GAS PIPELINE TRANSPORT MARKET: AN AGENT-BASED APPROACH

Main author

C. Pelletier
University of Groningen
Faculty of management and organization
Landleven 5
P.O. Box 800
9700 AV Groningen
The Netherlands
Since the 50's structural gas market reforms has been launched around the whole world. Their aim is to introduce competition in the wholesale gas supply and to insure fair access to transport to any eligible third party. As a consequence, the national/local gas monopolies are split between energy trade and the energy transport. This led to the emergence of new stakeholders, and a decentralization of the decision-making processes, reflecting different localized policies. The different stakeholders are adapting their behavior to a continuous changing competitive environment. Moreover, because the maturity of the process in the various countries is uneven, the legal environment and practices within different countries lack of homogeneity, and increase the complexity of the gas market.

Understanding how the gas and more largely the energy market is running and being able to predict its evolution over time in terms of production, consumption structure and in terms of price pattern, is crucial to do planning for any gas related enterprise. In the gas market, analytical models have been developed to support operational and long-term planning. These models have often difficulties to take into account the localized decision processes, and are limited in adapting to the changing complex environment of the gas business. Hence, to understand the gas market and to improve the planning capabilities, models able to adequately analyze the complicated network of interaction among all the participants in the new gas are needed.

In this paper, we propose a model allowing the modeling of the distribution of the decision centers in the context of the wholesale cross-border sale planning. This model is combining agent modeling approach with multi-criteria decision making methods.

The multi-agent approach supports naturally the modeling and the simulation of organization’s network dynamics (1. ). It views the network as composed of a set of intelligent agents, each responsible for one or more activities. In particular, agent-based models allow the solution to be the results of individual multi-lateral trades among different involved participants, with the possibility to represent each participant with its own unique business strategy, risk preference, and decision model.

Multi-agent wholesale cross-border trade planning model has already being proposed in the context of the power industry (2. ). It nevertheless considers the cost as being the only trigger for the participant in their trade choices. If the cost is without any doubt an important criterion of trade choice, the reliability of the participants involved in the trade plays also an important role. In the following, we formulate in the modeling language developed in the agent laboratory at the University of Groningen (the TAL modeling language (3. )) the wholesale cross-border trade planning problem using an agent-based approach. Then, in a we present the mathematical models supporting the decision processes of different agents participating in the gas wholesale cross-border trade.
1 INTRODUCTION

Since the 50’s structural gas market reforms has been launched around the whole world. Their aim is to introduce competition in the wholesale gas supply and to insure fair access to transport to any eligible third party. As a consequence, the national/local gas monopolies are split between energy trade and the energy transport. This led to the emergence of new participants, and a decentralization of the decision-making processes, reflecting different localized policies. The different participants are adapting their behavior to a continuous changing competitive environment. Moreover, because the maturity of the process in the various countries is uneven, the legal environment and practices within different countries lack of homogeneity, and increase the complexity of the gas market.

The unbundling of the transmission services has led to new challenges for the companies providing these services. One of them concerns the long term wholesale cross-border planning. In Europe, gas cross border trade is very important. European countries are mainly importing gas and its transport is mainly done via pipe networks. The European pipeline system is composed of interconnected pipeline networks that are owned by national/regional companies. These networks are used to deliver gas to local customers and also to support the transit of gas toward other national/regional destinations. In the context of scarcity of the resources and the growing distance between production and consuming areas increase the necessity, for a transport company, to forecast how the GRID it is managing will be used for transit purpose and identifying possibilities of development. In other words it is important for a transport company to be able to simulate wholesale cross-border trade planning under different scenarios.

There are basically two approaches to simulate wholesale cross-border trade planning: a centralize approach and a distributed one. The centralized approach assumes the existence of a central decision process following which a global optimal cross-border transmission plan, in term of cost, can be build up within the capacity constraints. The costs for each participant are then deducted from this global solution. In addition to the absence in reality of such central decision process, the limited flexibility of such approach, and the sensitivity of the plan to modification such as the addition of a new participant or the change in demand or production volumes for example can lead to completely different outcomes for the participants for whom nothing changed locally. Moreover, the models, developed from this centralized approach, are not really able to adequately analyze the complicated network of interaction among all the participants in the new gas markets. The decentralized approach addresses naturally the distributed decision making aspect of such type of planning.

