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Multi-Echelon Supply Chain Design in Natural Gas Industry

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Abstract: In this paper, a framework is proposed for integrating of the operational parts of Natural Gas Transmission Systems (NGTSs) through pipelines and better coordination for the flow of natural gas and information in the system. The objective functions of this study are to provide a brief review of literature in natural gas supply chain modeling and to design a multi-echelon Supply Chain for the Natural Gas Transmission Systems (NSTSC). To achieve this, extensive and detailed studies in this field of research have been done. Subsequently, a complete study on the transmission of natural gas through pipelines, as well as the supply chain and its application, has been made in gas industry. Next, based on the operational systems in the natural gas industry, the supply chain levels are developed. These designs are very effective for modeling and optimization of the gas networks. In addition, the developed supply chain helps to reduce the costs of the NGTSs and increase customer satisfaction.

Key words: Natural Gas Networks · Optimization · Transmission Pipeline · Modeling · Review

INTRODUCTION

In today's competitive world, suppliers would be wise to ensure that their various products should be made available according to customer requests. Customer demand for high quality and rapid services have increased the pressures that did not exist before. Thus, enterprises not only need to inspect their internal organization and the resources they require. They also must monitor resources and associated organs, which are outside the organization because the goal is to achieve competitive advantage and gain more market share. Therefore, activities such as supply and demand planning, material preparation, production and product planning, product maintenance, inventory control, distribution, delivery and customer service, which are already being done in a company, are now components of the supply chain. A key issue in supply chain management is to coordinate all these activities. Supply chain management is a phenomenon through which customers can receive quick and reliable service with high quality products at minimum cost. Therefore, in general, the supply chain connects organizations to each other via the flow of materials, information and financial resources. These organizations may be firms, which produce raw materials and final products or services such as distribution, storage, wholesale and retail. Applying supply chain strategies can reduce costs and increase profitability for the company.

One of the most important and costly industries to which supply chain management should be implemented is the natural gas industry. Natural gas is the most commodious and cleanest energy source in the world. It is consumed in large quantities by commercial and residential users. The Natural Gas Transmission Systems (NGTSs) are one of the most effective ways for moving natural gas over long distances by pipelines. In these networks, gas is first refined in gas refinery and the sour

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gas becomes sweet. Then it is transmitted through pipelines to cities, power plants and storage areas and is even exported to other countries [1]. In some oil-rich countries, sour gas is transmitted through the transmission pipelines to revive of oil wells. One of the key issues in the Natural Gas Transmission Systems (NGTSs) is minimizing the costs of the networks. The supply chain can be an important tool to optimize production, distribution and storage resources of a fixed network in order to respond properly to external conditions. Therefore, the Natural Gas Transmission Network Supply Chain (NGTSC) decreases the NGTSs costs and increases customer satisfaction and it is essential for any natural gas industry. The objective of this paper is to study the literature in the supply chain modeling, optimization, the transmission of natural gas through pipelines and to design a multi-echelon Supply Chain for the Natural Gas Transmission pipelines industry (NGTSC).

The paper is organized as follows: Section 2 presents the literature on existing studies on the supply chain and gas transmission network; Section 3 explains the design of a multi-echelon Supply Chain in the Natural Gas Transmission industry (NGTSC); and Section 4 develops a three echelon NGTSC on a case study in the real world. The paper is ended with Section 5 with conclusions and directions for future studies.

Literature Review of Supply Chain and Natural Gas Supply Networks: In this section, supply chain management and natural gas supply networks are explained separately, according to their importance.

Supply Chain Management: Supply Chain Management (SCM) has been described with too many terms and expressions. As a primary definition, it can be said that SCM includes a managing system of activities and facilities that begins with purchasing raw materials, produce and finally distributes the product to customers. All vendors and manufacturers, service providers, distributers and warehouses and retailers are linked together as a chain in SCM [2]. Furthermore, SCM can be considered as a set of concepts utilized to efficiently integrate all elements in the supply chain, from suppliers to retailers, to produce goods and to distribute them at the right quantity and to right locations at the best time (Figure 1). As defined by the Council of Supply Chain Management Professionals (CSCMP), "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities. More importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers and customers. In essence, supply chain management integrates supply and demand management within and across companies. SCM is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations and it drives coordination of processes and activities with and across marketing, sales, product design and finance and information technology". Supply chain planning has been widely investigated by many researchers [2-22]. Facility location [23], supplier selection [24] and integrated modeling [25] are some of the main issues in SCM. The main objective is to minimize costs and to maximize profits simultaneously while reaching service level requirements [26, 27].

