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TRANSPORTATION RESEARCH FORUM

Natural Gas Network Modeling as Part of the National Energy Transportation Study

*by Robert E. Brooks, Ph.D.**

1. INTRODUCTION

A. Background on the National Energy Transportation Study

IN APRIL OF 1977 President Carter presented his National Energy Plan. In this plan he recognized the importance of having sufficient transportation capacity to move the vast amounts of energy needed by this country from its primary production regions and import points to the various consuming regions around the U.S. Because of this he authorized the organization of a DOE-DOT Task Force to undertake the National Energy Transportation Study (NETS). The principal purpose of this study was to examine the transportation requirements which the future demand and supply of energy may impose and the capability of the Nation's currently planned transportation system to meet these requirements.

Energy products to be considered in this study included crude oil, petroleum products, various types of coal, natural gas, electricity, and nuclear fuel. Modes of transport for these fuels were rail, highway, waterway, pipeline, and wire.

In order to perform this study, two primary consultants were hired by DOE and DOT to develop computer based models of the energy production, transportation, and demand sectors and to use these models to analyze the energy transportation network for the period 1985 to 1995.

One of these consultants, Transportation and Economic Research Associated, Inc. (TERA) was to develop a methodology for forecasting supply and demand by the Bureau of Economic Analysis economic area (BEA) given DOE forecasts of National and regional supply and demand. In addition TERA was charged with projecting origin-to-destination flow volumes for each energy commodity for each BEA to BEA pair.

These O/D flows were then to be given to the second contractor, CACI, Inc. as input to a modified version of its INSA transportation network model (COE, 1976). This model would be used to identify which routes and modes of transport would be used to accomplish the energy flows projected by TERA and in particular to identify which links in this transportation network might not have sufficient capacity to handle the projected loads.

In addition, because of its lengthy modelling experience in the natural gas transportation area, TERA was selected to utilize a modified version of the GASNET 3 natural gas transportation network model (Brooks, 1978) for use in identifying bottlenecks in the U.S. gas system.

The purpose of this paper is to describe the NETS Gas Flows Model, its assumptions, development, implementation, and results.

B. General Approach

In order that DOE, DOT, the President and other users of this study could enjoy a consistent view of the energy and transportation futures projected, these futures should be consistent with other forecasts which DOT and DOE have made. For this reason, it was decided that NETS would use as a starting point the National and regional projections of energy supply and demand from DOE's Mid-Term Energy Forecasting System (MEFS). MEFS is a comprehensive system which produces consistent forecasts for all energy commodities simultaneously. These forecasts are made for a variety of assumptions regarding economic growth, actual resource base, and world energy prices for three time periods 1985, 1990, and 1995.

In MEFS the Nation was divided up into 14 gas producing areas and ten gas demand regions. (See Figures 1 and 2). The first task in the NETS methodology was to disaggregate these regional production and demand forecasts into BEA level projections (Figure 3).

The second major task consisted of constructing a BEA level network model of the existing and planned U.S. natural gas pipeline network model. This model would have to represent the physical capacities of pipelines to deliver gas from one BEA to the next on the way from producer to final consumer. The complexity of the network to be modelled is shown in Figure 4 which shows the pipe-

**Vice President, TERA, Inc., Hollywood, California.*

MEFS GAS PRODUCING AREAS

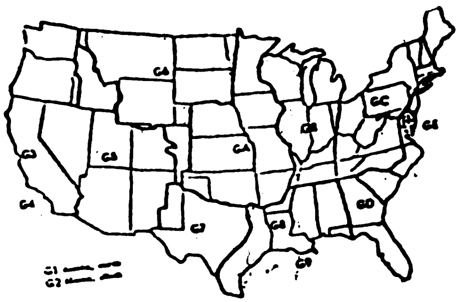

FIGURE 1

MEFS GAS DEMAND AREAS

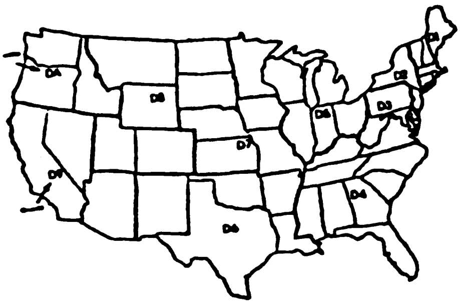

FIGURE 2

BUREAU OF ECONOMIC ANALYSIS ECONOMIC AREAS (BEA's)

FIGURE 3

line network existing as of June 30, 1978 (FERC).

