EVALUATION OF INTERACTION BETWEEN RURAL REGIONAL TRANSPORTATION AND ENERGY AVAILABILITY

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The energy crisis of 1973 can be considered an indicator of future problems. The impact on personal and goods mobility alone will have far-reaching consequences, not only in the urban areas but also in the rural regions. In fact, because of the less dense population distribution, rural regions are more sensitive to changes in energy form, cost, and availability. Maintaining the desirability of U.S. rural regions as a place to live is important to the welfare not only of this country but also of other countries of the world who depend on U.S. food exports for their survival. The wholesale abandonment of unproductive railroad lines imposes limitations on the economic viability of bypassed small cities. It creates constraints in the options for electric power generation and distribution system development and will have a dramatic effect on the economics of grain terminal locations and grain transportation. Even the system for providing heat to isolated farm homes and small towns will be interrelated with transportation forms of the future. Transportation system decisions have far-reaching implications on individual life-styles and the welfare of the nation, and it behooves decision makers to consider these interrelationships.

•THE energy crisis of 1973 created concern among governmental administrators and policy makers and persons involved in business and industry. In fact, many citizens for the first time became aware of how sensitive their life-style and mobility are to changes in the availability of energy. They noted that their homes were heated by natural gas or fuel oil and that the electric power generating plant used these same energy sources. A critical shortage in these forms of energy would have an immediate effect on personal comfort, especially for those in the cold winter areas of our nation. Some persons recalled that the conversion from coal to natural gas or fuel oil, for heating the home, had been a source of joy and that the conversion from coal to natural gas and fuel oil, as the fuel for the local electric generating plants, had only recently been accomplished.

Everyone recognizes the complex social and economic structure of our large metropolitan areas. The interrelationship of home location, shopping, business, recreation, and place of work in carrying out the activity of urban living has been studied and modeled extensively.

Perhaps less well known is that an equally complex social, cultural, and economic system has evolved in rural regions. And, because of the less dense population distribution, the rural region system is more sensitive to changes in the form of energy, its availability, and its costs.

Public transportation may become a more widespread substitute for the automobile if gasoline availability is restricted. In a rural region this change in personal mobility would dramatically influence the perceived desirability of that location as a place to live.

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The loss of railroad service to a small urban area imposes limitations on economic viability of that city. Certain types of industry depend on rail. In addition, if the motor carriers were to move to an uncompetitive position, the community without an alternate mode would have a reduced potential for economic development.

As the availability of natural gas and fuel oil is reduced, the applicability of alternates will be influenced by transport requirements and capabilities. Rural region dwellers are concerned about heating their homes and about the generation and distribution of electricity. Coal is an alternate, but its applicability is influenced by rail accessibility.

THE CURRENT SITUATION

Personal intraregional and interregional travel in rural regions is done almost exclusively by private automobile and intercity bus, but a generation removed traveled extensively by train. The availability of low-priced gasoline and the ubiquitous automobile led to the development of an extensive, publicly financed highway system. As each family acquired a private automobile, the potential for railroad passenger service declined. The intercity buses finally replaced the railroad in all but a few locations.

The freedom that the automobile with a high degree of flexibility gives a person makes rural regions more attractive. The attractiveness of a small city (or a farm home) is in large part due to the easy accessibility of recreation, culture, shopping, and other activities available at varying distances. However, because of the dispersed population distribution and low densities, the personal satisfaction of living in a rural region is sensitive to personal mobility. Public transportation in its present form is not an acceptable alternative to the car for a rural resident with a choice.

If the attractiveness of the automobile is diminished (e.g., because of cost, rationing, or peer pressure), the mobility aspects of alternative locations will be enhanced to a certain degree. The degree depends on flexibility, extensiveness of the system, and quality of service. It appears however that any change in personal transportation will reduce the perceived desirability of a rural region. Thus, the form of personal transportation is highly correlated with degree of location satisfaction.