The exhaustive definition of SCM enables it to be successfully applied in a wide range of industrials such the automobile industry, home appliance, petroleum equipment and aircraft manufacturing. The most important questions that should be considered when a supply chain is going to be designed are: Are there existing facility location models which already fit into the supply chain context? Does SCM need facility location models at all? How many raw material suppliers and partners should be selected and which one is better? Which kind of physical structure should we use for supply chain facilities? How many echelons should be included in supply chain and where should they be established? How many products should be produced by each factory? When and where should they be reserved? Which kind of networking and

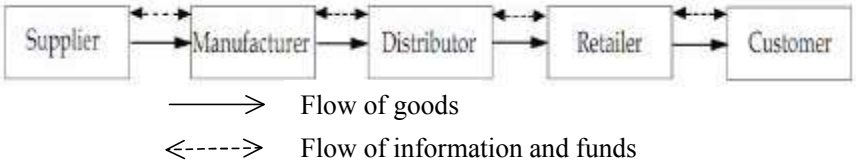

Fig. 1: The basic supply chain [51]

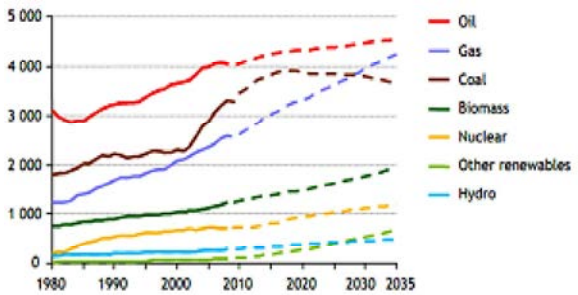

Fig. 2: World energy demand between 1980 and 2035

communication style should be used in the supply chain? How many distributors and warehouses should be included in the supply chain? All these questions lead us to have an optimized supply chain.

Natural Gas Supply Networks: Natural gas has become an increasingly important fuel in recent years. World natural gas demand is expected to almost double by 2030 and by then, natural gas is forecasted to overtake oil as the dominant fuel in the industrial sector. Figure 2 illustrates that worldwide natural gas consumption is forecasted to grow at an average rate of 2.4% annually as compared with 1.4% for oil in the next 25 years [28].

Since, natural gas suffers from low energy density, it is so difficult to store and transport when compared to liquid fossil fuels such oil and gasoline. The production, transmission and distribution infrastructure for natural gas requires a large capital investment and many types of equipment. All unique features of gas production, transmission, distribution and storage have major implications for the entire supply chain. It is clear that a gas supply chain operation involves tightly coupled subsystems and they must be closely coordinated and aligned with each other for the proper functioning of the entire chain. This means that the weakest link can severely disrupt the entire supply chain. In the next section, we will discuss the natural gas supply chain concept.

Natural gas networks have been widely investigated by many researchers. The different aims and methods have been considered to achieve satisfactory and optimum results for the gas networks. The reviewed papers on the scope of natural gas optimization and the relevant gas supply chain are tabulated in Table 1. In most of the studies, the objective function is to attempt to minimize the costs of gas networks. Therefore, different layers in the gas networks are defined and then they were analyzed in various periods.

According to the classified information, it is obvious that there is a need for a precise definition of supply chain and its use in the natural gas industry. Combining this study and the implementation of this chain, we can accurately identify and separate the existing systems in the gas industry based on the final products and their functions. Then, we can use various scientific methods to reduce costs and to increase customer satisfaction.