Fortunately TERA had at its disposal the GASNET 3 natural gas distribution model which already contained a representation of this network at a similar level of detail. Using GASNET 3 as a base, TERA was able to develop the BEA level gas network model.

Given a network representation and the BEA level production and demand vectors, the next step in the methodology was to estimate the flows from net producer BEA's to net consumer BEA's along the gas network. Where such a procedure predicted a load greater than the capacity of a given BEA to BEA link, the model was designed to build additional capacity at a high cost. Thus the results of a run of this model could reveal a set of links where capacity was underutilized, another where it was utilized at normal levels, and a third set which required additional capacity to carry the projected load.

Once these data were calculated, analysis of the over and under utilized arcs could reveal which gas corridors and even which companies could be expecting difficulties in the period 1985 to 1995.

2. NETS GAS MODEL

A. Description of System to be Modelled

Getting gas from supply areas to demand regions is a complex multi-leveled process involving thousands of gas producers, hundreds of gas transmission companies and distributors, and millions of end-users in the U.S.

Typically a gas transmission company, also known as a "pipeline," buys gas from one or more producers of gas, transports that gas over distances ranging from a few miles to many hundreds and then sells the gas "for resale" to one or more gas distributors. These distributors in turn sell the gas to final end-users in the residential, commercial, or industrial sectors. But while this is the typical manner in which gas is delivered to consumer markets, there are many variations. For example, some pipelines also own their own wells and gas reserves. These pipelines are acting as both producers and transporters. Other pipelines sell gas directly to end-users. They are acting as distributors. And some pipelines both produce gas and sell to end-users. They are completely vertically integrated.

Pipelines frequently deliver and receive gas from each other. This can occur by sale, exchange, or transportation agreement. Exchanges occur when two pipelines agree to deliver equivalent amounts of gas to each other's system at different locations or at different times. Such agreements are useful when pipelines have excess supply in one region and excess demand in another.

Transportation agreements occur when pipelines purchase or produce gas in areas where they have no pipeline fa-

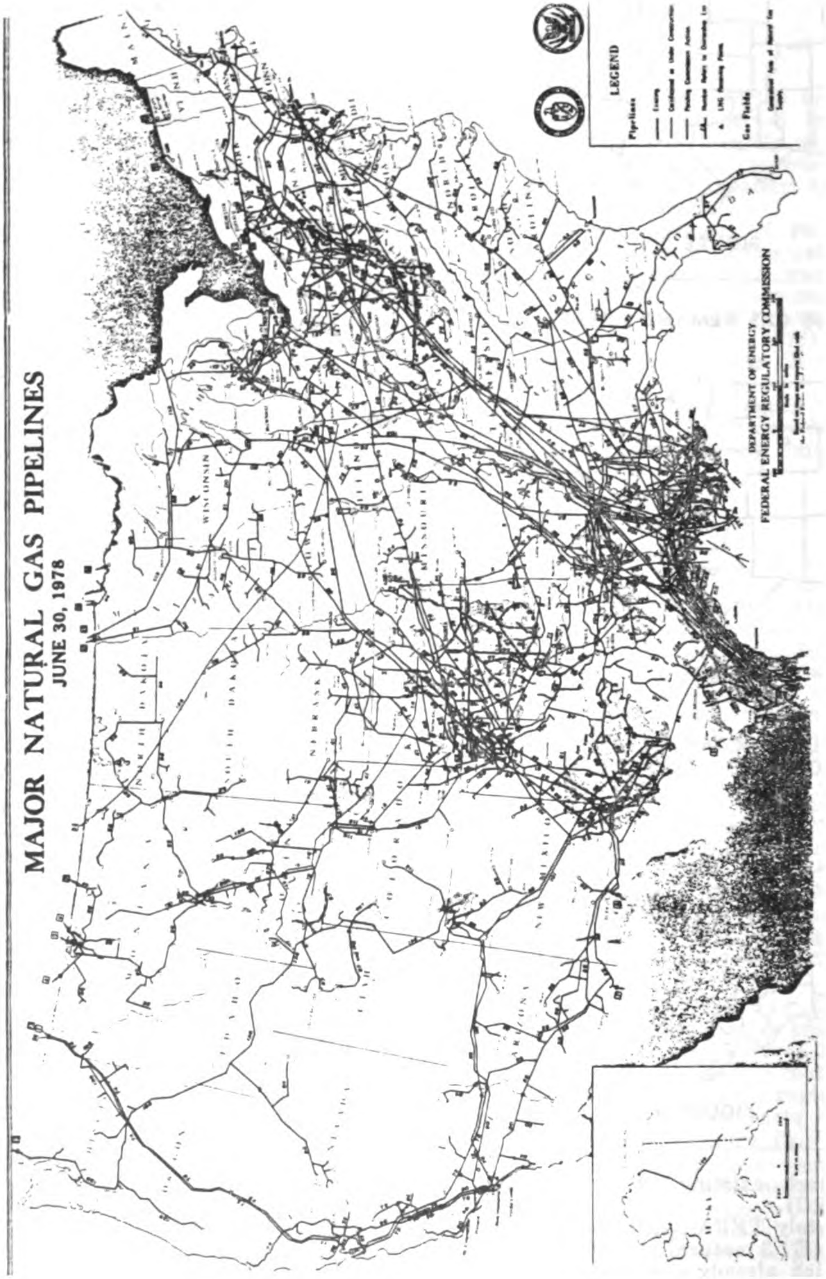
MAJOR NATURAL GAS PIPELINES
JUNE 30, 1978
LEGEND
DEPARTMENT OF ENERGY
FEDERAL ENERGY REGULATORY COMMISSION

