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The Integrated Application of Pipeline Models and Gas Management Systems to Gas Transmission Networks

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ABSTRACT

This paper addresses gas nominations and allocations in gas transmission networks. An integrated system is designed to use both the current state of the network and the operational schedule to verify the feasibility of each Shipper's nomination.

After the description of the gas management system, a case study will be used to demonstrate the integrated application of the gas management system and the on-line models to an operational pipeline network. The applicability of the integrated approach to other networks will then be addressed together with its potentials and limitations.

DEFINITIONS

GMS: Gas Management System.

RiF: Rate in Force.

Producers: entities that have gas reserves.

Consumers (also "Offtaker"): entities that have gas demand.

Shippers: dealers or brokers of gas who broker transactions between the Producers and the Consumers. Shippers may also trade allocated capacity with other Shippers. A Shipper can request a series of nominations for registered consumers. A consumer is serviced by a single Shipper.

Transporter: operator and maintainer of the pipeline network - PGN (PT Perusahaan Gas Negara Tbk) in the case study.

Receipt Point Operators: parties who are responsible for defining the pipeline control settings to meet the requested Rate in Force ("RiF") for all contracted Shippers.

BBTU: Billions of British Thermal Unit (BTU). A BTU is the amount of heat necessary to raise one pound of water by 1 degree Farenheit (F). 1 British Thermal Unit (BTU) = 1055 J.

INTRODUCTION

As the demand for gas increases continuously and government authorities de-regulate in many countries, pipeline operating companies are facing increasing challenges. Many companies are now using computer software systems to help pipeline operators to manage their complex networks with multiple demands, (Ref [1], [2], [3], [4]).

Recently, government authorities have recently started to specify Gas Management Systems as part of the approval requirements for constructing and operating gas transmission pipelines. For example, in Indonesia, the Transporter was requested to procure and operate a GMS (Ref [5]). Not only is the GMS required to manage daily nominations, it has to accurately model the pipeline transients and dynamics. This requirement made it necessary to develop a GMS that meets all the rules specified in the Pipeline System Rules (Ref [1]) and is fully integrated with a hydraulic simulation package.

In the following sections the GMS is described in detail and its application to the gas transmission network is discussed. The paper then closes with the conclusions section.

THE GMS

An on-line pipeline hydraulic modeling system is an excellent tool for calculating and reporting the current (or future) state of a gas pipeline network. The primary function of the GMS is to superimpose onto this model a system of contractual rules, and an awareness of the current status and future requirements of individual stakeholders within the system. It also acts as the primary reporting system, and the real-time messaging manager.

For example, a hydraulic modeling system is aware of the amount of gas being supplied at the defined receipt points, and the amount taken off the system at the delivery points. However, many different Shippers could be supplying gas through a single receipt point, for delivery at any combination of delivery points (see Figure 1 for a simple schematic view of this). Also, although the modeling system can calculate current linepack values, it does not know who is responsible if the levels begin to move outside of safe limits, or what future changes stakeholders may request that could impact safety within the network.

To solve these problems, the GMS allows the monitoring of the complete network status, even down to the individual stakeholder level. The GMS becomes the single interface for data gathering from, and data presentation to, all stakeholders within the system. It combines manually entered information from the stakeholders, along with the current status of the pipeline network from the hydraulic model and SCADA inputs, to create a unified picture of the current network operation.

A gas pipeline has many stakeholders, although the naming or responsibilities may change in different systems depending on the geographic region, and the prevailing regulatory conditions. Depending on the specific market, the stakeholders in the gas transmission process may include producers, consumers, shippers and transporters.

The commercial relationships between these various entities are encapsulated in the business rules of the GMS:

- Nomination rules represent requests for gas transportation from one or more receipt points to one or more delivery points;
- Allocation rules permit access to transportation capacity. They take into account fuel gas charges (if applicable); the maximum daily quantity permitted for a producer or shipper; and maximum capacities available at receipt and delivery points;
- Prioritization rules account for the type of service (firm, interruptible); and
- Proration (attribution) rules distribute the delivered gas fairly among the consumers at delivery points.

System Architecture

The schematic overview of the GMS design is shown in Figure 2. The GM Application (shown as the orange block) consists of a web site, a continually running background service, an OPC client, and a persistant storage object (in this case, an SQL Server).

The web site is the stakeholder-facing part of the system, and all relevant data (both manually-entered and displayed) goes through it. Relevant parties receive unique logins, and the system serves content specific to each individual user. A web-driven approach offers many advantages for this type of data-centric application:

- Security can be maintained, as the central application controls all interaction and will block attempts to access data which is not relevant to the current user.
- The central application can better deal with concurrent users attempting to alter the same information, as it sits between the users and the persistant data storage.
- No software needs to be installed on client machines. If updates become necessary, only one update (the central application) is necessary.
- System administrators remain in control of the system at all times. Users can, for example, be de-activated so they no longer have access to the system. The central system can also inform administrators of users who have failed to enter any required data.

