HOW TO COMMERCIALIZE RELIABLE CAPACITIES ON A COMPLEX TRANMISSION NETWORK ?

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ABSTRACT

CRIGEN is the GDF SUEZ Center for Research and Innovation in gas and new energies. It was asked by GRTgaz, the main French transmission network operator, to design and develop specific algorithms to deal with the issue of calculating and guaranteeing transmission capacities.
In this paper we give an overview of GRTgaz contractual and physical network and show how complex it is to commercialize reliable transmission capacities. Then we specify the problem of scenario feasibility-checking with a focus on inter-connecting stations. We present the software developed by the CRIGEN, its results and the way it is used by GRTgaz. Finally, we propose several perspectives for improvements or new functions.

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1. INTRODUCTION

1.1. Context

GDF SUEZ develops its businesses around a model based on responsible growth to confront the great energy and environmental challenges: meeting energy needs, insuring the security of supply, fighting against climate change, and optimizing the use of resources.
The Group provides highly efficient and innovative solutions to individuals, cities and businesses by relying on diversified gas supply sources, flexible and low CO2 emission electricity production, and unique expertise in four key sectors: liquefied natural gas, energy efficiency services, independent electricity production and environmental services.
GDF SUEZ has 218,350 employees worldwide and 2010 revenues of €84.5 Billion. Listed in Brussels, Luxembourg and Paris, the Group is represented in the leading international indexes: CAC 40, BEL 20, DJ Stoxx 50, DJ Euro Stoxx 50, Euronext 100, FTSE Eurotop 100, MSCI Europe, ASPI Eurozone and ECPI Ethical Index EMU.

GRTgaz is a subsidiary of GDF SUEZ which owns, develops, maintains and operates the main part of the French transmission network. Developing capacities to meet the market demands and guaranteeing their availability to shippers is therefore one of the most important missions of GRTgaz. However, given the complexity of its physical network, it is not an easy issue to deal with. This is why GRTgaz asked the CRIGEN, a research center of GDF SUEZ R&I division, to develop specific algorithms to address this problem.

1.2. The physical and the contractual network: 2 different visions of the same transmission system

With more than 32,000 km of pipelines and 25 compressor stations, GRTgaz is one of the biggest transmission operators of natural gas in Europe. There are 5 interconnecting points with other transmission operators and 2 LNG terminals. Shippers bring gas which comes from many different supply sources : Norway, Algeria, Russia, Netherlands, … the transmission system is also interconnected to 13 underground storage facilities.
The transmission system is divided into the main transmission system (pressure from 45 bar to 85 bar, diameter from 500 mm to 1500 mm) and regional networks (pressure from 20 bar to 45 bar, diameter from 100 mm to 400 mm). The main transmission network supplies big industrial customers and the regional networks. The regional networks supply industrial customers and distribution networks, which are operated by other operators, mainly GrDF which is also a subsidiary of GDF SUEZ. Figure 1. shows the main network of GRTgaz.

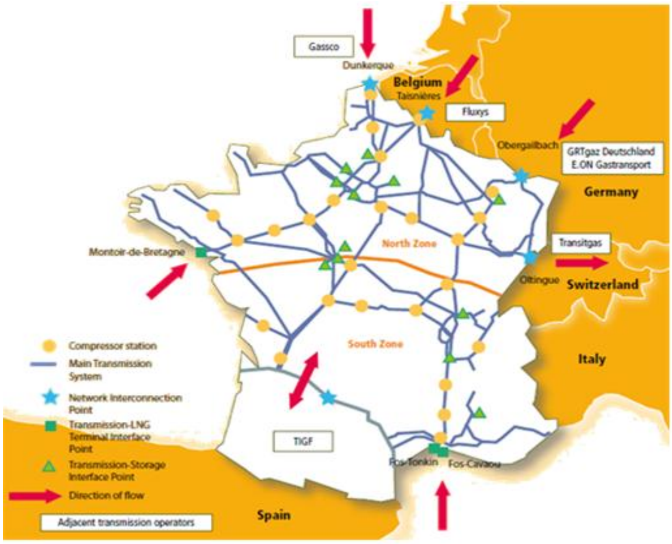

Figure 1: Overview of GRTgaz's physical network

In France, third-party access to the network is based on interconnected balancing zones. Each of the Balancing Zones constitutes an "entry - exit" system: the Entry Capacities and Exit Capacities and the Link Capacities between Balancing Zones can be subscribed separately. The size of the zones is limited by the network's physical structure, in particular by physical congestions that could result from an enlargement of the zone. Physical congestion is the material impossibility to ship gas according to some entry and exit scenarios.

