DNV·GL

SELECTED TOPICS FOR THE REINFORCEMENT PROJECT

Evaluation of the Gaz Métro Capacity Assessment Process

Gaz Métro

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EXECUTIVE SUMMARY

DNV GL was requested to perform a review and make recommendations to Gaz Métro regarding a number of selected topics related to its capacity assessment processes.

Gaz Métro has been applying its current capacity assessment methods for several years. By the end of 2013, Gaz Métro had set-up a series of actions and investigations to assess its capacity assessment process in the context of, amongst other things, a possible significant investment following Gaz Métro's observations that parts of its transmission networks are operated at, or close to, maximum capacity.

Initially, DNV GL performed a high level review, based on Gaz Métro's implementation of criteria outlined in the document "Critères appliquées à la conception et à l'opération du réseau de distribution". That review identified a number of topics with room for improvement.

At the beginning of 2014, DNV GL was asked to perform a further investigation of a number of topics. This investigation covers three of the criteria that were previously reviewed in the high level review of 2013, as well as some general observations regarding the parameter basis for the capacity assessment process. Note that the investigation conducted by DNV GL is only one of the investigations conducted within the broader scope of actions and investigations currently being undertaken by Gaz Métro in support of the regulatory application for leave to invest in network reinforcement.

When reading the recommendations, it is important to note that Gaz Métro's capacity assessment process has been undergoing changes since the end of 2013. Gaz Métro is actively improving its processes, and we believe that the capacity assessment process is being developed in a manner that is consistent with good industry practice. Portions of the recommendations contained within this report may already be in the process of implementation.

On criterion 11 regarding entry pressure, we recommend that Gaz Métro rely only on contractually agreed upon minimum supply pressures for long term network design. However, in the current situation where reinforcements are anticipated but not yet commissioned, the application of best efforts contract values instead of contractually guaranteed values is valid, particularly in light of the fact that Gaz Métro has already successfully begun negotiations to temporarily upgrade entry pressures from best efforts to guarantees with its suppliers. Although it has only minor significance at the moment, we recommend the inclusion of a pressure drop over entry stations in the network simulations, and occasional verification of the implementation of those simulations and associated assumptions.

On criterion 13 regarding redundancy, we recommend the application of the N+1 redundancy philosophy for critical equipment such as compressors. In station design, the reserve policy and station availability should be taken into account, as well as desired work areas, need for flexibility and expected load duration.

On criterion 14 regarding compression, we recommend the use of the transient simulation method as a supplement to the steady state simulations. This should be performed in such a way that any additional capacity loss found using the transient analysis method is subtracted from the available capacity resulting from the steady state simulation. We recommend that the applied down-time be based on a summation of all relevant technical/operational factors and human/organisational related factors. In the short term, we recommend an assessment of the sensitivity of the simulation procedure to changes in the flow profile that is used. We also recommend logging downtimes and typical relevant flow profiles for use in future analysis and assessments.

On the parameter set-up in the current capacity assessment approach, we recommend that all parameters, procedures, and assumptions be specified, documented, and explained. An important

consideration is the difference between the maximum observed gas flow rate (to be used in performance reporting) and the maximum predicted gas flow rate (to be used as an input to the capacity assessment). We recommend that the hydraulic simulations be based on the market investigation and that Gaz Métro should calculate the sensitivity of the technical capacity calculation of a sub-network for possible changes or uncertainties in timing and location of market predictions. We recommend that detailed investigations for determining required reinforcements be initiated a sufficient number of years ahead of the year that utilisation is expected to reach 100%.

With respect to the internal parameter spare capacity, we recommend that Gaz Métro should focus primarily on the precision and certainty of the spare capacity determination process rather than on simplification of the results with a view to ease of understanding. It is therefore important to distinguish spare capacity between different locations in the network, spur lines and/or branches where necessary. We recommend that Gaz Métro increase the update frequency of the spare capacity determination to twice a year, and more frequent if need be.

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1 INTRODUCTION

DNV GL was asked to review and make recommendations to Gaz Métro regarding a number of selected topics related to its capacity assessment processes.

1.1 Background and approach

Gaz Métro has been applying its current capacity assessment process for several years. The current practice involves the practical application of a list of criteria Gaz Métro has developed regarding the planning and operation of its network (in French, /1/). Table 1 shows the 23 criteria on this list (translated from the French table in /1/).

By the end of 2013, Gaz Métro had set-up a series of actions and investigations to assess its capacity assessment process in the context of, amongst other things, a possible investment following Gaz Métro's observations that parts of its transmission networks were being operated at or close to maximum capacity. Initially, DNV GL executed a high level review of the entire capacity assessment process (shaded in the table), with a focus on the transmission capacity assessment procedure and the transmission network simulation set-up (framed in the table).

Table 1 The 23 criteria Gaz Métro applies for network design and operation (translated from the French table in /1/)

Category	No	Topic	Trans-mission	Distri-bution
Customer needs	1	Maximum hourly flow	x	x
	2	Minimum delivery pressure	x	x
	3	Special operations request	x	x
	4	Interruptible customers	x	
	5	Future maximum hourly flow forecast	x	x
Capacity Assessment of the network	6	Technical specification	x	x
	7	Maximum gas velocity	x	x
	8	Maximum flow at the delivery station	x	x
	9	Minimum pressure in the network	x	x
	10	***Minimum temperature of the last winter***	**x**	x
	11	**Minimum contractual supply pressure**	**x**	
	12	Equipment capacity at the delivery station	x	
	13	**Redundancy of critical transmission equipment**	**x**	
	14	**Compression ratio and maximum flow**	**x**	
	15	***Observed hourly flow (coincident)***	**x**	
	16	Class location	x	
	17	Room for flexibility	x	
	18	Maximum seven hours flow for ≥500 m³ /h customers		x
	19	Equipment capacity at the city gate station		x
	20	Redundancy of critical distribution equipment		x
Network Design	21	Position of the network extension	x	x
	22	Network integration		x
Cost Analysis	23	Cost	x	x

That review identified some of the criteria as having room for improvement with respect to use in the capacity assessment (10, 11, 13, 14, and 15) as well as some other general observations beyond the direct scope of the criteria listed above.

Subsequently, DNV GL was asked to perform further investigation into a number of topics. This investigation covers three of the criteria (11, 13, and 14). Some of the observations regarding organisational issues which pertain to the capacity assessment process are outside the scope of this report and Criteria (10 and 15) were assigned to Artelys by Gaz Métro.

For each of the topics, the investigation approach was threefold:

1) **Practice at Gaz Métro.** We identified the current practice at Gaz Métro by conducting interviews and information exchanges with relevant Gaz Métro personnel;

2) **Assessment.** We assessed Gaz Métro's current approach, taking into account relevant documents, expertise, and industry practice; and

3) **Recommendation.** We identified recommendations regarding specific parts of the process. Recommendations consist of a general recommendation on the topic, numbered Rx, supplemented with detailed recommendations, numbered a, b, c, etc., where appropriate.

1.2 Reader's guide

In Chapter 2, we discuss a selection of practices used in the capacity assessment, covering minimum contractual supply pressure, redundancy of critical transmission equipment and compression ratio and maximum flow (criteria 11, 13 and 14 from /1/). Chapter 3 provides an assessment of the parameters used in the process, network division, and formalisation of the capacity assessment process within the company. In Chapter 4, the recommendations in this report are summarised.

When reading this report, please note that:

- The investigation conducted by DNV GL is only one of the investigations conducted within the broader scope of actions and investigations currently being undertaken by Gaz Métro in support of the regulatory application for leave to invest in network reinforcement. For example the criteria listed in italic bold text in *Table 1* were assigned to another consulting company, Artelys /7//9/. Their statistical investigation was executed parallel to this one. Recently another consultant, KPMG SECOR /8/, was assigned to perform further market analysis for Gaz Métro. Where the market-related assessments, performed by Gaz Métro or its consultants, are relevant to the current investigation, they are referred to within this report as the market assessment.

- Because of this extensive series of concurrent actions and investigations by Gaz Métro, this report describes an investigation of an evolving practice. In principle, we based the recommendations on our observations of the capacity assessment procedures and practices at Gaz Métro as they were applied until 2013, and investigated by us in the review conducted at the end of 2013 and in 2014. As of the date of issuance of this report, Gaz Métro is in the process of reviewing and improving the entire procedure (of which this investigation is considered part). Recent changes are described where they are deemed relevant to the discussion.

- Investment decisions to reinforce transmission networks are not made overnight. Once the need for investment has been identified, a lengthy process is followed in which a number of milestones exist. Where initially not all of the details are known, they are gradually filled in throughout the process. Here we focus on the processes around the Project Establishment Decision (PED). Stages like alternative selection and final engineering design are outside of the scope of this investigation.

- In the long run, DNV GL recommends that Gaz Métro should reconsider the parameters currently used in its capacity assessment process, as in our view, they represent simplified terms and do not fully reflect the complexity of the issues that should be taken into consideration. However, these parameters have now been in use at Gaz Métro for several years for performance reporting and for the information of the sales department; therefore, for this investigation, we assume their continued use for the time being.

- As agreed with Gaz Métro, we focussed on the transmission networks Estrie and Saguenay as these networks are currently the most congested. However, it is expected that the recommendations identified in this report will also apply to other networks, or can be relatively easily adapted.

2 ASSESSMENT OF THREE CRITERIA

This chapter discusses the agreed selection of implementation practices of the capacity assessment process, covering criteria 11, 13 and 14 from /1/: minimum contractual supply pressure (section 2.1), redundancy of critical transmission equipment (section 2.2) and compression ratio and maximum flow (section 2.3).

2.1 Minimum contractual supply pressure (criterion 11)

The entry pressure is an important input parameter to a capacity assessment as it is the driving force for gas being transported through a network. Given a minimum delivery pressure at the exit points (delivery stations), the entry pressure determines a significant share of the maximum throughput. The entry pressure is determined by taking the pressure at which the supplier delivers its gas at the entrance of the entry station, and reducing it by the pressure loss across the station. Both the supply pressure and pressure drop across the station are discussed below.

2.1.1 Supply pressure at entry points

2.1.1.1 Practice at Gaz Métro

Although Gaz Métro had best efforts contracts in place for higher entry point pressures at specific places, until 2013, Gaz Métro typically used the contractually agreed upon pressure of 4000 kPa as the starting pressure at the entry points. In practice, Gaz Métro observed that the actual supply pressures were significantly higher than the agreed upon minimum pressure. In order to bridge the period until the proposed reinforcements can be commissioned, Gaz Métro chose to loosen some parameters in the capacity assessment process to use less restrictive values. This resulted in the application of higher entry pressures based on the existing best efforts agreements between Gaz Métro and suppliers Trans Québec and Maritimes Pipeline (TQM) and TransCanada Pipelines Limited (TCPL). This is intended as a temporary solution, used to determine whether it is possible to connect new customers in the period until network investments can be realized.