The transport of goods and commodities within and between rural regions has a comparable historical record of shift from rail to highways. Rail shipments are trending to bulk commodities between long-haul markets. The privately owned and financed, highly regulated railroads are abandoning all but the profitable main lines as rapidly as possible. The abandonment of these branch lines is of concern to the cities and towns located on the route. Currently motor carriers of freight can efficiently and economically transport small shipments over short distances. But a city limited to only one mode has a reduced potential for expanding in the economic marketplace. In the long run, the reduced attractiveness to industry, with the resultant loss of economic spin-off and employment opportunities, is a factor in measuring the attractiveness of that rural region.

In small cities homes are primarily heated by natural gas and fuel oil, and in rural areas they are heated by liquified petroleum and fuel oil, all delivered by pipeline and truck. As these forms of energy are depleted, alternates will probably be based on coal, perhaps as electricity or manufactured gas. Although a pipeline-truck transportation system is currently serving this need, the future may see a need for railroad service to deliver coal to a central plant or distribution center.

Many small cities and towns have municipally owned electric power plants. These have almost exclusively converted to natural gas and fuel oil. A change in availability of this form of energy interacts with the total electric generating system and in the transportation system providing the fuel. If the city does not have access to rail service it probably is faced with interconnecting with a power grid and purchasing its entire needs. The alternatives for other than rail transportation of coal for a local operation are not feasible.

The recent pioneering activity in using solid waste as a portion of the fuel for coal-fired electric generating plants is related to the energy-transportation problem being discussed. The lack of rail service to a community probably negates its opportunity to use this technique. Ames, Iowa, will soon start substituting 20 percent solid waste for coal in its municipal power plant operation.

RAILROAD NETWORK

As in most states, Iowa had developed an extensive railroad system by the turn of the century. The distribution of this network is shown in Figure 1 [7,600 total route miles (12 200 km)]. All counties were served, and the viability of a community was based on rail service. Since World War II however there has been a concerted effort by the railroads to abandon branch and spur lines. Through a program of deferred maintenance and poor service, the railroad has the power to discourage traffic. In 1973, Iowa derailments due to track conditions cost the railroads over $3.7 million.

The mechanism for allowing railroads to abandon nonprofitable lines has been simplified. Low-traffic lines will be abandoned rapidly in the future. It has been hypothesized that rail-line abandonments may in fact become so intense that the system will virtually be reduced to main-line Interstate routes. Such a system (category 1) for Iowa is shown in Figure 2 [1,600 total route miles (2575 km)].

ELECTRIC POWER GENERATION

The generation and distribution of electric power in Iowa are a complex mix of public and private ownership and of interconnections between these individual companies and agencies. Hydropower is purchased and distributed from the government dams on the Missouri River and privately owned dams on the Mississippi. Privately owned nuclear power stations and other large fossil fuel plants are operating in Iowa. Figure 3 shows the existing electric generating plants in Iowa superimposed on the rail network of Figure 2. Notice that, under the bare-bones rail network, a large number of the smaller utilities are located off any rail access.

In addition, many of these plants are municipal electric generating plants. The cities that have elected to operate their own electric generating power plant do so primarily for control and dependability. Frequently they have chosen to reduce production through interconnection and purchase of power but still maintain the local generating plant as a standby. In most cases, the fuel for these electric generating plants is natural gas or fuel oil.

The fuel for the nonnuclear, nonhydro municipal plants is usually natural gas or fuel oil. In a few cases coal is still used. The trend in fuel sources for U.S. generating stations is given in Table 1 (3). Notice that coal and oil use has continued to increase and that the effects of a natural gas shortage can be seen in recent years.

To obtain the proper perspective of the role of each form of fuel's application to electric power generation, one must examine the current and planned uses. Internal combustion and combustion turbine (gas or oil) are more significant power fuel sources in the upper Midwest (Table 2, 3). However, examination of future electric generating plant fuel sources indicates tremendous added fossil steam (coal) generating capabilities (Table 3, 3).