A back end service (The “GM Engine”) runs continuously and is the interface between the user-entered data and the “real world” information provided by the hydraulic model and the SCADA inputs. It uses the OPC client to collect the current pipeline status, including such information as:

- Valve States.
- Current Receipt and Delivery Point flow rates.
- Totalized values for the day at receipt and delivery points.
- Heating Values throughout the system (for conversion from energy to volume units).
- Linepack in all gas-holding pipelines.

The information is received from the OPC server in the Pipeline Management machine (PM) – see Figure 2. Some of the information is direct from the SCADA, whereas other values (such as linepack in all sections) are output from the PM hydraulic model, which continually runs in real-time. The values are stored in the SQL Server database so that they form a record of the pipeline performance throughout the day.

It may be a requirement, in case of emergency, that any or all of this data be entered into the system manually. Although it is always possible to “inject” values via OPC, the web interface offers a clearer, auditable method of data entry should the need arise and is the approach taken by the GMS.

Now that the GMS has this information, it can review the requirements of individual stakeholders. This requires two distinct phases.

Phase 1 - Validating Nomination Data and Stock Accounts

For clarity in the following sections, it is assumed that there are only two stakeholders in the system, Shippers and the Transporter.

At various fixed points throughout the day, Shippers need to inform the Transporter of their requests for gas transportation for the next day, or next few days (the "Nomination"). The Shipper uses the GMS to enter or modify these requests; the Transporter uses the GMS to see if the demands can be met.

The first validation phase can begin once the Shipper has entered their nomination data. In this phase, the Shipper's individual case is considered. Many of these considerations are tied closely to the business rules (i.e. contractual as opposed to engineering) in place for a particular system. For example, the Transporter may allow (or even require) a Shipper to maintain a "stock account", where excess gas received into the system is stored within the pipeline for future delivery.

To complete this phase, the following questions must be answered by the GMS:

- Will the Shipper supply sufficient gas to satisfy the demand requirements?
- Will the Shipper have sufficient gas in their stock account at the end of the day to maintain their contractual minimum?
- Does the Shipper require temporary stock transfers from other Shippers in order to maintain its stock balance?

These questions can be answered based on simple mathematics following the rules laid down by the Transporter, using the current system values as a starting point. For example, to calculate a Shipper's closing stock at the end of the current gas day:

```
PredictedClosingStock(Day)=
   OpeningStock(Day) +
   ActualReceipts(DayUntilNow) –
   ActualDeliveries(DayUntilNow)  +
   ShipperDailyEstimates(NowToEndOfDay) –
   OfftakerDailyEstimates(NowToEndOfDay)
```

The opening stock for the day is retrieved from the SQL Server, where it was stored after calculation of the previous day's real values (this is discussed later). The most recent Actual Receipt and Delivery totalized values are retrieved from the SQL server. The estimates that have been entered by the Shipper into the GMS via the web interface are used to create future values from now until the end of the gas day.

The result of these calculations will determine if an individual Shipper has supplied a valid nomination. If necessary the GMS will change the nomination as appropriate so that contractual obligations can be met, and inform the Shipper of the change.

Phase 2 - Validating the Gas Totality

The second validation phase is more complex as it must look at the total volume and flows of gas within the system to see if they conform with the overall pipeline operating and safety criteria. For example, if a number of Shippers request above normal gas flows, they may exceed their own contractual requirements and/or the overall flow of gas in the system may be too high.

A local copy of the hydraulic model is used to check for this, (See Figure 2). The PM model runs continually, in real time. It saves its state at regular intervals, which the GMS copies to its own database.

A useful feature in a hydraulic modeling system is the ability to "look ahead"; that is, starting with a known state and predicting future results based on new inputs. The GMS calculates new flows at all receipt and delivery points, based on the nomination data entered by all Shippers. These new inputs are used in a look-ahead run to determine the linepack in all pipelines over the next 24 hours. These values can be compared against the maximum and minimum allowed values. If these are breached, the GMS will alter the nominations for all affected Shippers appropriately, and again inform Shippers of any changes in their nominations.

It is possible that the actual flow rates do not match those entered in the nomination stage. To check for this, the look-ahead process is run automatically at regular points throughout the day to check that the pipeline is safe if current actual values are projected forward. This process is also useful in the event of an emergency capacity reduction; the lower maximum allowable linepack value is entered into the GMS, and the look-ahead run will then inform all stakeholders of new applicable rates automatically.

Assigning Gas to Stakeholders

In order for all this to happen, the GMS needs to know whose gas is in which pipe. One of the major challenges of the system was to create the ability to quickly determine how gas is getting from each Shipper's receipt points to their delivery points. This is a key for a number of reasons:

- Should the amount of gas in any section become too low or too high, only relevant Shippers should be affected.
- For stock and billing purposes, Shippers whose gas supply routes pass certain gas-consuming pieces of

equipment (for example, compressors, where a certain percentage of the gas is used to fuel the equipment itself) need to have the amount of gas consumed deducted from their available stock.