Designing a Multi-echelon Supply Chain for the Natural Gas Transmission Industry (NGTSC): Energy is an important resource for the development of the society and economy in any country. As explained, the natural gas is one of the cleanest and most economical energy. Globally, the need for natural gas increases alongside the growth of industrial and agricultural activities. Therefore, the natural gas industry is a major industry and it plays an important role in the economy of a country. Countries, which are rich in natural gas, receive great economic benefit from the development and planning of natural gas networks. Even just a little improvement in system utilization and planning will reduce a great amount of costs since the overall investment of the pipeline network is so huge. In this industry, various topics have attracted the attention of many researchers and these include generating, transmitting and distributing by the natural gas networks.

In natural gas supply networks, gas is first extracted from wells and refined in gas refineries. Then it is transported through pipelines to cities, power plants and storage areas and is even exported to other countries. Cities, power plants, storage areas, export ports and import ports are linked in pairs with pipelines (Figure 3). Hence, a direct gas flow between any two nodes is permitted. Export and import ports are the points that connect country networks together. Storage areas serve dual roles. They serve as consumption points when gas is injected into them and they serve as production nodes when gas is withdrawn from them.

Gas can be stored in storage areas for later use when demand is greater than supply or when the production cost is increasing. The natural gas transmission pipelines, due to their large diameters and volumes, are considered as storage.

There are three types of systems for natural gas delivery: Natural Gas Gathering System (NGGC), Natural Gas Transmission System (NGTS) and Natural Gas Distribution System (NGDS). The function of a NGGS is to transmit the sour gas from the wells to collection points and refineries. A NGGS may need one or more compressors to move the gas to the pipelines.

Table 1: Classification of natural gas supply chain mathematical models

Author(s)	Objective function	Natural gas delivery system	Supply chain levels / Gas network	Planning levels
[33]	To minimize the energy consumed by the compressors in the system	Transmission system	Gas network	Operational
[34]	To minimize the sum of the investment and operating costs	Transmission system	Gas network	Strategic
[35]	To construct an automated support system for optimizing natural gas pipeline operations	Transmission system	Gas network	Operational
[36]	To minimize the fuel cost consumption by the compressor stations	Transmission system	Gas network	Strategic
[37]	To construct an expert system for optimizing natural gas pipeline operations	Transmission system	Gas network	Operational
[38]	To estimate the effects of maximum daily demand of natural gas and pipeline length on the capital cost of the system	Distribution system	Gas network	Strategic
[39]	To minimize the fuel consumption by the compressor stations	Transmission system	Gas network	Strategic
[32]	To construct an decision support system for the local distribution company	Distribution system	Three echelon network	Strategic and operational
[40]	To minimize the fuel cost	Transmission system	Gas network	Strategic
[41]	To minimize the fuel consumption of compressor stations	Transmission system	Gas network	Strategic
[42]	To minimize the overall cost of pipes in the network	Distribution system	Gas network	Strategic
[43]	To minimize the Net Present Worth (NPW) of operating and capital costs	Transmission system	Gas network	Strategic
[29]	To minimize the cost of pipelines	Distribution system	Gas network	Strategic
[30]	To minimize the fuel consumption by compressor station	Transmission system	Gas network	Operational
[44]	To minimize the annual operating cost of compressor stations	Transmission system	Gas network	Strategic
[45]	To minimize the total amount of fuel consumed by the compressor stations	Transmission system	Gas network	Operational
[46]	To minimize the investment costs on an existing gas transportation network	Transmission system	Gas network	Strategic
[47]	To provide a decision aid tool that assists operators	Transmission system	Gas network	Operational
[48]	To simulate flow through a gas pipeline by considering heat transfer term	Transmission system	Gas network	Strategic
[49]	To forecast the natural gas consumption for residential as well as commercial sectors	Distribution system	Gas network	Strategic
[50]	To minimize the life cycle cost for the gas transmission system	Transmission system	Gas network	Strategic