As the natural gas and fuel oil supply is exhausted, two alternates will probably exist. The first involves the consolidation of electric power generation in the state into a few larger coal-using facilities, and power will be distributed to those users who do not elect to convert or rebuild their existing generating plant to use coal. The second alternative is for a local plant that uses natural gas or fuel oil to remodel or rebuild to a plant using coal. Such a decision requires direct access to a railroad line.

Figure 4 shows a map of Iowa with the main-line railroad system previously discussed. Each number on the map (53 in total) represents an existing electric generating plant that would not have access to this streamlined rail network. These generating plants would probably be abandoned, and an interconnection to a distribution system would be made. The local control would have been transferred, and the potential for

Figure 1. 1971 railroad system route structure in Iowa.

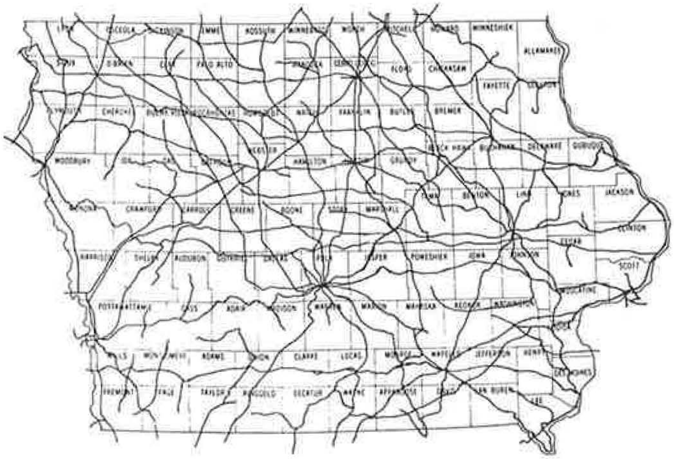


Figure 2. Category 1 system.

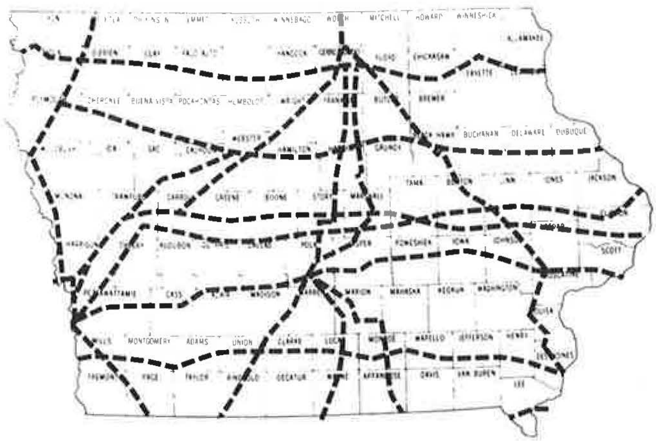


Figure 3. Category 1 railroad system and electric generating plants.

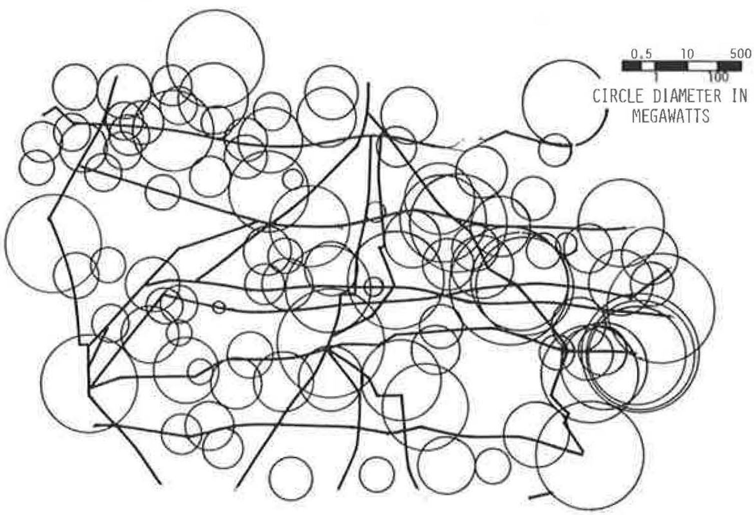


Table 1. Consumption of coal, oil, gas, and nuclear fuel in U.S. generating stations.