FIGURE 4

cilities. They bargain for the use of other pipeline facilities to transport the gas to their own systems.

Recently the Federal Energy Regulatory Administration (FERC), the regulatory body charged with oversight of interstate gas pipeline companies, has allowed gas end-users to go to producing areas to purchase gas and then to have that gas transported by interstate pipelines. In this case pipelines do not take title to the gas, but act only as transporters in interstate commerce.

In order to transport gas from one location to another, a pipeline company must push the gas through the system using high powered gas compressor units in compressor stations located along the pipeline path. These compressor stations are usually located from 50 to 100 miles apart. To power the compressors a portion of the transported gas is diverted into and burned in either reciprocating or gas turbine engines which compress the gas thus forcing it further along the line.

Use of this gas in the compressor station causes gas to be lost to the pipeline, i.e., some of the gas is for the company use in the transportation process. Other gas is lost in the system due to leaks in the pipe, accidental ruptures of the pipe, and transfer operations. Accounting for these losses is a difficult process due to fluctuating pressures and temperatures which cause the density and thus the volume of a given quantity of gas to change.

In order to increase the quantity of gas flowing through a given segment of pipe (to handle peak loads for example), the compressor stations have to work harder, to compress the gas even more. This results in greater fuel use, i.e., less efficient operation. In addition, the maximum amount which can flow through the pipe (its capacity) is determined by the power of the compressor and the size of the pipes which transport the gas.

Another very important feature of the gas supply system is storage. Because gas use is seasonal, being much greater in the winter (for home heating) and less in the summer, gas is stored in underground storage fields and/or liquified and stored as LNG. Thus, typically gas is produced at fairly constant rates for maximum production efficiency, transported by pipeline at fairly constant rates (to reduce the need for a greater capacity pipe to handle peak load demands), stored away in the summer and withdrawn in the winter for delivery by gas distributors to end-users. (Note: This is a generally accurate picture. However, there are fluctuations in production and transportation levels due to changing demands).

In recent years beginning in the early 1970's, domestic gas supplies have been declining relative to the demand for gas. Even prior to the 70's, the U.S. imported about 5% of its supply from Canada through pipeline connectors along the Nation's northern border. Increasingly, alternative supply sources for natural gas have been sought. Several non-traditional sources have been found which will substantially modify previous gas transportation patterns and call for the addition of major new pipeline systems. These include the discovery of gas in Northern Alaska, the development of coal gasification plants in the Northern Plains States, importation of LNG and Mexican gas, production of synthetic natural gas (SNG) from naphtha, and conversion of waste materials and biomass to gaseous fuel.

Finally through all of this, the cost of gas transportation remains a primary concern for gas pipeline companies. While fixed transportation costs are a function of the pipelines' capital rate base, variable costs are primarily a function of pipeline haul length and pipe size. Cost per unit of gas transported is a direct function of mileage and because of economies of scale, an inverse function of pipe size. In addition, when volume exceeds the pipeline's capacity, new pipeline must be added (looping) or compressor horsepower increased. These capital expenditures are a major concern to both pipelines and FERC which must give its blessing to each such planned addition.

In summary, a model of the transportation of gas must take into account regionally separated supplies and demands, large numbers of interconnected transportation companies, reduction in gas quantities during transport due to company use in compressor stations, limited capacities of compressor stations and gas pipe, storage patterns, supplemental supplies, and gas transportation costs.