In 2009, GRTgaz's market was simplified from four entry-exit zones to only two. And by the end of the year GRTgaz will release a study to merge them into a single zone. On one hand, this makes GRTgaz's commercial offer clearer and easier to use for gas shippers. On the other hand, defining commercial capacities and making sure they are reliable gets all the more complex.

Figure 2 shows the two Balancing Zones, called North and South. The Entry Capacities relate to the Entry Points : Network Interconnection Points, Transport LNG Terminal Interface Points, Transport Storage Interface Points and Transport Production Interface Point. The Exit Capacities relate to the Exit Zones: the Network Interconnection Points and the Transport Storage Interface Points. The Balancing Zones are made up of Exit Zones (27 in the North Zone, 14 in the South Zone) defined by the Consumer Delivery Points, the Regional Network Interconnection Points and the Transport Distribution Interface Points associated with them.

To transfer gas between the two Balancing Zones, it is necessary to reserve Link Capacities between.

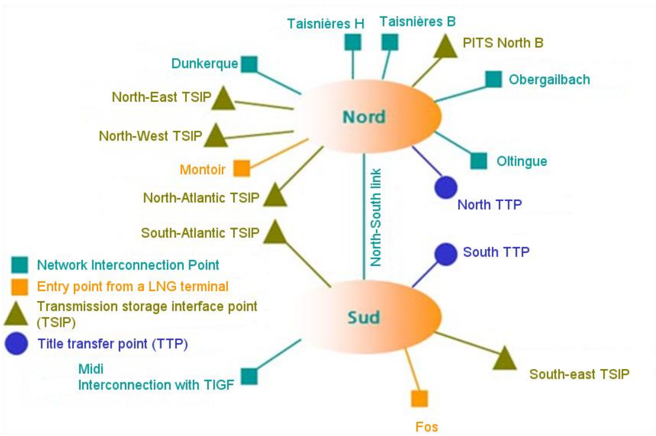

Figure 2: GRTgaz's contractual network

1.3. Translating the physical constraints into a commercial offer : not an easy match

Firm capacities must be reliable, which means that they are to be available at any time, no matter the use of the network by GRTgaz clients.

One has to understand that finding capacities is actually looking for the ideal balance between a simplicity-constrained commercial offer and a physically-constrained network. Indeed, the physical capacities of a network depend on a great number of factors, including the flow directions and the consumption values. Therefore, accepting the use of a single set of firm capacities as the one description to GRTgaz's commercial offer is an obvious approximation that has to be minimized through the use of clever ideas, such as interruptible capacities.

2. THE SPECIFIC ISSUE OF COMPUTING CAPACITIES ON GRTGAZ NETWORK

2.1 Fundamental elements of a gas network

The fundamental elements that constitute gas networks won't be described in detail here, but the Figure 3. shows a quick summary, with the icons used for each gas device type in this article.

Device type name	Icon used	Fundamental properties
Transmission pipeline		Transmits gas from its higher-pressure end to the other, leading to a pressure drop
Compressor station		Raises gas pressure (limited by the physical capabilities of the station compressors)
Regulation valve		Forces a pressure drop (managed by operator)
Gas source / Storage facility		Brings gas to be transmitted through the network or takes gas out of the network
Gas consumption		Consumes gas brought by the network

Figure 3: The fundamental elements of a transmission network

Tree-like networks with a single gas source can be constituted and operated using only the devices listed above. But in the case of meshed networks, such as the GRTgaz network, the direction of gas flows is not the direct conclusion of the network structure. Figure 4. shows the example of a rather simple network. In this example, both pipelines (represented by blue rectangles) can be used in either direction, depending on gas flow rates provided by the sources (thus, indirectly, by the shippers) and the energy needs of consumptions.