Year	Coal (tons × 10^6)	Oil (barrels × 10^6)	Gas (ft^3 × 10^9)	Coal and Equivalent Oil or Gas (tons × 10^6)	Coal Rate (lb/kW-h)
1963	211.25	93.31	2,143.51	320.27	0.856
1964	225.43	101.14	2,322.90	345.67	0.857
1965	244.79	115.20	2,321.10	369.33	0.858
1966	266.40	140.94	2,608.77	412.43	0.869
1967	274.18	161.28	2,746.35	431.77	0.870
1968	297.78	188.64	3,147.91	475.48	0.870
1969	310.64	251.03	3,487.64	524.48	0.880
1970	320.82	335.50	3,932.00	583.46	0.909
1971	327.93	396.24	3,993.00	618.28	0.918
1972	351.05	493.93	3,978.67	671.58	0.911
1973	386.55	565.51	3,754.21	723.68	0.916

Note: 1 ton = 907 kg. 1 ft^3 = 0.028 m^3. 1 lb/kW-h = 0.126 kg/MJ. 1 barrel = 0.16 m^3.

Table 2. Installed capacity of utility generating plants by type.

Item	Entire United States	West North Central States	Iowa
Hydro			
Plants	1,159	64	7
kW	61,280,602	3,134,339	131,625
Steam			
Plants	1,017	193	39
kW	339,427,661	24,833,124	3,107,967
Gas turbine			
Plants	457	51	9
kW	32,876,778	2,118,865	418,528
Internal combustion			
Plants	989	460	126
kW	4,908,050	1,879,529	449,236
Total			
Utilities	1,162	407	93
Plants	3,622	768	181
kW	438,493,091	31,965,857	4,107,356

Note: Data are as of December 31, 1973.

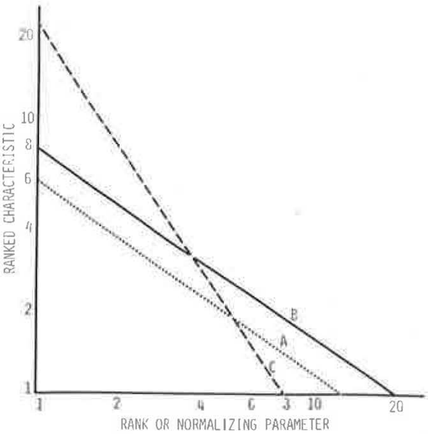
Table 3. Future electric generating capability (MW).

Type	Added in 1973	Planned 1974	1975	1976	1977 and Later	Total
Hydro	48	–	–	–	60	60[a]
	1,311	137	1,404	1,901	8,362	11,804[b]
Pumped storage	–	–	–	–	1,191	1,191[a]
	3,622	1,616	2,035	100	13,056	16,807[b]
Fossil steam	1,883	–	1,116	1,789	11,014	13,919[a]
	19,773	23,138	23,905	18,578	97,763	163,384[b]
Nuclear steam	455	1,803	562	200	1,730	4,295[a]
	6,367	12,097	11,314	10,323	165,519	199,253[b]
Internal combustion	27	39	10	12	45	106[a]
	62	52	29	180	265	526[b]
Combustion turbine	541	780	361	618	591	2,350[a]
	4,765	6,314	2,835	2,620	14,516	26,285[b]
Total	2,954	2,622	2,049	2,619	14,631	21,921[a]
	35,900	43,354	41,522	33,702	299,481	418,059[b]

[a]West north central region. [b]Contiguous United States.

Figure 4. Location of electric generating plants with no rail access, category 1 system only.

Figure 5. Rank-size analysis concept.



allied uses such as power from solid waste would be lost.