In order to better manage the associated risk, Gaz Métro has entered into negotiations with its suppliers regarding higher entry pressures and has already concluded an agreement guaranteeing a higher entry pressure of 5750 kPa for the Estrie network, up to 2017. For the Saguenay network, three years (until October 2017) of higher entry pressure (4650 kPa) may be possible, and negotiations are underway.

2.1.1.2 Assessment

Generally in the industry, contractual minimum pressures are used in capacity determinations. In practice, the actual pressure that is measured at the entry point, and thus the maximum flow that can be transported may be much higher. Sometimes there exists a mutual understanding or a provision in the contract for the supplying company to deliver at a higher pressure level on a best efforts basis; however, the transmission or distribution company responsible for the transportation of the gas cannot rely on higher pressure being available in critical situations (e.g. the design case). Selling more capacity than that which can be delivered with the contractual entry pressure carries a risk that the company will not be able to deliver on those sales promises. Therefore, the contractual values should always be used in the capacity assessment for long term design.

When confronted with a case where network reinforcements or expansions are required before technical solutions for acute capacity problems can reasonably be commissioned, companies have only a few options to manage the risk of delivery failure during the investment period. These options can be divided into operational (e.g. temporarily using a mothballed pipeline or temporarily weakening station settings) and commercial solutions (e.g. temporarily changing contractual conditions, through negotiations with contractual partners: suppliers and customers). It is advisable to explore all of these options in order to minimize the temporary risks.

As part of the series of actions and investigations based on the findings and observations from the high level review conducted by DNV GL (see section 1.2), Gaz Métro began exploring commercial and operational possibilities, which resulted in the negotiations with suppliers discussed above[1]. As such, weakening parameters (e.g. using the best efforts pressure rather than the minimum contractual pressure) is an acceptable solution to manage risks and bridge the period until reinforcement projects can be implemented. Action must be taken to ensure that long term solutions are sustainable.

2.1.1.3 Recommendation

R1	**For long term network design, rely only on contractually agreed upon minimum supply pressures.**
a	The application of best efforts contract values instead of contractually guaranteed values should be applied only during the interim period until reinforcements are commissioned.
b	During the interim period until reinforcements are commissioned, explore options to reduce risks, for example negotiations with suppliers to temporarily upgrade entry pressures from best efforts to guaranteed.
c	Ensure at all times that long term solutions are sustainable.

2.1.2 Station pressure drop at entry points

2.1.2.1 Practice at Gaz Métro

Until 2013, Gaz Métro did not take into account pressure drop across the entry stations. Recently, Gaz Métro revised their approach as follows:

- For the Estrie network, the entry station, including valves and pipeline sections, was modelled within the SynerGEE model, which takes the pressure drop into account. This resulted in a maximum calculated pressure drop of approximately 25 kPa at higher flow rates.
- For the Saguenay network, Gaz Métro performed a review and decided not to take into account any pressure drop nor model the station lay-out. Gaz Métro instead uses the outlet pressure that was measured at the outlet of the station during real time compressor testing conducted at maximum load. Therefore the actual pressure drop is inherently included in the capacity calculations.

2.1.2.2 Assessment

In pipelines, gas pressure decreases proportionally to the square of the velocity of the gas, the result of which is that where the pipeline diameter changes the pressure drop increases when there is an increase in gas velocity. In pipes with a rough inner surface, the pressure decreases faster than in smooth pipes due to the increase in friction. The complexity of the geometry also plays a role; valves, manifolds, bends, and T-junctions cause increases in pressure drop. Entry stations without compression (e.g. valve stations, measuring stations) may therefore have a significant impact on the pressure drop along a transmission route. Depending on the design and operating conditions, typical pressure drops over stations range from 0 to 50 kPa for simple stations, but can increase to hundreds of kPa when filters or scrubbers are installed. When pressure is determined at the upstream side of an entry station, any

[1] Other possibilities are outside the scope of this investigation, and therefore not further discussed here.

pressure drop across it will result in a lower effective pressure at the upstream side of the network. Due to the possible impact on the capacity of a network, it is recommended that the pressure drop across such non-compressor entry stations be taken into account in the simulations. Many companies use average values for these pressure drops, based on field measurements taken in high flow situations.

Where an entry station includes compression, it is relevant to consider whether it is regarded as part of the network being is assessed (in which case both the compressor characteristics and pressure drop over appurtenances (e.g. manifolds) should be taken into account) or whether the outlet of the compressor station is regarded as the entry of the network (in which case the outlet pressure and flow are input for the simulation, and no further pressure drops need to be included).

Modelling the actual set-up, as Gaz Métro is doing for the Estrie network, is a valid approach, which, in principle, will lead to more accurate results. It is recommended that the simulations be verified, if possible, against measurements taken upstream and downstream of the station during winter in high flow conditions. However, given the results of the calculations, showing the very low station pressure drops in comparison to the typical overall network pressure drops, this verification could be considered low priority.

The method applied by Gaz Métro to Saguenay is also a valid approach, as it is based on the outlet pressure of the entry station. It is recommended that the validity of the assumptions be verified occasionally through measurements taken during high throughput conditions.

2.1.2.3 Recommendation

R2	**Include the pressure drop over entry stations in the network simulations.**
a	Periodically verify the validity of the station modelling in SynerGEE (Estrie) and the pressure assumptions at the station exit (Saguenay) against actual measurements taken in high throughput conditions.

2.2 Redundancy of critical transmission equipment (criterion 13)

2.2.1 Practice at Gaz Métro

The compressor station at St-Maurice, at the entry of the Saguenay network, is designed as a station with a full scale back-up in a 1+1 configuration. This means that the entire station capacity can be delivered by a single compressor. In case of failure of the primary compressor, the second, or reserve, compressor can take over; however, this procedure takes a certain amount of time (see also section 2.3), which is accounted for in the capacity assessment.

Although the two compressors can run independently of each other, certain systems, such as power supply and control systems are shared; therefore, should a failure occur on one of those systems, both compressors will be inoperable, and the reserve compressor will be of no use.

2.2.2 Assessment

In engineering, redundancy is the duplication or multiplication of critical components of a system with the intention of increasing the reliability of the system (i.e. the ability to maintain system operability in the event of component failure or other unavailability). The choice of redundancy is driven by a calculation of the risk of failure of components offset by the consequence, or cost, of failure.

In gas transport, redundancy is often employed for all kinds of station equipment, but typically not for the pipelines themselves. Although the consequence of a pipeline failure (e.g. loss of supply, loss of transportation revenues, penalties) is high, the probability of such an event is extremely small and when the cost of insuring against the failure is taken into account (i.e. the cost to construct a pipeline loop), it can be difficult to justify the expenditure. Elements of the pipeline system that are more localized and that have a vital function in the system's capacity, such as compressor stations, are almost always equipped with a reserve.

Redundancy aimed at increasing the availability of the system is often referred to as the 'N+1-philosophy', as it is generally implemented by adding one spare unit to the existing operational units, although other configurations are possible. Backup components are not active during normal operation, but the role of backup may alternate between the available units. Adding a back-up to a single compressor increases the average availability of the station significantly, since the failure rate (i.e. the frequency with which it fails, expressed as the number of failures per time unit) or failure probability (i.e. the probability that it fails, expressed as the ratio of failed time over total time) of a compressor is generally low, and the failure rate or probability of two at the same time, being the square of that low value, is even lower.

The failure probabilities of individual components of a station can be calculated by determining the average of measured life times and repair times of the component and dividing the average repair time by the sum of the two. In addition, for compressors the probability of a failure to start and the time needed for start-up also contribute to the probability of failure. The failure probability of a station is then calculated from the individual failure probabilities of the components, supplemented by a common cause failure probability, taking into account events where all compressors fail at the same time by the same cause (e.g. an outage of the power supply). Maintenance activities also play a role in the availability of components and stations. Further background and information regarding these factors are provided in Appendix D.

Note that the amount of the spare capacity (the '+1' in 'N+1'), capacity that is by definition not used, is at its maximum for N=1. For increasing N (i.e. the station capacity is delivered by a number of smaller machines), the absolute amount of reserve capacity will decrease. Despite the fact that this results in a smaller amount of over-capacity, larger values of N generally require higher investment costs. Therefore the tendency in gas transport is to choose the lowest possible value of N. However, it is often worth considering values of N > 1, for flexibility reasons. When the projected load profile over the year is expected to have significant variation, low flows may be below the minimum capacity of a large compressor, and the compressor will run less efficiently (energy-wise), produce more emissions and/or require additional cooling due to the need to recycle part of the flow (environmental issues).

In practice in gas transport, the number of parallel units, N, is relatively small (typically between one and four), and redundancy is usually confined to '+1' (one additional unit). This is largely driven by the high investment costs associated with installing additional compressor capacity. Reasons to deviate from this rule may include the necessity to have a very high availability (and therefore the need to have an additional spare unit), large common cause failure probabilities (resulting in the need for separate systems or stations; each of which may have their own spares or shared spares), or the decision to use smaller units for flexibility reasons (and thus an additional unit is installed to increase reserve and/or account for maintenance).

The decision to establish an investment project (PED) is generally made on the basis of the required capacity. Rough cost estimates in the beginning of the process usually incorporate standard amounts of back-up. When it comes to station design, including the determination of the number of parallel machines, number of back-ups, choice for and sharing of energy supply, auxiliary systems, etc., the operational availability plays a role, balanced against requirements such as desired work areas, need for flexibility and expected load duration.

2.2.3 Recommendation

R3	**At compressor and other stations, apply the N+1 redundancy philosophy for critical equipment.**
a	In station design, the reserve policy and station availability should be taken into account, as well as desired work areas, need for flexibility and expected load duration.

2.3 Compression ratio and maximum flow (criterion 14)

2.3.1 Practice at Gaz Métro

Gaz Métro uses the hydraulic simulation package SynerGEE to run simulations of its system. With respect to compressor stations, Gaz Métro uses validated and physically verified operating ranges of installed compressors as boundary conditions for the hydraulic models. The Gaz Métro process for capacity assessment relies mainly on steady state simulations, meaning that in the hydraulic model, all flow and pressure parameters are assumed to be constant. An exception applies to the case of sub-networks with a compressor station at the entry point where dynamic changes in flows and pressures are taken into account, as these may be caused by compressor failure. For its compressor stations, Gaz Métro uses a switching procedure, which is applied in case of compressor failure, wherein when one compressor fails, the reserve compressor can be started to take over operation. As this changeover is not instantaneous, compressor down-time is taken into account in the capacity assessment.

Gaz Métro recently changed the procedures for its sub-networks. Until 2013, Gaz Métro executed a procedure where a static capacity component was used to represent the switching procedure in case of compressor failure (a dynamic operational issue). It was recognized that, because this approach inherently assumes a constant high demand at the exits, this procedure could provide results that are too conservative. Therefore, in the spring of 2014, Gaz Métro investigated the dynamic behaviour of the network through a series of transient simulations (wherein flow and pressure parameters are not assumed to be constant) in which the effects of changing throughput conditions over time was taken into account. The input for these simulations was a realistic demand profile as observed during the previous winter.