Multi-agent approach supports naturally the modeling and the simulation of organization’s network dynamics (1. ). It views the network as composed of a set of intelligent agents, each responsible for one or more activities. The agents are interacting with each other during planning and executing their responsibilities. Agent-based modeling, analysis, simulation and system development are supported today by mature frameworks and tools (1. , 2. ). In this paper we use the framework developed at the University of Groningen (3. ) where, besides the agent concept, a distinction is made between two additional main concepts: interaction and role. The role concept is defined as being a set of responsibilities, authorizations and interaction patterns (5. ). The interaction is a conceptual unit that captures the nature of a relationship between two or more roles. An agent can play more than one role (even in the same time) and the binding between role and agents should allow a role to be played by multiple agents. By separating the agent from the role and focusing on the modeling of interactions, the resulting models are far more flexible and can be developed in an iterative, bottom-up and local manner. Following the TAL procedure (3. ), the identification of the agent-based model is realized in two steps. First, the organization of the wholesale cross-border trade is defined in terms of roles, interaction between roles, and distribution of the roles between the different actors or agents involved in the gas business. Then the behavior linked to each role is described.

Multi-agent wholesale cross-border trade planning model has already being proposed in the context of the power industry (2. ). It nevertheless considers the cost as being the only trigger for the participant in their trade choices. If the cost is without any doubt an important criterion of trade choice, the reliability of the participants involved in the trade plays also an important role. In this paper, we propose a multi-agent model that addresses the gas wholesale cross-border trade planning, where the trade is based on a multi-criteria decision model. In particular, this agent-based model allows the
arising of a wholesale cross-border trade plan that is the results of individual multi-lateral trades among the different involved participants, with the possibility to represent each market participant with its own unique business strategy, risk preference, and decision model.

In the following, we formulate in the modeling language developed in the agent laboratory at the University of Groningen (the TAL modeling language (3.)) the wholesale cross-border trade planning problem using an agent-based approach. Then, in a we present the mathematical models supporting the decision processes of different agents participating in the gas wholesale cross-border trade. In a last section, we conclude and draw the lines for further development of this work.

2 CROSS-BORDER TRADE MULTI-AGENT MODEL

• The general structure
In the language developed in the TAL, the basic structure of the system is described through the Role-Interaction diagram. In the wholesale cross-border trade, the roles played are the one of producer, trader and transporter. Traders (often called shippers and suppliers) are the link between gas consumers and gas producers. They are responsible for the organization of the transport and the distribution. These traders must have access to the pipeline system, managed by transporter. Thus, between the trader and the producer a contracting production capacity relationship exists and between the trader and the transporter a contracting transport capacity relationship occurs. Figure 1 shows the role-interaction model associated with this situation. The roles are representing by ellipses and the relationships between the roles are symbolized by pentagons.

Figure 1: Cross-border trade role-interaction diagram

Because of the legislation, it is impossible for a same agent to perform both roles of trader and transporter, it is the same for producer and transporter. Eventually it should be possible for a same agent to perform the roles of producer and trader, we are considering here that the accumulation of both role is not possible.

• Trader local behavior
Each trader is purchasing gas to a producer and contracting the transport capacity necessary to transfer the purchased gas via the network of interconnected GRID from the production to the consumption area. Its goal is to perform these tasks at a minimal cost, and a minimal risk; that means to avoid too much risk concerning the supply and delivery. The management of this risk has then to be tackled simultaneously with the cost.

Organizing the transport of the gas is done following three main steps:
- inquiring for the remaining capacities on interconnected GRID network,
- determining the cheapest and less risky trajectory for the gas in function of the capacity availabilities on the network,
- contacting the transporter and producer simultaneously in order to contract the needed capacity on the identified transfer path.

If each contacted person confirms by an offer the feasibilities of the solution looked for, then the trader book immediately the capacity. If one (or more) of the contacted parties is offering less than what has been requested, the trader looks for another transfer path.