The ability to use solid wastes as a substitute for coal has far-reaching implications. Foremost in most persons' minds perhaps are the reduced energy needs from conventional sources as well as the reduced waste-disposal problems. Perhaps more intriguing for Iowa residents is the potential to use high-sulfur Iowa coal. When a substitute material with near zero sulfur content constitutes 20 percent of the input fuel, Iowa coal may become a practical fuel. It may be feasible to develop Iowa's vast reserves of high-sulfur coal in the future by combining combustion with solid waste.

Some of the previous ideas expressed imply that the abandonment of local electric generating plants and connection to the grid are undesirable. The economy of scale achieved in a few large generating plants, as opposed to many inefficient smaller plants, may be obvious. However, the smaller generating plants do provide a level of local control that perhaps is the reason for their continued existence today. The undesirable aspects of very high voltage transmission line services, the lack of local input into company policies and practices, and the definite hazards of being without power for a number of days following a major ice storm are reasons put forth for the continued existence of local electric generating plants.

AGRICULTURE

Iowa's economy is geared to farm production. The large-scale operations that have evolved require the transport of equipment and fertilizers to the farm and the shipment of products to all parts of the world. It is anticipated that future demands to feed undeveloped nations will intensify.

Two aspects of agricultural production are related to the energy-transportation interaction phenomenon. The first involves the production and distribution of fertilizer. In recent years, large volumes of natural gas have been converted to fertilizer at geographical distribution centers served by pipeline. The transportation to the retail outlet and to the individual farms is efficiently accomplished by motor vehicles. However, the shift from natural-gas-based fertilizers to other forms of fertilizer may involve the economics of transporting bulk commodities over long distances. Rural regions not served by rail may find the alternative terminal and distribution structure places them at an economic disadvantage.

The second aspect of the energy-transportation interaction as it relates to agriculture is the distribution of farm products. Large-scale farm operations generate great quantities of corn, grain, and soybeans for export. The collection and concentration of these commodities may be accomplished by motor vehicles, but the large terminal elevators can only be economically served by bulk-moving carriers, such as rail or barge, for the long-distance trip. A future change in energy availability will reduce the viability of the motor carrier for moving farm bulk commodities. The distribution of elevator terminals and subterminals and their access to a railroad line will be important if the United States is to remain competitive in world food production.

QUANTIFICATION OF TRANSPORTATION VARIABLE

Research recently conducted by the Engineering Research Institute at Iowa State University has attempted to quantify individual transportation modes and to aggregate them into a single regional measure. The relationship of transportation to regional growth was then analyzed through rank-size analyses techniques (1). The following adjusted transportation index formula was developed:

$$\mathrm{ATI} = 0.68\ \mathrm{HSI} + 0.17\ \mathrm{TSI} + 0.06\ \mathrm{WRMI} + 0.01\ \mathrm{WRBO} + 0.07\ \mathrm{ASI} + 0.01\ \mathrm{WBBO} \qquad (1)$$

where

ATI = adjusted transportation index,
HSI = highway sufficiency index,
TSI = truck service index,
WRMI = weighted rail mileage index,
WRBO = weighted rail boarding opportunities,
ASI = airport service index, and
WBBO = weighted bus boarding opportunities.

The technique for evaluating the regional transportation system was adopted from the rank-size analysis concept of order statistics. The distribution of community sizes for a centrally placed community and its associated hinterland communities is well described by the following relationship:

$$\log S = \log A + B \log R \tag{2}$$

where

S = size of community,
A = constant,
B = constant, and
R = rank of the community, with 1 as the largest.

This relationship has also been used for defining the data limits of trip characteristics considered in urban planning. It is hypothesized that a corresponding relation appropriately describes the regional variation of transportation to provide intercity connectivity within the region.

Figure 5 shows the ATI rank-size analysis plot for a typical multicounty rural region. Line A is the least square fitted linear regression line for the current ATI ranked data. A relatively flat slcpe indicates the existence of region-wide accessibility between communities with the potential to encourage decentralized development. A relatively steep slope such as line C indicates lack of regional accessibility and the resultant problems in decentralized development.