The results of this procedure were compared to those of the steady state simulation procedure, and the lowest resulting available capacity was chosen. Gaz Métro intends to execute this procedure every year. The steps of the new procedure are described in Appendix C.

2.3.2 Assessment

A change in pressure or gas velocity at one end of a gas pipeline is not immediately felt at other points along the line; this is due to the buffering effect of the volume of gas in the pipeline, which delays and dampens the disturbance. This effect is referred to as line pack and depends on the geometry of the pipeline (e.g. length, diameter) and the operational conditions.

The moment a compressor suddenly fails to operate, and the moment the compressor station comes back into operation, the operational conditions in the pipeline suddenly change. Besides the network configuration, the procedure for dynamic assessment of the effects of these changes relies on both the timing, represented by the downtime of the station, and the operational conditions, represented by the measured flow and pressure patterns, at the moment the compressor fails. These are discussed below.

Determination of down-time

In the case of a compressor failure where a back-up unit must be started, the calculation of the downtime of the compressor station is made up of a number of variables. These different variables add up to the total down time that must be taken into account; this is usually a simple summation, unless there is a proven interdependence between factors. The variables can be divided into two main categories:

- First, there are the 'technical' times, including the pre-heat period, the start-up time, and the speed-up period of the compressor. Note that the technical times may be dependent on operational aspects, such as parallel or idle-running operation of the compressors, and maintenance intervals.
    - The pre-heat period is usually prescribed by the manufacturer and may be influenced by the starting temperature.
    - Start-up times can be given by the manufacturer or may be determined from past experience and include a certain amount of uncertainty relating to the probability that the compressor does not start on the first attempt. Should the compressor fail to start on the first attempt, the number of attempts allowed in a given period (which is dependent on the configuration) also plays a role.
    - The speed-up period of the compressor is the period of idle-running or running at slower speeds that is required before the compressor can be used at full load, and is also often provided by the manufacturer.
- Second, there are the human or organisation related times. This begins with the time taken by the operator to make note of the failure and react accordingly: initiating the start-up procedure (often performed remotely). It may also include the additional time required to dispatch a technician onsite and perform repairs should the second compressor not start as anticipated. These times are often longer and more uncertain than the technical times described above and may be dependent on a number of factors including the availability of service personnel; manning of the station and/or number of personnel available for servicing; travel time to the location; the time of the day; personnel stand-by agreements; etc.

As such, several operational circumstances and arrangements play a role in analysing these times in order to obtain a representative value that can be used in transient simulations; however, analysing real cases can be impeded by the small number of examples available for use as inputs. It is therefore recommended that a careful review of the analysis including the arrangements for future data collection be undertaken. Gaz Métro has already begun such an analysis, as described in /4/.

Please note that operational circumstances and agreements are not constant; they can be consciously modified and therefore provide ways of influencing the mentioned times. Travel times, for example, can be reduced by manning the station or servicing the station from a nearby office; on the other hand travel times could increase with increasing traffic congestion on the prescribed routes.

Representativeness of the used flow pattern

In contrast with the previous procedure, the current procedure used by Gaz Métro takes into account the fact that the maximum flow is seldom a steady state flow for prolonged periods. Instead the procedure relies on a measured flow pattern, which peaks for a limited amount of time and then decreases. This approach has the advantage of representing a recent actual case. However, similar to the maximum flow case discussions (see section 3.2), the level to which the pattern is representative of the typical flow pattern in the system, and therefore the accuracy of the outcome, is less certain.

It is recommended that a sensitivity analysis be executed on this procedure. Initially, this can be performed by applying moderate variations (on the order of ten percent) to the existing flow pattern, for example:

- Broaden/tighten the period of very high flows (wider and narrower peaks in the profile);
- Increase or decrease the interval between consecutive periods of very high flows;
- Increase or decrease the average flow level (amplitude stretching);
- Relocate the peak into a period with lower or higher flows (line pack build-up and let-down).

In upcoming years, it is recommended that Gaz Métro should build and analyse a database of relevant profiles and effects to decrease uncertainty within the procedure.

Network analysis and investment projects

The decision to establish an investment project (PED, see section 1.2) is generally made on the basis of a standard analysis of the needs of the network. This long term analysis is generally performed for a steady state; however, some companies do take into account failure analysis and dynamic effects. In the case of Gaz Métro, we recommend the continued use of the steady state procedure, combined with additional transient analyses for the networks with compressor stations. In practice, this means that the transient analysis method is supplementary to the steady state procedure and should be taken into account when the resultant available capacity is lower than that determined by the steady state procedure. Should that be the case, the difference in available capacity determined by the transient analysis should be subtracted from that found by the steady state analysis.

In the investment project process, the transient simulation method should be applied as an additional analysis to underpin station design decisions. Furthermore, the transient analysis can help to establish whether the period until the reinforcement can be bridged by benefiting from the dynamics of the system.

After commissioning, it is recommended that logging and analysis of down-times be performed again, as input for any consecutive capacity assessments.

2.3.3 Recommendation

R4	**Continue to use the steady state simulations as the basis for the analysis, using the transient method as a supplementary source of information where it is relevant.**
a	Carefully assess the down-time determination procedure by adding up all relevant technical/operational factors and human/organisational related factors.
b	Assess the sensitivity of the simulation procedure to changes in the flow profile that is used.
c	Log downtimes and typical flow profiles for use in future analyses and assessments.

3 ASSESSMENT OF GAZ MÉTRO'S PARAMETER DEFINITIONS

Clear parameter definitions have a direct influence on the quality of decision making. Inconsistent interpretation of definitions introduces a potentially significant source of uncertainty in the value of the parameter, which can lead to errors in timing and/or decision making.

3.1 General overview of parameters

3.1.1 Practice at Gaz Métro

Gaz Métro applies the following definitions, which are further described in Appendix A, and individually assessed in the following sections:

- **Percentage of network utilisation [%].** This parameter is used as an indicator of network congestion. It serves as a performance parameter as well as an indicator for investment investigations.
- **Spare capacity of the network [m^3/h].** This parameter is used as an indication of whether any new volumes (with associated capacity requirements) can be sold. It serves as a decisive factor in sales processes.

These two parameters are based on the results of two different types of hydraulic simulation analyses, which provide:

- **Maximum gas flow case [m^3/h].** The gas flow that is representative of a maximum throughput case. This flow may be either observed during winter or may be a predicted value.
- **Technical capacity [m^3/h].** The theoretical maximum flow that can be transported through a network or sub-network without violating any of the constraints that are imposed on it (e.g. pressure levels or gas velocities).

Percentage of network utilisation is defined as the ratio of the maximum gas flow case to the technical capacity, and spare capacity is defined as the difference between technical capacity and the maximum flow case. This means that if the maximum gas flow case is equal to the capacity, the percentage of network utilisation is 100% and spare capacity is 0 m^3/h.

3.1.2 Assessment

Parameters like network utilisation and spare capacity represent simplified terms, and do not fully reflect the complexity of the issues that should be taken into consideration. In DNV GL's experience, these parameters are therefore not generally used as sole decisive factors; decisions are made on the basis of extended analyses collected in a Business Case or similar process. They are however very suitable as indicators of a need for further analysis and investigation, and can be used as supporting evidence in investment and sales decisions. Still, they should be used with care and uncertainties should be taken into account. It is critical that definitions and determinations, as well as the inputs, assumptions, and conditions are logged and an explanation of their application is provided. This will ensure clear definition and help avoid differences in interpretation. Furthermore, by properly addressing any uncertainty related to the procedure, the inputs or any assumptions that are made, the existence of uncertainties and impacts thereof are explicit for decision makers.

3.1.3 Recommendation

R5 When presenting capacity parameters (network utilisation, spare capacity, maximum gas flow case or technical capacity), clearly explain all assumptions, inputs, uncertainties, and conditions.

3.2 Definition of the maximum gas flow case

3.2.1 Practice at Gaz Métro

At Gaz Métro, the maximum flow case of a network is simulated in a set of calculations, referred to as Maximum Demand, where the flows in the network are simulated with minimum pressure at the entry point(s) and maximum projected demands at the delivery points. This type of simulation provides delivery pressures at the delivery points, which can then be checked against minimum required values. Should these comparisons reveal that the minimum pressure requirements are not met, this is an indication that the given demand projection cannot be transported in the current network.

Until 2013, the demand in these simulations was based on historical peak realisations from the previous winter, and, for future years, on the market assessment (see section 1.2). Gaz Métro distinguishes between two cases, one without interruption and one where the clients were all interrupted without allowing additional agreements for a limited period. Currently, Gaz Métro is reviewing the modelling of the peak demand to introduce a distinction between the realised flow in last winter and analysis based flow predictions, described in /9/ as part of the market assessment investigations (see section 1.2).

3.2.2 Assessment

It is important to distinguish between the maximum gas flow cases based on observations and those based on predictions due to the differing natures of the figures, and their implications for the assessments. These are used as inputs to performance reporting and capacity assessment respectively.

In performance reporting, the maximum gas flow case usually refers to a historically realised maximum case. Gaz Métro uses the flow case in a network, or sub-network, of the single hour during last winter when the sum of all exits was at its maximum, both for the case with and the case without interruptions. This is not necessarily, and in most cases is certainly not, equal to the maximum expected gas flow case. This lower value is the result of a combination of causes including the actual temperature during that hour, demands that have lower off-take (e.g. factory in temporary shut-down), and peaks that do not occur simultaneously. This implies that when high maximum gas flow realisation cases are reported (close to or even exceeding the technical capacity) the flow could potentially have been even greater, and therefore the actual probability of failure is higher. As such, in a capacity assessment, the maximum gas flow case should refer to the maximum expected or desired case, which can also be referred to as the design case. The design case represents the maximum load situation, or situations, that the network should be able to accommodate without failure. The design case is a very important input for the design of the network. Should the design case be insufficiently stringent, the company faces an increased probability of failure; on the other hand, if it is too stringent, the company risks overdesign and overinvestment. As all decisions defining the maximum flow case have direct impact on the need for capacity, these should be substantiated and documented in detail, and be agreed upon at a sufficiently high management level (i.e. senior management up to company president).

Since the process of defining the maximum predicted gas flow case includes a number of choices (e.g. how to interpret historical data, how many years to take into account in an analysis, which economic growth predictions to apply) and uncertainties (e.g. weather uncertainties, timing aspects, location of market predictions), it is recommended that, in order to properly support investment decisions, these choices should be well understood. Gaz Métro is investigating this topic in parallel to the current investigation; it is therefore not discussed further here.

3.2.3 Recommendation

R6 Distinguish between the maximum observed gas flow rate (to be used in performance reporting) and the maximum predicted gas flow rate (to be used as input for capacity assessments).