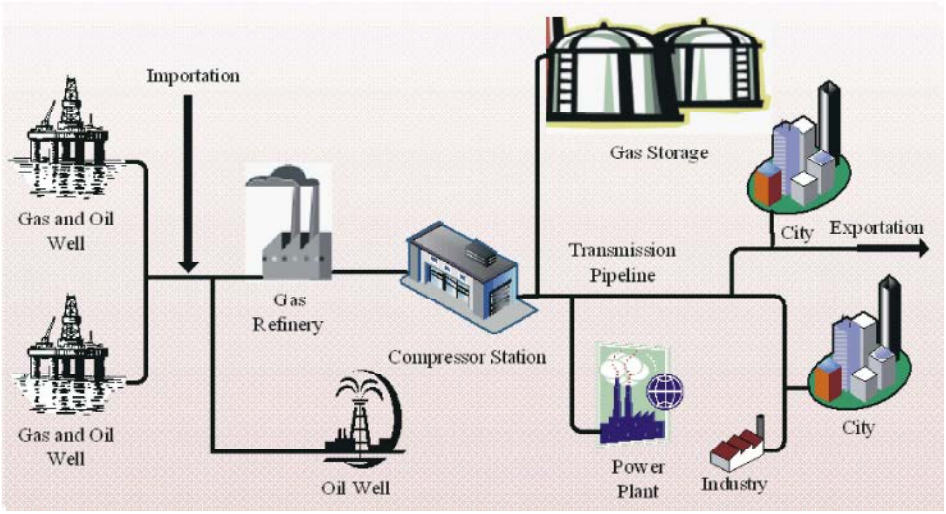

Fig. 3: The natural gas supply network and pressure reduction

Table 2: Natural gas delivery system with type of facilities

Natural Gas Systems	Gathering System	Transmission System	Distribution System
Executive Companies	Drilling and Generating Company	Transmission Company	Local Distribution Company
Pressure (psi)	More than 1500	1500 - 800	1000 - 1/4
Components	Oil and Gas Well, Well Pressure Control System, Wellhead Equipment, Collection Systems, Gas Refinery and Pipeline	Compressor Stations, Gas Turbines, Pipeline, Shutoff Valve, Gas Storage, Pig Launcher and Receiver Station, Importation and Exportation	City Gate Station, Filter, Heater, Odorant, Pipeline, Valve, Regulator and Town Boarder Station

Table 3: Differences between natural gas transmission and distribution networks

Gas Networks	Gas Pressure	Pipe Diameters	Consumers	Facility	Privacy
Transmission	High	Big Sizes	Export Points and Local Distribution Companies	Compressor Station, Shutoff Valve	Out of City
Distribution	Middle and Low	Small Sizes	Major Industries, Commercial and Residential Customers	City Gate Station, Town Board Station, Odorant, Heater	Urban Boundary and Major Streets

Table 4: Guideline for physical entities in natural gas supply chain

Contractual shape	Physical entities in natural gas network	Physical entities in natural gas supply chain
	Refinery	Supplier
	Importation	
	Transmission Gas Company	Wholesaler
	Compressor Station	
	Transmission Pipeline	
	Storage Well	Warehouse
	Transmission Pipeline	
	Local Gas Distribution Company	Consumer
	City Gate Station (CGS)	
	Power Plan	
	Domestic & Commercial	
	Exportation	
	Pipeline	Transportation mode

Transmission of gas means transmitting a huge amount of natural gas at high pressure over a long distance from the refineries to distribution centres and gas distribution is the process of transmitting the gas to individual customers (Table 2). There are a few differences between the NGDS and NGTS. The NGDS has a network, which has smaller diameter pipes operating at low and medium pressure (Table 3). The NGDS is less complicated as it operates without compressors or nozzles [29].

The NGTSs are wide complex systems (in length, measuring several hundred kilometers and even in the thousands) designed for transmission of natural gas by pipelines. At various points in any pipeline, it is essential to add energy into the gas to prevent frictional pressure losses. Hence, series-parallel banks of compressors are generally put at 40 to 200 kilometer intervals along the transmission pipeline. Operational control of the pipeline is allowed by these compressor stations. A range of complicated nodes, devices and other equipment are present to control a NGTS. Thus, natural gas is sent to sales stations from receipt points through the NGTS with specific flows and pressures [30]. The distribution of the correct choice for pressure and flow can dramatically affect the efficiency of operation [31].