The degree of regional accessibility between two lines (different regions, different time references, or different ATI system values) can be quantified through the angle relationship between the lines. The use of different time periods for ATI values is a measure of change in mobility. Line B represents ATI values for the same region as line A, but at a later date. The upward shift in the line represents an improved degree of mobility.

Figure 6 shows this evaluation technique. Each plot represents the ATI rank-size analysis for an Iowa rural region. A region-wide change in mobility between 1960 and 1970 can be noted in regions 2, 3, 15, and 16. Note also a difference in the degree of mobility for the centrally placed city between regions. A number of accessibility interpretations may be obtained from these time-series analyses.

A sensitivity analysis reflecting a change in freight mode was undertaken using this technique. Assuming that the railroads will vigorously pursue an abandonment policy, the main-line railroad system shown in Figure 2 may result. The change in the ATI rank-size analysis regression line is shown as the long-short dash line in Figure 7. With the exception of region 5 and to a lesser extent region 16, the effects of reduced railroad mileage are inconsequential in terms of region mobility and the centrally placed city rank. This indicates that a continued vigorous abandonment policy with no change in energy availability would have a minor effect on existing regional transportation.

A second alternative included the reduced railroad mileage and also a long-range energy shortage requiring a fuel allocation policy. This policy emphasized rail move-

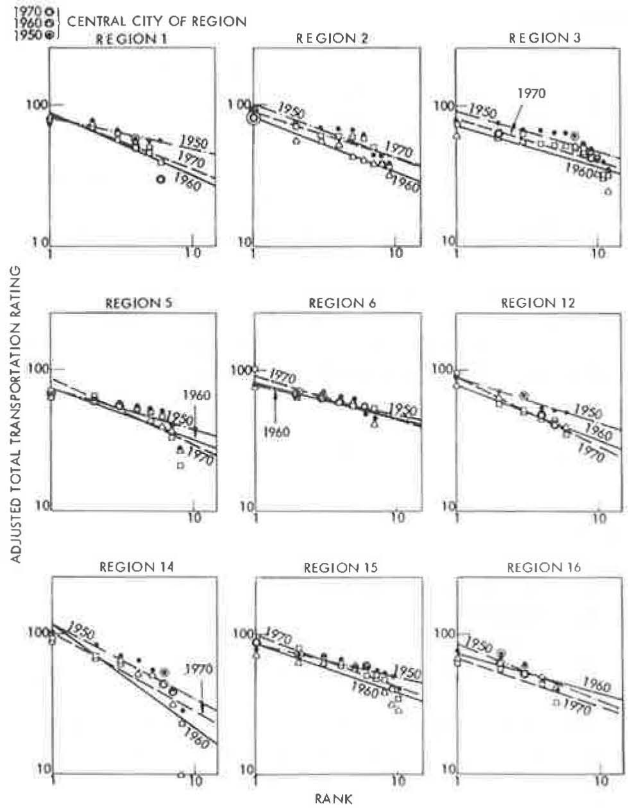


Figure 6. Adjusted transportation index rank-size analysis.

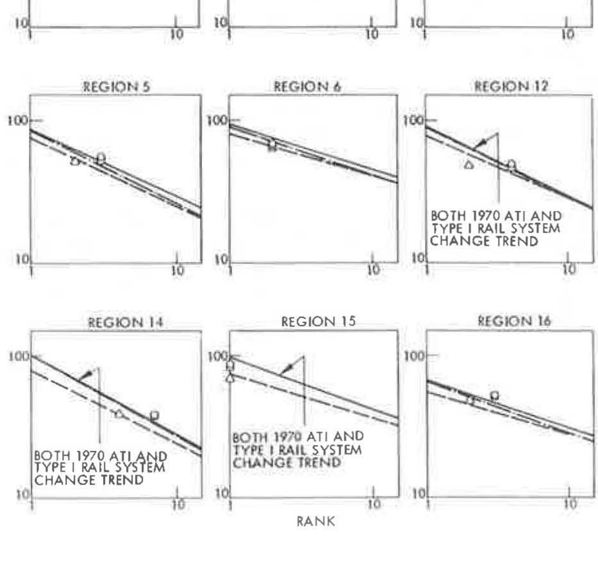


Figure 7. 1970 adjusted transportation indexes for region, centrally placed city, and reduced railroad mileage.