3.3 Definition of the technical capacity to be assessed

3.3.1 Practice at Gaz Métro

At Gaz Métro, the technical capacity of a network is determined on the basis of a set of simulations, referred to as Minimum Delivery Pressure simulations, where the flows in the network are modelled for a case with minimum pressure at the entry point(s) and minimum pressure at the delivery point(s) at the end(s) of the transmission network.

The Gaz Métro network consists of a number of separate sub-networks which are not interconnected (see Figure 1; the Gaz Métro network is indicated in blue). Each of these networks is supplied with natural gas from the TQM, TCPL or Champion transportation systems (light green, yellow and pink lines, respectively). The networks range from relatively simple to moderately complex, and each is modelled separately.

The Estrie network is one of the more complex networks (see enlarged in Figure 2) as it has two distinct but physically connected main branches and two entry points. The branches are referred to as the Sabrevois/Courval branch (the western branch of the network, indicated in green) and the Waterloo/Windsor branch (the eastern branch, indicated in red).

In the capacity determination these branches have previously been treated by Gaz Métro as both combined and separate systems; in recent years they have been treated separately. This decision is based on the fact that the simulations revealed that there is capacity available but only in the Sabrevois/Courval branch. Gaz Métro observed from simulations that under current circumstances this spare capacity could be used without affecting the pressure in the other branch. Verifications have been performed using simulations to ensure that there is currently no mutual pressure dependency, confirming that separate treatment of the branches is a valid approach.

Figure 1 Schematic overview of the Gaz Métro network (in blue); with TQM, TCPL and Champion transport systems (in light green, yellow, and pink respectively)

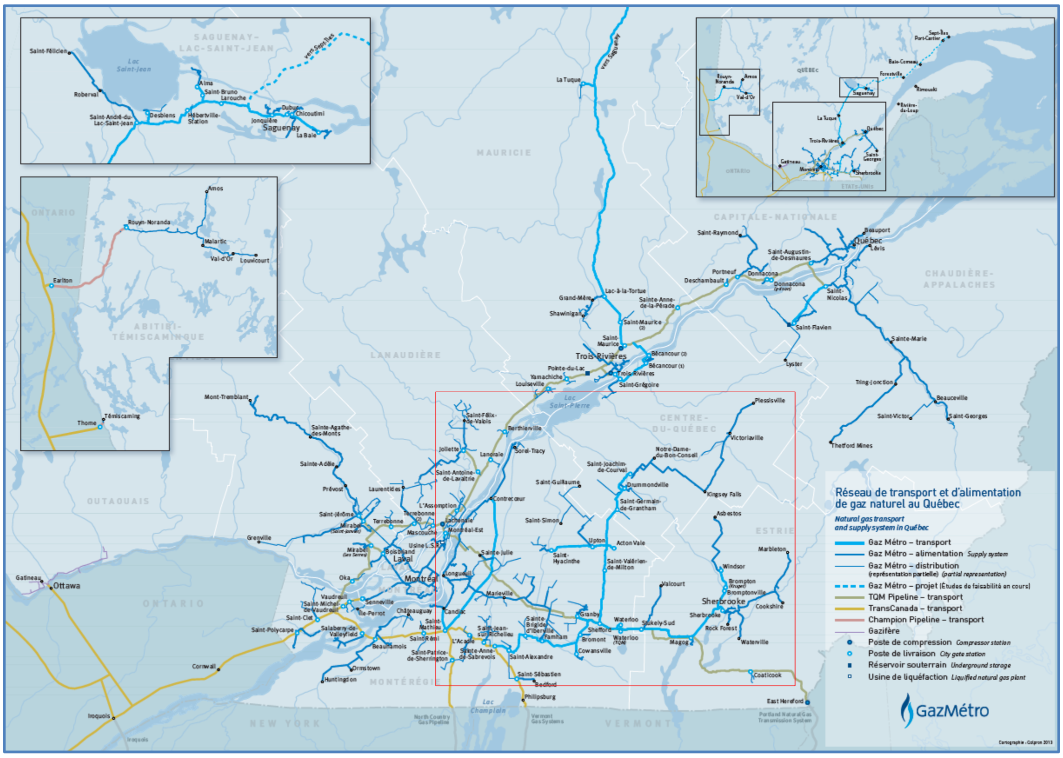
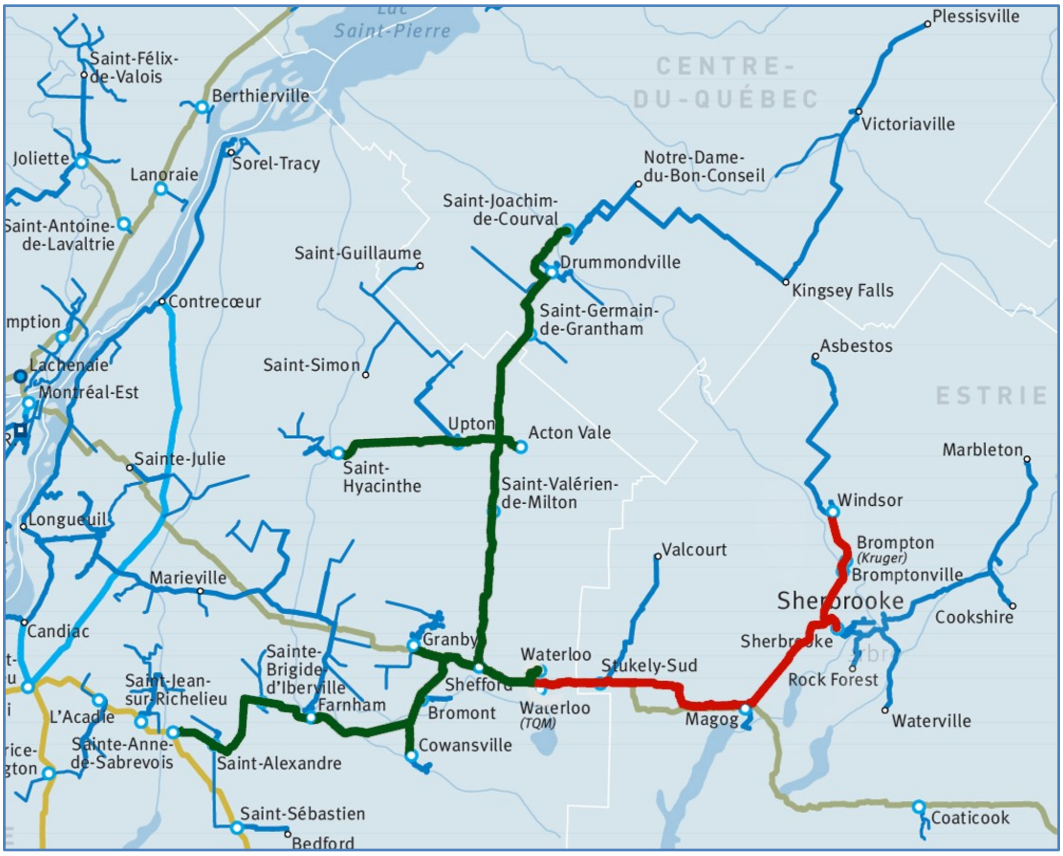


Figure 2 Gaz Métro Estrie transmission network; Green: Sabrevois/Courval branch, Red: Waterloo/Windsor branch



3.3.2 Assessment

The technical capacity of a network, or sub-network, refers to the theoretical maximum flow that can be transported through it under a given set of circumstances, without violating any of the constraints that are imposed on it (e.g. pressure limits). Flow simulation computer programmes such as SynerGEE, which is used by Gaz Métro, are widely used to calculate the technical capacity of pipelines and networks. SynerGEE can be regarded as a simulation platform, providing tools which can be used in a variety of ways to execute capacity analyses and other investigations. It is therefore highly recommended that the specific application and assumptions for each simulation be carefully documented. The main issues to address in the calculation of technical capacity relate to the network complexity and the demand and its distribution (demand forecasts), which are discussed below.

Network complexity

The calculation of the technical network capacity becomes increasingly complex with increasing complexity of the network[2]:

- **Simple.** For a single pipeline, the technical capacity can be defined as a single value when the following parameters are known: diameters and lengths, maximum operating pressure, minimum delivery pressure, physical properties of the gas, and friction at the pipeline wall[3]. To calculate the technical capacity of a pipeline system with a simulation model, additional flow is superposed stepwise at the exit point, until a level is reached where the delivery pressure can no longer be maintained.

  In the Gaz Métro system, the Abitibi transmission network is an example of a very simple case with only one entry point (Earlton) and only one exit point (Rouyn).

- **Intermediate.** For a network, the precise distribution of the demands also plays a role in the determination of technical capacity. Consider, for example, a network consisting of one pipeline with one entry point and several side branches and exit points along the route. The highest value for technical capacity would be found when all of the demand is located at the exit point closest to the entry point. By contrast, the lowest capacity would be found when all of the demand is located at the exit point farthest away from the entry point, as the gas has to travel a greater distance. Technical capacity then becomes a range of values depending on the assumptions regarding the geographic distribution of the demands. An illustration of this variation is given in Appendix E with a fictional network example.

  In the Gaz Métro networks, Saguenay is an example of an intermediate network: it has one entry-point at St-Maurice, and side branches/exits at La Tuque, Jonquière, and La Baie, among others. This network could transport more gas if all demand were located at a point close to the entry point (i.e. La Tuque) than if it were located at the far end (i.e. La Baie).

- **Complex.** In the case of even more complex networks with, for instance, spur lines, side branches and/or closed loops, the maximum and minimum cases cannot be easily determined. There will be a range of different technical capacities possible, depending on a range of assumptions regarding the geographical distribution of the demands. In a number of cases this may be overcome by splitting the network (as Gaz Métro is doing for the Estrie network), or by defining separate technical

2 Note that in the descriptions here, we focus on variation in exits or demands, not on entry or supply. This is done because this approach is most relevant for the Gaz Métro network. If desired, the same could be done with a focus on entry or supply. Networks with both multiple exits and entries are usually categorised as 'Complex'.

3 This may be limited by restrictions to, for example, maximum gas flow, (e.g. when a pipeline is damaged or there are noise/pulsation problems).

capacities for side branches or spur lines. Where systems contain closed loops, this becomes more difficult.

In the Gaz Métro networks, Estrie is one of the more complex networks. Gaz Métro has no networks containing closed loops.

For relevant sub-networks, we recommend that the technical capacity be calculated for two cases: considering the entire network as a single network and considering relevant branches treated as separate networks, investigations should be carried out as to whether further separation is needed for side branches or spur lines. This recommendation applies to both the technical capacity determination and the maximum gas flow case, particularly for the Estrie network. For upcoming capacity assessments, it is recommended that the execution of the assessment for both the sub-networks considered as a single network and as separate sub-networks should continue. Currently, the case where the network is considered as two separate networks is the determining case, as it reveals where new capacity can be sold without a resultant capacity reduction in the other part of the network. We recommend that Gaz Métro should verify every year whether the arguments for separate treatment of the network are still valid or if any changes (i.e. further separation[4] or re-integration) should be made in the treatment of branches and/or spur lines.

