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## **State of the Art for the Optimization and Simulation of the Distribution of Hydrocarbons**

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**Abstract.** Hydrocarbons distribution networks are strategic for the oil industry. That is why the research being presented in this article focuses on thoroughly reviewing everything that has been developed on the subject in different parts of the world over the last fifteen years. The reviewed articles have been classified according to the models that were built, the methods used to solve said models and the approach that has been developed. Because of the characteristics of the problem in general, there is more research available that uses mathematical models and finds the solution with different optimization methods. Secondly, though no less important, we found simulation models for studying some aspects that are differentiated from the optimization models.

**Keywords:** Hydrocarbons, distribution networks, optimization, simulation.

Article Info

*Received Dec 12, 2018*

*Accepted Mar 13, 2019*

### **1 Introduction**

Petróleos Mexicanos is currently one of the 100 largest companies in the world. Its most profitable business is oil exploration and production which is done through Pemex Exploración y Producción (PEP), the only company in the Pemex Group with a special tax régime.

In 2004 PEP was the third biggest oil producer in the world with a yearly average of 3.4 million de barrels a day, of which 2.1 million came from Cantarell, one of the highest producing oil fields in the world. Since then, Cantarell has suffered a natural decline and nowadays only produces about 200 thousand barrels a day.

The challenge for Pemex Exploración y Producción is to replace the fall in Cantarell's production, stabilize production and eventually profitably, surely and sustainably increase the platform.

It also faces the challenge of adjusting the cost structure to a scenario of low prices and the historic opportunity to use all the tools provided by the Energy Reform, in other words, it can develop a similar operation to all the other oil companies in the world, which will allow it to share technical, technological and financial risks throughout the value chain.

In order to achieve this, Pemex put into operation its Business Plan, which it uses to encourage alliances to be created throughout Pemex's value chain as a mechanism for increasing its investments and efficiency. For example, Petróleos Mexicanos and the Australian company, BHP Billiton, signed the license agreement for the development of the deepwater Trion block.

This is the first partnership for exploration and production via *farm-out* or partnership that Pemex has entered in all its history, taking advantage of the mechanisms and flexibility it is granted under the Energy Reform. The Trion block, discovered by Pemex in 2012, has total 3P reserves of 485 million barrels of equivalent crude oil, so there is certainty about its commercial viability.

However, it must be pointed out that oil acquires its true economic value on being sold, meaning that the hydrocarbons distribution process, which starts at the production complexes and ends at the points of sale, is particularly important.

Nowadays no tool or procedure makes it possible to analyze the overall economic value that can be obtained through Pemex Exploración y Producción's hydrocarbons distribution, collection and treatment infrastructure, which it makes available to the Oil Concessions and new operators, if necessary.

This article gives state of the art for the different techniques that have developed solutions over the last eighteen years for the distribution of gas mainly and, in some cases, crude oil. This bibliographic review deals with the optimization and simulation models used, which will allow us to frame the contribution to the optimization and simulation of PEMEX's Hydrocarbons Distribution System that we intend to outline in a later article. Said model will allow us to generate higher economic value by optimizing mixtures.

Another objective of this article is to present the various articles that have been published on this subject for those interested in researching it.

The proposed methodological basis is based on optimization theories and techniques, mixed integer programming, which is suitable for the design of a large-scale complex networks model, and whose results support decision-making for adjusting the cost structure for the hydrocarbons distribution under a low-price scenario. Then, given the characteristics of the integer models, simulation will be used to create scenarios.

Several systems have been put together to represent the operation of the hydrocarbons transportation and collection system, using virtual routes without taking into account the real routes, the installed capacity and economy of hydrocarbons. These efforts have been very valuable and have enabled us to see the importance of having more precise tools that include economic aspects.

This article is organized as follows: Section 2 briefly describes the problem and its main characteristics. Section 3 presents a state of the art where the models and methods employed in the relevant literature are reviewed, with attention being paid to optimization, optimization-simulation and simulation models, with a small mention of artificial intelligence. Section 4 shows the most relevant lines of research and analyzes the literature. Finally, we give our conclusions and suggestions for future research.

## **2 Description of the Problem**

The hydrocarbons distribution, collection and treatment system consisting of hundreds of pipelines and facilities of various types and capacities that make up a highly complex network that, through multiple routes, connects the production complexes with the points of sale.

This complexity is multiplied by this system being used to distribute several products of varied qualities that are mixed with each other to obtain new products while being transported through the network.

Another particularity of the network is that the nodes can be associated with different processes, some of which specifically relate to transport, such as compression for gases or pumping for liquids, and others for the conditioning of the products, such as dehydration, desalination and mixing, to name but a few.

Both the economic information for each pipeline and the prices associated with the products are preponderant for the programming of the economy that is implicit in the distribution, collection and treatment system.

The problem to be solved consists of finding the routes that optimize the distribution of hydrocarbons from the production complexes to the points of sale, maximizing expected profits and giving customer satisfaction in terms of the quantity and quality of the product, in other words, the mixture that reaches the points of sale must meet the required quality.

Every transfer node that receives production from two or more nodes must have a process module for obtaining the quality of the outlet mixture. Routes generally have several transfer nodes.

In this regard, the problem can be identified as a maximum distribution problem in a network with minimum costs and with the following characteristics and restrictions.

This is a multimodal network as it considers two products: oil and gas, as well as having three types of pipelines: oil pipelines, gas pipelines and oil and gas pipelines. The methods to be employed for finding a solution may consider every product in the multimodal network, or else break the network down into layers by each product.

This problem consists of maximizing the profits obtained from the sale of the hydrocarbons that circulate in the system while at the same time considering the minimum cost. Some authors describe this problem as one of maximum flow at minimum cost. A minimum-cost maximum flow for a  $G = (V, E)$  network is a maximum flow with the lowest possible cost. This problem combines the maximum flow (obtaining the highest possible flow from the source node (or nodes) to the sink node (or nodes), with the lowest cost path from the source to the sink node.

There are several source nodes and several sink nodes.

What goes into the transfer nodes is the same as what comes out, as long as they are not transferred nodes that deal with mixtures or processes, in which case the products leave the node improved and differentiated by quality and other characteristics.

The pipelines have an installed capacity that depends on their diameters, length, intake and outlet pressures, while also considering chemical factors that are inherent to the product.

Costs per section (pipelines) are considered as is the volume that flows. It is a large-scale network as it has more than 300 nodes and 500 arcs.

The following figure 1 shows a part of the network in simplified form.

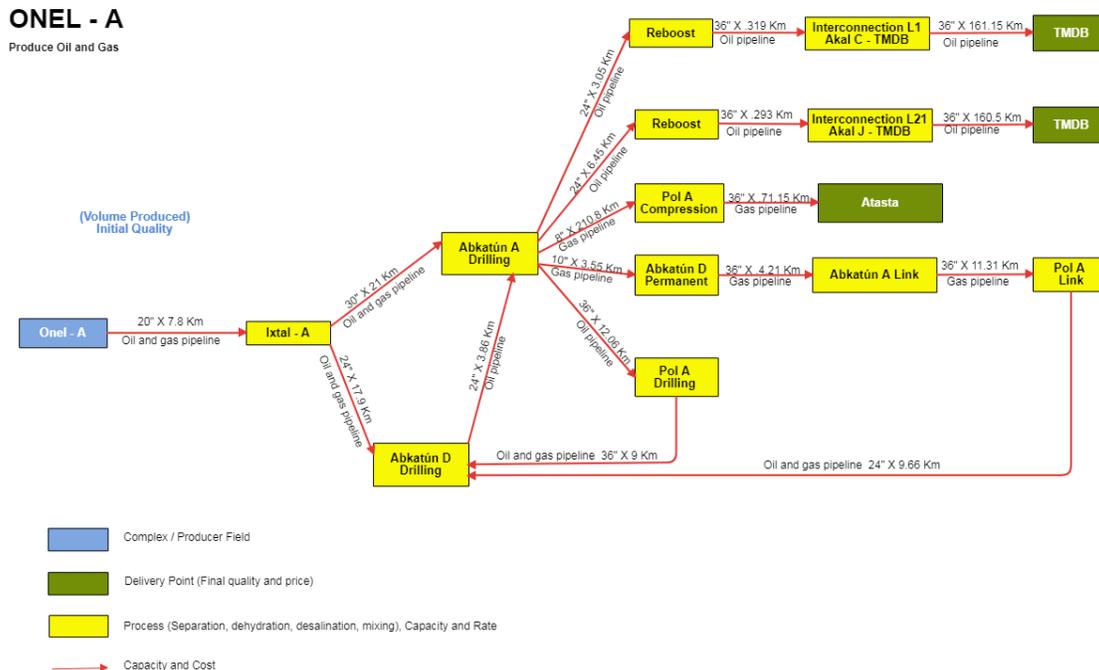


Figure 1. Simplified network of the problem. Source: By authors.