On the figure 3, the trader view of the wholesale cross-border trade planning process is described. It is describing its local-behavior (LB). On the right side of the diagram is represented the part of the process performed by the trader, while on the left side, is represented the one the transporter/producer is performing. On the right side, the black plate represents the beginning of the process and the rectangular shapes the activity to perform. The end of the process is symbolized by a black plate with a double ring. To go through the whole process, the trader needs inputs from the transporter (respectively producer). The interaction with the transporter (respectively producer) is
modeled via the exchange of message. The exact process performed by the transporter/producer being unknown to the trader, they are represented by clouds.

Figure 2: Trader capacity booking LB

- **Transporter /producer local behavior**
  
  Capacity booking is an activity anterior to any other interaction between transporter (producer) and trader. It corresponds to the phase where a trader is contracting the production and transport capacities he needs satisfy the demand of its clients. The interaction with the transporter (producer) and the trader start with the reception of the transporter (producer) of a request from the trader corresponding to a demand of a capacity offer, for a fixed period of time. The transporter (producer) answers by sending an offer of service corresponding as much as possible to the capacity requested. The next step for the transporter (producer) is two folds. The trader is not reacting within the two working days and the offer is considered obsolete. The Trader books out of the quantities offer
capacities (it has to be less or equal than the available quantity proposed in the offer). Then the transporter (producer) check if the trader is admissible for the quantities it wants to book and also if the booked capacities are still available. If one of these tests is negative, the booking is rejected; if none of the test is negative, the capacity is secured for the trader, for the period requested. When the period is over, the transporter (producer) informs the trader that the contract is over and updates its database concerning the availabilities.

On figure 4, the transporter/producer local view of the global contracting capacity process is drawn. On the left side is presented the process followed by the transporter/producer. The corresponding part of this process accomplished by the trader is presented on the right side. The transporter/producer ignores the way the trader proceeds really, thus the process is represented in the transporter/producer model using clouds.

3 MATHEMATICAL MODEL
A multi-agent system describes how agents are interacting within an environment in order to reach their individual objectives. In wholesale cross-border trade planning, the environment where the agents - producer, transporter and trader - are interacting is a network of interconnected GRID. The way the different agents acts is also function of the environment; the relationship of the agents with their environment is then essential to the model.
As stated earlier, it is assumed that an agent can perform only one role among the three possible. So, the type of agent will be differentiated by the role they are playing. In the following sub-sections, we formalize first the environment, second the relationships between the agents and the environment, and third we describe the decision models that are supporting the agents in their decision making.

- **The formalization of the environment**
  The wholesale cross-border trade is happening in a network of interconnected local GRID. Let $G = (N, A)$ be the graph associated to this interconnected GRID network, where the nodes are representing the regional GRIDs and production areas, and the arcs the connections between them. On this network, integral-value of resources of a unique type is transmitted. That means that only one type of gas quality is transmitted on the network, and that only an entire number of unit of gas can be transmitted. Moreover we assume that the transmission through the network is perfect, that means that there are no losses either via the nodes, either via the arcs. The distinction between the source nodes (production areas), the sink nodes (demand areas) and the intermediate nodes (transit GRID) is made via the parameters $S_i^+, i \in M$. Each parameter $S_i^+$ indicates what is the maximal gas quantity, that can be supplied at the area associated to the node $i$. If this parameter is positive, the node is considered as source, sink if the parameter is negative and intermediate if the parameter is null. The sets of source, sink, and intermediate nodes are noted $P$, $D$ and $T$ respectively. To each node $i$, it is also attached a Boolean variable $b_i$ that is true if the gas flow is going through the considered node, and a cost, $t_i$, related to the use of the services proposed at this node (production for a source node, right to cross the GRID at an intermediary node). These costs are fixed and defined per unit of gas flow. The cost at a sink node is considered as null. At each arc $(i, j) \in A$, linking the node $i$ and $j$, is associated a cost, $c_{ij}$, denoting the cost per unit of gas flow on $(i, j)$, and a maximum capacity $f_{ij}^-$. It is assumed that the production and transport capacity is enough to meet the demand load.