B. Model Formulation

The NETS model formulation can be divided into three principal pieces:

- BEA production model
- BEA demand model
- BEA to BEA network model

The network model is used as an integrating model which combines the results of the first two models to compute network flows and identify possible difficulties in the transportation network.

1. PRODUCTION MODEL

Recall that the general notion of the NETS model was to produce results which were consistent with official DOE forecasts produced during the MEFS model. In essence the production model developed by TERA for the NETS gas model is a disaggregation model which takes regional forecasts and logically breaks them down into the smaller BEA areas.

The methodology developed to accomplish this disaggregation is based on the assumption that for sub-areas within a larger area, future production shares can be estimated as a function of existing production and reserves. Mathematically this can be written as:

$$\frac{P_{ij,t+n}}{P_{j,t+n}} = f(P_{ijt}, R_{ijt}) \qquad (1)$$

where i is a subarea within the larger region j, t is some initial time and t + n is the time n periods later, P is production, and R is reserves.

The rationale for such a function is that it takes into account both existing production facilities and development as well as future development.

Statistical estimations were made for this model using a generalized Cobb-Douglas form for the production function. Specifically estimates were made using:

$$P_{i,t+n} = cP^a_{it} R^b_{it} \qquad (2)$$

for i = 1,42 the 42 AGA production regions, t the years 1955 to 1977, and n a parameter set equal to 1,2,3, etc., for each different regression run. a,b, and c were the estimated coefficients.

Results of these regressions varied greatly for different values of n. Around n = 15 results were fairly stable, however, and since the base year of 1976 would imply a t + n of 1991, a year close to the center of the forecast range 1985-1995, these values were utilized in the production model.

The statistical outcome for n = 15 is shown below.

$$\left.\begin{aligned} a &= 0.24608 \ (2.74869) \\ b &= 0.17773 \ (1.80986) \\ R^2 &= 0.4212 \\ F &= 12.372 \end{aligned}\right\} \qquad (3)$$

Although R^2 was somewhat low, both t-and F- stats were quite good.

The value of c in the regression is irrelevant, of course, since it merely acts as a proportionality constant. Final production shares for each subarea become:

$$\text{share} = \frac{P^a_{it} R^b_{it}}{\sum_i P^a_{it} R^b_{it}} \qquad (4)$$

where summation is carried out over all subareas within the larger region.

Once production shares are known, DOE forecasts can be disaggregated to the BEA level. This is done simply by multiplying the DOE regional forecast by the BEA share of that region.

One final step is necessary, however. DOE also forecasts supplementals (LNG, SNG, coal gas, and imports). TERA's disaggregation model takes each of these forecasts and assigns them on a project-by-project basis to the BEA in which the project exists or is planned. Thus individual SNG and coal gas projects are included in their appropriate locations. LNG and natural gas pipeline imports are handled by defining pseudo-BEA's (numbers 174-188) to represent each of these source's origin.

2. DEMAND MODEL

Just as in the case of production, the NETS demand model utilizes an existing DOE demand forecast for a larger region as the starting point for forecasts for subareas (BEA's) within that region.

In the case of demand, however, there are four unique sectors whose forecasts must be estimated in different ways. These are the residential, commercial, industrial, and electric utility sectors.

The basic idea for the projection of subarea demand shares is that the growth in demand in that subarea is proportional to some measure of the growth of that subarea. In the case of residential, population is such a measure. For commercial, wholesale and retail trade is a good measure of growth. For industrial use, the level of manufacturing might be used. The case of electricity generation is more complicated. Since the National Energy Act requires utilities to phase out their use of gas for electricity generation, using the base year demand shares (i.e., assuming that subarea shares remain constant) is probably the most logical approach for utilities.

Mathematically, the demand model is:

$$D_{i,t+n} = c \, D_{it} (1+r_i)^n \qquad (5a)$$

$$c = \frac{D^*_{t+n}}{\sum_i D_{it} (1+r_i)^n} \qquad (5b)$$

where the summation is taken over all subareas i within a given DOE demand region. In equations (5a) and (5b), i refers to a given subarea, t is the base year, t + n is the forecast year, D^*_{t+n} is the DOE region demand for the forecast year, r_i is the economic growth rate variable for subarea i, $D_{i,t}$ is demand in subarea i during year t, and c is a proportionality constant.

Sensitivity analysis of the BEA demands to values of the parameters r_i show that for this demand share model, the percentage error in demand will be less than the percentage error in the growth parameter for values of r_i less than 6% per year.

Since population and economic growth are far below 6%, this means that the model should be relatively insensitive to reasonable errors in the economic forecasts.