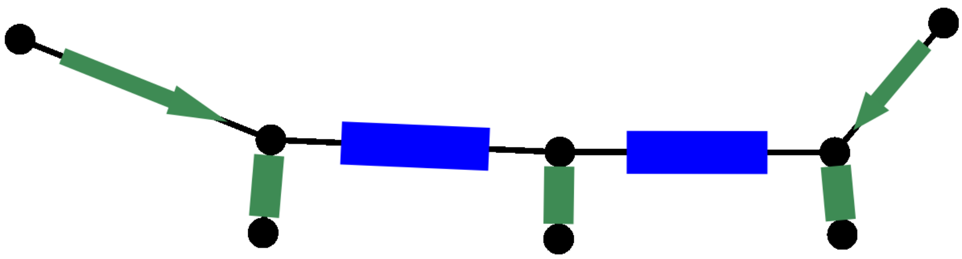

Figure 4: A simple transmission network

GRTgaz must study the case where only one of the two sources is used (we will see why later in this paper). In this case, a compressor station would be needed, but it will have to be able to compress gas in both directions. This is where interconnection stations come up. Figure 5. shows the typical use of interconnection stations: an interconnection station has been inserted between the two original pipelines and one gas source has been shut down.

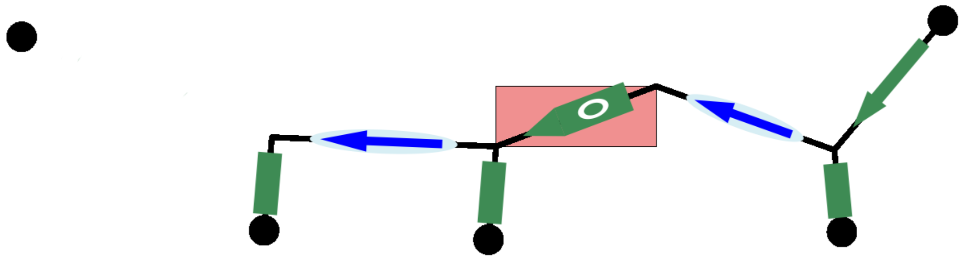

Figure 5: Worst-case scenario #1 for simple network

Each interconnection station is mathematically described by a list of available gas devices, a list of network vertices to which it is connected, and a list of configurations, which represents the functional capabilities of the station, through the description of subnetworks, using listed vertices and gas devices. In Figure 5., we can see that the example interconnection station has one device (a compressor station), refers two network vertices and defines two available configurations (one for each direction of use for the compressor station). The physical reality of interconnection stations is much more complex: they contain a lot of short pipelines and isolation valves. It is a deliberate choice to extract and list functional capabilities of interconnection stations rather than describe all the devices they contain.

2.2 The resulting astronomical complexity of the GRTgaz network

The GRTgaz network is much more complex than that of the example. For the purpose of our computations, it is modeled with 29 gas sources, 56 consumptions, 106 pipelines, 36 interconnection stations (with a mean of 40 configurations per station). Simply deciding which configurations to use is a choice to be made between 8.10^{42} combinations! And it still leaves open the question of active devices (compressor stations and regulation valves). See Figure 6. for an illustration of the meshing of the GRTgaz network. Today it requires a great deal of expertise to answer seemingly-simple questions such as evaluating the volume of gas that the network can transmit and how.

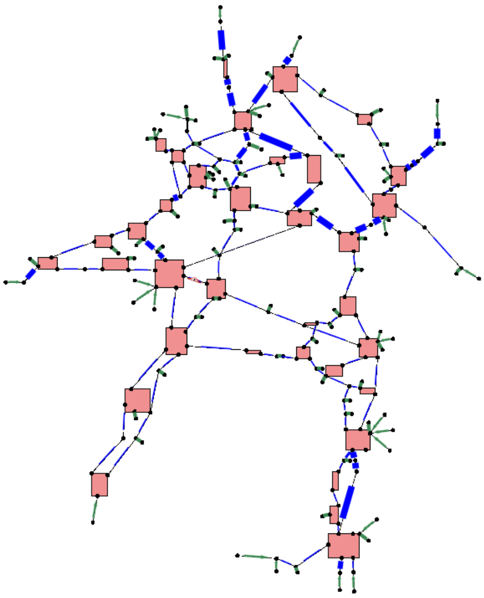

Figure 6: GRTgaz's transmission network modeled by CRIGEN

As has been explained earlier in this article, it is crucial for GRTgaz to be able to guarantee the capacities it offers. Given the set of entry points in the contractual network, numbered from 1 to N, each having a capacity C_i, every situation in which the sum of energy consumptions equals the sum of energy brought into the physical network must be doable by GRTgaz. Let's illustrate this idea, using the (now classical) example of our two-source network.