- **The relationships of the agents with their environment**
  The capacity and the production cost at a node $i \in P$ are managed by a unique producer agent. The capacity and cost associated to a node $i \in T$ representing a local GRID is managed by a transporter agent. More precisely, this agent is responsible of the management of the capacity of the incoming flows $f_{ij}^-$, $(i, j) \in A$. These capacities are evolving with the volume of capacity trader agents are booking. Each of these agents, producer and transporter are associated to a unique node, and has a local view of the network; their knowledge is limited to the information concerning the node they are associated to.

  The trader agent aims at buying and organizing the shipping of the gas from production areas to the demand areas, so that its client’s needs are satisfied. For this purpose, the trader agent complete the public information concerning the production and transport capacity on the network, with its internal knowledge concerning the location of the demand areas (sink nodes), $i \in D$, and the volume of gas that as to be delivered at these places; the parameters $S_i^-$. The trader agent is also evaluating the reliability of each production and transport agent. The reliability $r_i$ of a producer or a transporter agent has its value between 0 and 10, and measures the risk of using the services of a producer or a transporter for one gas volume unit. The value of this risk is subjective to the trader agent. The reliability of a shipping path corresponds to the sum of the reliabilities of each nodes involved in the path. The decision variables for a trader agent are the value of the flows $f_{ij}^-$, $(i, j) \in A$, going from producer nodes to the demand nodes via a set of transit nodes, such as the total demand is satisfied, the cost of the whole cross-border shipping as the risk associated to the plan are minimal. Risk is assessed in term of reliability and number of agent involved in the plan. For the coordination of the system, it is assumed that once a trader agent found a good shipping plan, it requests simultaneously the booking of the capacity to every producer and transporter agent involved with the plan.
The decision models

In the multi-agent model proposed, the behavior of the producer and the transporter agent is restricted to the local management of their local production and transport capacity. This management consists in checking the feasibility of each trader agent capacity request, before accepting or rejecting it. We assume that the procedures, followed by a producer agent and a transporter agent, are identical. Both adopt the first in first out procedure to treat the trader agent requests. This procedure is the way the transport companies are actually dealing with their clients, in order to meet the regulator constraints of non client discrimination in capacity access.

The trader agent has a more complex behavior. It has to identify the best plan possible meeting the demand of its clients. This identification is performed in a multi-criteria context. The mathematical program below corresponds to the overall internal problem that the trader has to solve.

\[
\min(z) = \left( \sum_{(i,j) \in A} c_{ij} f_{ij} + \sum_{j \in D \cup T} t_j \sum_{(i,j) \in A} f_{ij} + \sum_{i \in P} \sum_{(i,j) \in A} t_i f_{ij} \right) + \sum_{i \in M} b_i + r_i f_{ij}
\]

subject to:
\[
\sum_{j \in (i,j) \in A} f_{ij} - \sum_{k \in (k,j) \in A} f_{ij} \leq S_i^\text{max} \quad \forall i \in M
\]
\[
0 \leq f_{ij} \leq f_{ij}^\text{max} \quad \forall (i,j) \in A
\]

The first component of the objective vector, the cost associated to the plan, is composed of three terms corresponding to the costs associated to the use of the interconnection pipes, the cost of crossing the grid represented by a transit or demand node, and the cost linked to the purchase of the gas at each production site. The second and third components of the objective vector are measuring the risk associated to the plan. The second component measures the number of agent involved in the plan and the third the sum of flow weighted by the unreliability of each node. To treat the multi-criteria aspect of the program, an axiomatic method is applied, to insure the agent choice to be sound and representing a set of values. The trader agent is selecting its plan using the Koehler’s dual algorithm insuring the selection of a prudent plan (6.).

The procedure to solve this program is iterative and stops when the trader succeeds to get a plan to face the demand of its clients. This procedure is applied till all the needed capacity is booked.

Step 1) Initialization of the variables and parameters.
  o Set the \( f_{ij} \) s to 0 for every \((i, j) \in A\).
  o Set the value of \( f_{ij}^\text{max} \) as read on the public information site
  o Set the values of \( S_i^\text{max} \) for every. If \( i \in P \), \( S_i^\text{max} \) corresponds to the maximal gas production capacity as read in the public information site. If \( i \in T \), \( S_i^\text{max} = 0 \), and if \( i \in D \), \( S_i^\text{max} \) corresponds to the opposite of the quantity ordered by the trader clients.
  o The parameters \( r_i \) are set.