### 3 State of the art

We will now review and describe a variety of articles published over the last few years. These articles are important for the definition of the models and tools to be used for solving the problem, however some of them were considered because of the problem's structure, such as a distribution network, even though in several of them the product is natural gas.

We will make a classification of the articles according to the type of problem being posed in the network or the approach for optimizing it, thus we get:

- The products that go through chemical processes at certain nodes, as well as the characteristics inherent to said products.
- Maintenance and/or safety of the network.
- Analysis of and improvements to the design of the network
- Focus on the network's supply chain.

The above classification is framed around the models and their solution methods, which are basically optimization and simulation models. There are a series of tables at the end of this article that clearly show the models together with the solution methods and approaches.

The transport of hydrocarbons is a very important process for the oil and gas industry and, as such, needs to be performed with maximum efficiency. Pipeline systems are known to be the most economical, effective and safe means of transporting these products, but this literature review is required to support said assertion.

#### 3.1 Optimization Models

Because of their relevance, since 2001 efforts have been made to optimize hydrocarbon transport networks. That year, Jokic et al. [1] developed a nonlinear programming model (NLP) for optimizing a network for oil transport specified the volumes to be transported and considered the pressures at the intake and outlet from the pipelines, thus managing to minimize the operating cost. The model was solved using Mathcad 2000 software.

Other works related to optimization models are the ones are described here, most of them gas network optimization that are explained first, and second the ones with multi products or oil optimization.

##### *Gas network optimization*

Adeyanju and Oyekunle [2] developed a nonlinear optimization procedure NLP (objective function and nonlinear constraints), for a natural gas transportation network using an adaptation of the generalized reduced gradient algorithm, with which they determined the optimum economic conditions under which natural gas can be transported through a network of gas pipelines and compression stations.

Selot [3] analyzed short-term (2-12 weeks) supply chain management in upstream natural gas networks. A global optimization model (GO) is used for the production system, as it is a nonlinear mixed integer programming (MINLP) model.

It is important to explain the terms "upstream" and "downstream": "Upstream" and "downstream" are general business terms referring to oil or Gas Company's location in the supply chain. The closer to the end user a function or firm is, the further downstream it is said to be. Raw material extraction and production are elements of the supply chain considered to be upstream. Upstream companies identify oil and natural gas deposits and engage in the extraction of these resources from underground. These firms are often called exploration and production companies. Refiners represent the downstream element of the oil and gas supply chain.

Upstream oil and gas operations identify deposits, drill wells and extract raw materials from underground. This sector also includes related services: such as rig operations; feasibility studies; leasing machinery and supplying extraction chemicals. China National Offshore Oil Corporation and Schlumberger are examples of long companies that focus on upstream services. Many of the largest upstream operators are major diversified oil and gas firms, such as Exxon-Mobil.

Chebouba et al. [4] proposed a nonlinear integer model (NLIP) for which they designed an ant colony optimization algorithm for gas pipeline operations with a constant flow. This is a system consisting of connected compression stations. The decision

variables are chosen to determine the number of turbochargers in operation and the discharge pressure for each compression station. The objective function is the power consumed by these stations in the system.

With the rise in global demand for energy, natural gas plays an increasingly important role in the energy market. To meet demand, optimization techniques, producing some promising results, have been widely used in the natural gas industry. In this vein, Zheng et al. [5] made a detailed analysis of optimization models in the natural gas industry, focusing on production, transport and the market.

In Borraz-Sánchez doctoral dissertation [6], developed some models for solving the problem of optimizing gas pipelines. Due to the compressible nature of dry gas, large reserves can be stored inside the pipe for subsequent extraction when flow capacities elsewhere in the system break down. Since it is likely that such unpredictable events do occur, keeping a sufficient level of line-pack, therefore, becomes critical to the transporter. Managing the line-pack in a gas transportation network means optimizing the refill of gas in pipes in periods of sufficient capacity and optimizing the withdrawal in periods of shortfall.

In this project, a multi-period model is proposed to tackle *the line-packing problem*. The model has nonlinear constraints and both continuous and integer decision variables, and qualities thus as such as a mixed-integer nonlinear programming (MINLP) model. In the project, authors develop an extensive numerical experiment to evaluate the computability of the model. This experimental phase is based on a GAMS formulation for the MINLP model, while applying the global optimizer BARON.

Jin and Wojtanowicz [7] developed a study aimed at optimizing the natural gas network to minimize its energy consumption and cost. They used four different optimization methods: the penalty function method; pattern search; implicit enumeration and non-sequential dynamic programming, to solve the problem. The results show that cost savings, because of global optimization, are reduced with increased throughput.

Domschke et al. [8] studied the technical optimization problem of a transient gas network, which can be considered a minimum-cost flow problem with a non-linear objective function and additional non-linear constraints on the network arcs. They solved it through a “combination of a novel mixed integer linear programming approach based on piecewise linearization and a classic sequential quadratic program applied for given combinatorial constraints”.

Hübner and Haubrich [9] proposed a method based on genetic algorithms for planning and optimizing natural gas distribution networks from a long-term planning perspective. The method is capable of calculating network structures that are cost-efficient in terms of all the technical and economic conditions.

Babonneau, Nesterov and Vial [10] developed a multi-objective model to get around the difficulty represented by the operation of gas distribution networks, because of the total energy dissipated in the network. The two objectives posed in the model correspond to the investment cost function and the energy that is required to transport the gas. This bi-criterion problem turns out to be convex and easily solvable by convex optimization solvers. The continuous optimization formulation can be used as an efficient continuous relaxation for problems with non-divisible constraints, such as a limited number of commercial pipe dimensions available.

Borraz-Sánchez and Haugland [11] approached the flow maximization problem in a natural gas transportation pipeline system. Their model incorporates the variation in pipeline flow capacities with the specific gravity of the gas and compressibility. Given that the proposed model is not convex and, therefore the global optimization can take a long time, they propose for their solution a heuristic method based on an iterative approach where a simpler NLP model solved in each iteration.

MohamadiBaghmolaei et al. [12] carried out a study for minimizing the fuel consumption of a pipeline system that includes reinforcement units. For the analysis, they used the steady-state non-isothermal natural gas flow. Due to the lack of information and difficulties in predicting gas turbine and compressor efficiency, intelligent systems may be used to find the relations between the parameters involved, including the Artificial Neural Network (ANN), the Adaptive Neuro-Fuzzy Inference System (ANFIS) and the Fuzzy Inference System (FIS), for predicting and optimizing the pipeline network from the IGAT 5 system that transports the natural gas from Asalouyeh (South Pars Energy Zone-IRAN) in order to injected into the oil wells. The results showed that ANN is slightly more precise than the other two predictive methods. Therefore, the ANN results were introduced into a Genetic Algorithm (GA) to determine the optimum speed for each compressor and its compression ratio.

For their part, Alinia Kashani and Molaei [13] proposed a multi-objective approach to finding the optimum operating conditions for a natural gas network. For this purpose, they made a thermodynamic model of natural gas through the main elements of the

network. Their aim is to find the optimum values of three objective functions: i) the maximum gas delivery flow; ii) the line pack and iii) the minimum operating cost. Here, a fast and elitist non-dominated sorting genetic-algorithm (NSGA-II) is applied by considering fourteen decision variables: the number of running turbo-compressors (TCs) and their rotational speed in compressor stations as well as the gas flow rate and pressure at injection points. The results of multi-objective optimization are obtained as a set of multiple optimum solutions, called 'the Pareto optimal solutions'. Sensitivity analysis of change in the objective functions, when the optimum decision variables vary, is also conducted and the degree of each parameter on conflicting objective functions is investigated.