Every point in Figure 7. defines a combination of {consumed energy, energy brought by first source, energy brought by second source}. Each should be studied to make sure that the physical network can absorb the corresponding situation. Of course, the consumed energies in the graph do not represent all possibilities. They could also be below 200, above 400, or between the considered discrete values (235, for example). It should now be clear that computing all scenarios is an out-of-reach approach.
We assume that physical congestions are higher on extreme points, this for any given value of consumed energy. So the hypothesis that has been made is that it is sufficient to validate the physical network only on extreme points (two scenarios per value of consumed energy : first source brings all necessary gas –second source being shut down–, and the other source brings all necessary gas –first source being shut down). In theory, there might be cases in which disconnections in compressor functional ranges would lead to having invalid non-extreme scenarios (in our example, a scenario where consumptions would be filled using both gas sources at the same time), but such cases have never induced operational trouble, so it's pretty fair to ignore them. Moreover, a limited set of global consumption values has to be defined and studied. Each corresponds to a particular anticipated constraint in the system.

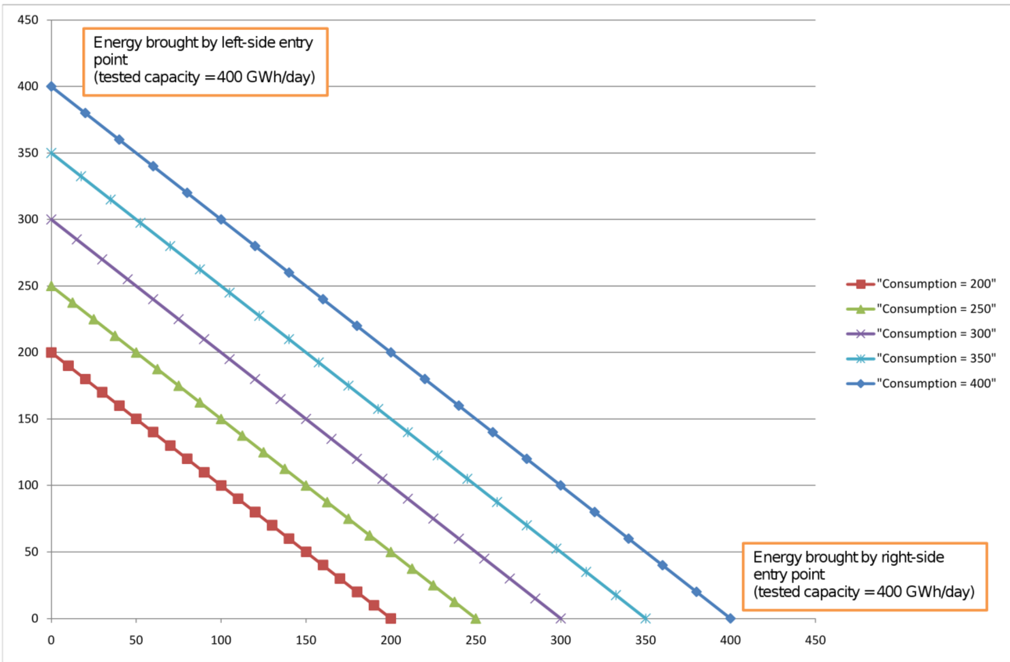

Figure 7: Use cases to be tested for simple network

3. CREATING A TOOL TO HELP GRTGAZ ENGINEERS

The issue we are dealing with can be theoretically separated into two: one that consists in using all available levers to find a physically valid use of the network for fixed energy values of every entry-exit point of the network and the second that handles the exploration of entry-exit scenarios.