- As valve states can change within a pipeline system, routes are not necessarily static. Routes need to be regularly checked for validity.

In a complex pipeline system, there can be many tens of thousands of ways of getting from A to B, depending on the valve states. It could take a fast system several hours to iterate through each possible route, checking each valve state to see if the flow of gas is feasible.

The GMS intelligently splits the network into smaller, physical, gas-holding sections of pipe and the connections between them. It then looks at how these sections connect together to form a higher level schematic view of the pipeline. It uses this view to calculate the valid routes between all receipt and delivery points, which reduces the possibilities down into the order of hundreds rather than thousands, which can be handled much more quickly.

Once this is done, each Shipper is attached to the pipeline sections along which thier gas travels. If, for example, a capacity reduction requires that receipt point flow rates be reduced, the Shippers in the affected pipeline section are known, and their necessary reductions can be calculated.

End of Day Calculations and Reporting

We have shown how, during any particular day, values such as Shipper stock accounts are calculated as a mixture of actual values and values entered as nomination data. Once we reach the end of the gas day, the nomination data is no longer required since real data will then be available for the entire period.

This data forms the basis for the daily reports. These are the permanent record of each day using the actual SCADA data, and are calculated by the GMS for storage in the SQL Server database. Some recourse to the contractual rules may be necessary, especially when it comes to attributing (prorating) delivered volumes where more than one Shipper is using the same delivery point.

Reports are viewed using the same web interface as used for the nomination data, with all the advantages of the central approach (such as security).

CASE STUDY

Pipeline Network Description and Application Requirements

The GMS has been applied to the network as shown in Figure 3. It consists of the following sections:

- 122 mile (196 Km), 36 inch pipeline from Grissik to Pagardewa.
- 2.5 mile (4 Km), 28 inch pipeline from Pertamina to Pagardewa.
- 232 mile (373 Km), 32 inch pipeline from Pagardewa to Bojonegara.
- 266 (428 Km), 32 inch pipeline from Pagardewa to Muara Bekasi.

A compressor station is located at Pagardewa and crossover valves are located at Pagardewa, Terbanggi Besar and Labuhan Maringgai. These are used to ‘mix’ the gas from Pertamina and Grissik and allow it to be supplied to both Muara Bekasi and Bojonegara.

The main stakeholders of this pipeline are:

- Shippers
- Receipt Point Operators
- Transporter
- Consumers (also "Offtaker")

Figure 4 outlines the relationship of the above stakeholders in a diagram.

As part of the approval requirements to construct and operate the above pipeline, the Transporter (PGN) had to procure and subsequently operate a GMS in accordance with the Operating Priorities. The following top level requirements had to be met:

“The GMS shall calculate for each Day the Shipper Forecast Closing Stock that is required to ensure that each Offtaker Nominated Rate and Offtaker Daily Estimate shall be fulfilled without the pressure at any Delivery Point falling below the relevant minimum Delivery Pressure. In calculating such Shipper Forecast Closing Stock, the GMS shall accurately model the pipeline transients and dynamics based on information provided by that Shipper, including the Offtaker Nominated Rate, the Offtaker Daily Estimate, the Shipper Availability, the Shipper Forecast, the Shipper Receipt Point Proportion and the Offtaker Forecast.

The GMS shall calculate and issue Rates in Force for each Shipper and manage the Stock Account for each Shipper, in order to manage the receipt of Gas into, and the delivery of Gas from, the pipeline system.”

PGN and ATMOSi collaborated closely on the development of the GMS in order to meet these requirements.

Hydraulic Simulation of the Pipeline Network

As discussed, an on-line hydraulic simulation system (ATMOS GSIM) is used to provide the current state of the pipeline. In addition to providing states to the GMS the on-line hydraulic models provide the following main functions :

- State estimation.
- Line pack and pressure analysis.
- Gas composition and quality tracking.
- Hydrate detection and condensation warning.
- Pipeline efficiency calculation.
- Scraper tracking.
- Look-ahead modeling.

Accurate modeling of the network is very important to optimize the use of pipeline inventory. The simulation software uses an automatically adaptive timestep and also an automatically adaptive spatial mesh to meet the specified accuracy. After specifying the desired simulation accuracy, the user need not be concerned with configuring details of the numerical solver as the software will configure itself to model the pipeline as accurately as required. This means that the simulation time can be reduced significantly for steady-state simulations.

Figure 5 shows the network model as configured by the simulation software and the flow and pressure trend at a delivery point. Details of the Pagardewa compressor station are shown in Figure 6. As the GMS must validate possible gas flow paths within the network, the hydraulic model has to include all possible equipment that could change the gas route within the transmission system.