Fabro et al. [14] presented a model to assist in the operational decision-making of scheduling activities in a gas pipeline that transports heavy oil derivatives. The approach they proposed develops a decomposition procedure that uses a sequence of mathematical and heuristic programming models (MILP), which were run on the CPLEX program to solve the problem.

Wu et al. [15] built a MINLP optimization model for natural gas trunk pipelines for balancing the maximum operation benefit and the maximum transmission amount. The sum of weight method was used to combine the two objective functions and, in this way, modelled a hybrid objective function. To weight each objective function, the Analytical Hierarchy Method (AHP) was used. Restrictions related to node pressure, flow rate and temperature were considered as restrictions of the model. The power and condition of the compressor, the pressure and temperature equations of the pipeline were also incorporated into the model. As the model is non-linear, the particle swarm optimization algorithm (PSO) was used to solve it, and the adaptive inertial weight adjustment method was adopted to improve the basic PSO for its premature defect. The IAPSO shows a faster convergence speed and better solution results than those of the other four PSO.

Pfetsch et al. [16] researched methods for solving gas transportation issues, particularly the validation of the nomination problem that takes as a given a gas transmission network consisting of passive pipelines, active, controllable elements and an amount of gas at every entry and exit point of the network; for which operational settings are sought for all the active elements in such a way that there is a network state that fulfills all the physical, technical, and legal constraints. The authors described a two-stage approach for solving the nonlinear feasibility problem; the first phase with four algorithms: the methods of mixed integer linear programming (MILP), mixed integer non-linear programming (MINLP), nonlinear reduced gradient (GRNL) and de complementarity constraints (CRP) for calculating the possible settings for discrete decisions; while the second phase employs a continuous nonlinear programming model of the gas network.

Chebouba [17] addressed the management of the "GZ1 Hassi R'mell-Arzew" gas pipeline network. For this system, the decision-making on the line pack usually involves a delicate balance between the minimization of fuel consumption in the compression stations and the maximizing of the gas line pack. They used multi-objective decision-making. The first step in the development of this procedure is the derivation of a numerical method to analyze the flow through the pipeline under transient isothermal conditions, for which the NSGA-II (Non-dominated Sorting Genetic Algorithm) algorithm of the mode FRONTIER (coupled with a Matlab program) was used to solve the multi-objective problem.

In recent years, a large amount of research has been conducted on problems in the natural gas industry and, specifically, in the optimization of the pipeline network. Ríos-Mercado and Borraz-Sánchez [18] present a review of the current state of the art. The authors focus on categories such as: short-term storage (line packing problems), gas quality satisfaction (grouping problems) and compressor station modeling (problems of fuel cost minimization). The optimization models were discussed, highlighting the modeling aspects and the most relevant solution approaches known to date.

Although the technical literature on the problems of the natural gas transmission system is quite extensive, this is, as far as we know, the first comprehensive review that covers this specific area of research on the transmission of natural gas from an operational research perspective. Therefore, this article can serve as a useful tool to obtain information about the evolution of the many real-life applications and the most recent advances in solution methodologies that arise from this area of research.

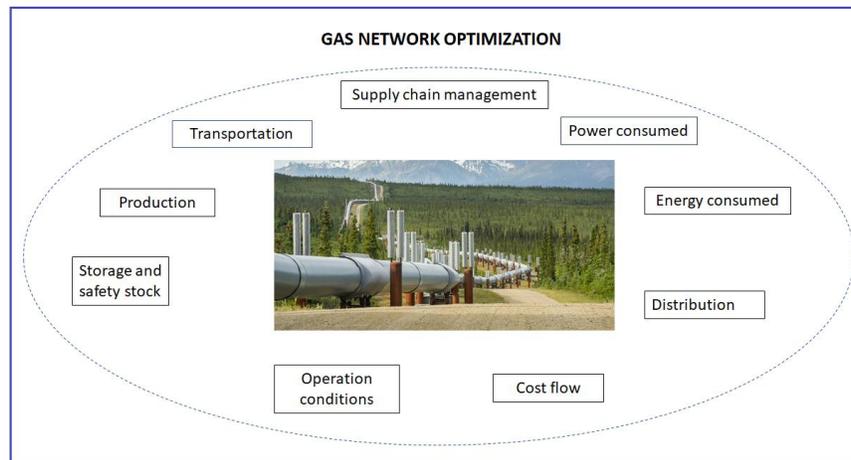
Sedliak and Zácik [19] designed a methodology for solving optimization tasks for gas transport in a pipeline system such as: finding of maximal outflow; minimization problems (e.g., finding minimal gas consumption under certain transport conditions), and multi-objective optimization (e.g., minimal energy consumption and prescribed line pack). To this end, they made modifications to the evolution strategy algorithm. The proposed algorithm was implemented in C++ programming language as an embedded module in software MARTI Studio—a general tool for solving tasks in gas industry.

Zhang and Liu [20] developed an optimal operation model based on an improved genetic algorithm for natural gas pipeline network. For its solution, they chose the maximum benefit and maximum flow as the objective function, and selected several

conditions as the constraints including the input and output of gas, the input and output pressure of gas, the handling capacity of the compression station, the strength of the pipeline, the pressure drop in the pipeline, the compressor, the valve, and the flow balance of the node of the pipeline network. They also establish an optimal mathematical operation model for the natural gas pipeline network. For this, they propose an improved genetic algorithm as the possibility of the fitness value of an individual in the initial population is abnormal and the possibility of the probabilities of the crossover and the mutation are too high or too low.

Mikolajková et al. [21] presented a model of a pipeline network for gas distribution considering the supply of gas, either from external gas networks or as injected biogas or gasified liquefied natural gas (LNG) at terminals. The model is based on mass and energy balance equations for the network nodes, equations of the pressure drop of a compressible gas in the pipes, as well as expressions of gas compression in compressor nodes. The model is applied within an optimization framework where the optimal supply of natural gas to the customers has studied under a multi-period mixed integer nonlinear programming (MINLP) formulation, considering possible extensions of the pipeline network to new sites as well as the potential supply of the gas from LNG terminals. The natural gas network in Finland is used in a case study, which determines the network's size and operation conditions.

Next figure 2 shows an overview of the problems solved in the previous articles.



**Figure 2.** Problems solved for the gas network optimization.

Source: by authors and image from <https://www.manhattan-institute.org/html/america-needs-more-pipelines-10478.html>.

### ***Oil and multiproduct network optimization***

MirHassani and Ghorbanalizadeh [22] presented an integer programming approach to oil derivative transportation scheduling. The system they reported is composed of an oil refinery, a multi-branch multi-product pipeline connected to several depots and local consumer markets that receive large quantities of refinery products. Batches of refined products and grades are pumped back-to-back in the pipeline, without any separation device between them. The sequence and length should be carefully selected for such pumping runs to meet market demands while, at the same time, satisfying many pipeline operational constraints, such as minimum interfaces. The model was a MIP and was solved using CPLEX.

Analyzing the distribution of petroleum products in China, Huanchao Tang et al. [23] developed a logistics model for oil, based on the inventory-transportation integrated optimization problem - a linear problem (LP) using LINGO (Optimization Modeling Software for Linear, Nonlinear, and Integer Programming) software - to check and compare its results with traditional optimization methods and be able to prove its superiority.

Gupta and Grossmann [24] presented an efficient strategic/tactical planning model for the problem of the development of offshore oilfields, which is generic and can be extended to include other complexities. The model, which is multi-period and mixed integer non-linear programming MINLP, is proposed for multi-field sites and includes three components (oil, water and gas) explicitly in the formulation. Aimed at maximizing the present total net value for the long-term planning horizon, the model involves decisions relating to the installation of FPSO (Floating Production Storage and Offloading), well drilling schedules and

rates of production for the three components in each period. This model can be effectively solved using DICOPT (DIScrete and COntinuous OPTimizer) developed by Grossman and is useful for real cases as it gives good quality solutions.

