Chapter 1

Introduction

N.V. Nederlandse Gasunie, Gasunie for short, is the Dutch natural gas transporting and trading company. It buys, transports and sells all natural gas produced on the Dutch territory. To do so, Gasunie maintains a huge technical system of pipelines and plants. In the planning of investments in this system, uncertainty of future market conditions is a serious problem. This thesis describes mathematical instruments in order to deal with this uncertainty. Its basic idea is derived from the results of the project Plato-OOG, a cooperation of Gasunie and the University of Groningen.

1.1 Gasunie

Gasunie was founded to exploit the huge, world-famous gas well that was found in 1963 in Slochteren, in the north-east of the Netherlands. Since then, many other wells have been found and developed, both on- and off-shore. To spare the Slochteren field, Gasunie employs a successful policy of buying all gas that is produced in the Netherlands. Gasunie offers good conditions to producers, like a standard commitment to buy a specified amount of gas per year, the so-called Annual Contracted Quantity. As a result, the development of even very small gas fields is made profitable.

Shortly after the introduction of the Slochteren gas, almost all Dutch households were connected to the then constructed nation-wide gas network. The Slochteren gas also found its way to industrial users, like power generating stations, and to foreign countries like Germany, Belgium, France, Switzerland and even Italy. Almost all gas is used for fuel, only a few industries use the methane as an ingredient in a chemical production process. An important quality indicator of the gas is the energy content, also called the heating value or calorific value. Typically, most gas wells outside Slochteren produce gas with calorific values that are higher than that of Slochteren. To specify the burning properties of natural gas in consumer contracts, the so-called Wobbe index is used. Originally all burners were conformed to the Wobbe index of Slochteren gas. Since more and more gas fields of different composition and burning quality
were found, different industrial and export markets have been developed, all with their own Wobbe index specifications.

To deliver the gas at the customer, Gasunie controls a huge transportation network. The main body of it is made up by the high pressure (67 to 40 bar) pipeline system, for transportation over large distances. Due to resistance of the pipe surface, the pressure of the gas drops during transport. To keep it under pressure, large compressors and pressure regulators have been put in. From this system the gas is delivered to regional distribution systems, with lower pressures (less than 40 bar), and directly to large-scale industrial consumers and to export stations.

Since a great part of the gas is used for heating purposes, especially in the household market, demand tends to vary with temperature. The transportation system of Gasunie is designed to guarantee delivery under extremely low temperatures. Especially the declining pressure of the Slochteren field makes this increasingly difficult. To guarantee delivery under extreme conditions, backup production capacity has been installed in the form of a liquefied natural gas (LNG) facility. In future, two underground storages are to be installed, to add more backup production capacity.

Many of the production sites outside the Slochteren field deliver a gas type which does not fit into a specific market. To bring it on market specification, the quality of these types of gas should be converted. Another, more important reason for quality conversion is that the amount of gas of deviant quality that is involved in the Annual Contracted Quantities is too large to be sold only on the appropriate markets. A growing part of the gas of non-Slochteren origin is mixed with Slochteren quality gas and nitrogen, to be disposed into the Slochteren quality system. To match all annual production commitments with demand, large facilities like nitrogen production plants are needed.

This thesis will focus on this matching problem. In general, there is no buffer storage capacity: the gas immediately flows from producer to customer. On a daily basis, the matching process is demand driven: production and conversion have to match demand. On an annual scale, the Annual Contracted Quantities of the producers have to be satisfied, and the matching process gets supply driven as well. This can be realized by means of existing freedoms in the production planning per day, the conversion capacity and the use of the Slochteren field as a closing entry on the balance sheet of gas flows. The increasing amount of Annual Contracted Quantities with deviant quality makes the matching problem increasingly difficult. One way to absorb this problem might be to add more conversion capacity. Another possibility which has been studied in recent years is the use of underground storage capacity to uncouple production and demand per day. In this way the demand driveness of the production planning is relaxed and the balancing function of the Slochteren field is supported.
1.2 Investments and commercial uncertainty: the Plato-OOG project

To be able to fulfil its obligations, Gasunie may need to invest in technical equipment, like transportation, conversion and storage capacity. Gasunie is constantly scanning the future for the necessity of changes in the technical system. If investments seem to be needed, alternative solutions are designed and their effectivity is studied. Relatively small changes, like incremental extensions of the regional distribution systems, are implemented within a year. But investment projects concerning the high pressure system or the conversion means are very expensive and time-consuming. Including the acquisition of permits and the design and construction of hardware, a lead time of four years is normal.

Projects with a long lead time must be started well before their effects are needed. On this long term, commercial circumstances are very uncertain, both on producer and on consumer side. Since Gasunie has a policy of buying all gas that is offered on the inland market, the supply side obligations are directly connected to the new gas wells that are found and developed. This depends on factors like geologic conditions, oil prices and sheer luck. It is almost impossible to say anything beforehand about the quality of gas fields to be developed. Demand, in the long run, depends on weather conditions, but also on changing patterns of household and industrial use of gas influenced by economic developments, the availability and prices of other energy sources, and the competition on the export market.