From Nomination to Delivery

Once the Shippers and the Transporter have entered their daily nominations, the GMS is run to check the feasibility of the proposed supply and delivery quantities based on the current network state. Real-time pipeline data are used to update the hydraulic simulation and GMS system. A detailed description of the data flow from field instruments to Shipper nomination is provided in Figure 7.

Two examples of possible nomination verification scenarios are now presented:

Example 1: Operation Approved without Modification

The Predicted Opening Stock is 0 for both Shippers in this example.

Shipper 1 has entered a Target Closing Stock of 240 bbtu. The expected gas supply and delivery amount for the next seven days is shown in Table 1.

Shipper 2 has entered a Target Closing Stock of 240 bbtu. The expected gas supply and delivery amount for the next seven days is shown in Table 2.

With the above data and current state of the pipeline, the GMS analyses all the possible links between the sections of pipe and finds a valid path between the specified Receipt Point and Delivery Point. In this example, the nominations are approved without modification. Emails are then sent to Shipper1 and Shipper2 informing them of:

- The nomination's approval without modification.
- The approved RiF (this should be identical to that nominated initially).
- The existence of any equipment requiring fuel gas within the utilised gas route.

Example 2: Operation Approved Subject to RiF Reduction (Insufficient Stock in Line)

The Predicted Opening Stock is 0 for both Shippers in this example.

Shipper 1 has entered a Target Closing Stock of 0 bbtu. The expected gas supply and delivery amount for the next seven days is shown in Table 3.

Shipper 2 has entered a Target Closing Stock of 0 bbtu. The expected gas supply and delivery amount for the next seven days is shown in Table 4.

With the above data and current state of the pipeline, the GMS analyses all the possible links between the sections of pipe and finds a valid path between the specified Receipt Point and Delivery Point. In this example, the nominations are approved with a decreased Offtaker Rate as the closing stock from the previous day is insufficient to meet the required demand. Emails are then sent to Shipper1 and Shipper2 informing them of:

- The nomination's approval subject to modification
- The approved Offtaker Rate (smaller than that nominated initially)
- The existence of any equipment requiring fuel gas within the utilised gas route.

CONCLUSIONS

The GMS, integrated with an accurate hydraulic modeling package, has become an essential part of managing gas transactions and operating the pipeline network. The combined application of the GMS and modeling software is a powerful tool that could benefit many other gas transmission pipelines around the world.

Although there is no limit to the application of the combined solution, it is critical that the Transporter and the vendor co-operate closely in the development of the GMS. Since every pipeline system has its unique combination of stakeholders, market conditions that define the business rules, and of course the incorporation of unique Transporter user requirements, it follows that close cooperation is the key to the successful deployment of a GMS that the Transporter and other stakeholders can count upon.

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TABLES

Receipt Point	**Avail.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, time rounded down to nearest hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
Grissik	360	360	360	360	360	360	360	Day + 1	30	30	30	30	30	30	30	30	30	30	30	30
								Day + 2	30	30	30	30	30	30	30	30	30	30	30	30
Delivery Point	**Quant.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, nearest whole hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
Muara Bekasi	120	120	120	120	120	120	120	Day + 1	10	10	10	10	10	10	10	10	10	10	10	10
								Day + 2	10	10	10	10	10	10	10	10	10	10	10	10

Table 1 – The Expected Gas Supply and Delivery Quantities by Shipper 1 over the Next Seven Days for Example 1

Receipt Point	**Avail.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, time rounded down to nearest hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
SPG Pagardewa	360	360	360	360	360	360	360	Day + 1	30	30	30	30	30	30	30	30	30	30	30	30
								Day + 2	30	30	30	30	30	30	30	30	30	30	30	30
Delivery Point	**Quant.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, nearest whole hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
West Java	60	60	60	60	60	60	60	Day + 1	5	5	5	5	5	5	5	5	5	5	5	5
								Day + 2	5	5	5	5	5	5	5	5	5	5	5	5
Krakatua Daya District	60	60	60	60	60	60	60	Day + 1	5	5	5	5	5	5	5	5	5	5	5	5
								Day + 2	5	5	5	5	5	5	5	5	5	5	5	5

Table 2 –The Expected Gas Supply and Delivery Quantities by Shipper 2 over the Next Seven Days for Example 1

Receipt Point	**Avail.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, time rounded down to nearest hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
Grissik	240	240	240	240	240	240	240	Day + 1	20	20	20	20	20	20	20	20	20	20	20	20
								Day + 2	20	20	20	20	20	20	20	20	20	20	20	20
Delivery Point	**Quant.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, nearest whole hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
Muara Bekasi	360	360	360	360	360	360	360	Day + 1	30	30	30	30	30	30	30	30	30	30	30	30
								Day + 2	30	30	30	30	30	30	30	30	30	30	30	30

