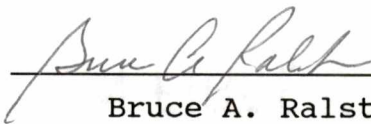


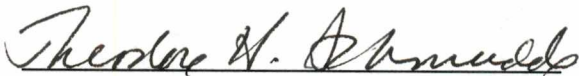
To the Graduate Council:

I am submitting herewith a thesis written by Jun Hu entitled "Optimal Planning of Coal Transport in China." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.



Bruce A. Ralston
Major Professor

We have read this thesis
and recommend its acceptance:



Accepted for the Council:



Vice Provost and Dean of The
Graduate School

OPTIMAL PLANNING OF COAL TRANSPORT IN CHINA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Jun Hu

December 1988

ACKNOWLEDGMENTS

In the course of this thesis research, a number of scholars have assisted me generously. In particular I am indebted to Dr. Bruce Ralston who served as my advisor, and Dr. Thomas Bell and Dr. Theodore Schmudde, my committee members. With their consultation, criticism, and encouragement, I was able to achieve results otherwise impossible. Any errors remaining in my work, however, are solely my responsibility.

I would also like to thank Clell Harral of the World Bank who supplied the majority of data used in this study.

ABSTRACT

Coal transport has been identified as a serious problem in the future economic development of China. The comparative advantages of coal production in the North and government encouragement have caused a large amount of coal flows moved from the North to the Northeast, East, and South Central regions of China. The increased requirements of coal shipments and the lack of sufficient improvements to the shipping capacities of various transport modes have brought about enormous coal transport pressure on saturated railway networks, which directly affect coal production and consumption on a national scale. This study aims to find efficient ways of relieving present coal transport pressure and balancing coal production and consumption in China. Previous studies are reviewed, major modes for coal transport are discussed, and three strategies for relieving present coal transport pressure are evaluated.

Optimal planning is recommended as the most comprehensive approach to relieving present coal transport pressure. A Linear Programming model is used to demonstrate its potential utility in optimal planning. Since Chinese coal transport is a very complicated problem which involves many factors, nonlinear models may be needed for more realistic optimal planning of coal transport in China.

TABLE OF CONTENTS

CHAPTER	PAGE
1. THE COAL TRANSPORT PROBLEM IN CHINA.....	1
Introduction.....	1
Literature Review.....	5
2. THE IMPORTANCE OF COAL IN CHINA.....	15
Coal as a Dominant Energy Resource.....	15
Coal as an Important Commodity Flow.....	24
3. COAL TRANSPORTATION BY MAJOR MODES.....	38
Railway Transport of Coal.....	38
Road Transport of Coal.....	43
Waterway Transport of Coal.....	46
Other Modes of Coal Transportation.....	50
4. STRATEGIES OF RELIEVING COAL TRANSPORT PRESSURE...	52
Direct Investment.....	52
More Coal Production in South and East China....	56
Transport of Coal as Electricity.....	57
The Need for Comprehensive Planning.....	60
5. LP APPLICATION OF OPTIMIZING COAL TRANSPORT	
IN CHINA.....	63
The Coal Transport Network in China.....	63
The Linear Programming Model.....	66
The LP Model Used in This Study.....	67
Data Input.....	70
Interpretation of the LP Results.....	71

6. CONCLUSION AND PROBLEMS FOR FURTHER STUDY.....	78
Intensive Data Collection.....	83
Transshipment.....	83
Location Studies.....	84
Price Distortion.....	84
Summary Remarks.....	85
BIBLIOGRAPHY.....	87
APPENDICES.....	90
APPENDIX A. NODE FILE.....	91
APPENDIX B. ARC FILE.....	92
APPENDIX C. OPTIMAL ALLOCATION OF COAL FLOWS....	93
APPENDIX D. BALANCE OF COAL SUPPLIES AND DEMANDS	95
VITA.....	96