Ribeiro de Lucerna et al. [25] generated an optimization method for submarine pipeline routes, employed to carry the oil & gas from offshore platforms. Several methods associated with the modelling and solution of the optimization problem were addressed, including: the geometrical parameterization of the candidate routes; their encoding in the context of a genetic algorithm (GA) and the incorporation into the objective function of the several design criteria involved in the route evaluation.

Kazemi and Szmerkovsky [26] proposed a deterministic mixed integer linear programming (MILP) model for a downstream petroleum supply chain (PSC) network to determine the optimal distribution center (DC) locations, capacities, transportation modes, and transfer volumes. This model minimizes multi-echelon multi-product cost along the refineries, distribution centers, transportation modes and demand nodes.

Liu Xianwen and Wang [27] analyzing the characteristics of oil-gas production process and the relationship between subsystems, a multi-objective optimization model is proposed with maximizing the overall oil production and minimizing the overall water production and comprehensive energy consumption for per-ton oil. And then the non-dominated sorting genetic algorithm-II (NSGA-II) is used to solve the model. To further improve the diversity and convergence of Pareto optimal solutions obtained by NSGA-II algorithm, an improved NSGA-II algorithm (I-NSGA-II) is proposed.

Zhou et al. [28] described, in a document, the optimization problems of pipeline transport for multi-phase flows. This article established a route optimization model that combines the hydraulic calculations with optimization theory and adopt the general genetic algorithm (gGA) and the steady-state genetic algorithm (ssGA) for its solution. It also obtains the optimum route and discusses the influence of the parameters set the result. This algorithm was applied to determining optimum pipeline routes in the methane collection and transportation system in the coalfields of Shanxi province, China. The result showed that the algorithm is feasible and improves the hydraulic properties by reducing the pressure drop along the line.

Ye, Shengming and Yushan [29] studied the programming and routing of the tramp shipment and the oil supply chain. With this objective, they developed two models of whole programming (MILP) for the assignment between tasks, deposits and timing problems.

Zhang et al. [30] developed a hybrid method for detailed programming of a pipeline with multiple pumping stations. They explain that a multi-product pipeline is the most effective way to transport refined products and is of vital importance in the energy supply chain. The essential task in the actual operation of the pipeline is to schedule the delivery and injection of numerous types of products. The article presents a nonlinear mixed integer programming model (MINLP) for ducts with a single source and multiple pumping stations. The model has considered factors such as the migration of lots, the price of local electricity, the time window of demand, the avoidance of the inactive segment, the change of the minimum flow rate and the objective function related to non-linear hydraulics. The model contains two parts and is solved by a hybrid computational approach, the ant colony optimization algorithm (ACO) and the simplex (SM) method.

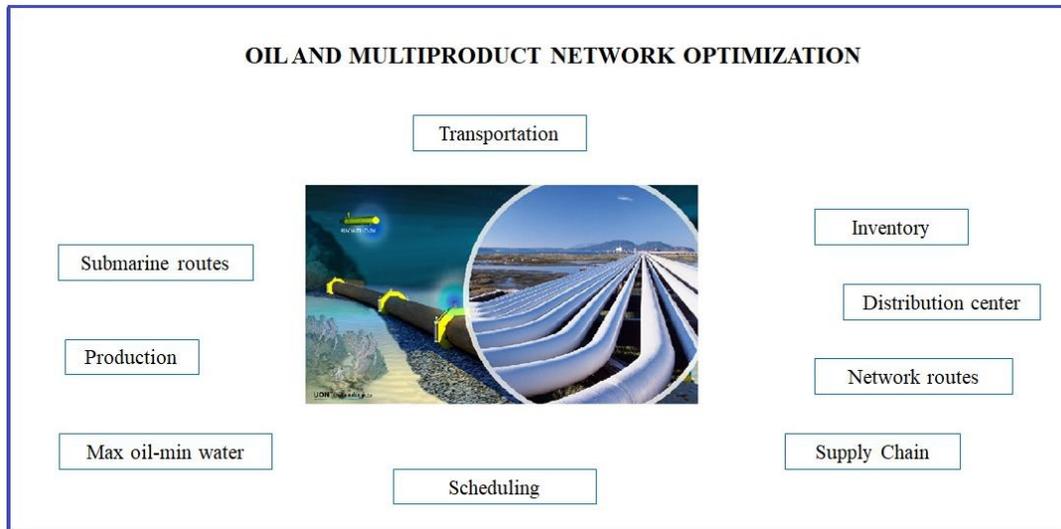
Finally, the formulation is successfully applied to a virtual and a real-world pipeline to verify the stability, convergence and practicability.

Yea, Lianga and Zhua [31] investigated the refined oil transportation problem considering the intersection of the scheduling and routing of tramp shipping and the petroleum supply chain, with unprecedented large-scale and complex rules. Two mixed-integer linear programming formulations MILP are developed for the assignment between tasks, vessels, and timing issues. The first model uses a time-slot concept under a continuous-time representation, where the constraints that deal with vessel assignment, capacity, timing, demand, and slack stock control are considered. The second model uses a discrete-time representation with time assignment, portal counting, and strict stock control constraints. Finally, the impact of the model parameters is analyzed under different optimization scenarios.

Chen et al. [32] explained how to optimize the detailed schedules of a multi-product pipeline. They presented a MILPD mixed discrete-time linear integer programming model, through an objective function that consists of the minimum sum of the pump speed variations in each pipe segment along a pipeline during a planning horizon. It was concluded that the more stable the pumping speed of a pipe segment, the lower the friction loss for the pumping products. The proposed MILP model is successfully tested in two real-world multiproduct pipelines using CPLEX.

Zhang et al. [33] explained in their paper that the optimization of multi-product pipeline scheduling is complicated due to multi-batch sequent transportation and multi-point delivery. Based on the fact, authors considered batch interface migration and divided the model into time nodes sequencing issue and a mixed-integer linear programming (MILP) model with the known time node sequence. And a self-learning approach is proposed through the combination of fuzzy clustering analysis and ant colony optimization (ACO). This algorithm is capable of self-learning, which greatly improves the calculation speed and efficiency. At last, a real pipeline case in China is presented as an example to illustrate the reliability and practicability of the proposed model.

Next figure 3 shows an overview of the problems solved in the previous articles.



**Figure 3.** Problems solved for oil and multiproduct network optimization. Source: by authors, images from <https://worldfinance100.com/2012/plains-all-american-pipeline/> <http://www.uontechnologies.com/about.php>

Tables 1 and 2 show the author’s contribution model and methods.

**Table 1** Optimization Methods

Author/Year	Model	Net	Method/Approach
Jokic et al. (2001)	NLP	OIL	Mathhead 2000/net optimization
Adeyanu et al. (2004)	NLP	GAS	GRG/net optimization
MirHassani et al. (2008)	IP	CRUDE, OIL, GAS	CPLEX
Selot (2009)	GO/MINLP	GAS	Supply chain/production
Chebouba et al. (2009)	NLP	GAS	ACO/net optimization, power and potency
Huanchao et al. (2009)	LP	OIL	LINGO/inventory and transportation
Zheng et al. (2010)	NLP	GAS	Linearization and metaheuristics/production, transportation and market
Borraz Sanchez (2010)	MINLP	GAS	GAMS, BARON/Inventory and gas refill
Jin et al. (2010)	MINLP	GAS	Penalty, Pattern search, implicit enumeration, Dynamic programming/Minimum cost and energy
Domschke et al. (2011)	MILP	GAS	Linearization and QP sequency/minimum cost flow
Gupta et al. (2012)	MINLP	CRUDE, GAS, WATER	DICOP, GA/máximum NPV
Hübner et al. (2012)	MINLP	GAS	GA/net optimization with pressure in nodes
Babonneau et al. (2012)	Multiobjective	GAS	GA/Minimize energy and investment
Borraz-Sánchez et al. (2013)	NLP	GAS	Heuristics/Maximum flow
MohamadiBaghmolaei et al. (2014)	MINLP	GAS	ANN, GA/Fuel consumption minimization
Alinia et al. (2014)	Multiobjective	GAS	NSGA II/Max flow minimum cost
Fabro et al. (2014)	MILP	HEAVY OIL	CPLEX/Operative decisions
Wu et al. (2014)	MINLP	GAS	AHP, PSO, IAPSO/maximum operation benefit and the maximum transmission amount
Ribeiro de Lucerna et al. (2014)	INLP	OIL, GAS	GA/submarine routes optimization

Notation:

ACO= ant colony optimization; AHP = analytic hierarchy process; ANN = artificial neural network; GA = genetic algorithms; GRG = generalized reduced gradient; NSGA II = Non-dominated Sorting Genetic Algorithm II; PSO= particle swarm optimization; IAPSO = inertia adaptive PSO.