There are few studies on supply chains in the natural gas industry. For instance, Contesse, *et al*. discussed the third level chain in gas supply networks [32]. As mentioned earlier, there are three complex systems in natural gas supply networks, which are the NGGS, NGTS and NGDS. The gas pressure in each of them is different, the executive essence of each of them is separate and each system is run by separate companies that specialize in implementation and repair. Therefore, every system needs a separate supply chain. The supply chains establish a correlation between entities of a system and the real world. Every chain includes all entities of the system and they are able to work together (Table 4).

In this section, the design of a multi-echelon Supply Chain for Natural Gas Transmission Network (NGTSC) is outlined. The NGTSC is very huge and complex. It is designed as a network including suppliers, wholesalers, warehouses and consumers (Figure 4). The chain starts from the gas refineries where sour gas is converted to sweet and dry gas and gas pressure is reduced. These refineries are known as suppliers. The importations are also regarded as suppliers. Next in the chain is the wholesaler, the gas transmission company that supports gas transmission via compressor stations and

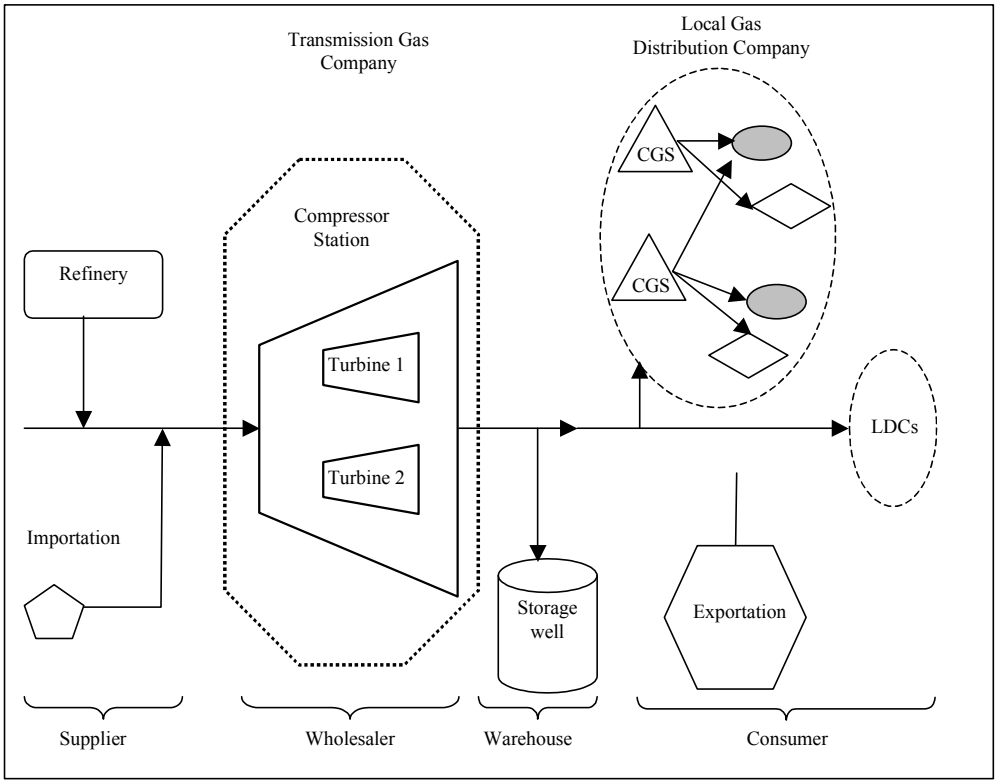

Fig. 4: Process of natural gas network and its supply chain

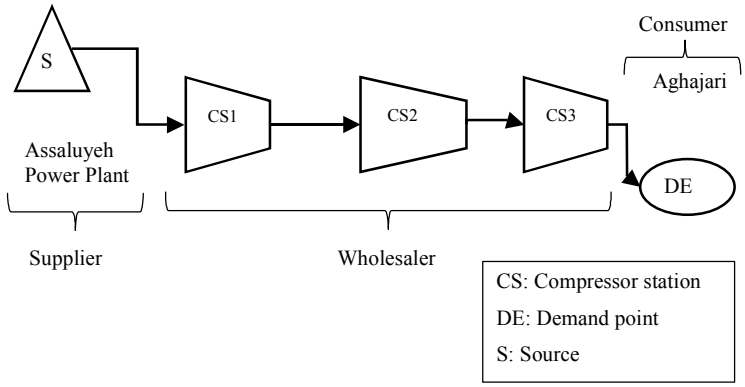

Fig. 5: Assaluyeh to Aghajari gas transmission pipeline

transmission pipelines. The extracted gas is directed by the long transmission lines to different places. If a big diameter gas transmission pipeline is used, gas pressure must be increased in order to ease gas transmission. Hence, gas stations are designed with huge gas compressors in the pipelines. Sometimes, the gas transmission pipelines are used for moving sour gas to oil wells to revive them. Storage facilities are the next in the chain. These are warehouses and their duty is to save gas when demand is low. The last component of the supply chain comprises the consumers, which are the Local Distribution Companies (LDCs) and the gas exportations.

There are many companies in this final part of the chain so that it can be regarded as a perfect market. Similarly, a supply chain can be designed for the NGGSs and NGDSs. The subscriptions in the systems should be identified.

Then, participatory planning is done for linking different areas and systems with different outputs. The participatory planning integrates and improves the business performance of the system and it is effective in operational planning. The designed supply chain has emerged, as an important component of the integrated system and as a tool for optimizing production, transmission, and the storage resources of a network. To improve this supply chain, we can fit in the flow of natural gas between the system and its suppliers and customers, and to determine the least cost of the system to satisfy the demands of all customers without exceeding the capacities of the warehouses and refineries.