LIST OF FIGURES

FIGURES	PAGE
2.1 The Location of Major Coal Mines in China.....	29
2.2 The Spatial Distribution of Coal Surplus and Deficit Provinces in China.....	31
3.1 Railways for Coal Transport.....	39
3.2 Roads for Coal Transport.....	44
3.3 Waterways for Coal Transport.....	48
5.1 Railway Network and Optimal Allocation of Coal Flows.....	72
5.2 Actual Coal Flows on Railways in 1980.....	73

LIST OF TABLES

TABLE	PAGE
2.1 CHINA: Primary Commercial Energy Production and Consumption.....	16
2.2 Percentage Shares of Commercial Energy Consumption in China, 1980.....	17
2.3 Comparison of Coal Resources and Reserves in USSR, US and China.....	19
2.4 Types of Coal in China.....	20
2.5 Chinese Retail and International Energy Unit Prices in Early 1985.....	22
2.6 Average Mine-mouth Coal Prices for Selected Countries, 1982.....	23
2.7 Coal as a Percentage of Total Freight Transportation.....	26
2.8 Freight Turnover by Mode of Transport in China...	27
2.9 Rail Freight by Commodity in China.....	28
2.10 Major Coal Producing Centers in China.....	30
2.11 Coal Production and Consumption Summary by Province, 1980.....	33
2.12 Coal Demand and Supply Nodes.....	34
2.13 Comparison of Total Cost for Coal in Shanxi and Northeast China.....	36
4.1 Combined Rail-water Routes for Coal.....	54

CHAPTER 1

THE COAL TRANSPORT PROBLEM IN CHINA

1.1 Introduction

Coal transport is an important issue in the economic development of China. Coal is the dominant energy resource, accounting for more than 70 percent of the country's commercial energy uses.¹ It comprises 40 percent of total national rail freight transportation due to the uneven distribution of coal reserves and demand areas. Large and cheap coal reserves are concentrated in north China while major demands are in the populous and industrial south and east regions. The resulting need for large-scale coal transport has put serious pressure on the existing transport system of China.

The purposes of this study are to evaluate the coal distribution problem in China and to perform a preliminary analysis of more efficient ways of allocating coal flows, such that coal produced at mines can be shipped out to meet the demands in coal consumption areas at a minimal cost. Various strategies for relieving current coal transport pressure are compared and evaluated. This study will also present some suggestions for the Chinese government in

¹World Bank, CHINA, The Energy Sector, Washington D.C.: World Bank, (1985). p. 88.

terms of investment priorities in the transportation sector.

Coal transportation covers two important aspects of Chinese economic structure: energy and transportation. Presently, both are regarded by the Chinese government as essential components to accelerate future national economic development. However, planning, management, and investment have been ignored in these two sectors for the past two decades. The direct result is an imbalance of coal demand and supply on a nationwide scale. Although proven coal reserves are plentiful, there are annual shortfalls of at least 20 million tons of coal in production industries which use coal. Perhaps as much as 20 to 30 percent of industrial production cannot be fully utilized because of energy shortfalls. In 1982, per capita household consumption of coal was 145 kg. With the exception of Beijing, the capital city of China, most cities ration coal.² The State Economic Commission determined that southern cities should provide 15 kg of coal per person per month.³ This target, however, is not feasible in many small cities because of limited transport capacities.

The supply shortfalls of coal in China can be attributed to many factors such as price distortions,

²McGurk, S.J. China, Coal Transport Planning Study, Modeling and Discussion Paper. Beijing, People's Republic of China: World Bank, (1987). p. 1.

³Ibid. p. 1.

confused regulatory structure, and weak and non-comprehensive management of coal production and distribution.⁴ However, I perceive the constraints of transport capacity and non-optimal coal distributions to be key to the problem of supply shortfalls.