3.1 First part of the resolution : fixed energies for entry-exit points

Supposing we are now considering each selected scenario separately, network experts have to face the difficult task of using all available levers in the network to validate it. The main lever is the configuration of interconnection stations, but experts may also choose the output pressure of compressor stations, and have to balance pressures and flows across the entire network, while respecting (1) Kirchhoff laws (for each vertex, the sum of all input energies equals the sum of all output energies) and device-specific constraints (pressure drop for pipelines (2), pressure drops on valves (3), compressor limitations for compressor stations (4, 5)).
One has to solve the simplified mathematical problem of Figure 8., where, for each vertex *i*, s_i is the energy value which arrives at this vertex is s_i is positive, or leaves this vertex if s_i is negative. E_p is the set of pipelines, connecting vertices i and j. E_v is the set of regulation valves and E_c is the collection of compressor stations. $W_{i,j}$ is the needed power to compress the gaz from pressure P_i to P_j. $Q_{i,j}$ is the energy flow going from vertex *i* to vertex *j*. This description of the mathematical problem is already complex without even including the larger problem consisting of a more subtle gas description (higher heating value, density, etc.) and interconnection stations. What we expect from our first in-house tool in this domain is to tell us whether a particular use case is valid and describe a map of flows and pressures that correspond to applied constraints (Figure 9.).

$$\sum_j Q_{i,j} = s_i, i \in V (1)$$
$$P_i^2 - P_j^2 = c_{i,j} Q_{i,j} |Q_{i,j}|, (i,j) \in E_p (2)$$
$$Q_{i,j}(P_i - P_j) \geq 0, (i,j) \in E_v (3)$$
$$W_{i,j} = \gamma_1 Q_{i,j}((P_j/P_i)^{\gamma_2} - 1), (i,j) \in E_c (4)$$
$$1 \leq P_j/P_i \leq \tau_{i,j} < 3, (i,j) \in E_c (5)$$

Figure 8: Simplified mathematical model for the feasibility-checking problem

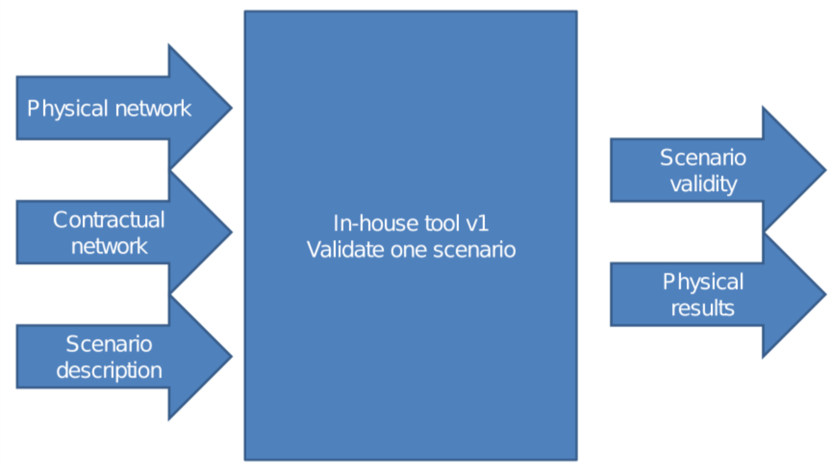

Figure 9: Use case for first version of in-house tool

Great research efforts have been made to tackle the issue of automatically managing all network levers to find a solution to each submitted scenario. Today, such a tool exists and works. This result has been obtained gradually over the years, with a set of 36 scenarios –where energies are fixed for entry-exit points- used to validate it. Energy flows, pressure values, interconnection configurations have been compared to the original Excel non-automated tool which has been historically maintained by GRTgaz engineers for all 36 scenarios, until they eventually matched.
First, this problem has been addressed with manually-configurated interconnection stations. This makes the issue simpler but still not easy. Remaining levers left to the computing software are the use of regulation valves and compressor stations. It can be translated into a non-linear non-convex mathematical problem. Solving it requires an interior point solver and a transfer of some constraints into ponderated terms of the objective. The reasons for this are the non-convexity property of the problem and the uncertainty over the existence of a solution.
The complete problem has then been addressed using two different algorithms : the first that tries to find a solution incrementally choosing configurations for every interconnection station, and a second one which is built to find a solution starting from configurations believed to be quite close to the result (if a result can be found). The second part of the resolution is based on a genetic algorithm, where genes describe which configurations are chosen for the network's interconnection stations. Specific strategies have been designed and tested. Modifications have also been integrated to raise the level of precision of the physical results.

3.2 Second step: exploring network use cases and determining capacity limits

From the first version of our tool at hand, it was quite simple to try a first draft of addressing the question of finding network limits. Its use heavily lies on the engineer/user's ability to describe the relative influence of entry points. GRTgaz engineers know how to choose and synchronize such points. They just tell our tool to try and find a validity limit for the network by raising the fixed value of one entry point while decreasing another one. The ultimate valid computed network provides the quantified limit which the GRTgaz engineer is looking for (Figure 10.). This is a simple level of description for capacity-limitation factors. It already works and calls for more subtle research work to be made even more efficient in the future.