Step 2) Looking for the best trajectory
  o Choose \( i_0 \in D \), such as the demand at this area has not been completely satisfied.
  o List all the possible path linking a producer point to the node \( i_0 \)
  o For every possible path, compute the value of the three criteria associated to this path for one unit of flow.
  o Rank each path following each criteria, and build in the outranking matrix \( O = [o_{ij}] \), where \( o_{ij} \) corresponds to the number of criteria that rank the path \( i \) before the path \( j \). If \( i \) and \( j \) are ex equo on a criteria, then each of them score 0 on their outranking coefficient.
To identify the best paths, run the Koehler's dual algorithm (6.).

- Till the demand is not satisfied, maximize the flow on the remaining best identified path.
- Send a request for offer to every agent involved with the chosen plan.

Step 3) Updating the value of the parameters

- Update the value of the $f_{i,j,k}$ and the $S_{i,m}$

- If there is still an $i \in D$ such as $S_{i,m}$ if not equal to 0 go back to Step 2, else, end.

At the end of Step 2), the trader agent is requesting a capacity offer corresponding to the plan it computed. It sends these requests simultaneously to every agent that is concerned with the chosen plan. If one of the agents contacted is not answering positively to the request, the trader agent go to the Step 3) and search a new plan satisfying the demand. If all the agents contacted answer positively, the trader agent immediately book the capacity asked, mark the demand as satisfied, and go to the next step.

It is noticeable that the restriction of the internal model of the trader agent to a mono-objective program aiming to minimize only the cost is similar to the model presented by Wei and al. in the context of power industry (2.). These authors have proved that their model leads to a similar solution as the centralized approach (2.). The choice of the Koelhner’s dual algorithm to rank the alternative paths and thus be used to build up the best plan is grounded on the properties of the solution obtained by applying this algorithm. This algorithm insures the prudent selection of alternative, i.e. the choice of a consensual alternative in regards to the criteria of choice.

4 CONCLUSION AND FURTHER WORK

Understanding the development in time of its GRID use under different plausible scenarios is of prime importance for gas transport company, particularly in the new business context that has emerged from the liberalization of the gas market. Simulation tools allowing the adequate analyze of the complicated network of interaction among the various participants involved in the new gas markets, can support these transport companies in this task.

In this paper we provided a model supporting the simulation of wholesale cross-border trade planning, we have restricted it to the transport of gas using an interconnected GRIDs network. The proposed model uses a multi-agent approach where the interacting agents are acting as transporter, trader, or producer. Each of these agents has their own view of their environment, an interconnected GRIDs network where costs and capacity are fixed, and behave in function of their objectives in relation with this environment and the other actors. The traders particularly are competing for resources, by looking for the best trades.

We have considered important for modeling and simulating of wholesale cross-border trading planning to capture some essential factors a trader may use by making trade decision. These factors are in the proposed model cost and risks. These are measured in function of the producer or transporter agent’s reliabilities. In order to increase the variability of the trader agent preferences in the modeled system, the producer and transporter agent’s reliabilities relays on the trader agent internal evaluation. To allow the trader agent to take into account this multi-criteria decision context when selecting the best trade, it has been equipped with a decision process using a multi-criteria ranking method, using Koelher’s results (6.). This choice of method induced some properties concerning the trader agent behavior while selecting its best trade: the prudence. It means that a trader, by applying Koelher’s algorithm, will avoid to select a trade very unbalanced (very cheap and very risky, or very expensive and very safe for example).

By playing on the parameter’s value as cost, and capacity, or on the interconnected GRID network structure, a transporter company can evaluate different scenarios. It can also modify the profile of the trader agent in term of reliability evaluation. The multi-agent approach allow this type of change naturally.

In future works, we want to extend the trader model by allowing the trader agent to choose different strategies for selecting the best trade. We want also to extend the number of criteria that can be used
to select a trade. We plan to include other components playing a role in the cross-border trade planning: stoking possibilities and LNG trade are one of them.

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5 REFERENCES