Data used for r_i (i = 1,173 for each BEA) were obtained from the Bureau of Economic Analysis OBERS projections for the base year and forecast years 1985 and 1990. Average growth rates between 1976 and 1990 were used to project further out to 1995.

3. GAS NETWORK MODEL

The development of the NETS Gas Flows Model proceeded along similar lines to that used by TERA in several previous gas network modelling efforts. (Brooks, 1975, 1976, 1977, 1978, 1979). In particular, the network model of the interstate pipeline network utilized in the GASNET 3 model was used as the starting point in the assembly of the required BEA level model. But whereas the GASNET 3 format separates out all individual pipelines, this level of detail was not required in the NETS model. In particular, those portions of GASNET 3 which represent pipeline interconnections (i.e., deliveries between pipelines) were not needed here.

The methodology used consisted of four steps:

- develop structural model of network at BEA level
- estimate capacities along each arc of the network
- estimate unit transportation costs along each arc of the model
- estimate efficiency of transportation within each BEA

The structural model was developed by first identifying each of the approximately 140 interstate and intrastate pipelines which moved gas from one BEA to another in the base year and adding to this list the known planned pipeline systems under study by FERC.

Each such system was modelled individually. The model consisted of a set of nodes representing BEA's crossed by the pipeline and arcs representing the inter-BEA connections. Using Federal and state pipeline maps TERA personnel were able to estimate the mileage of each BEA to BEA arc and to identify diameters of pipes located there. In the aggregated BEA model, there were many instances where two or more pipelines had pipeline links between the same BEA-BEA pairs. In such cases, the model combined these into a single system with capacities equal to the sum of their individual capacities and weighted averages of transportation cost and mileage.

Capacities for individual arcs were calculated using a statistically estimated relationship between capacity and pipeline diameters. This function appears below:

$$\left.\begin{aligned} &\log C = 1.443 + 0.9691 \log A + 0.1242D \\ &\qquad\qquad\quad (17.95) \qquad\quad (2.76) \\ &R^2 = 0.849 \\ &F = 227.7 \end{aligned}\right\} \quad (6)$$

In this regression C is capacity, A is pipeline cross-section (i.e., proportional to diameter squared) and D is 0-1 "dummy" variable used to divide the set of pipelines used in the analysis into two strata: those which had competition on the arc and those which didn't. Capacity and diameter values were obtained from FERC Form 2 reports and pipeline maps.

From the regression results it is apparent that both A and D are highly significant as is the equation as a whole.

While the interpretation of D as a "competition" variable may be open to question, it may be simply that the demand is so high downstream that both duplicate suppliers and higher horsepower in each line are called for. In any case, the result is that these lines have about 33% greater capacity for a given pipe diameter.

Transportation costs were also estimated using regression analysis. In this case gas transportation agreements data were used. Cost per thousand cubic feet of (MEF) were hypothesized to be directly related to mileage and inversely related to capacity (economies of scale). The results are indicated below:

$$\left.\begin{aligned} &\log(K/M) = 2.73436 - 0.484197 \log C \\ &\qquad\qquad (4.61278)\,(8.24654) \\ &R^2 = 0.2812 \\ &F = 68.0564 \end{aligned}\right\} \quad 7$$

In this regression K/M is unit cost per mile, i.e., \$/mcf-mile, and C is capacity in mcf/hr. The R^2 statistic is not particularly good, indicating that other unknown variables also influence the cost of transportation here. However, the results indicate a strong dependence on capacity for the cost value (t-stat of 8.24) and a good overall fit is implied by the F statistic.

The final parameter needed for the network is efficiency. This is the parameter which indicates how much gas is used in transportation and lost from the network. Efficiencies were calculated for each BEA based on the amount of gas used by compressor stations in the BEA and the amount lost. The total of these "losses" was divided by the total flow into the BEA from other BEA's plus production in that BEA to get the percent of total inputs lost in the BEA. This was then substracted from unity (1.00) to get the corresponding efficiency factor. In the model this efficiency factor is used as a multiplier for all projected flows into the BEA and for production in that BEA as well.

4. NETWORK EXPANSION MODEL

The ultimate purpose of the NETS study is to identify places in the transportation network where current and/or planned capacity is either insufficient to meet projected requirements or badly underutilized.

For this purpose the network model must be modified. In NETS this is handled by allowing not just one but four different flows on each BEA-to-BEA link. These four flows are divided into four different regimes as follows:

0-30% capacity
30-90% capacity
90-180% capacity
180+% capacity

In the first regime, the link is being underutilized, i.e., less than 30% of the link's capacity is being used. The second regime is between 30% and 90%, the maximum which could be expected under normal circumstances. The third regime refers to an expanded operation where the existing pipeline is "looped" with a parallel pipeline of the same capacity. The final regime accounts for an expansion of greater than twice the current capacity.