It is a notoriously difficult problem how to deal with long term uncertainty in planning. Classical decision-theoretic approaches like simulation, be it scenariowise ('what-if simulation') or stochastic, give a fair insight. But still the founding of the final decision is a difficult and time-consuming process. Long term planners are often faced with the limited utility of existing planning instruments.

In 1989 the project Plato-OOG started. In this project Gasunie and the Department of Econometrics of the University of Groningen cooperated in surveying and analysing the needs in the field of investment studies under uncertainty. The investment planning process of Gasunie was described in detail. Much attention was paid to the description and quantification of the uncertainty of the information used, and to the analysis of its influence on the uncertainty of investment performance. Some ideas were developed as to the explicit incorporation of these uncertainties in the investment planning process. The results were published in October 1991 in the final report Uncertainty in the commercial-technical planning of the N.V. Nederlandse Gasunie, the Plato-OOG report, for short. See Boorsma, Broens and Fournier (1992).

If Gasunie expects that it cannot solve the matching problem and meet future commercial obligations using the existing system, investments are obviously needed. On the other hand, for the case that future commercial obligations are expected to be feasible, in the Plato-OOG report it is suggested to
identify bottlenecks or weak spots in terms of commercial variables. A central concept, proposed in Plato-OOG, is the space for unexpected commercial developments, left open by the technical system and unforeseen obligations. This information, focusing the attention of the planners to the weak spots on the market (not so much in the technical system), can be used for instance to anticipate problems, to calm down a nervous planning system and to feed back information towards the commercial decision-makers. In Plato-OOG this suggestion was not worked out in detail.

In this thesis, these ideas are formalized and their use in a long term investment planning context is explored. Instead of the Plato-OOG project, which covered all commercial-technical planning of Gasunie, this thesis is restricted to the context of the matching problem, described in Section 1.1. Using a simple model of the matching problem as a starting point, mathematical tools are developed for the assessment of the effects of investments on the commercial capabilities of the company. Special attention is paid to measures for the robustness of the future technical system, be it before or after investments, against long term uncertainty of commercial circumstances. These tools are tested on a numerical example of the matching problem, both for the simple model and for generalizations.

1.3 Outline of the thesis

The future short term production and transportation planning determines whether Gasunie will meet its commercial obligations. It is by influencing the future transportation and conversion capabilities that investments affect the ability to match different commercial requirements. Therefore an analysis of the future short term planning problem should play an important role in a study of the commercial consequences of an intended investment project. In Chapter 2 the annual matching problem, as described in Section 1.1, is presented in terms of linear restrictions representing technical and contractual constraints. The model contains essential aspects of the complexity of the real life problem, but it is highly simplified and aggregated. This simple model of the short term planning problem serves as a starting point for the discussion of investment decision-making under commercial uncertainty.

In Chapter 3 mathematical tools will be described, using which an investment planner can evaluate the robustness of investment alternatives against commercial uncertainty. The central concept of Chapter 3 is the commercial scope: the set of future commercial scenarios yielding a feasible production planning problem. The resulting commercial scope is a basic property of an investment proposal, from which both deterministic and stochastic characteristics are derived to quantify the commercial consequences of the proposal.

For many purposes it would be nice to know the commercial scope explicitly. In principle it is possible to achieve such a description directly using duality, but this technique turns out to be impractical. On the other hand it appears
that it is not necessary either, for the calculation of the characteristics, to have an explicit description. Still, one easily obtains explicit descriptions of ‘induced’ constraints on the uncertain variables, describing relevant parts of the boundary of the scope.

In Chapters 4 and 5 the tools defined in Chapter 3 will be used in some investment planning experiments, based on the matching model. The data used in these experiments are fictitious and they do not support any conclusion as to the real situation of Gasunie. In the case at hand it turns out that a sufficient characterization of the scope can be obtained by only a few induced constraints. Special attention is paid to the interpretation of these constraints. To investigate the applicability of the concepts in a broader context, in Chapter 6 small alterations of the simple matching model are introduced and studied with respect to their influence on the results.

The value indicators of investment proposals derived from the scope can usefully be incorporated into an investment planning process. In Chapter 7 some suggestions are given as to the question how this could be realized.

1.4 A warming-up exercise

As a warming-up for the following chapters, this section shows a small and very simplistic model of the matching problem. It serves as an introduction both to the short term decision problem to be considered in Chapter 2 and to the specific investment planning approach which is to be developed in later chapters. Two important concepts, the commercial scope and induced constraints are introduced. They are shown to be influenced by investments.