**Table 2** Optimization Methods

Author/Year	Model	Net	Method/Approach
Pfetsch et al. (2015)	MILP MINLP	GAS	GAMS BARON Linearization, Branch and cut, heuristic, MPEC/Optimal operative configuration
Chebouba (2015)	Multiobjective	GAS	NSGA II FRONTIER/ To maximize the system line pack as the first, and to minimize total power as the second objective function.
Liu et al. (2015)	Multiobjective	OIL GAS	NSGA II/Maximize oil production and minimize wáter.
Kazemi (2015)	MILP, PSC, DC	GASOLINE, DIESEL, JET FUEL	GAMS NEOS/ To minimize the costs related to the location and allocation of the petroleum products considered in the study thereby minimizing the total annualized downstream petroleum supply chain cost.
Ríos-Mercado and Borraz-Sánchez (2015)	NLP, MINLP	GAS	A state of the art
Sedliak et al. (2016)	Multiobjective	GAS	MARTI/ Minimum energy consumption
Zhou et al. (2017)	ILP	OIL GAS	gGA, ceGA/ route optimization
Zhang and Liu (2017)	NLP	GAS	GA/máximum flow
Ye et al. (2017)	MILP	OIL	Heuristics/Assignment and inventory control problems.
Zhang et al. (2017)	MILP, VRP, IRP	Multiproduct	Tabu Search, GRASP, GAMS, CPLEX/Multicommodity supply chain
Yea et al. (2017)	MILP	REFINED OIL	ACO, SM/ Scheduling problem
Chen et al. (2017)	MILP	Multiproduct	CPLEX/ scheduling problem.
Mikolajková et al. (2017)	MINLP	GAS	MATLAB/ k-medoids function
Zhang et al. (2018)	MILP	Multiproduct	ACO and fuzzy clustering analysis/self learning algorithm

Notation:

ACO= ant colony optimization; GA = genetic algorithms; NSGA II = Non-dominated Sorting Genetic Algorithm II; SM = Simplex Method.

### ***Maintenance and Safeguarding***

The maintenance, safety and security of pipelines are issues that are very important for the Mexican oil industry. In this sense, PEMEX's efforts to solve the problems involved with them are evident.

SCADA PEMEX [34] was a project aimed at being able to operate more efficiently and reliably; ensure a capacity to respond and mitigate events where there is a risk to personnel, the general population and the environment; and contribute to the fight against the illegal hydrocarbons market in the transportation systems associated with the selected pipelines being carried out by Pipelines and Facilities, belonging the Distribution and Marketing Office (SDC) of PEMEX Exploración y Producción (PEP) by monitoring them and their remote control through a Supervisory Control and Data Acquisition System (SCADA) that enables us to have timely information for decision-making and take the necessary actions to minimize any negative impacts on the business, as well as ensuring the personnel is provided with the necessary know-how to operate and maintain the transport system.

Sun and Yu [35] studied the problem of optimizing the operation of pipelines in low flow and super flow, for operating safely and economically with energy saving. Ultra-low-flow tests are done on low-flow pipelines to find the minimum flow of the pumps. More research was done on the transportation of different oil blends, intermittent transportation of wax-bearing crude, drag and viscosity reduction of high solidification point crude oil and the shutdown and restart of the pipeline.

Based on the analysis of data, such as pressure, electric power, parameters of the pumps, ultimate load, and best operating range – they were able to determine the best operating flow by using the SCADA (Supervisory Control and Data Acquisition) system, with related software such as EMP and data analysis software. This can provide technical support for the optimal selection of pumps.

Wang and Lu [36] considered both shipping and pipeline transport. This paper first analyzed the risk factors for different modes of transport for imported crude oil. Then, based on the minimum transport cost and overall risk, a multi-objective programming model was established to optimize the imported crude oil transportation network, and genetic and ant colony algorithms were employed to solve the problem. The optimized result showed that pipeline transport is more secure than sea transport. Finally, this document gives safeguarding suggestions for the transportation of imported crude oil.

Farzaneh-Gord and Hamid Reza Rahbari [37] deals with the behaviour of a natural gas pipeline network, which may be subjected to extreme conditions, such as pipeline rupture, suddenly changed demand, that should be properly identified to prevent network failure and have an ongoing pipeline operation under these extreme conditions. These conditions usually cause unsteady behaviour of the pipeline network. Consequently, it is necessary to develop an unsteady state mathematical method to study natural gas pipeline networks under unsteady conditions. To achieve this goal, an analytical approach has been developed by these authors to analyze natural gas pipeline networks. The governing equations derived for one-dimensional isothermal compressible viscous flow with Kirchhoff's laws have been employed to develop a method for studying pipeline networks under unsteady conditions. The proposed method has been compared with previous studies for validation purposes.

Psarropoulos, Tsoukranis and Antoniou [38] described a smart tool for supporting decisions developed in a geographic information system (GIS), for (a) the quantitative assessment of various geohazards along the route of a pipeline, and (b) the consequent optimization of the pipeline's routing. The tool can determine the optimum pipeline routing, taking into consideration various criteria apart from the geohazards, such as distance minimization, avoidance of critical areas, land use, environmental constraints, etc. The tool has been verified in three case studies in south-east Europe: two onshore pipelines and one offshore pipeline.

Zhang and Xiaojie [39] proposed a defect recognition model for oil and gas pipelines based on the RBF neural network model with optimal parameters selected using particle swarm optimization (IPSO-RBFNN). They used this to establish a two-dimensional pipeline defect model.

Salsano de Assisa et al. [40] studied the scheduling of operations in a crude oil terminal within the midstream segment. The first challenge consists in deciding how the crude oil that arrives in vessels should be uploaded to the storage tanks. At the same time, the operations engineer must decide which storage tanks will feed the pipeline connected to the refinery to satisfy its demand. This work concerns the crude oil terminal of the national refinery of Uruguay. To schedule terminal operations, this work proposed an iterative two-step MILP-NLP algorithm based on piecewise McCormick relaxation and a domain-reduction strategy for handling bilinear terms.

Layouni, Salah and Tahar [41] in their paper inform that signals collected from the magnetic scans of metal-loss defects have distinct patterns. Experienced pipeline engineers can recognize those patterns in magnetic flux leakage (MFL) scans of pipelines, and use them to characterize defect types (e.g., corrosion, cracks, dents, etc.) and estimate their lengths and depths. This task, however, can be highly cumbersome to a human operator, because of the large amount of data to be analyzed. This paper proposes a solution to automate the analysis of MFL signals. The proposed solution uses pattern-adapted wavelets to detect and estimate the length of metal-loss defects.

Coramik and Ege [42] studied the safety of pipeline networks. Nowadays hydrocarbons and petroleum products are transported through pipelines that have a high degree of safety. Most of these pipelines are buried however deformations such as corrosion, dents and cracks destroy the integrity of the pipeline and with this highly dangerous risk such as economic losses or even lives as well as environmental pollution. The prevention of such adversities before they occur is possible by inspecting the pipes at specific intervals. In this article, the importance of pipeline inspection is emphasized first and the studies on pipeline inspection in the literature are examined. According to the data obtained from the study, suggestions are made about the inspection of pipes.