Table 3 – The Expected Gas Supply and Delivery Quantities by Shipper 1 over the Next Seven Days for Example 2

Receipt Point	**Avail.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, time rounded down to nearest hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
SPG Pagardewa	240	240	240	240	240	240	240	Day + 1	20	20	20	20	20	20	20	20	20	20	20	20
								Day + 2	20	20	20	20	20	20	20	20	20	20	20	20
Delivery Point	**Quant.** (bbtu)	**Forecast** (bbtu)							**Estimates** (bbtu, nearest whole hour)											
		Day + 2	Day + 3	Day + 4	Day +5	Day +6	Day +7		00	02	04	06	08	10	12	14	16	18	20	22
West Java	180	180	180	180	180	180	180	Day + 1	15	15	15	15	15	15	15	15	15	15	15	15
								Day + 2	15	15	15	15	15	15	15	15	15	15	15	15
Krakatua Daya District	120	120	120	120	120	120	120	Day + 1	10	10	10	10	10	10	10	10	10	10	10	10
								Day + 2	10	10	10	10	10	10	10	10	10	10	10	10

Table 4 – The Expected Gas Supply and Delivery Quantities by Shipper 2 over the Next Seven Days for Example 2

FIGURES

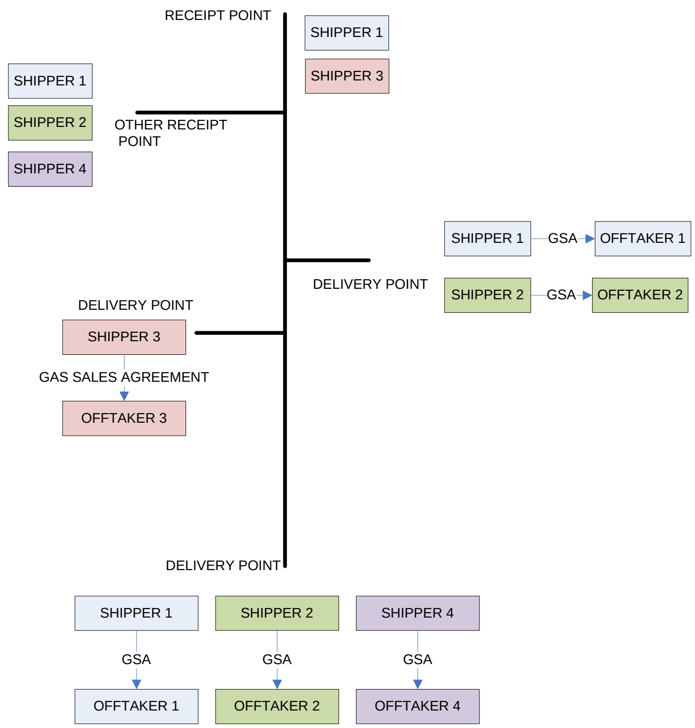

Figure 1 – Schematic View of Shippers' Gas Routes in a Pipeline

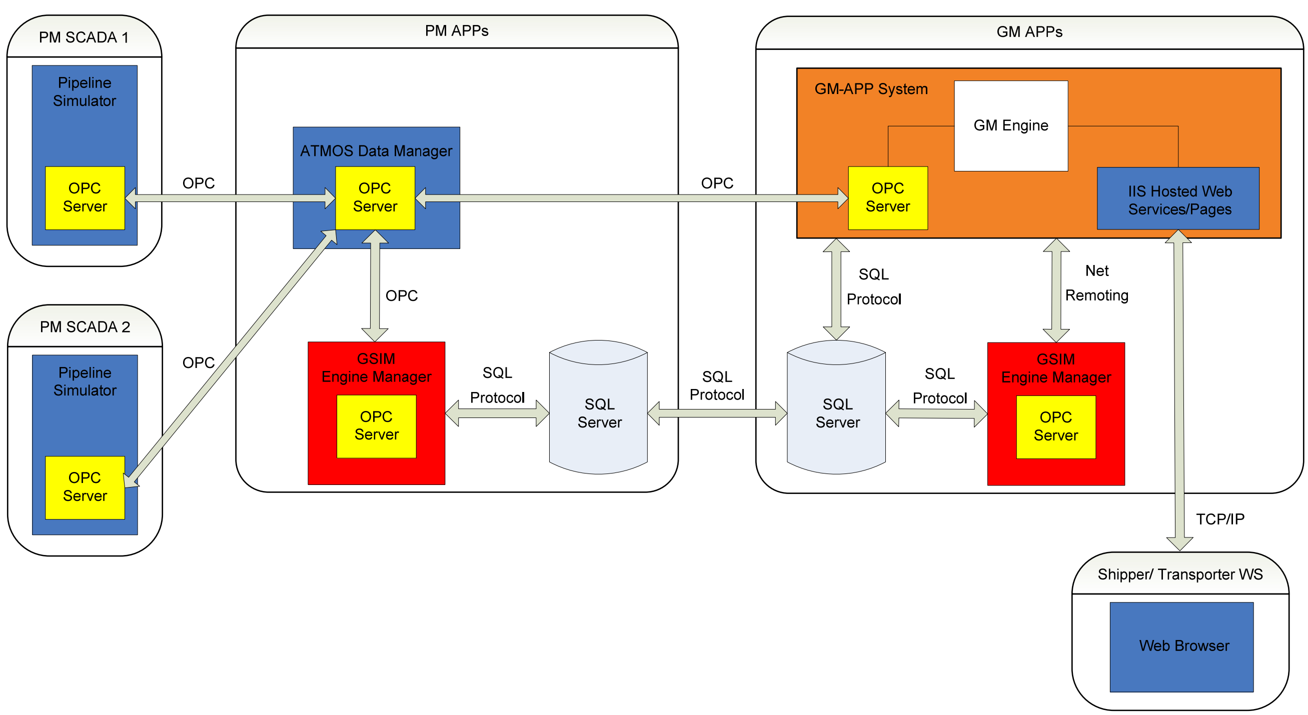

Figure 2 – System Architecture of the GMS and the Associated Pipeine Management (PM) Application System