Demand and demand distribution

As the previous section described, the distribution of demand plays a role in the determination of the technical capacity, and both the current and future demand and demand distributions are relevant inputs for the capacity assessment. Gaz Métro is investigating the demand and peak demand predictions in parallel to the current investigation (see section 1.2). With respect to network capacity, the location of demand (growth) includes some parts of uncertainties that should be considered within those parallel investigations. Examples of such uncertainties may include accelerated or delayed connection of projected customers; larger or smaller demands from projected customers; changes in projected connections of new customers to different locations or different sub-networks; variations regarding disconnection; or increase or decrease of demand from existing customers.

If no information regarding the demand distribution and uncertainties associated with demand developments is available, the capacity modeller must make assumptions regarding the location of the additional demand in the network in order to calculate the technical capacity for future years. This leaves the modeller several options including:

- **Farthest away.** The most conservative case is achieved by an assessment where all additional demand is superposed on the exit point located farthest away from the entry point.
- **Pro rata.** A very commonly applied assessment is one where the demand of each of the exit points is increased by the same relative amount so that exit points with larger demands grow faster. This involves an inherent assumption of uniform market growth.

  This method is very suitable for markets with large numbers of relatively similar clients. Such markets will follow general economic growth and welfare increases, and are not sensitive to the demand changes, connection, or disconnection of single clients.
- **As predicted.** Another commonly applied assessment is one where the superposed capacity follows market predictions (when not available from the market assessment, see section 1.2, the modeller will make a prediction based on other information). The result is that exit points where many new

4 For example, further sub-branching (e.g. the Sabrevois/Courval branch into a Sabrevois/Shefford branch and a Shefford/Courval branch) and/or separating side branches (e.g. the side branch to Saint-Hyacinthe), in order to maximize the capacity available for the market.

customers are expected in the upcoming period will grow faster in the simulations than exit points where that expectation does not exist. This option is more suitable for markets with relatively large, single customers and where a credible market growth assessment is available. This option is applied by Gaz Métro.

The 'As predicted' procedure will provide the most accurate result in a case like Gaz Métro’s, given the nature of the market it serves; the ‘Farthest away’ procedure will provide the most conservative result. In both the Saguenay and the Estrie networks, we recommend that demands be increased in accordance with the statistical study /9/.

It is recommended that Gaz Métro undertakes an assessment of the market development uncertainties by a delta-analysis, determining the magnitude of the effects of potential deviations from the predicted market developments. The deviations taken into account in the capacity assessment, and an estimate of the probability thereof, should come as a result of the market assessment (see section 1.2). Should such detailed information not be available, Gaz Métro could execute the sensitivity assessment based on deviations by fixed amounts (e.g. ten or twenty percent).

3.3.3 Recommendation

R7	**Specify and document the methods and assumptions used in the technical capacity assessment.**
a	Use the design case based on the statistical study /9/ as input in the hydraulic simulations.
b	Specify the method of increasing demands in the model used to calculate the technical capacity of a sub-network; we recommend the ‘As predicted’ method.
c	Calculate the sensitivity of the technical capacity calculation of a sub-network for possible changes/uncertainties in timing and location of market predictions.
d	For those sub-networks where it is relevant (e.g. Estrie), calculate the technical capacity not only for the entire network as a single network, but also with relevant branches and/or spur lines treated as separate networks.
e	Annually verify the validity of the procedure and assumptions regarding the separate treatment of branches.

3.4 Derivation of the percentage of network utilisation

3.4.1 Practice at Gaz Métro

Gaz Métro defines percentage of utilisation as the division of the maximum gas flow case and the technical capacity (respectively the results of the two series of simulations described above). It is expressed in [%], relative to the technical capacity.

Percentage of utilisation has been used by Gaz Métro as a performance reporting parameter in its reporting to the Régie /1//2/ for several years. In /2/, Gaz Métro reports maximum values for the percentage of utilisation, based on the maximum hourly demand of the last winter, with and without the contribution of interruptible contracts. In past years, performance reports have shown high percentage of utilisation for both Saguenay and Estrie networks. Gaz Métro initiated its reinforcement plans on the basis of high reported and projected percentage of utilisation figures.

3.4.2 Assessment

It is vitally important to distinguish between the use of percentage of utilisation as a performance reporting parameter and as a decisive factor for reinforcement plans. This is due to the definition of the maximum flow case, and to a lesser extent the definition of technical capacity, upon which the percentage of utilisation is determined.

Percentage of utilisation is a parameter which indicates how fully an asset is currently being used. For gas transmission, it indicates the amount gas flowing through the network during a defined period of time compared to the technical maximum capacity of that network.

Note that within the practice of performance reporting, utilisation may have different meanings. In many cases, utilisation refers to an average use of the pipeline or system, rather than the maximum use case. See for example on the website of the American Energy Information Administration (EIA)[5] /5/:

> ***Overview of Pipeline Utilization***
>
> *Natural gas pipeline companies prefer to operate their systems as close to full capacity as possible to maximize their revenues. However, the average utilization rate (flow relative to design capacity) of a natural gas pipeline system seldom reaches 100%. Factors that contribute to outages include:*
>
> - *Scheduled or unscheduled maintenance*
> - *Temporary decreases in market demand*
> - *Weather-related limitations to operations*

Where, in this report, we focus on a case related to peak usage, similar to the third bullet, many utilisation reports focus on average usages cases. The EIA indicates in the same webpage that average utilisations are generally well below 100%, because of both capacity-related causes (e.g. technical capacity) and demand related causes (e.g. flow case):

> ***Measures of Pipeline Utilization***
>
> *There are several ways that natural gas pipeline system utilization may be estimated, as demonstrated in the following cases:*
>
> - *As a measure of the average-day natural gas throughput relative to estimates of system capacity at State and regional boundaries*
> - *The system wide pipeline flow rate, which highlights variations in system usage relative to an estimated system peak throughput level*
> - *A system peak-day usage rate, which generally reflects peak system deliveries relative to estimated system capacity*

5 The U.S. Energy Information Administration (EIA) collects, analyses, and disseminates independent and impartial energy information. It was established by the Department of Energy (DOE) Organization Act in 1977 as the single Federal Government authority for energy information, independent from the rest of DOE.

The website of the Canadian National Energy Board[6] /6/ reports average utilisations over months, and states that:

> *… determining the capacity on a pipeline is complex. Capacity varies with ambient temperature on gas pipelines and, for both oil and gas pipelines, is affected by maintenance, pressure reductions, etc. Additional factors must be considered for oil pipelines including the type of product, product mix, type of batching and pipeline configurations.*

In this section, we focus on utilisation figures based on a peak case, and disregard any monthly or annual utilisation rates.

Performance reporting

Since the technical capacity of a network of intermediate or large complexity is not always straight-forward (see section 3.23.33.3), neither is the percentage of utilisation. Recording and explaining the underlying assumptions and conditions, as well as the meaning and implications of the reported values, is critical to this process.

The observed maximum gas flow case is usually lower than the predicted maximum gas flow case or design flow case (see section 3.2), which implies that when high percentages of network utilisation cases are reported (close to or exceeding 100% of the technical capacity), the future utilisation based on predictions may be even higher. Therefore the probability of failure (i.e. the chance of a non-delivery case) is higher than what would be expected based on reported utilisations.

Network analysis and investment projects

In the gas industry, network utilisation in and of itself is recognised as an indicator, meaning that if it approaches or passes a certain value, this may trigger further investigation. The actual investment decisions (see section 1.2) are normally based on a thorough assessment of customer requirements, as stated in contracts or in connection agreements, or on a pipeline company's view of the market, in relation to the capabilities of the current network. Such analyses reveal not only the network utilisation figures for the entire network, but also the bottlenecks of the current system, which should be countered by the investment.

At predicted percentages of utilisation of 100% or more, when market growth may be expected, action in the form of detailed analysis needs to be taken. Gaz Métro could choose to use a lower value as threshold (<100%), to ensure that it is able to compensate for factors such as uncertainties in determination and in timing of the demand growth. However, at the moment, we believe it is acceptable to leave the threshold at 100%, and stay in-line with the practice at other Canadian gas distribution companies which apply the same threshold. It is recommended that Gaz Métro keep abreast of market developments, preferably incorporated into an annual planning calendar so that action can be taken in a timely manner should market growth accelerate.

However, the possibility of operational back-ups (reserve components, alternative routes, etc.) should be taken into account; for systems or sub-systems with few operational back-ups and large failure probabilities, lowering the threshold from 100% could be considered. The average percentage of market growth could serve as an indication of the amount by which the threshold could be lowered, as this would advance a project establishment decision to increase the capacity. Should a further decrease be necessary, it would be more appropriate to improve network operation and/or increase component or

6 The National Energy Board (NEB or Board) is an independent federal agency established in 1959 by the Parliament of Canada to regulate international and interprovincial aspects of the oil, gas, and electric utility industries in the Canadian public interest.

system availability, as these may be problems that will not always be solved by advanced capacity investments.

Apart from the actual value of the threshold itself, we recommend that Gaz Métro takes into account historical and predicted developments regarding the percentage of network utilisation in deciding whether a reinforcement investigation project should be initiated.

3.4.3 Recommendation

R8	**Distinguish between network utilisation as a performance reporting parameter and network utilisation as a decisive factor.**
a	Initiate detailed investigations for determining required reinforcements a sufficient number of years ahead of the year that utilisation is expected to reach 100%.

3.5 Derivation of spare capacity

3.5.1 Practice at Gaz Métro

Gaz Métro defines spare capacity as the difference between the maximum gas flow case and the technical capacity (respectively the results of the series of simulations described above). It is expressed as a capacity in [m^3/h].

Currently at Gaz Métro, spare capacity for each of the networks/branches is calculated and communicated annually in the spring. It is expressed as a single value of the capacity that can be sold by the sales department.

3.5.2 Assessment

The term spare capacity generally refers to any capacity in the system that is not yet contracted, and is therefore available to the market. For distribution, capacity is mostly not contracted separately, but included in volume contracts. In this sense, contracted refers to capacity that needs to be taken into account for the delivery of contracted volumes. Spare capacity refers to volumes that the system is capable of transporting, but have not yet been sold. Spare capacity is typically used as an internal parameter: it is determined by a technical planning or engineering department, and is used by the sales department. This is the case at Gaz Métro. As with the percentage of utilisation, the determination of the spare capacity relies on the technical capacity calculation (see section 3.3) and the maximum flow case (see section 3.2) (i.e. the combinations of demands the system should be able to handle). As these input values are dependent on location and conditions, spare capacity needs to be defined and interpreted with care.