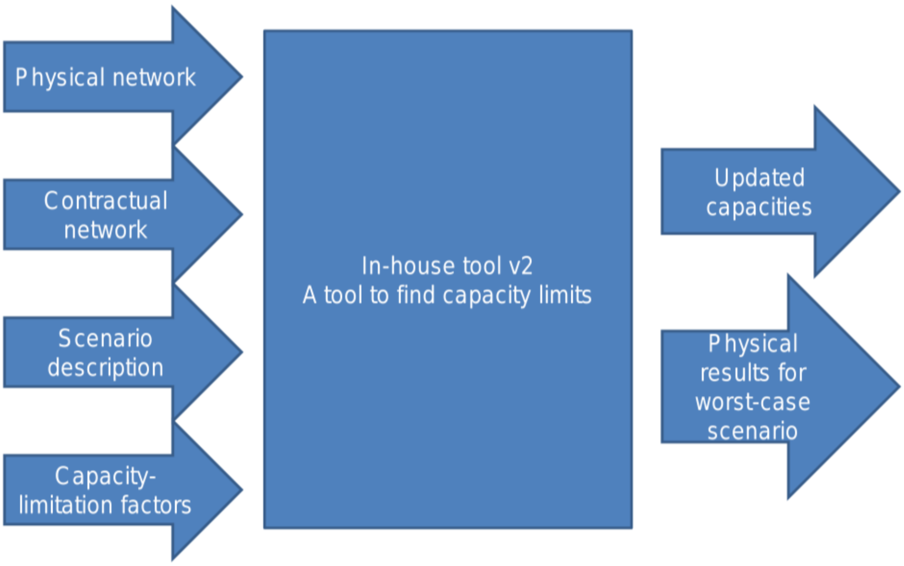

Figure 10: Use case for second version of in-house tool

Figure 11. shows how our new tool basically works. the second version of our tool runs sequential computations of the original first-version functionality. It could lead to dramatically increased computation times, but this new version uses as much as possible previous results to prevent this potential problem. The time needed for such a calculation has been proven very close to that of previous calculations with the first version of our tool.

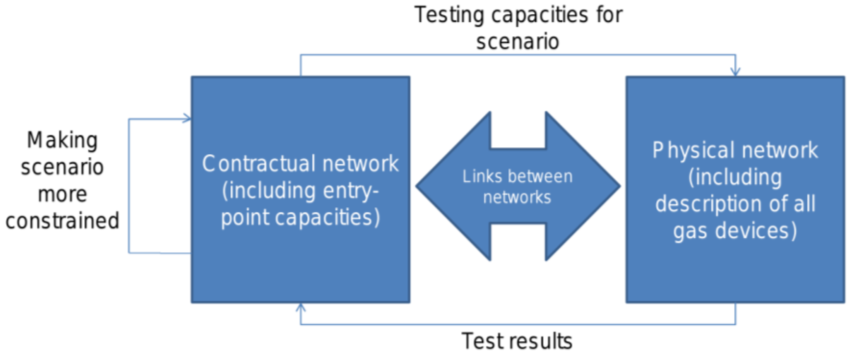

Figure 11: Inner workings of second version of in-house tool

4. RESULTS AND PERSPECTIVE

4.1 Results

While the second version of our tool aim at computing guaranteed available capacities for the GRTgaz French network, so far it has been used to evaluate limitations in capacity availability. The main result of this study is the following graph, in which each point of the blue curve can be described as the minimal energy flow that must be withdrawn from north storage devices for a given temperature (between -10°C and 0°C) to be able to guarantee capacities. If this condition is not met, one can find at least one use case (in itself extremely unlikely) in which the network will overpass its capabilities.