Figure 3 – The Schematic Diagram of PGN's Gas Transmission Network

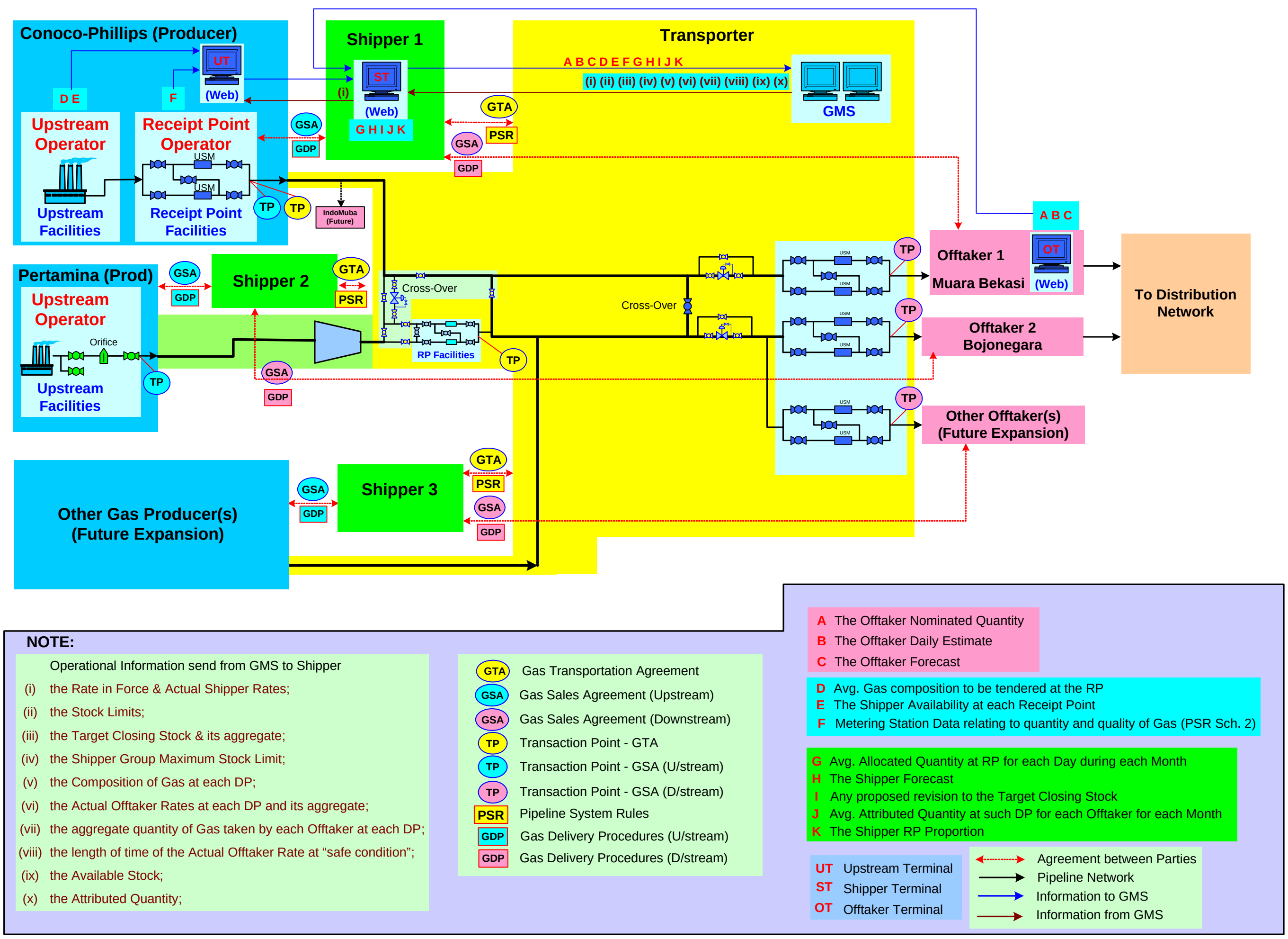

Figure 4 – The Main Stakeholders of the PGN Pipeline