There are certainly advantages to relatively simple capacity statements (i.e. stating a single capacity value for a whole network) as these are simpler to understand and work with, particularly for personnel outside of the engineering field. However, such an approach may lead to too much generalisation and thus either to large uncertainties or (in order to rule out uncertainties) to spare capacity values that are too low. It is therefore recommended that Gaz Métro increases the granularity of the spare capacity by differentiating the values by location in the network. Separate capacities associated with spur lines are useful in case there are exit points in these lines that could cause large pressure drops resulting in reduced capacity in the rest of the network. Similarly, where there are branches in the network, as is the case for the Estrie network, these should be clearly distinguished in the spare capacity statement and the sum of the individual spare capacity values for spur branches should not exceed the spare capacity of the overall network. An alternative could be to provide the sales department with a total load by location; then once capacity is sold to this level, all further enquiries are referred to the engineering department for review and approval.

It is recommended that Gaz Métro define a location-independent spare capacity and additional capacities at individual points/branches/segments where appropriate. Assumptions and conditions form an integral part of the spare capacity statement, and should be logged and explained with every update.

We recommend that Gaz Métro update their assessments as part of quality assurance, beginning with an update frequency of twice per year, and investigating benefits and costs to see if more frequent review would be beneficial.

3.5.3 Recommendation

R9	**Focus on the precision and certainty of the spare capacity determination process rather than on simplification of the results with a view to ease understanding.**
a	Distinguish spare capacity between locations in the network, spur lines and/or branches, only where necessary.
b	Increase the update frequency of the spare capacity determination to twice a year, and more frequent if useful.

4 RECOMMENDATIONS

This chapter collects the recommendations that were made throughout the report, regarding the criteria 11, 13 and 14 from /1/ as well as the general parameter definitions underlying the capacity assessment approach.

An overview of the recommendations is given in Appendix F. When reading these recommendations, it is important to note that Gaz Métro's capacity assessment process has been undergoing changes since the end of 2013 when Gaz Métro initiated a series of actions and investigations to improve its procedures in the light of anticipated investments. Gaz Métro is actively improving its processes, and we believe that the capacity assessment process is being developed in a manner that is consistent with good industry practice. Portions of the recommendations below may already be in the process of implementation.

On criterion 11 regarding the minimum supply pressure to take into account in the capacity calculations, we recommend that Gaz Métro rely only on contractually agreed upon minimum supply pressures for long term network design. However, in the current situation where reinforcements are anticipated but not yet commissioned, the application of best efforts contract values instead of contractually guaranteed values is valid, particularly in light of the fact that Gaz Métro has already successfully begun negotiations to temporarily upgrade entry pressures from best efforts to guarantees with its suppliers. Although it has only minor significance at the moment, we recommend the inclusion of pressure drop over entry stations in the network simulations, and occasional verification of the implementation of the network simulations and associated assumptions.

On criterion 13 regarding redundancy of critical transmission equipment, we recommend the application of the N+1 redundancy philosophy for critical equipment such as compressors. In station design, the reserve policy and station availability should be taken into account, as well as desired work areas, need for flexibility and expected load duration.

On criterion 14 regarding compression ratio and maximum flow to take into account in the capacity calculations, we recommend the use of the transient simulation method as a supplement to the steady state simulations. We recommend that the applied down-time be based on a summation of all relevant technical/operational factors and human/organisational related factors. In the short term, we recommend an assessment of the sensitivity of the simulation procedure to changes in the flow profile that is used. We also recommend logging downtimes and typical relevant flow profiles for use in future analysis and assessments.

On the parameter set-up in the current capacity assessment approach, we recommend that all parameters, procedures, and assumptions be specified, documented, and explained. An important consideration is the difference between the maximum observed gas flow rate (to be used in performance reporting) and the maximum predicted gas flow rate (to be used as an input to the capacity assessment). We recommend that the hydraulic simulations be based on the statistical analysis (being performed as described in /9/) and that Gaz Métro should calculate the sensitivity of the technical capacity calculation of a sub-network for possible changes or uncertainties in timing and location of market predictions. We recommend that detailed investigations for determining required reinforcements be initiated a sufficient number of years ahead of the year that utilisation is expected to reach 100%.

With respect to the internal parameter spare capacity, we recommend that Gaz Métro should focus primarily on the precision and certainty of the spare capacity determination process rather than on simplification of the results with a view to ease of understanding. It is therefore important to distinguish spare capacity between different locations in the network, spur lines and/or branches where necessary. We recommend that Gaz Métro increases the update frequency of the spare capacity determination to twice a year, and more frequent if need be.

5 REFERENCES

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/2/ *Niveau de saturation du réseau par région, suivi la décision D-2012-158*; Société en commandite Gaz Métro, Rapport annuel au 30 septembre 2012, R3831-2012 (in French), February 2013.

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APPENDIX A
Capacity parameters at Gaz Métro

Gaz Métro uses the network modelling tool SynerGEE to perform network simulations to determine the capacity of their transmission network and its usage. This appendix briefly describes the parameters used by Gaz Métro, and their determination.

Definitions and outline of procedure

Gaz Métro distinguishes between the **maximum technical capacity** and the **utilised capacity** at maximum flow conditions, the latter of which reveals how much spare capacity exists in the network. In order to do this, the flows in the network are determined for two situations using steady state simulations:

- **Type 1 simulation ('Maximum Demand'):** the flows in the network are simulated for a case with minimum pressure at the entry points and maximum demand at the delivery points. This type of simulation reveals delivery pressures at the delivery points, which can be checked against minimum required values. The sum of the flows at the delivery points ($q_{max,use}$) represents the maximum utilisation flow ($Q_{max,use}$);
- **Type 2 simulation ('Minimum Delivery Pressure'):** the flows in the network are simulated for a case with minimum pressure at the entry points and minimum pressure at the delivery points located at the end(s) of the transmission network, while maintaining the maximum flow used in the Type 1 simulation at all other delivery points. In this type of simulation, the maximum flows that can be transported within the pressure constraints are determined. The sum of the flows at the delivery points ($q_{max,tech}$) represent the technical maximum flow in the system ergo this type of simulations reveal the technical maximum capacity($Q_{max,tech}$).

With the results of these simulations, the utilised and spare capacities can then be derived as follows:

- **Utilised capacity:** the quotient of the maximum utilisation ($Q_{max,use}$) divided by the technical maximum flow ($Q_{max,tech}$) through the system is called the utilised capacity of the network. It is expressed as a percentage of the technical maximum capacity:

$$Utilised\ capacity = \frac{Q_{max,use}}{Q_{max,tech}} \cdot 100\ [\%]$$

- **Spare capacity:** the difference between the technical maximum flow and the maximum utilisation flow is called the spare capacity of the network. It is expressed as a capacity in [m^3/h]:

$$Spare\ capacity = Q_{max,tech} - Q_{max,use}\ [m^3/h]$$

APPENDIX B
Capacity assessment at Gaz Métro

General outline

To determine the capacity and usage of the transmission network for worst case supply and demand conditions in SynerGEE, the following items should be taken into consideration:

- **Network configuration and parameters:** a network's capacity is primarily determined by the physical lay-out of the network and its translation into standard parameters within the simulation model.
- **Operational requirements in the network**: the most important requirements to consider are the maximum operating pressures and minimum pressure requirements for certain locations.
- **Demand:** the worst case demand situation is defined as the maximum gas demand that can be expected in a given hour at the delivery points, for both current and future predicted scenarios.
- **Supply:** the worst case supply situation is determined by the maximum flow and the minimum pressure conditions at the entry points.

Gaz Métro is currently in a position where it must bridge the interim period until proposed reinforcements can be commissioned. This appendix focusses on key areas of Gaz Métro's standard assessment procedure.

Network configuration and modelling parameters

The Gaz Métro transmission network actually consists of seven sub-networks, which are connected to one another and supplied by TQM and TCPL. In coordination with Gaz Métro, the scope of this investigation was limited to the two transmission sub-networks with the highest percentages of utilisation: Saguenay, located north of Montreal, and Estrie, located southwest of Montreal.

- **Saguenay.** The Saguenay network is located north of Montreal and has a total length of approximately 365 km. The network serves approximately 2850 customers, of which about 900 are in the residential sector (~30% by number).

  The Saguenay network runs from an entry point at Saint-Maurice up to La Baie, with several delivery stations along the route. It is supplied with natural gas by the TQM system. The network has one compressor station, located near the entry point at Saint-Maurice.

- **Estrie**. The Estrie network is located southwest of Montreal and has a total length of approximately 270 km. The network serves approximately 9000 customers, of which about 3300 are in the residential sector (~37% by number).

  The Estrie network consists of two main branches, referred to as the Sabrevois/Courval branch, the western branch of the network, and the Waterloo/Windsor branch, the eastern branch of the network. The Sabrevois/Courval branch runs from an entry point at Sainte-Anne-de-Sabrevois to the most downstream delivery station at Saint-Joachim-de-Courval, and includes side branches and delivery stations along the route. It is supplied with natural gas by the TCPL system. The Waterloo/Windsor branch runs from an entry point at Waterloo to the most downstream delivery station at Windsor and includes a number of delivery stations along the route. It is supplied by the Lachenaie-East Hereford branch of the TQM Pipeline. The Waterloo/Windsor branch is faced with congestion issues around the city of Sherbrooke.

These two branches are physically connected and in the capacity determination they are treated by Gaz Métro both as combined and as separate systems. This is done because, in the case of the combined assessment, the simulations reveal that there is spare capacity available. However, the spare capacity is known to be zero for the Waterloo/Windsor branch. Gaz Métro observed in the separate system simulations that this spare capacity can be used without affecting the minimum pressure in the Sabrevois/Courval branch.

Operational requirements

Operational requirements are derived from network design and contractual conditions. In Gaz Métro's case, the most important conditions are the maximum operating pressures and the minimum pressure requirements at the delivery stations.

The maximum operating pressures (MOP) in the Gaz Métro transmission network are different depending on the sub-network. For the Saguenay network the MOP is 7070 kPa; given that the maximum pressure in the TQM supply system at the entry point has the same value, the MOP is not a limiting factor in the simulations for that network. In the Estrie network the MOP is 6840 kPa; given that the maximum inlet pressures at both entry points are higher, the MOP is the limiting factor in the simulations for this network.

At all delivery stations, the minimum design pressure is 2750 kPa. This pressure is determined by the sum of the minimum pressure in the distribution network (2400 kPa) and the minimum pressure differential required for the regulation equipment to function properly.

Demand: maximum expected flow

Gaz Métro supplies gas to individual households (i.e. residential customers) and to industrial and commercial customers. They are distinguished by their annual volume. Contracts between customers in these sectors and Gaz Métro specify the minimum delivery pressure, the annual volume, and the maximum flow rate. Some customers have a seasonal off-take (i.e. only receive gas in the summer).