The development of mathematical models in the NGTSCs has many applications. The models could be have different objectives, including optimization of the NGTSCs and design of components of the NGTSCs and minimization the fuel and investment costs in the NGTSCs. The defined multi-echelon NGTSC is suitable for reducing the level of vulnerability, to increase their flexibility according to customer demand, to provide superior quality for its product, to deliver on time, and finally, to eventuate saving of huge investments in gas transmission from suppliers to consumers.

The Application of Gas Supply Chain: Case Study 56" Gas Pipeline Assaluyeh-aghajari Description: In this section, a case study describes and illustrates the real application of the NGTSC and optimization model in the natural gas network.

One of the important natural gas projects in country of Iran is 56" Export Gas Pipeline Assaluyeh-Aghajari to develop the offshore and onshore facilities for phase 6, 7 and 8 of the South Pars Gas Field, which is located approximately 100 KM offshore in the Persian Gulf and 500 KM onshore.

According to the section 3, for developing an appropriate NGTSC in this case, the networks before and after power plant and also the onshore and offshore networks are separated, because design factors of pipelines, pressure of natural gas in the pipelines and finally kind of product after power plant are different. Therefore, the network consists of one source in the Assaluyeh, one demand point in the Aghajari and four pipe legs connected in series by three compressor stations. And the NGTSC is defined based on the three echelons: S supplies gas for the transmission pipeline network from the Assaluyeh power plant. DE is gas demand point. Three compressor stations CS1, CS2 and CS3 are set to supercharge in order to transmit gas smoothly and meet gas pressure for demand points. The

supply chain from Assaluyeh to Aghajari has been demonstrated in Figure 5. To help the defined NGTSC, an appropriate mathematical model for optimizing the locations of compressor stations, the pipelines diameter and other characteristics of the network is able to design.

CONCLUSION AND FURTHER RESEARCH

In this paper, it was proposed two objectives: (1) to classify definitions of supply chain management and information of gas transmission operational network according to the information needed to design the supply chain, for which we provided a brief literature review about this research; and (2) to design a supply chain as a set of relationships among suppliers, wholesalers, warehouses, retailers and consumers that facilitates the transformation of sour gas into the final product. Although the supply chain comprises a number of natural gas transmission network components, the chain itself is viewed as a single entity. This supply chain framework has emerged as an important component of the integrated system to reduce the level of vulnerability, to increase their flexibility according to customer demand, to provide superior quality for its product, to deliver on time and finally to reduce costs. It is suggested that future studies are needed to use this chain in modeling and optimization the natural gas transmission network.

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