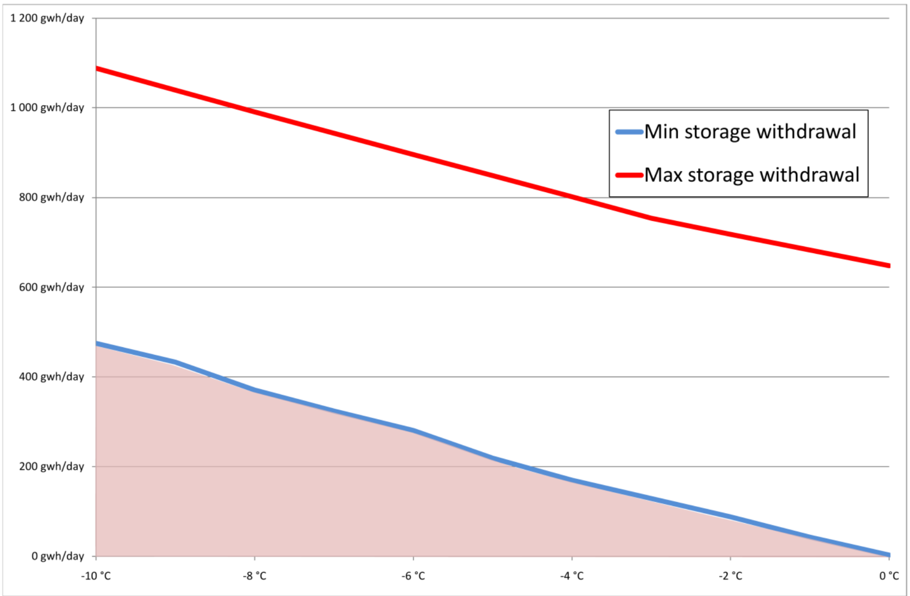

Figure 12: Minimal and maximal storage withdrawals to ensure the availability of capacities

4.2 Perspective

Without modifying the actual tool, one may see potential uses in different areas, such as the evaluation of restrictions for entry points when some gas device(s) have to be shut down. This type of process is not rare, since much maintenance work has to be done on gas devices between May and October in order to prevent any incidents. This work is anticipated and leads to restricted capacities because it handicaps the physical network. Figure 13. Shows how it works today and how it could be more automatic in a new version.
In the future, even more functions are planned for our in-house tool, especially the computation of saturation indicators (which may be a very step towards automatically detecting where the physical network needs to be reinforced).

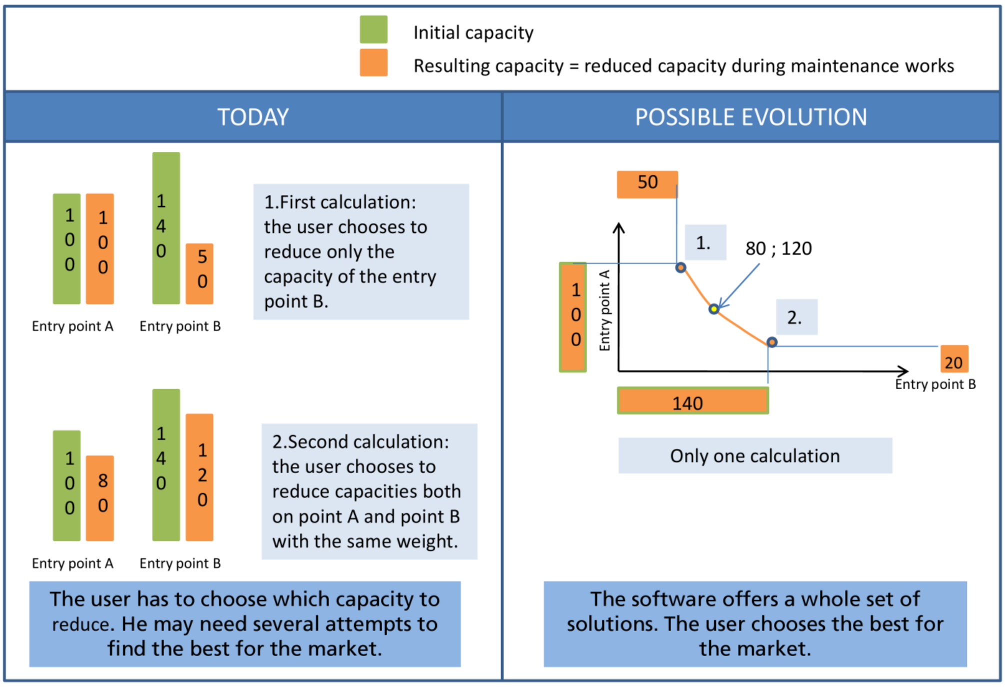

Figure 4 : Calculation of the impact of maintenance works on capacities

LIST OF FIGURES