In a model of this type, it is important that the four arcs in any link be utilized in the correct order, i.e., the first arc (0-30%) should be filled before the second and so on. This can be accomplished through the selection of a set of transportation costs which increases for each of these arcs. This selection can also be used to satisfy other criteria as will be seen in the next section.

5. THE NETS GAS FLOWS MODEL

Combining the models discussed in 1-4 above results in the completed NETS Gas Flows Model. This is accomplished using a linear programming format with a modified goal programming type approach to represent a multi-level objective function. Specifically, the model has been designed to utilize a set of BEA production levels, demands, and the constraints imposed by a finite distribution network (the network model) to project inter-BEA flows which utilize existing pipeline capacity to the greatest extent possible before building new capacity. This is accomplished by assigning a zero cost to the first 30% of each link's utilization, a normal cost for the range 30-90%, 10 times that cost for the 90-180% range, and 100 times that for the greater than 180% arc.

The multipliers (10 and 100) in this model are not particularly important. They are set as high as they are simply to satisfy the criterion that existing capacity be utilized to the greatest extent possible prior to building new capacity. Thus the model can be considered to be rather conservative. It should predict the minimal new construction needed to satisfy projected gas flows.

Mathematically the model can be stated as follows:

$$\begin{aligned}
\text{Minimize } & \sum_{ij} (k_{ij} x_{ij2} + 10 k_{ij} x_{ij3} + 100 k_{ij} x_{ij4}) \\
\text{s.t. } & \sum_i e_j z_{ij} - \sum_m z_{jm} = d_j - e_j s_j \\
& z_{ij} = \sum_{n=1}^{4} x_{ijn} \\
& x_{ij1} \leq 0.3 C_{ij} \\
& x_{ij2} \leq 0.6 C_{ij} \\
& x_{ij3} \leq 0.9 C_{ij} \\
& x_{ijk} \geq 0
\end{aligned} \qquad (8)$$

where summations are over appropriate index sets representing the network, z_{ij} is total flow from BEA i to BEA j, x_{ijn} is that portion of the flow in regime n, k_{ij} is unit cost for link (i,j) and C_{ij} is capacity on (i,j).

Experiments using other values for the multipliers 10 and 100 do not change results unless they are reduced to values below 2 and 10 respectively. Thus the solution to be discussed in the next sections are relatively insensitive to these values.

6. IMPLEMENTATION OF MODEL

The development and implementation of the model described above was accomplished using the DOE's IBM 370 computer system in Rockville, Maryland. (Note: This system has been upgraded since to an IBM 3033 located at DOE facilities in Washington, D.C.).

Programs used in the disaggregation methodology were based on the FORTRAN IV language. Statistical estimations were done using TSP. The mathematical programming model used for computing gas flows was implemented using MPS[3] with DATAFORM for matrix generation and report writing.

In addition to the programs described above an additional program was developed to interface with the DOE's MEFS model results files. This enabled users of NETS to produce NETS solutions from any MEFS output run without manual intervention.

7. RESULTS AND ANALYSIS

A. Description of Scenarios

For the purposes of the National Energy Transportation Study three different scenarios were selected. These three were defined by assumptions which DOE made in its 1979 projections for the DOE Energy Information Administration's Annual Report to Congress (ARC). The scenarios selected were all based on the Series C runs made by DOE which assumed "medium" supply and demand conditions in the mid-terms. For series C three scenarios were generated depending on DOE's projections of the level of world oil prices. These three were then labelled C-High, C-Low and C-Medium.

For all three of these scenarios, DOE projected National and regional production and consumption for 1985, 1990, and 1995, i.e., a total of nine snapshots or situations were projected. Of these five were selected by DOE for the NETS disaggregation and flow analysis. These were:

- 1985 C-Medium
- 1990 C-Medium
- 1995 C-Medium
- 1990 C-High
- 1990 C-Low

B. Results of NETS Runs

Tables 1, 2, and 3 and corresponding Figures 5, 6, and 7 graphically illustrate the results of the NETS projections for the C-Medium scenario. These tables and maps show the locations of potential bottlenecks for 1985, 1990, and 1995.