On transmission networks, demand is defined as the demand at the delivery stations and is the sum of the demands of all individual customers in the network(s) downstream of these stations. In order to determine the maximum expected flow at these delivery stations, Gaz Métro uses a method whereby it incorporates measured values from a recent winter to determine the maximum load for each sub-network. This maximum demand is then corrected for flows under interruptible contracts which may be interrupted at Gaz Métro's notice in severe load situations.

In order to extrapolate the simulations into the foreseeable future with a 10 year forecast, Gaz Métro bases its assumptions on a market study.

Worst case demand scenario – Current situation

The worst case demand determination consists of two steps: first Gaz Métro determines a maximum load based on the single hour during the previous winter with the greatest demand. At the end of this process, the resulting flows at each individual delivery station, measured for the hour in question are input into the simulation model in SynerGEE as the worst case scenario (i.e. highest load to the network: a type 1 simulation). This procedure has been followed for several years.

- **Step 1: maximum realized demand in previous winter.** Gaz Métro bases the determination of the maximum expected load in each network or sub-network on flow measurement data from the whole of the previous winter by determining the single hour where the sum of the flows at all delivery stations for the given network or sub-network was at its highest. This hour is referred to as $t_{max\ flow}$, and the flow as $Q_{max,use}$, called the coincidental flow.

Flow is measured at most of the delivery stations in the Gaz Métro system. For those stations that do not have flow metering facilities, the maximum contractual value (if available) or an estimate of the peak flow, based on the consumed volume and behaviour of similar customers, is used.

- **Step 2: correction for interruptible contracts.** In the Gaz Métro network, a number of commercial and industrial customers have contracted a portion of the capacity under interruptible contracts. This means that their delivery may be interrupted given notice by Gaz Métro. The tariffs, conditions to call these interruptions, and the number of days that the flow may be interrupted are specified in the contract. Typically, Gaz Métro should notify the customers one day in advance of the interruption, in case of emergencies, this notice period can be reduced to two hours. Gaz Métro bases the calling of interruptions on, amongst other things, forecasted temperatures.

  Gaz Métro uses linearized temperature-flow relationships at delivery stations to determine the amount by which the measured maximum coincidental flow at a delivery station can be decreased without violating the service agreements with the interruptible clients. The temperature-flow relation depends on the behaviour and mix of consumers supplied by the delivery station.

  Gaz Métro then applies a correction to the measured flows at the delivery stations for those portions of the flow that fall under interruptible contracts, but were not interrupted.

Worst case demand scenario – Future situation

An analysis of the demand itself is not within the scope of this investigation; however, it must be considered during the capacity assessment.

SECOR performed a market study to determine the increase in demand that can be expected in the short term (1-2 years) and in the long term (10 years); the result of which is that Gaz Métro expects the natural gas demand in its service area to increase in the near future.

In order to determine the worst case demand scenario the maximum flows in the market study data are entered as inputs into the simulation model without modifications or alterations. The predicted increase in flow is specified by customer group and by geographical location and then assigned to the delivery station corresponding to the specified location. The new maximum flow value for each delivery station in the transmission network is then the sum of the maximum measured flow and the value from the market study. The derived maximum demand is used in a type 1 simulation ('Maximum Demand').

The following items are critical for consideration in capacity assessments of predicted scenarios:

- **Residential demand.** For the residential market, the market study distinguishes between houses and condos/apartments by the maximum flow they require on average in the winter; the latter have 50% lower maximum demand. The average maximum demand per house depends on many factors such as the type of house, the degree of isolation, the type of gas use in the house (e.g. heating, appliances), weather conditions, family size, and energy usage of the occupants. The demands used in the market study are therefore based on historical amounts. The maximum demands found in historical data are generally much lower than the technical maximum capacity of the connections (for houses, the technical capacity of a connection is 6 m^3/h; however, the maximum flow is, on average, 1 m^3/h).

- **Commercial and industrial demand.** In the commercial and industrial market sectors, where volume and capacity are contracted, future demand growth is largely determined individually by known or expected new customers that will be connected during the simulation horizon. In the first year of a predicted connection, the contractual maximum flow of the new customer will be used in the capacity assessment in order to be sure that the contractual value can be delivered to the customer. In subsequent forecasted years, the flow of the new customer is included in the maximum measured values at the corresponding delivery station. The expected maximum flow is based on the maximum consumption of the equipment that will be installed, or estimates thereof, based on typical values for similar customers.

- **Seasonal demand.** Customers with seasonal delivery contracts for the summer only are not taken into account in the capacity assessment, as they do not contribute to the high load in the winter.

Supply: minimum supply pressure

In Gaz Métro's situation, the supply pressure is the supply parameter that is most relevant to the capacity assessment. In general, Gaz Métro uses the contractual minimum supply pressure at the entry points in its simulations, without taking into account any pressure drop across the stations, measuring equipment, valves, etc. Gaz Métro networks and sub-networks are supplied by TQM and by TCPL, and contractual minimum pressure is defined in the supply contracts with those companies. Currently the minimum pressure for all entry points is 4000 kPa. Gaz Métro assumes that the capacity of the supplying pipelines will not be a limiting factor in its networks.

For the Estrie network, the maximum pressure in the TCPL system upstream of Sabrevois is 7070 kPa, and the maximum pressure in the TQM system upstream of Waterloo is 9928 kPa. Since these pressures are equal to, or higher than, the MOP in the Gaz Métro network (see section 2.3), the MOP becomes the limiting factor.

For the Saguenay network the MOP is the same as the maximum pressure in the TQM system which supplies it. However, Saguenay contains a compressor station close to the entry point, the maximum compression ratio of which is around 1.5. Gaz Métro has indicated that with an inlet pressure of 4000 kPa, the gas can be compressed to 6350 kPa; the maximum outlet pressure is 6850 kPa.

Note that in compressed sub-networks, those with a compressor station at or immediately downstream of the entry of the network, the procedure for assessment is different, as Gaz Métro intends to take into account downtime of the station in case of compressor failure (see Appendix D).

APPENDIX C
Dynamic simulations Saguenay network

The process of capacity assessment relies mainly on steady state SynerGEE simulations; however in the case of sub-networks which have a compressor station at the entry point an exception is made. Gaz Métro recently changed its procedures for these sub-networks.

Previous procedure

Until 2013, Gaz Métro executed a procedure wherein a static capacity component was derived to represent the switching procedure in case of compressor failure (a dynamic operational issue) on those sub-networks. To derive this static component, a number of dynamic simulations were carried out in order to assess whether line-pack in the sub-network would be sufficient to compensate for the lack of compression power during the switching procedure, which inherently assumes a constant high demand at the exits. The results of these simulations were used to determine a reduction in maximum flow to be applied to the entry point of the respective network. For the Saguenay network, based on a switching period of 30 minutes, this resulted in a reduction of the maximum flow of the compressor station of approximately 10%.

Recently adopted procedure

In the spring of 2014, Gaz Métro investigated the dynamic behaviour of the network with a series of transient simulations using a realistic demand profile, based on the realisations of the previous winter where, in order to simulate peak demand to the desired level, the realised profile is scaled pro rata. According to Gaz Métro, this procedure can be applied not only to existing stations but also to the design of new stations. For Saguenay, it was executed for two cases: once with the entry pressure at the lowest level (4000 kPa) and one at a higher level (4650 kPa).

The procedure is comprised of the following steps:

I. **Determine the maximum capacity of the compressor station**. This capacity corresponds to the maximum throughput of one compressor, chosen because the station at St-Maurice is a (1+1) configuration (see section 2.2.1). The maximum throughput is derived from the operating envelopes of the compressor, and is dependent on the inlet and outlet pressures.

II. **Determine the downtime of the compressor station**. This downtime is an estimate in the event that a compressor fails during full operation and is based on estimates for the reaction time of the remote operator, the pre-heating period for the compressor, and speed-up period of the compressor. In case the second compressor cannot or does not start by remote action, the additional time required to dispatch a technician onsite and effect repairs is added to the estimate. Note that this estimate of downtime assumes the most probable simple problems such as an electric fuse that needs to be reset, and does not include serious failures, which require significant repair operations. For Saguenay, Gaz Métro concluded that it should include approximately 85 minutes of downtime; although further testing has demonstrated that this downtime could be reduced to 15 minutes.

III. **Analyse the realised demand pattern** and determine the peak moment, t_{max}, with the highest total load and **scale the realised demand pattern.** The demand is scaled with a factor, such that at $t = t_{max}$, the flow rate corresponds with the maximum compressor capacity level. At this point, a number of checks are executed, to ensure that the simulation is handling a realistic case. Examples of these checks are the exit pressures, which should remain within the acceptable bands, and power consumption of the compressor, which should remain below its maximum.

IV. **Simulate the scaled demand pattern** with transient simulations in SynerGEE. These transient simulations reveal the effect of a one-hour-shutdown of the compressor station, during which time the switch is made between the compressors, commencing at $t = t_{stop}$. The timing of t_{stop} is varied in order to identify the case with the greatest impact on the system (i.e. the case with the lowest pressure at one of the exit points).

V. **Determine the level of lowest pressure** and compare it with minimum delivery pressure. If the lowest pressure is exactly the same as the minimum delivery pressure, then a downtime of a maximum of one hour can be endured without delivery failures at the end of the network. If the lowest pressure remains above the minimum delivery pressure, even larger downtimes can be endured. On the other hand, if the lowest pressure is below the minimum delivery pressure, the system will fail delivery within the hour. Should that be the case, the assessment is repeated with lower scaling factors, until the one-hour-criterion is met.

Note that the outcome of the transient calculations is used as a stand-alone procedure to determine total capacity; it is not fed back into any steady state calculations.

Compare the results of this procedure with the outcome of the standard steady state procedure and determine which capacity is limiting and should thus be used as the decisive factor.

APPENDIX D
Compressor station availability

Unavailability factors

The availability of a compressor station is determined by a number of factors, including:

- **The probability of functioning** of a compressor indicates the availability of normally operating compressors. It is often determined by analysing the failure histories of compressors in the field. The probability (P) is calculated from statistically determined values for Mean Time To Fail (MTTF), which is the average lifetime of a compressor until it fails, and Mean Time To Repair (MTTR) which is the average repair time of a compressor. P = MTTF/(MTTF+MTTR). In general, the probability of functioning is relatively high, but not one; in the case of multiple units, the probability of at least one unit functioning is very high. Note that the probability of functioning is generally assumed to be independent for individual components, meaning that the probability of functioning of compressor A is the same whether compressor B is in operation or has failed.
- Besides failure of individual components, **common cause failure probabilities** need to be taken into account. Examples of common causes are shared energy supplies that can fail, ESD systems that are actioned, etc. In case of a common cause failure, none of the compressors in the same location or building can be operated. For vital systems, and depending on the probability of these common cause failures, this may result in a need for separate energy supplies, separate buildings and/or separate safety and control systems for clusters of units.
- For compression, **the probability and duration of start-up** of units that have been non-operational has to be taken into account. This applies specifically to compressors and less to other equipment, as history has shown that pushing the 'start' button does not always result in an immediate start of the machine. This probability can also be determined from examination of historical logs. Furthermore, Mean Time To Start (MTTS) and starting time (the pre-heating and idle run period necessary before the compressor can be actually used to compress gas) also play a role.
- Regular and scheduled **maintenance** of large scale gas transmission compressors often takes a number of consecutive days or weeks (not including renovation and upgrading, which may take months). In general, electrically driven compressors require less maintenance time than gas driven machines. Whether maintenance downtime plays a role in the design of the station is, in large part, dependent on the configuration of the station and the anticipated load profiles. In case of a large seasonal load profile, maintenance can be more easily planned and executed during summer months, where unavailability of one compressor will not result in service failures. In the case of lower, or less predictable, seasonal load profiles, and cases with fewer compressors, maintenance must be carefully planned and may result in a lower availability of the station. In a case with many smaller compressors running in parallel, it is often assumed that, aside from the spare compressor, one will always be unavailable due to maintenance.