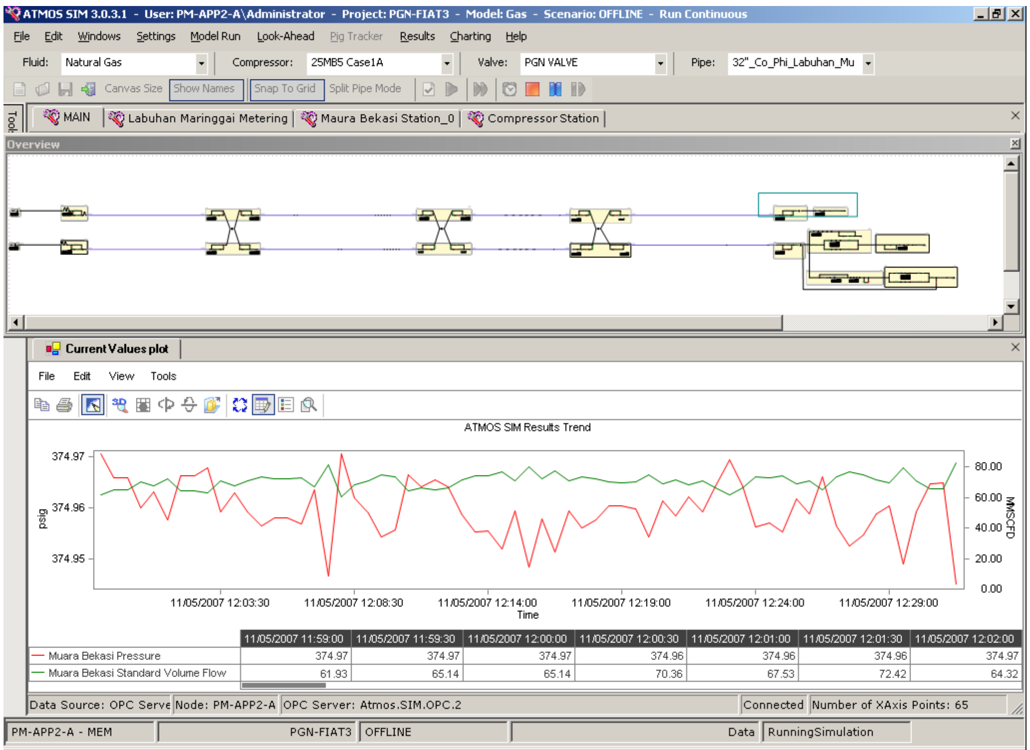

Figure 5 – The Network Model of the PGN Pipeline and the Flow/Pressure Trend at a Delivery Point