The first most obvious observation is that the list of bottlenecks grows markedly over this period. This is evidence that changing sources of supply will make corresponding demands for changes in the gas delivery system over this period. A second observation is that while bottlenecks in 1985 are rather scattered and non-indicative of major trends, trends become more obvious to point out in 1990 and 1995. In particular, in 1990 one sees the addition of bottlenecks in the upper midwest and north-

TABLE 1

POTENTIAL BOTTLENECKS 1985 (C-MEDIUM CASE)

ORIGIN	DEST'N	FLOW	CAPACITY	LOAD RATIO*	COMPANIES
14	5	375,024	279,882	1.49	Algonquin, Tenneco
43	41	44,843	21,042	2.37	South Georgia Nat. Gas Co.
44	42	88,839	68,889	1.43	Southern Natural Gas
44	48	32,843	21,480	1.70	Southern Natural Gas
112	114	484,213	535,052	1.01	Panhandle Eastern
118	117	294,517	278,769	1.17	Arkansas-Louisiana Gas

Source: TERA, Inc.

* LOAD RATIO = FLOW ÷ 90% of CAPACITY

POTENTIAL BOTTLENECKS 1985 (C-MEDIUM CASE)

FIGURE 5

TABLE 2

POTENTIAL BOTTLENECKS 1990 (C-MEDIUM CASE)

ORIGIN	DEST'N	FLOW	CAPACITY	LOAD RATIO*	COMPANIES
43	41	48,234	21,042	2.55	South Georgia Nat. Gas Co.
44	42	114,225	68,889	1.84	Southern Natural Gas
44	48	38,664	21,480	2.00	Southern Natural Gas
88	89	27,498	21,042	1.45	Northern Natural Gas
91	87	153,723	130,568	1.31	Northern; Great Lakes
93	96	616,787	613,200	1.12	Montana Dakota; N. Border
96	97	757,309	613,927	1.37	Montana Dakota; N. Border
97	98	749,336	613,200	1.36	Northern Border
98	99	746,000	613,200	1.35	Northern Border
99	104	745,694	613,200	1.35	Northern Border
112	114	484,183	535,052	1.01	Panhandle Eastern
118	117	264,006	278,769	1.05	Arkansas-Louisiana
149	147	24,583	13,657	2.00	Western Slope Gas
162	161	34,534	36,704	1.05	Southwest Gas

Source: TERA, Inc.

*LOAD RATIO = FLOW ÷ 90% of CAPACITY

POTENTIAL BOTTLENECKS 1990 (C-MEDIUM CASE)

FIGURE 6

ern plains where the Northern Border portion of the Alaskan Natural Gas Transportation System is planned. This indicates that additional capacity might need to be planned for that pipeline to handle some lower 48 production in the northern border area, i.e., Montana and North Dakota. This would include as well the coal gasification facilities planned for this region.

One can also see in 1990 the beginning of a constraint on gas produced in the Rocky Mountain areas to be delivered to the midwest. This may indicate a greater need for capacity than is currently being planned for pipelines in this area.

In 1995 these trends accelerate and another appears as well. Lines from the Oklahoma and Kansas to the industrial Midwest are becoming bottlenecks. This appears to be caused by two factors: reduced Canadian supplies to the midwest creating additional demand for domestic gas and additional supplies of gas in the Oklahoma area.

Table 4 illustrates the effect that the world oil price has on these results for 1990. One can easily see that high world oil prices results in fewer bottlenecks. This result occurs because gas prices are assumed to be related to world oil prices. Thus higher world oil prices indirectly produce lower natural gas demand.

Table 5 presents the identifiable patterns of underutilization for the system. As is indicated there the traditional links from Texas and the Gulf Coast both East and West will tend to be utilized less and less as production shifts northward to the Rocky Mountains and Alaska.

C. CONCLUSIONS

In general the NETS model validates much of the planning in new pipeline facilities which the industry has taken on itself. New pipelines for Alaskan and Rocky Mountain gas have been designed and applications have been made to FERC for their approval. NETS shows these pipelines to be needed and that they will be well utilized. In fact, in some cases, these pipelines may need more capacity than is currently being planned.

In addition NETS concludes that a reduction in Canadian imports in the 1990-1995 period will strain existing pipeline capacity in the mid continent area.