Consider a trivial short term planning problem within one day. Only one type of gas is considered, for instance with low calorific value (L-gas). It is assumed that all supply has a quality such that it fits into the requirements of the market. The demand for L-gas during the day is denoted by $D_L$. Assume further that the production $pl$ is bounded by a given capacity $PLU$ and a given minimum production per day $PLL$. Then the production decision problem is to find a production $pl$ that satisfies the following restrictions:

$$PLL \leq pl \leq PLU$$
$$pl = D_L$$

Of course, this is a trivial problem, since there is at most one possible answer: simply produce as much as is demanded. However, this production is only feasible if the demand for L-gas $DL$ is not too large or too small. In mathematical terms: the production planning problem has a feasible solution if and only if $DL \in [PLL, PLU]$.

The value of $DL$ is the result of commercial commitments. Therefore $DL$ is a commercial variable. In the long run, commercial variables are uncertain.
They can perhaps be influenced by the gas producing company, but not completely, and certainly not by the investment planner. As long as $DL$ falls within the given interval, a production plan can be made. In the subsequent chapters, such an interval will be called the commercial scope. It describes all values for the commercial variables for which the production planning problem is solvable. In general, the commercial scope describes the technical capabilities of the company. For this problem, it depends on the parameters $PLL$ and $PLU$ which, in the long run, can be influenced by investments in production facilities. The parameters $PLL$ and $PLU$ are called investment decision variables.

Now this is all very trivial, so let us extend the example. Assume that also gas of another quality is produced, say of a high calorific value (H-gas). Assume that of this gas a given amount per day $PH$ has to be disposed into the L-gas market. Since this is a result of commercial commitments, it is also a commercial variable. What is left of demand has to be matched by the L-gas production:

$$pl = DL - PH$$

Since H-gas has a higher calorific value than L-gas, it is only possible to pass H-gas to L-gas demand if the L-gas demand contracts allow other qualities than that of L-gas production. Assume that a restricted deviation is allowed: the fraction of H-gas in the mixture that is delivered to the customer may not exceed a small given fraction $c$. This assumption leads to the following quality constraint:

$$PH \leq c \cdot (pl + PH)$$

Including the technical restrictions on the production of L-gas, which were described before, the extended production planning problem is to find a value for the production $pl$ that satisfies the following set of restrictions:

$$PLL \leq pl \leq PLU$$

$$PH \leq c \cdot (pl + PH)$$

$$pl + PH = DL$$

Again, the production decision problem is trivial since there exists at most one possible solution: if possible, produce $DL - PH$. The commercial commitments on demand and supply side can only be fulfilled if the planning problem can be solved. Since $pl$ then necessarily is equal to $DL - PH$, this problem only has a feasible solution if and only if the commercial variables satisfy three constraints, which we call induced constraints. These constraints are in terms of the uncertain commercial variables and the investment decision variables. The first two state that

*Demand should be between minimum and maximum total production.*
1.4 A warming-up exercise

\[ PH + PLL \leq DL \leq PH + PLU \]  \hspace{1cm} (1.1)

The third one states that, for quality reasons,

The L-gas market can digest only a limited amount of disposed H-gas

\[ PH \leq c \cdot DL \]  \hspace{1cm} (1.2)

The commercial scope \( S \) is defined as those combinations of demand and supply commitments that satisfy the restrictions (1.1) and (1.2):

\[ S := \{ (DL, PH) \mid PLL \leq DL - PH \leq PLU, \; PH \leq c \cdot DL \} \]

Naturally, both \( DL \) and \( PH \) cannot be negative. Note that, if \( PH = 0 \), the original one-dimensional scope prevails. The commercial scope is traced out in Figure 1.1, along with a certain combination of demand and supply commitments \( (DL_o, PH_o) \). Obviously, this combination satisfies the technical constraints (1.1). But since it does not satisfy the quality constraint (1.2), it is not feasible with the given system.

In the long run both demand \( DL \) and supply \( PH \) are uncertain. The commercial scope indicates which combinations of demand and supply are realizable. If the scope is not large enough to contain most relevant combinations, it can be changed by investments in L-gas production means. Figure 1.2 illustrates the results of investments in L-gas production capacity \( PLU \). Obviously, \( (DL_o, PH_o) \) still is outside the scope. In fact, it cannot be included through investments in L-gas production facilities. A more powerful way to enlarge the
Figure 1.2. Extension of the scope $S$ by extra production capacity

scope would be the introduction of conversion capacity, for instance in the form of nitrogen production. Basically, by adding nitrogen (having caloric value 0) to the H-gas, it is possible to pass more H-gas to the L-gas demand. In other words, the value of $c$ will increase. After a sufficiently large increase, the scope will contain the point $(DL_o, PH_o)$. This situation is typical for the situation of Gasunie: Gasunie has to dispose so much high calorific gas into L-gas demand, that it would be infeasible without conversion means like nitrogen facilities. It is beyond the scope of this simple exercise to discuss the details in this place.

In Chapter 2 the central model of this thesis is explained. It is more sophisticated than this warming-up exercise in the way it treats demand, supply, gas quality, the mixing process and conversion means. Instead of only one day, a whole year will be considered, divided up into subperiods.