PERGAMON

Engineering Applications of Artificial Intelligence 13 (2000) 465–475

Engineering Applications of
ARTIFICIAL
INTELLIGENCE

www.elsevier.com/locate/engappai

An integrated expert system/operations research approach for the optimization of natural gas pipeline operations

Chi Ki Sun[a], Varanon Uraikul[a], Christine W. Chan[b,*], Paitoon Tontiwachwuthikul[a]

[a] *Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada S4S 0A2*
[b] *Department of Computer Science, Faculty of Science, University of Regina, Regina, Saskatchewan, Canada S4S 0A2*

Abstract

This paper reports on a project, conducted jointly between SaskEnergy/Transgas and the University of Regina, which aims at developing an integrated decision support system for the optimization of natural gas pipeline operations. In this integrated approach, both expert systems and operations research techniques are used to model the operations of the gas pipelines. The decision support system can perform the tasks of (1) determining the state of the line pack of the pipelines and recommending the control commands to be issued, (2) determining the associated horsepower requirement, and (3) determining the specific compressor unit to be turned on or off. The first two tasks are performed by an expert system, and the third by a fuzzy programming model. The expert system has been developed on G2 and validated using a simulation program.

Keywords: Expert systems; Operations research; Decision support systems; Gas pipeline operations

1. Introduction

Pipeline systems are very important for transporting gas, oil and petroleum products, as well as water, in Canada and North America, since they are the most cost-effective ways for moving fluid products over long distances. Each major city in North America needs pipeline systems for its drinking-water distribution. In addition, according to the Canadian Association of Petroleum Producers, 360,000 m^3 of crude oil and 0.5 billion m^3 of natural gas are transported daily in Canada, over 300,000 km of pipeline systems. The automation of gas pipeline operations could potentially optimize the operations. This paper reports on a feasibility study into gas pipeline automation, conducted jointly between a local gas-transportation company in Regina, Saskatchewan and the University of Regina.

The objective of the project is to construct an automated support system that enhances optimized operations of the gas pipelines in order to satisfy customer demand with minimal operating cost. The system consists of an expert system and a mathematical model. The integrated approach of combining two fundamentally different decision-making techniques (the expert system (ES) and operations research (OR)) has been adopted because most process-control and monitoring problems cannot be solved by either OR or ES techniques alone. The operator's critical decision-making processes usually involve both qualitative and quantitative information. Hence, both OR and ES techniques are needed for modeling these processes. Expert systems are used in problems where no mathematical models can be formulated to provide acceptable answers, but the knowledge of an experienced human expert can give a satisfactory solution. This technique has shown exceptional performance in process control

* Corresponding author. Tel.: +1-306-585-5225; fax: +1-306-585-4745.

E-mail addresses: chan@cs.uregina.ca (C.W. Chan), paitoon@uregina.ca (P. Tontiwachwuthikul).

0952-1976/00/$ - see front matter
PII: S0952-1976(00)00022-1

and monitoring when the working knowledge of the system is non-linear and incomplete. Operations research, on the other hand, can be used for problems in which well-constructed mathematical models are available, or can be developed.

This paper proceeds as follows: Section 2 gives some background on the application problem domain, and some relevant literature. Section 3 explains the knowledge acquisition and data analysis that precedes system development. Section 4 discusses, first, the motivation for adopting the integrated approach of combining expert systems and operations research, and the rationale for using fuzzy logic for representing uncertainty. Then, the integrated expert system/operations research solution for optimizing natural gas pipeline operations is presented. Section 5 presents in detail the mathematical formulation of the compressor-selection problem. Section 6 discusses how the integrated system can function in the operational environment, Section 7 is the conclusion, and discusses some of the benefits of the integrated approach to system automation.

2. Background

2.1. Problem domain: gas pipeline operations

Since the project was conducted primarily as a feasibility study, its focus was restricted to the gas pipeline in the St. Louis East area, which is one subsystem of the SaskEnergy/TransGas pipeline network located in southeastern Saskatchewan.

This subsystem consists of two compressor stations, which supply natural gas to meet the demand of two geographical areas, Hudson Bay and Nipawin. A schematic illustration of this problem situation is provided in Fig. 1.

Fig. 2 shows a typical display provided to the dispatcher during operation of the natural gas pipeline. Ideal operation requires a small comfort zone (CZ) and minimal fluctuation of the pressure curves. CZ is the safety factor that a dispatcher uses, and a smaller CZ means less fuel costs. Each dispatcher has his/her preferred CZ, and this changes over time. In addition, it is desirable that the system be operated with minimal fluctuation because the lower the fluctuation of the pressure curves, the smoother the operation. Excessive fluctuation causes unnecessary operating and maintenance costs. The more experienced dispatchers can satisfy customer demand with smaller CZ and lower fluctuation than the inexperienced dispatchers. It usually takes 4 months to train a dispatcher to operate a natural gas pipeline system, but it takes a number of years for the dispatcher to operate the system smoothly and cost-effectively.

In natural gas pipeline operations, a dispatcher is responsible for making two vital decisions: (1) when to increase and decrease compression, and (2) which individual compressor units to turn on/off. These decisions have a significant impact on the effectiveness of the operation of the natural gas pipeline. When demand from natural gas customers increases, the dispatcher will add compression to the pipeline system by turning on one or more compressors. On the other hand, if the customer demand for natural gas decreases, the dispatcher will turn off one or more compressors to reduce compression in the pipeline system. Incorrect decisions made by the dispatcher can cause substantial economic loss. Hence, natural gas pipeline operations involve complicated decision-making, and the dispatcher is often required to make the most appropriate decision within a short period of time. This is a problem when a dispatcher is unable to do so because he or she is under pressure, or does not have sufficient experience.

To support the dispatcher in this decision-making process, an expert system, called the Gas Pipeline Operations Advisor (GPOA), was constructed to determine whether the current line pack level of natural gas in a pipeline system can be expected to meet future customer demand. The knowledge base of the expert system was based on an analysis of historical data, heuristic knowledge from human experts in the natural

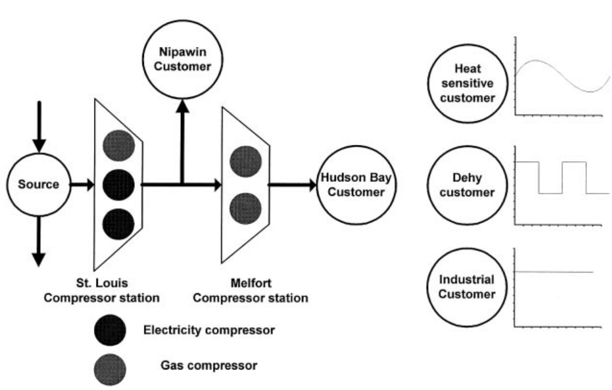

Fig. 1. Schematic representation of the East St. Louis Area.

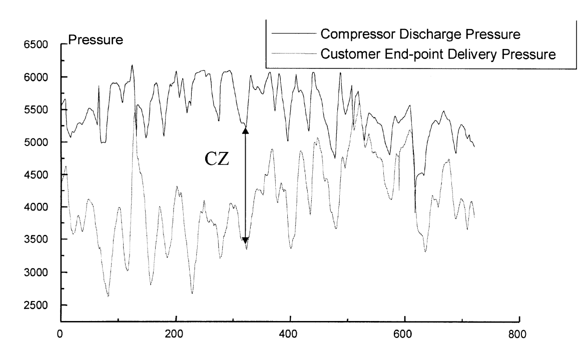

Fig. 2. Natural gas pipeline operations.