Coal is a tremendous load on a virtually saturated transport system; more than 1 billion tons are transported per year. Many major state mines cannot respond to coal shortfalls simply because the coal produced cannot be shipped out. Coal transport from Shanxi province provides an example. In 1985, there were 40 million tons of coal stacked up around the coal mines, unable to be shipped out.⁵ Some of this coal accumulation was lost due to auto-combustion. Because of the long term transport shortages, many mines in the southeast of Shanxi now restrict their production to transportable limits. In some cases, local mines radically slash prices to get rid of backlogs. This cheaper selling not only affects further coal production of local mines, but it also induces users to burn coal more inefficiently than they would if supplies were more efficiently regulated. Inefficient burning results in more coal waste and serious environmental pollution around coal mines, as well as the continuous shortages of coal in the demand areas.

⁴Ibid. p. 2.

⁵Ibid. p. 3.

The Chinese government is ready to take steps to solve these problems. Energy and transportation are given high priority in the recent state development plan for the national economy.⁶ Funds from the state planning budget and loans from foreign countries or international financial agencies such as World Bank, are ready or have already been allocated to improve Chinese energy and transport sectors.

However, the available financial resources in China for improving the transport network are limited. It is, therefore, essential that a priority investment plan and related cost-benefit analyses be completed before the government actually starts to build new rail lines or improve existing lines. China has made several major investment mistakes in the past,⁷ and poorly considered investment should be avoided in the new plans for transportation improvement.

⁶Research Institute of Comprehensive Transportation, Policy Study Report of Energy Transportation Technology. Beijing, P.R. China: State Economic Commission, (1984).

⁷A typical example is the building of the Baoshan iron and steel plant in Shanghai. This is a place which has neither raw material nor power advantages for the iron and steel industry. It cost the Chinese government Y20 billion to buy old equipment from Japan and to stabilize the sinking ground of the coastal area. The production cost of iron and steel will be high because the raw materials must be imported and power in the region is not sufficient for such an undertaking.

1.2 Literature Review

Coal transport in China has raised great concerns, not only from Chinese scholars, planners, and experts of transport and energy, but also from researchers outside China who are generally interested in China's economic development. Most of these studies are descriptive and qualitative, and they focus on the transport of coal from Shanxi province by rail. There is still no complete modeling study of coal transport in China.

1.2.1 Domestic Studies

The study of coal transport by Jia Yunzhen is a good summary work about coal production, transportation, consumption, reserves, and associated problems in China.⁸ He concluded that shipping capacity is the principal problem for coal transport, but he did not present any solutions for this urgent problem.

Considering the uneven distribution of coal and congested transport network, Li Xuesheng and Jia Qinxu proposed a location study of Chinese coal industry, aimed to relieve coal transport pressure.⁹ They break down

⁸Jia, Yunzhen, "Transportation of Coal in China," Coal-Trade, Transportation & Handling, Vol.4, (1986). p. 131-134.

⁹Li, Xuesheng and Qinxin Jia. "A Discussion of the Spatial Location of Coal Industry Production in Our Country," Coal Economics Research, Vol.6, (1986). p. 4-7. (in Chinese).

1983's proven reserves, coal types, and areas of serious shortages within each of seven areas--Northeast, East, Beijing-Tianjin-Hebei, South Central, Shanxi-Shaanxi-Neimeng, Southwest, and Northwest. The location of the coal industry depends, in their view, entirely upon coal supply. There is no discussion of coal production costs, coal transport or coal utilization.

The Coal Transport Conference, held in Shanxi province in 1985, focused on studies of coal transport in China. In attendance at the conference were about 50 road, rail, energy, and coal experts and Shanxi provincial planning, economic and science commission officials. The conference proceedings contain a comprehensive collection of recent coal transport studies.¹⁰ Experts presented several alternatives to solve the problem of congested coal transport. Ma Xiaochun proposed several ways to improve Shanxi coal out-shipment capacity. He suggested to improve conditions for short haul transport from local coal mine mouths to rail depots, with particular attention paid to centralizing management of mine production, increasing loading depot capacity and short haul transport capacity, increasing car loading facilities at all rail depots owned by the coal mines, developing more coal processing,