For a summary of these articles, see Table 3

**Table 3** Optimization methods for maintenance and safety

Author/Year	Model	Net	Method/Approach
SCADA-PEMEX (2013)	SCADA	GAS, OIL	SCADA/safe network
Sun and Yu (2014)	SCADA	OIL	SCADA, EMP/ Optimization operation in low flow and super flow for operating safely and economically
Wang and Lu (2015)	Multiobjective programming model	CRUDE	ACO, GA/ Minimum cost and risk
Farzaneh-Gord, et al. (2016)	Kirchoff'S law	GAS	Weymouth equation / Natural gas pipeline network under unsteady conditions.
Psarropoulos (2016)	GIS	OIL, GAS	ArcMap/Optimization of pipeline routing
Zhang and Yu (2017)	RBF	OIL, GAS	PSO, RBF, IPSO-RBFNN, ANSYS/Oil and gas pipeline defect recognition
Salsano de Assisa et al. (2017)	MILP, NLP	CRUDE	Global optimization solver / To schedule terminal operations.
Layouni et al. (2017)	MFL	OIL, GAS	MATLAB, ANN/ To automate the analysis of MFL signals.
Coramik et al. (2017)	MFL	MULTIPRODUCT	PIG, NDE/Safety of pipeline network

Notation:

SCADA = Supervisory Control and Data Acquisition; ACO= ant colony optimization; GA = genetic algorithms; RBF = radial basis function network; PSO= Particle Swarm Optimization; IPSO = Improved Particle Swarm Optimization; MFL = Magnetic flux leakage; ANN= Artificial neural network; PIG = Pipeline Inspection Gauge; NDE = Non-destructive Evaluation.

Figure 4 shows an overview of the problems solved in the previous articles.



**Figure 4.** Problems solved for maintenance and safeguarding. Source: by authors, image from: <https://www.aboutpipelines.com/en/pipeline-101/operation-and-maintenance/>

### **Network design**

The pipeline network design problem involves its length and diameter, the location of compression stations as well as the configuration of the network (Rivers Market et al. 2015).

Marcoulakia, Papazoglou and Pixopoulou [43] present an optimization framework for the routing and equipment design of main pipelines to be used for fluid transmission. The present approach proposes a systematic search for optimal and near-optimal solutions. The search is based on stochastic optimization and assumes that the same information and simulation tools as in the case of design by trial and error are available. An application example is used to demonstrate the approach and test the robustness of the optimal search using Simulated Annealing.

Gunes [44] on his Master thesis focused on a natural gas problem in Turkey. To supply gas demand, a pipeline network configuration with the optimal and efficient lengths, pressures, diameters and number of compressor stations is extremely needed. Because, Turkey has a currently working and constructed network topology, obtaining an optimal configuration of the pipelines, including an optimal number of compressor stations with optimal locations, is the focus of this study. Two existing optimization models were selected and applied to the case study of Turkey. Because of the fixed cost of investment, both models are formulated as mixed integer nonlinear programs, which require branch and bound combined with the nonlinear programming solution methods.

Üster et al. [45] considered the problem of designing a new natural gas transmission network or expanding an existing network while minimizing the total investment and operating costs. They developed an large integrated scale mixed-integer nonlinear optimization model to determine pipelines in the network, compressor stations and their capacities, timings of these installations in a multi-period planning horizon, and natural gas purchase and steady-state flow decisions for each period in the network. The model is solvable using state-of-the-art solution methodologies available online.

Li et al. [46] presented a paper on the impact that the gathering and transferring network of an oil-gas system has on the construction cost for whole oilfield engineering. Based on the analysis of optimization methods for oil-gas pipeline network layouts, this paper introduces some frequently used optimization design methods and discusses their advantages and disadvantages. In the first place, some classic algorithms are introduced and then they analyze the general topology model and the classification of oil-gas pipeline network layouts, where the well group division, optimization model and planning algorithms are systematically introduced.

Huang et al. [47] reported that underground oil pipelines are made of pressurized pipes and, when damage occurs, the consequences can be disastrous. Pipeline accidents caused by stress can be attributed to material corrosion, impractical design, manufacturing defect, environmental damage, and man-made destruction. In this study, by utilizing the stress analysis software CAESAR II, the stress of pipelines in high and steep slope areas was analyzed under the same operating conditions and different piping technologies. Comparing the different simulation consequences of each pipeline technology, an optimized laying process was proposed to reduce the stress of underground oil pipelines in high and steep slope areas; this process was named Sectional Pipe Laying Process.

Moradi Nasab and Amin-Naseri [48] addresses a new multi-period multi-echelon and multi-transportation integrated petroleum supply chain model to obtain a global optimal solution. The main feature of this paper is to design an integrated supply chain model that considers both installation and capacity expansion of pipeline routes and facilities simultaneously, and optimizes location-allocation facilities and routes, capacity expansion, inventory, production, exportation and importation, as well as routing and transportation modes over a vast geographical area. To achieve this, a deterministic mixed-integer linear problem was developed and applied to a real-world problem based on the information derived from Iran's petroleum chain.

Demissie, Weihang and Chanyalew [49] presented a multi-objective optimization model for optimizing the operation of natural gas pipeline networks. They considered a mathematical model established for different network configurations, such as linear, branch and looped topologies. They developed a set of constraints based on gas flow equations and compressors operating conditions. The model they developed is a non-linear programming problem that is solved using the NSGA-II algorithm. The solution obtained is a set of Pareto optimal points from which a specific preferred solution can be selected.

Zhang et al. [50] focused their article on a network of stellate pipes, cascade dendritic and dendritic pipelines, three common connection structures of the collection pipeline, and developed a mixed linear whole programming model considering the terrain conditions and obstacles. The objective was to minimize the total investment considering constraints of the central processing facility, the collectors, the flow velocity, the construction of the pipeline and the connection mode. Through the GUROBI software, they obtained the optimal topological structure, the position of the central processing facility, the diameter and the route of each pipeline.

Zhang et al. [51] studied the cost of construction of submarine pipelines that has a significant cost of the total investment in development in offshore oil fields, so an effective design of underwater pipelines is one of the main measures to reduce the cost in the oil field. In this article, a new method was proposed to design and optimize submarine pipelines, which considers both thermal-hydraulic performance and structural integrity, and uniformly solves the main parameters for the design of pipes, such as internal diameter, wall thickness, the thickness of insulation layer, pressure pipe and inlet temperature. The model also analyzed the uncertainties in the operating parameters, such as the ambient temperature, the overload pressure and the fluctuations of the delivery flow. For the calculation, four multi-swarm cooperative improved particle swarm optimization algorithms (MC-GPSO, MC-LPSO, MC-FIPSO and MC-SLPSO) were employed. Finally, Monte Carlo simulation was used to analyze the stochastic parameters.

Zhang et al. [52] presented a proposal for offshore oilfield gathering system. network construction, taking gathering radius, economic flowrate, terrain obstacles and production technic into consideration, building a mixed integer linear programming (MILP) model, figuring out the globally optimal connection topology, location of center platforms, pressure increment and dehydrating facilities and major parameters of each pipeline, and contributing to further optimal offshore oilfield engineering model.

For a summary of these articles, see Table 4.

**Table 4** Optimization methods for network design

Author/Year	Model	Net	Method/Approach
Marcoulaki et al. (2012)	Stochastic optimization	OIL, NATURAL GAS, WATER, BIOFUEL.	SA/routing and equipment design of pipelines
Gunes (2013)	MINLP	GAS	GAMS/ Minimize costs
Üster et al. (2014)	MINLP	GAS	COIN-OR/ minimize the total investment and operating costs.
Li et al (2015)	Network models	PETROLEUM, GAS	GA, PSO, ACO, / Optimization design methods
Huang et al. (2015)	Slope Gradient	OIL	CAESAR II/ The stress of pipelines in high and steep slope areas
Moradi Nasab et al. (2016)	MILP	PETROLEUM	ILOG OPL/Installation and capacity expansion of pipeline routes
Demissie et al. (2017)	Multiobjective optimization model	GAS	NSGA II/ To minimize annualized total cost
Zhang et al. (2017 a)	MILP	OIL, GAS	GUROBI, MATLAB/ Min total investment
Zhang et al. (2017 b)	Montecarlo	OIL	MC-(GPSO, LPSO, FIPSO, SLPSO)/ Design and optimization of subsea pipelines.
Zhang et al. (2017 c)	MILP	OIL	GUROBI, MATLAB/Optimization of the common offshore oilfield gathering network construction.

Notation: SA = Simulated Annealing; CAESAR II = Pipe Stress Analysis software; NSGA II = Non-dominated Sorting Genetic Algorithm; GUROBI = Gurobi is named for its founders: Zonghao Gu, Edward Rothberg and Robert Bixby; MC-(GPSO, LPSO,FIPSO,SLPSO) = Four multi-swarm cooperative improved particle swarm optimization algorithms.