Some notes on the statistical analysis of MTTF and MTTR

Historical realisation databases of compressor operation are usually diluted with practical events that should not necessarily be taken into account in a capacity assessment. For example:

- The period of time where a compressor is not failing (MTTF) also includes non-operational time when the compressor was not required. It will be impossible to tell whether it would have failed in this period had it been operating.

- The repair period (MTTR) includes repair time, but also delays like time to travel to the station and waiting time for delivery of spare components. It can be argued that average values of these delays should be taken into account for capacity assessment, as they are realistically to be expected. The average lengths of such delays can be actively influenced by manning the station permanently, contracting service personnel close to the station, or keeping spare components in stock.
- Depending on the maintenance and service set-up, over-night or even over-weekend delay may be included in repair time MTTR. For example: if a compressor fails at the end of the day, but is not expected to be needed that night, a decision may be made to repair the compressor in the morning during office hours, thus optimizing repair costs but increasing the MTTR.
- The quality of the analysis of MTTF and MTTR relies heavily on the availability and quality of the data. For example: if a unit is repaired in half an hour, but registration of the completed repair is forgotten and entered several hours later, the recorded MTTR will have increased significantly.
- Compressors usually have relatively high probabilities of functioning. This means that over a significant period of time, only a small number of failure incidents are likely to be available for analysis. This small sample size results in decreased statistical certainty of the outcome of the analysis. In the industry, databases with compressor histories are available to increase the data population for such analyses. However, such data should be used with caution as they may contain factors that are not relevant for the application in question, especially if the data are dependent on the maintenance and service set-ups of the operating company reporting to the database.

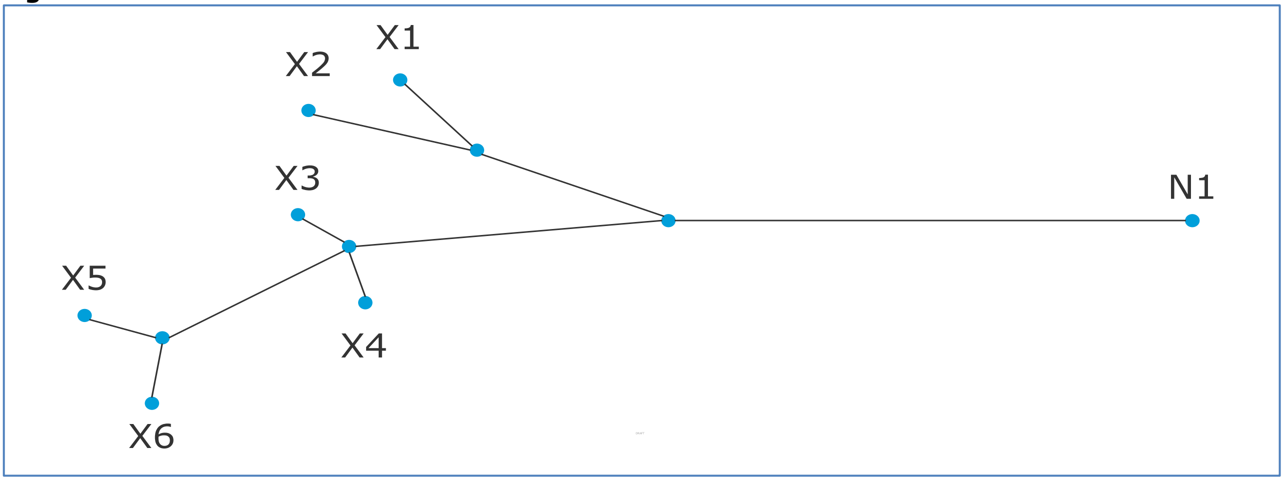
APPENDIX E
Technical capacity

A fictional case illustrating dependency on demand distribution

The capacity of a gas pipeline is dependent on its length and diameter and the flow through it. As flow rates increase, the pressure drop along the pipeline increases and with it the pressure at the exit point decreases. Given an entry pressure, one can determine the theoretical maximum flow that can be transported before the pressure at the exit point becomes lower than the minimum pressure limit; this can achieved using a series of simulations where demand is increased step-wise by a certain amount until the limit is reached.

In a network, the distribution of gas demands at the exit points also plays a role in how much gas can be transported. This is illustrated below with a fictional network, shown in Figure 6.

Figure 6: Fictional transmission network



This fictional network can be modelled in SynerGEE using hydraulic simulations to calculate the maximum possible throughput (i.e. the technical capacity). It contains 11 nodes and 10 pipeline segments, all of which have different lengths and diameters. The fictional network is supplied by one entry point (N1) and delivers to six different exit points (X1-X6) at the minimum pressures. The system has maximum and minimum allowable pressure limits as well as compressor and reduction stations (not indicated in the figure). Four different demand distribution cases are presented and the results are shown in Table 2.

Case 1 If no information about the distribution of gas demand is available, one could assume that all exits are equally sized. In this fictional case, the total capacity is 1500 (in arbitrary units), equally distributed over the six exit points (i.e. 250 units each). The limiting factor in the assessment is exit point X5, because, for example, its connecting pipeline has a small diameter and therefore a large pressure drop. Further increase of demand would result a delivery pressure below the acceptable minimum pressure at this point.

Case 2 In Case 1, there may be still more capacity available at one or more of the other exit points (X1-X4). This additional capacity may be determined by maximizing the demand at each individual exit point while all flows to other exit points are kept constant (ceteris paribus). This will result in an optimised technical capacity per branch, starting from the base load of Case 1. The resulting capacities may be higher than the ones in Case 1 when branches are relatively independent, or in the case of closed loops, which offer alternative routes.

Note that the sum of these capacities would result in an unsolvable case; therefore, this sum may never be used as technical capacity. For example, the additional 8 units in exit points X1 and X2 cannot both be sold.
Note that exit point X5 was indeed the limiting case: no additional flow can be added here.

Case 3 In reality there is often already a flow case, a current set-up of delivery contracts. A fictional example of such a set-up is defined as Case 3. In this case, exit point X1 is demanding a relatively large amount of gas (350 arbitrary units, 100 more than in Case 1), which is only possible because the other exits have lower off-takes.

Case 4 Again, in Case 3 there may be still more capacity available at one or more of the other exit points. This additional capacity may be determined in a similar 'ceteris paribus' way as was used in Case 2, but using Case 3 as the starting point. Due to the high offtake at X1, all other points can increase only 1 unit, with an exception for X4.

Please note that although the total demand in the contractual case (Case 3) is significantly below the capacity determined in the equal demand distribution case (Case 1), the spare capacity is very limited.

Table 2 Capacity results for fictional network (in arbitrary flow units)

Exit Point	Case 1 All demands assumed equal	Case 2 Maximized from Case 1	Case 3 Contractual situation	Case 4 Maximized from Case 3
X1	250	258	350	350
X2	250	258	15	16
X3	250	252	200	201
X4	250	260	80	84
X5	**250**	**250**	100	101
X6	250	252	60	61
Total	**1500**	**1530**	**805**	**813**

Note: This is a fictional case, in which the contractual situation resulted in a lower capacity than an equal distribution of demand over the exit points. This is not always the case; the opposite may also by true if, for example, the network was tailor-made to a specific contractual situation.

APPENDIX F
Overview of recommendations

R1	For long term network design, rely only on contractually agreed upon minimum supply pressures.
a	The application of best efforts contract values instead of contractually guaranteed values should be applied only during the interim period until reinforcements are commissioned.
b	During the interim period until reinforcements are commissioned, explore options to reduce risks, for example negotiations with suppliers to temporarily upgrade entry pressures from best efforts to guaranteed.
c	Ensure at all times that long term solutions are sustainable.

R2	**Include the pressure drop over entry stations in the network simulations.**
a	Periodically verify the validity of the station modelling in SynerGEE (Estrie) and the pressure assumptions at the station exit (Saguenay) against actual measurements taken in high throughput conditions.

R3	**At compressor and other stations, apply the N+1 redundancy philosophy for critical equipment.**
a	In station design, the reserve policy and station availability should be taken into account, as well as desired work areas, need for flexibility and expected load duration.

R4	**Continue to use the steady state simulations as the basis for the analysis, using the transient method as a supplementary source of information where it is relevant.**
a	Carefully assess the down-time determination procedure by adding up all relevant technical/operational factors and human/organisational related factors.
b	Assess the sensitivity of the simulation procedure to changes in the flow profile that is used.
c	Log downtimes and typical flow profiles for use in future analyses and assessments.

R5	**When presenting capacity parameters (network utilisation, spare capacity, maximum gas flow case or technical capacity), clearly explain all assumptions, inputs, uncertainties, and conditions.**

R6	**Distinguish between the maximum observed gas flow rate (to be used in performance reporting) and the maximum predicted gas flow rate (to be used as input for capacity assessments).**

R7	**Specify and document the methods and assumptions used in the technical capacity assessment.**

a	Use the design case based on the statistical study /9/ as input in the hydraulic simulations.
b	Specify the method of increasing demands in the model used to calculate the technical capacity of a sub-network; we recommend the 'As predicted' method.
c	Calculate the sensitivity of the technical capacity calculation of a sub-network for possible changes/uncertainties in timing and location of market predictions.
d	For those sub-networks where it is relevant (e.g. Estrie), calculate the technical capacity not only for the entire network as a single network, but also with relevant branches and/or spur lines treated as separate networks.
e	Annually verify the validity of the procedure and assumptions regarding the separate treatment of branches.

R8	**Distinguish between network utilisation as a performance reporting parameter and network utilisation as a decisive factor.**
a	Initiate detailed investigations for determining required reinforcements a sufficient number of years ahead of the year that utilisation is expected to reach 100%.

R9	**Focus on the precision and certainty of the spare capacity determination process rather than on simplification of the results with a view to ease understanding.**
a	Distinguish spare capacity between locations in the network, spur lines and/or branches, only where necessary.
b	Increase the update frequency of the spare capacity determination to twice a year, and more frequent if useful.

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