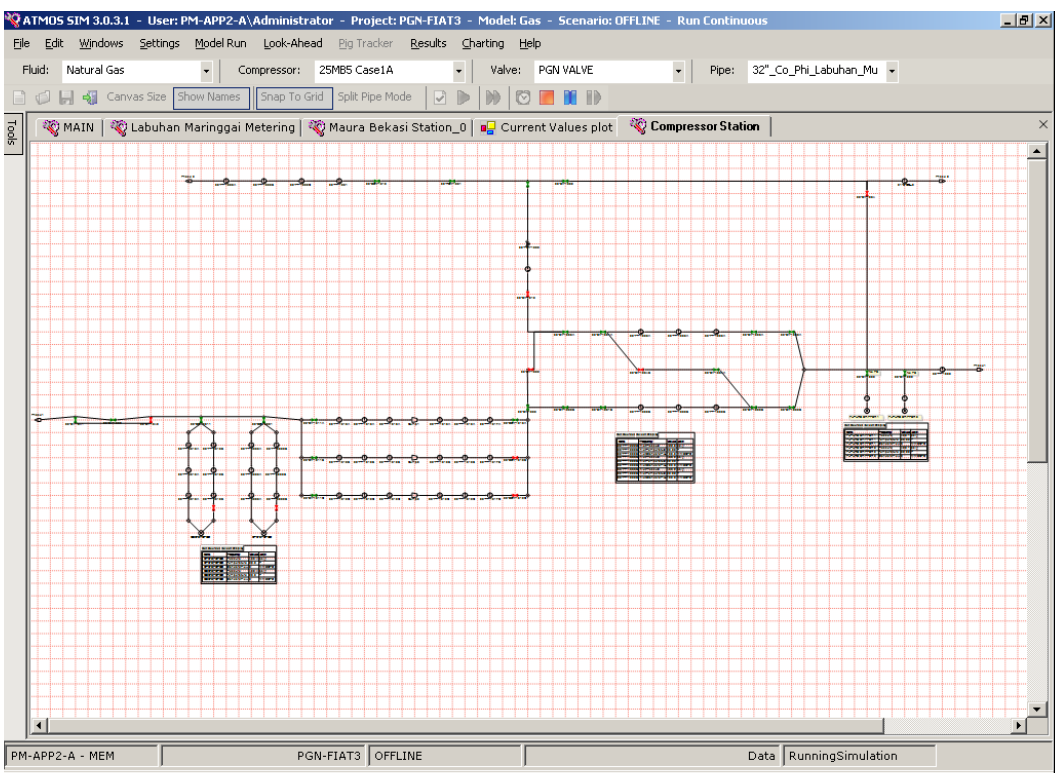

Figure 6 – An Example Station Configuration within the PGN GSIM model

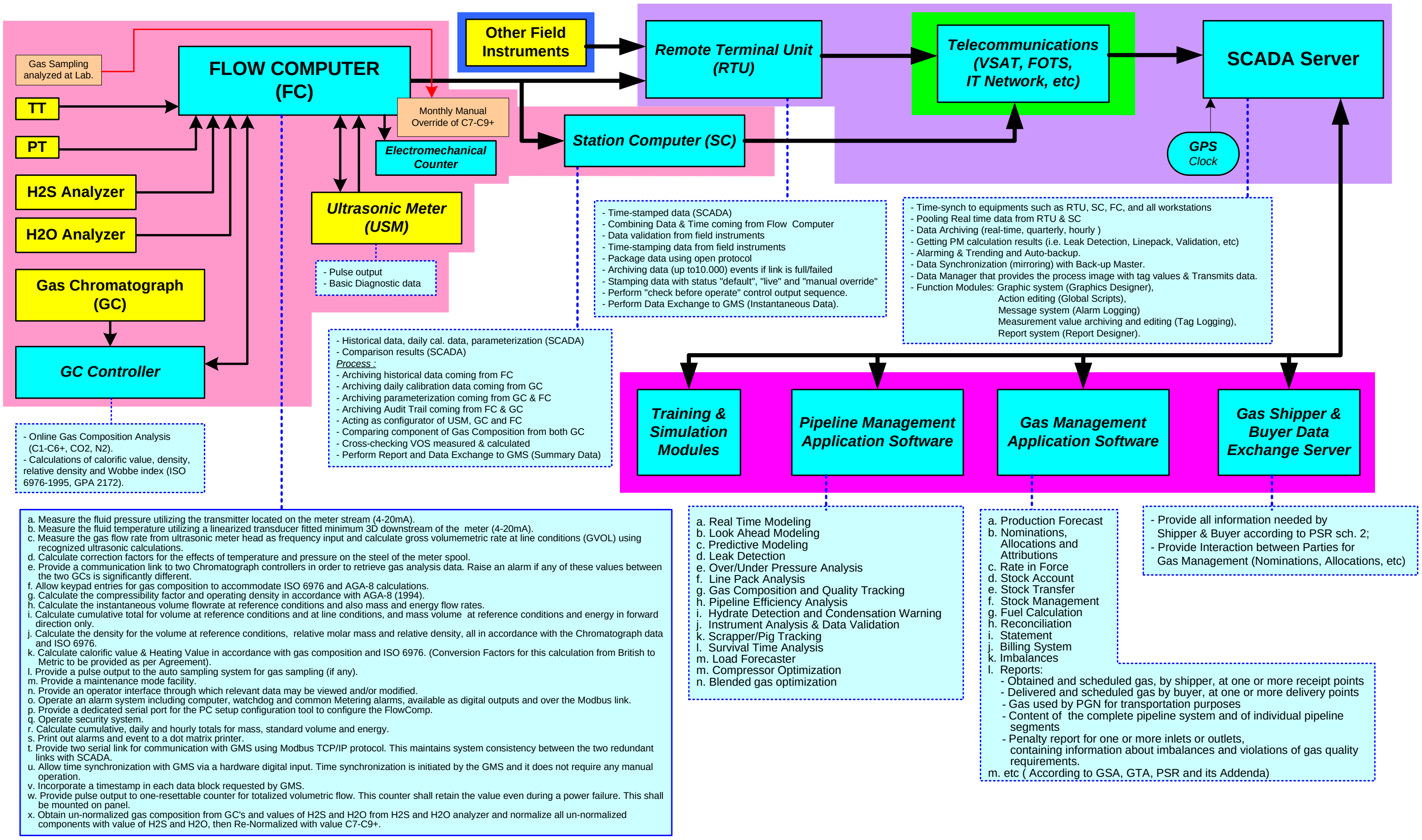

Figure 7 – Detailed PGN GMS Data Flow Diagram