In general, the NETS model appears to produce very reasonable results. Two

TABLE 3

POTENTIAL BOTTLENECKS 1995 (C-MEDIUM CASE)

ORIGIN	DEST'N	FLOW	CAPACITY	LOAD RATIO*	COMPANIES
10	67	100,348	55,749	2.00	Natural Fuel Gas
43	41	48,072	21,042	2.54	South Georgia
44	42	124,000	68,889	2.00	Southern Natural
44	48	37,783	21,480	1.95	Southern Natural
67	68	37,876	21,042	2.00	East Ohio Gas
75	69	107,380	107,319	1.11	Columbia Gas
79	82	364,562	254,723	1.59	Natural Gas Pipeline of America
80	79	1,480,281	1,208,880	1.36	Natural Gas Pipeline of America
88	89	24,329	21,042	1.28	Northern Natural Gas
91	87	152,632	130,568	1.30	Northern Natural; Great Lakes
95	96	91,872	95,116	1.07	Montana-Dakota Utilities
96	97	700,873	613,927	1.27	Montana-Dakota; Northern Border
97	98	588,967	613,200	1.07	Northern Border
98	99	588,437	613,200	1.06	Northern Border
99	104	585,293	613,200	1.06	Northern Border
104	106	424,781	355,095	1.33	Northern Natural
105	106	1,103,760	613,200	2.00	Northern Natural
106	80	1,503,337	1,251,007	1.34	Natural Gas Pipeline of America (NGPL)
106	113	494,640	224,747	2.45	Michigan-Wisconsin Pipeline
107	104	1,148,922	893,301	1.43	Northern Natural
108	107	1,883,494	1,899,649	1.10	Northern Natural; NGPL
109	111	1,881,171	1,135,673	1.84	Northern; NGPL; Michigan-Wisconsin
111	108	1,784,662	1,821,133	1.09	Northern; NGPL; Michigan-Wisconsin
116	119	18,733	10,407	2.00	Cities Service
119	110	279,547	207,875	1.49	Cities Service; Arkansas-Louisiana
125	126	33,145	18,414	2.00	Lone Star
125	127	970,898	539,388	2.00	Lo Vaca; Lone Star; Southwestern
127	120	126,144	70,080	2.00	NGPL; Lone Star Gas
129	128	393,048	218,360	2.00	Lone Star; Old Ocean;Lo Vaca; Bi Stone
131	118	24,583	13,657	2.00	Lone Star
145	124	318,467	176,926	2.00	El Paso
147	110	69,983	39,876	1.95	Baca; Colorado Interstate
149	147	24,583	13,657	2.00	Western Slope
162	161	34,051	36,704	1.03	Southwest Gas

Source: TERA, Inc.

* LOAD RATIO = FLOW ÷ 90% of CAPACITY

examples, may indicate the level of validity of the model. In Figures 5 and 6 a bottleneck is indicated between BEA's 118 and 117. When the model was developed, plans for the Ozark Pipeline were not known to TERA. When the application to FERC was announced, an analysis revealed that Ozark would be built between eastern Oklahoma and western Arkansas, exactly the same BEA 118 to 117 link predicted by the model. The model also predicted that some 70% of the planned capacity would be utilized in 1985. The model also predicted that capacity problems could exist in the Northeast between BEA's 14 and 5 unless greater imports from Canada into the Northeast were obtained. Since these projections, plans for an additional 250 Bcf/yr of Canadian imports into New England have been announced. Thus NETS has been useful in predicting the necessity of events which have later come to be. This is the ultimate test of a model's usefulness and validity.

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POTENTIAL BOTTLENECKS 1995 (C-MEDIUM CASE)

FIGURE 7

TABLE 4

COMPARISON OF THREE 1990 CASES, ADDITIONAL CAPACITY NEEDED

Origin	Dest'n	C-Medium	C-Low	C-High
43	41	155%	151%	37%
44	42	84%	73%	-
44	48	100%	100%	[illegible]9%
88	89	45%	44%	-
91	87	31%	31%	-
93	96	12%	-	-
96	97	37%	17%	21%
97	98	36%	17%	1%
98	99	35%	16%	-
99	104	35%	18%	-
112	114	1%	1%	-
118	117	5%	5%	12%
149	147	100%	32%	-
162	161	5%	-	-

Source: TERA, Inc.

TABLE 5

PATTERNS OF UNDERUTILIZATION

1985

- West Texas (Permian Basin) to California (El Paso, Transwestern)
- North Texas to Colorado (Colorado Interstate)
- Northern Great Lakes (Great Lakes Gas Transmission)
- Mid-Atlantic (various)
- Northeast (various)

1990

- West Texas to California (gets worse)
- Louisiana to Midwest (various)
- Gulf Coast to East (Transco)

1995

- Gulf to West, North, and East severely curtailed
- Gulf supplies mostly the South
- Northeast supplied by LNG, SNG, and Alaskan gas
- Midwest supplied by Midcontinent, Rocky Mtns, and Alaska
- California supplied by Alaska and intrastate sources.

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