ments at the expense of motor vehicles and left movements of common-contract, motor truck carriers about constant. The effect of this policy is shown in Figure 7 as the short-dashed line. Comparisons are made with the 1970 ATI solid line and with the long-short dashed line. They reflect a reduced railroad system. Note the consistent regional loss of mobility in regions 3, 5, 14, and 16. Regions 1, 6, and 12 present a more complex sensitivity pattern indicating a lower level of mobility and more uniform regional distribution. The reverse is true in region 2.

These sensitivity analyses of alternative policies indicate the potential long-term impact of interacting transportation and energy policies on communities and regions.

CONCLUSIONS

The desirability of a rural region as a place to live is a function of transportation availability, form, quality, and cost. Personal access to shopping and services and to cultural and recreational opportunities as well as the economic benefits accruing from competitively priced and efficient freight shipments are variables of concern. Accessibility to the individual is important, but no more important perhaps than viability for business and industry. Job opportunities determine a region's ability to attract and retain people in a desirable socioeconomic environment; however, industry needs energy and transportation. The imminent abandonment of large segments of Iowa's rail system reduces the potential of many regions to attract and support industry. Combined with the natural gas distributor's plan to eliminate electrical generating plant users by 1976 (2) and all interruptable users by 1978 and with the fuel oil shortage, the potential for economic health and growth and the interrelated social welfare of many communities may indeed be bleak.

As the availability and cost of petroleum fuels and natural gas change the interaction with the elements of transportation, the impact on life-styles must be recognized. In fact the interaction must be anticipated and planned for to minimize adverse results. The quantification of the transportation variable and the technique of rank-size analysis have demonstrated that changes in mobility can result from changes in energy policy.

An application of the impact of interacting transportation and energy policies is in the program of railroad abandonments. This issue is of concern not only in Iowa, but nationwide. Preliminary studies resulting from the Regional Rail Reorganization Act of 1973 indicate more than 15,000 miles (24 000 km) of unproductive mileage in the Northeast and upper Midwest are candidates for abandonment.

It appears highly desirable for states, localities, or other public bodies to acquire abandoned railroad rights-of-way to preserve the continuity and interconnectability of the system. In that manner, the potential exists to reinstitute railroad service should energy policy, heavy industrial development, or agricultural shipment demands necessitate such action.

Transportation system decisions, energy source decisions for power generation based on environmental criteria, and power generation and distribution system planning options for the future are all interrelated. Therefore, decisions of the U.S. Department of Transportation, Environmental Protection Agency, and Federal Power Commission are not independent of one another. We need to recognize this situation before our future options are limited by default caused by previous decisions (or lack of decisions).

Iowa has adopted legislation that provides for the upgrading of branch railroad lines. The Iowa Railroad Assistance Plan made available $3 million for financial assistance in 1974. However, the new Iowa Department of Transportation was not to be operational until July 1975. Consequently, decisions and expenditures made under this plan are not necessarily based on statewide goals and plans yet to be articulated.

The mix of governmental control and funding and private ownership of the various transportation modes and energy suppliers creates a barrier to implementing sound management principles. Government must establish transportation and energy goals and then develop the statewide plans to implement these goals.

ACKNOWLEDGMENT

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REFERENCES

1. R. L. Carstens and others. Integrated Analysis of Small Cities Intercity Transportation to Facilitate the Achievement of Regional Urban Goals. Engineering Research Institute, Iowa State Univ., 1974.
2. T. C. Jetton. Natural Gas Supply. Presented at 86th Annual Meeting, Iowa Engineering Society, Sioux City, April 18, 1975.
3. 1974 Annual Statistical Report. Electrical World, March 15, 1974, pp. 51-52, 53, 55.