are commonly encountered in the field of fluid dynamics, and are appear to be reflective of broader physical theory.

The continuity equation includes consideration of mass flow rate, pipe cross-sectional area, gas density, pipe length and time. The momentum equation includes consideration of pressure, gravity, gas density, frictional pressure loss, altitude, pipe cross-sectional area, mass flow rate, velocity, pipe length and time. The documentation describes that the frictional pressure loss is given by the Darcy-Weisbach equation, which uses a friction factor derived from equations known as Hofer (an approximation of Colebrook-White), Nikuradse or PMT-1025.

We have confirmed that the Darcy-Weisbach and Colebrook-White equations are regularly used in the field of fluid dynamics. We have also confirmed that Johann Nikuradse studied the frictional effects on fluid flow in the 1930s. We have been unable to confirm the exact Hofer equation construction; however, we have encountered academic references to Hofer. We therefore conclude that the flow characteristic equations are, or appear to be derived from, recognised and peer-reviewed fluid dynamic theories.

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[6] IEE Transactions on Systems, Man and Cybernetics; Vol. SMC-14, No. 4, July/August 1984: ‘A Universal Dynamic Simulation Model of Gas Pipeline Networks’, Králik, Stiegler, Vostrý & Závorka.

### 4.2.2 Equations of state

The software makes use of the following equations of state:

- AGA;
- Papay;
- Redlich-Kwong;
- two forms of Benedict-Webb-Rubin; and
- ISO 12213 part 2 (a.k.a. AGA8-DC92).

A discussion of the precise differences between these equations is beyond the scope of this study. However, Pöyry Energy Consulting can confirm that each of these equations can be found in academic literature related to fluid properties.

The equations of state section of the documentation also describes the equations for the thermodynamic properties of real gas (specific heat, isentropic exponent and Joule-Thompson coefficient), and the equations to derive specific gas properties from individual gas components.

### 4.2.3 Gas quality tracking

The documentation describes the processes employed for tracking gas qualities and parameters, and how parameters are used within the fluid dynamic calculations. The approach used in the software appears to be reasonable.

### 4.2.4 Heat dynamics

The software implements two versions of axial heat dynamics – a simple steady-state heat transfer model, and a more complex heat transfer model which takes account of the different rates of heating/cooling of the gas from surrounding burial material. We consider that both of these approaches are reasonable, although note that obtaining the required data to allow the dynamic heat modelling of the NTS would be particularly challenging.

In addition, the software also provides the ability to suppress the Joule-Thompson effects within a pipeline. We do not consider that this functionality would be of particular interest to the modelling of the NTS.

### 4.2.5 Compressors

The documentation describes several of the necessary considerations regarding compressor modelling. The basic thermodynamic equations describing:

- pressure ratio;
- adiabatic head;
- adiabatic efficiency;
- shaft power; and
- discharge temperature

all appear to be correctly specified.

We note that alternative discharge temperature equations can be used, either following Fasold, et al, or assuming that the compression process is isentropic and/or the gas is ideal. We also note that the isentropic exponent can be a specified constant, average temperature dependent, or computed from the applicable equation of state. The isentropic exponent is the ratio of the specific heat at constant pressure to specific heat at constant volume (for an ideal gas), and would therefore not be expected to vary much for natural gas in the compression conditions encountered in the NTS.

Simone incorporates a centrifugal compressor model which enables the calculation of speed and efficiency from a set of user-specified curves. An important distinction can be drawn with GF, which fits a series of curves from a set of coordinates – rounding error in coordinate specification can lead to incorrect interpolation and therefore an incorrect model. Enabling the specification of curves instead of coordinates should avoid this misinterpretation.

In addition, Simone makes use of 3-dimensional specification (biquadratic equations) rather than the GF approach of interpolating between 2-dimensional curves. The use of biquadratic equations also allows Simone to implicitly replicate the quadratic speed and elliptical efficiency shape assumptions used in GF.

Simone has more sophisticated after-cooler and local pressure loss modelling.

Given all of the above observations, we conclude that the compressor modelling used in Simone is far more capable and far less susceptible to error than the equivalent modelling used in GF.

### 4.2.6 Control valves

The documentation describes models for flow control valves and for simple pressure loss device. We have not confirmed the appropriateness of the flow control curve models for reasons set out in section 3.1.9. We note that the application of Joule-Thompson cooling, and preheating power calculations are correctly specified.

# 5. CONCUSIONS

After undertaking a review of the requirements for offline, long-term network analysis; observing the various tests; and briefly reviewing the mathematical implementation, we conclude:

- Simone has met all the requirements for modelling the NTS for long-term offline analysis required or contemplated by the Transmission Planning Code, and exceeded these requirements in many areas.
- Simone represents a significant improvement the stability of NTS network analysis.
- The Simone mathematics appears to be well specified and documented, and is capable of producing accurate network analysis results.

NGGNTS will need to ensure that a potential issue regarding short compressor loops and temperature calculations is appropriately handled, possibly through normal quality assurance procedures.

Simone offers additional mathematical and interfacing features not available in GF. These may become useful features into the future, for example through providing a greater level of transparency in regulatory communication.

Pöyry Energy Consulting considers that the lack of support for GF may become particularly concerning: if the unsupported technology were to irrevocably fail, NGGNTS would be unable to meet its obligations. Access to future developments of Simone, and the ability to drive particular developments Simone, coupled with the broader user base, should ensure that Simone is adaptable to any future network modelling needs.

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