### 3.2 Optimization and Simulation

Aalto et al. [53] pointed out that many pipeline systems are nonlinear, such as compression station shutdown or start-up. A dynamic, receding horizon optimization problem was defined, where the free response prediction of the pipeline was obtained from a pipeline simulator, and the optimal values of the decision variables were obtained by solving an approximate quadratic programming (QP) problem, where the cost function is the energy consumption of the compression stations. The problem was broadened using discrete decision variables to represent the compressors’ shutdown/start-up commands. A mixed logical dynamical system was defined, but the resulting mixed-integer quadratic programming problem was shown to be very high dimensional. Whereas, a sequence of these types of problems was defined that resulted in an optimization problem with a considerably smaller dimension. The receding horizon optimization was tested in a simulation environment and comparison with data from a true natural gas pipeline shows 5 to 8 % savings in compressor energy consumption.

Rizwan, Al-Otaibi and Al-Khaledi [54] presented an approach adopted by Kuwait Oil Company to establish an integrated Crude Oil Export Pipeline simulation model in South & East Kuwait area to achieve increase in overall asset-wide production and to improve future Pipeline & Facilities Design. The simulation used As-Built pipeline data along with field data to achieve the objectives of the study. The study had the following objectives:

- Identify additional capacity/ deficiency within the system.
- Perform Hydraulic Calculations (Pressure losses, Temperature Changes & Estimation of Pumping requirements from Gathering Centers).
- Determination of operating constraints/bottlenecks due to non-availability of any critical pipe segments.
- Optimization of Network.

The accuracy of the pipeline model was verified by comparing simulation results of the existing pipelines & Manifolds with the operating data to confirm that model results duplicated field measurements. The model developed in this study has the characteristics and the ability to predict the flows and pressures under a wide range of conditions — including various operational modes and constraints.

The model accurately predicted the capacities and raised few flags which were solved within a short time and subsequently the network was optimized. Hydraulics study revealed that no additional capacity or looping were required. Model was studied for the reliability of supply under wide range of conditions subject to potential bottlenecks and constraints which were identified in the study.

Huang et al. [55] analyzed underground oil pipelines, which are made from pressurized pipes, where, if there is any damage, consequences could be disastrous. Oil pipeline accidents caused by stress can be attributed to material corrosion, impractical design, manufacturing defect, environmental damage, and man-made destruction. In this study, by using the stress analysis software, CAESAR II, pipeline stress was analyzed under the same operating conditions and different piping technologies. Comparing the different simulation consequences of each technology, an optimized laying process was proposed to reduce the stress of underground oil pipelines in steep areas. This process was called the Sectional Pipe Laying Process. According to the results of CAESAR II, the stress and movement of underground oil pipelines in high and steep areas were drastically reduced and their safety was greatly enhanced. This article uses simulation and optimization.

For a summary of these articles, see Table 6.

**Table 6** Optimization and Simulation Methods

Author/Year	Model	Net	Method/Approach
Aalto (2008)	MIQP, Pipeline simulation	GAS	MATLAB, SIMONE/Dynamic horizon problem
Rizwan et al. (2013)	Integreted Simulation and Optimization Model	OIL	AS BUILT pipeline data
Huang et al. (2015)	Stress analysis	OIL	CAESAR II/underground oil pipelines

CAESAR II = Pipe Stress Analysis software

### 3.3 Simulation Methods

Herrán-González et al. [56] performed the modelling and simulation of a gas distribution pipeline network. Gas ducts are the most important components of such kind of systems since they define the major dynamic characteristics. Isothermal, unidirectional flow is usually assumed when modelling the gas flow through a gas duct. This paper presents two simplified models derived from the set of partial differential equations governing the dynamics of the process. These models include the inclination term, neglected in most related papers. Moreover, two numerical schemes are presented for the integration of such models. Also, it is shown how the pressure drop along the pipe has a strong dependency on the inclination term. To solve the system dynamics through the proposed numerical schemes a based MATLAB-Simulink library was built.

Behbahani-Nejad and Bagheri [57] developed an efficient transient flow simulation for pipelines and networks. The proposed transient flow simulation is based on the transfer function models and MATLAB-Simulink. The transfer functions equivalent to the non-linear control equations were derived for different types of boundary conditions. In the simulation, the effect of the inertia of the flow was incorporated. Efficiency is shown through several instances and it is verified that the proposed simulation is sufficiently accurate and computationally more efficient than other methods.

Woldeyohannes and Majid [58] discussed the use of a simulation model to analyze the effect of the age of pipes on the performance of a natural gas transmission system. The flow equations that govern the simulation were modified to consider the effect of the age of pipes. They evaluated and compared the performance of three groups of pipelines and the results of the simulation analysis showed a 2.16 and 4.35% drop in the flow capacity for 10 and 20-year-old pipes, respectively.

Woldeyohannes and Majid [59] developed a simulation model for the analysis of transmission pipeline network system (TPNS) with detailed characteristics of compressor stations. The compressor station is the key element in the TPNS as it provides energy to keep the gas moving. The simulation model is used to create a system that simulates TPNS with different configurations to get pressure and flow parameters. The mathematical formulations for the TPNS simulation were derived from the principles of flow of fluid through pipe, mass balance and compressor characteristics. In order to determine the unknown pressure and flow parameters, a visual C++ code was developed based on Newton-Raphson solution technique.

Cernelev, Chegus and Lin [60] focused their research on the problem of identifying and removing bottlenecks in a multi-terminal oil & gas pipeline network while achieving quality and delivery targets, which is a very real and complex problem. The most effective way to meet the above business objective was to develop a terminal network simulation model. This paper is a case study describing the approach in designing a complex multi-nodal pipeline network simulation model aimed at resolving a critical inter-company storage problem for a major refiner. Various complex system modelling techniques and approaches are elaborated with a focus on practical application. A case study is also presented to demonstrate the practical application of the modelling techniques for terminal network simulation model development.

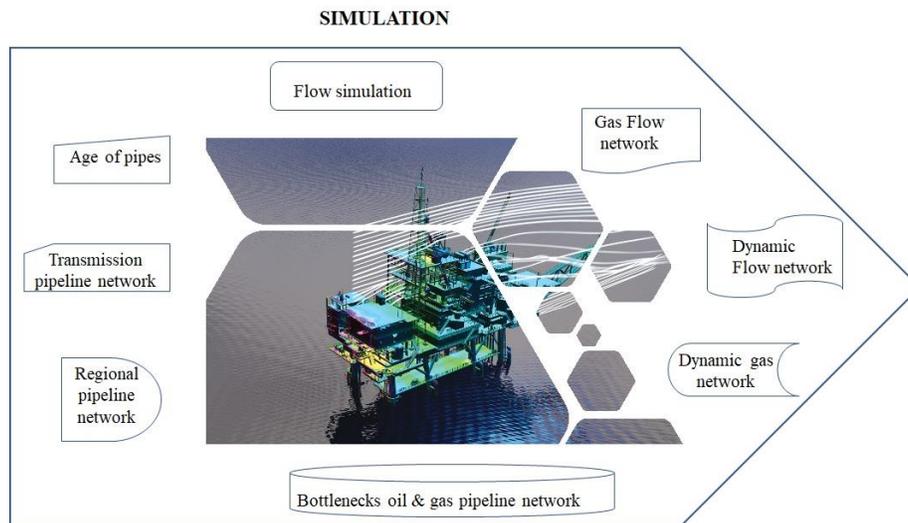
Costa et al. [61] explained that oil refining companies and distributors often use pipelines to transport their products. In highly integrated, geographically challenging contexts, this may result in complex logistical systems. Pipelines which transport multiple products connect tanks, forming a self-contained environment where distribution routes (called logistical channels), tactical inventory locations and operational criteria are defined to transfer, receive and deliver liquid oil derivatives. Authors describe a simulation model designed to represent such a regional pipeline network and include a case study of a Brazilian region with refineries, a maritime terminal, a hub terminal and distribution bases.

Szoplik [62] to elaborate a relation between the pressure and the current of gas introduced in the gas network for which gas modelling results were used in the network, obtained for the existing gas network and with real data about the load of the network depending on the time of day and the air temperature, this author presents an example of application. Based on the results obtained, it was concluded that this approach allows reducing the amount of gas supplied to the network by 0.4% of the annual load.

Addo Pambour, Bolado-Lavin and Dijkema [63] present an integrated transient hydraulic model that describes the dynamic behaviour of natural gas transport systems (GTS). The model includes sub-models of the most important facilities comprising a GTS, such as pipelines, compressor stations, pressure reduction stations, underground gas storage facilities and LNG Terminals. The accuracy of the model is confirmed by benchmarking the model against results from the scientific literature and the commercial software SIMONE.

Corbet et al. [64] described a dynamic flow model in networks, designed to inform analyses of disruptions in infrastructures and to help in the formulation of policies to design robust mitigations. They conceptualized the adaptive responses of infrastructure networks to perturbations as market transactions and business decisions of operators using simulation. They approximated commodity flows in these networks by a diffusion equation, with nonlinearities introduced to model capacity limits.

Figure 5 shows an overview of the problems solved in the previous articles.



**Figure 5.** Problems solved with simulation methods. Source: By authors, image from: [https://mdx.plm.automation.siemens.com/oil\\_and\\_gas](https://mdx.plm.automation.siemens.com/oil_and_gas)

See Table 5 for a summary of this part.

**Table 5** Simulation Methods

Author/Year	Model	Net	Method/Approach
Herrán González et al. (2009)	Dynamic network	GAS	MATLAB Simulink/flow pressure and inclination
Behbahani-Nejad et al. (2010)	Flow network simulation	GAS	MATLAB Simulink/Flow inertia
Woldeyohannes and Majid (2011a)	Network simulation	GAS	Simulation/pipeline age
Woldeyohannes and Majid (2011b)	Newton-Raphson	GAS	Visual C++/design and operation of the pipeline network
Cernelev et al. (2014)	Complex multi-nodal pipeline network	OIL AND GAS	ANYLOGIC/To identify and remove bottlenecks in a multi-terminal oil & gas pipeline.
Costa et al. (2014)	Simulation model for regional oil derivatives pipeline networks	Gasoline, Naphtha, two grades Diesel Fuel (DS10 and DS500) and Jet Fuel.	PROMODEL with Excel/Simulation considers batch scheduling and storage capacity.
Szoplík (2016)	Natural gas network simulation	GAS	GasNet/ A relationship between pressure and gas stream introduced into the gas network
Addo Pambour et al. (2016)	GTS, LNG-Terminals	GAS	SIMONE/simulation of a real-world gas system
Corbet et al. (2018)	Dynamic network flow	PETROLEUM	NetFlow Dynamics/To design robust mitigations.

### 3.4 Artificial Intelligence

Artificial intelligence has, for more than two decades, been used as a tool for the development of solutions in several areas of the Oil Exploration and Production industry: virtual sensors; production control and optimization; forecasting and simulation, among many others. However, these applications have not been consolidated in the industry as standard solutions and are still presented as case studies and pilot projects.

In 2014, a broad group of professionals involved in several Oil Exploration and Production operations and service companies. Bravo et al. [65] developed a literature review that captures the level of knowledge of Artificial Intelligence (IA) in the Oil Industry, the most common areas of application and users' expectations of Artificial Intelligence-based solutions.

This review helped to verify, among other aspects, that data mining and neural networks are the most popular Artificial Intelligence technologies used in the oil industry and that production is the area most affected by the applications of these technologies. The purpose of this paper was to be a guide for personnel in charge of production and asset management, about how the AI-based applications can add more value and improve decision-making. The results obtained illustrate how Artificial Intelligence techniques will play an important role in future developments of IT solutions in the Oil Exploration and Production industry.

## 4 Discussion and future research

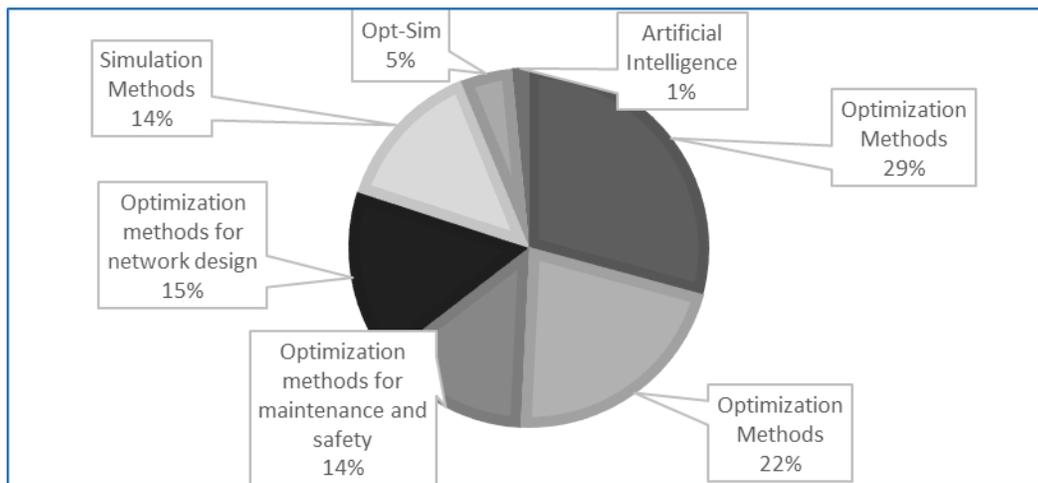
This state of the art shows the two main areas of research into the solution of problems involved with natural gas networks and hydrocarbon networks, in general. About optimization, models have been identified that, in their majority, are Mixed Integer Non-Linear Programming and the solution methods can be exact, using software such as CPLEX, among others, and heuristic methods particularly genetic, neural network and ant colony algorithms. The model varies depending on what the objective of the optimization is. Some articles only mention network optimization in respect of whether the flow being transported is gas or oil. Other articles consider the power, energy and fuel that are being consumed, either as the aim or as constraints of the model. Articles were also found that seek to optimize inventory and transport and production costs. Some others consider multi-objective optimization and use the right software for it.

Another important characteristic is the focus, whether a supply chain, a scheduling and routing problem, maintenance and safeguarding problems or network design is being considered.

Some authors have approached the hydrocarbons transport network problem in general and use optimization and simulation where a short, medium and long-term planning horizon is realistically considered, and the infrastructure and its useful age are considered.

As for simulation, the literature is not quite so abundant. However, we found results that, just like the authors that used optimization and simulation, consider infrastructure, the market and major planning horizons. By using simulation, the idea that the problem is stochastic is taken as a given, which enables us to have an analytical tool that can act as a support for the optimization techniques.

Of the sixty-five articles reviewed nineteen refer to optimization of the shipment and / or natural gas process. Another fourteen to oil optimization and multiple products. In maintenance and security nine articles, for network design optimization are ten. Considering simulation, for the hybridization of optimization with simulation three articles were found and using nine articles simulation. For artificial intelligence, only one article. This can be seen in the following figure 6.



**Figure 6.** Articles percentage by the method

A first phase consisted of reviewing and analyzing the articles published over the last few years on the subject. On this basis, the decision is made about which are the essential pieces for the development of the methodology, models and solution methods for solving the optimal routing problem. Afterwards, more factors in the network are considered, such as the production processes, blends and market. Another aspect that we believe is important is sustainability, vulnerability, resilience and environmental impact.

It is important to mention that only three articles consider optimization and simulation, and of these, the one that most closely approximates the objective of the research we are doing for PEMEX is that of Rizwan et al. [54], considering that the objectives are:

- Identify additional capacity/ deficiency within the system through simulation
- Consider product mix processes to measure quality and efficient delivery to destinations.
- Design optimization models for the hydrocarbon network that minimize costs and consider optimal shipping routes.

It should also be noted that the review of all articles allowed to review models that can be modified and adjusted to the Pemex network as well as the limitations that can be found, which allows a more realistic view of what is expected with the research.

Finally, it is important to consider the validation of the models and results that are obtained, together with their publication in international scientific media.

**Acknowledgements**

To PAPIIT project IT102117 Accesibilidad y movilidad del transporte público urbano en la ciudad de México, el caso de la delegación Tlalpan.

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