¹⁰Proceedings of the Academic Conference on the Shipment of Shanxi Coal. (this reference will be called "Proceedings" in subsequent references). Taiyuan, Shanxi Province: P.R. China. (1985). (in Chinese).

chemical and other energy-oriented industries in Shanxi province, and developing other non-rail transport modes, particularly roads.¹¹

Although he agreed with most of Ma's views, Han Yongchun argued that the best way for alleviating the Shanxi coal transport problem was to tighten administrative controls over approval of local and township mine production, such that the levels of local mine production did not exceed available transport capacity.¹² Obviously, it is a very conservative strategy, and is not good for long-term balance of coal production and consumption.

Contrary to Han and Ma, Li Chengyi thought that local mine production had not been blindly developed in an uncontrolled manner, nor should it be controlled administratively such that it should not exceed available transport capacity. Li feels that Shanxi township coal production is very poorly served by Shanxi's existing transport system.¹³ He asserted that one of the major reasons for transport shortfalls was the planners' belief that transport should constrain production.

¹¹Ma, Xiaochun. "Several Problems That Hamper the Improvement of Shanxi Coal Out-shipment Capacity", Proceedings. p. 25-29. (in Chinese).

¹²Han, Yongchun. "The Balance of Production and Transport of Shanxi Coal and Problems in Short Range Transport", Proceedings, p. 29-31. (in Chinese).

¹³Li, Chengyi. "The Relationship of Transport Construction and Shanxi Local Coal Mine Development," Proceedings. p. 31-34. (in Chinese)

For increasing rail transport capacity, it is commonly recommended that more powerful steam or diesel locomotives be adopted.¹⁴ However, the efficient use of existing transport capacity is also getting attention from Chinese scholars. Due to the scattered and isolated nature of local collective mines in Shanxi, the average number of cars loaded, turnaround time, and stopping time have increased in most sub-stations of the railways. This wastes much of the existing shipping capacities because of the time spent waiting for loading and filling rail cars. Centralization and modernization of loading and transport operations for local mines are, therefore, deemed necessary.¹⁵

Development of transport modes other than rail has also been proposed. For example, the Yellow River is expected to handle 4.1 million tons of coal per year after dredging.¹⁶ Based on a cost-benefit analysis, a high speed

¹⁴Xu, Hongsheng. "Increase Train Tonnage Loads, Expand the Capacity of Shanxi-coal Out-shipment," Proceedings. p. 39-41; Zhang Jiatong. "Problems in the Development of Superweight Coal Trains," Proceedings. p. 50-53; Wang Baoyi, "The Potential for Expansion in Shanxi Coal Out-shipment from Utilization of Electric Locomotives," Proceedings. p. 54-57; Li Daocheng. "The Direction of Development for Railroad Towering Power for Our Country's Coal Mines," Coal Economics Research, Vol.4, (1986). p. 26-29 (all in Chinese).

¹⁵Transport Research Office, Taiyuan Railroad Bureau Science Research Institute. "A Discussion of the Question of Joint Transport of Shanxi Small Coal Mine Output," Proceedings. p. 57-60. (in Chinese).

¹⁶Xu, Zhenhua. "An Underdeveloping Coal Transport Route--the Yellow River," Proceedings. p. 42-46.

single use coal highway from Yanquan city (Shanxi province) to Xingang port (Tianjin municipality) has been suggested. This highway is expected to transport 15 million tons of coal per year when it is completed in 1990.¹⁷

1.2.2. Outside Studies

The World Bank has conducted a detailed and comprehensive study of major issues in the economic development of China to the year 2000. Coal transport was identified as one of these issues. The Bank has a resident commission in Beijing to collect data, review Chinese literature, and prepare further modeling studies. A report finished by McGurk represents the latest progress of the Bank's study on coal transport in China.¹⁸ This research is strongly oriented toward transport modeling. Further discussion of McGurk's study is presented in the third section of this review.

The comprehensive study completed by the World Bank contains a detailed discussion about other major issues, such as population, education, agriculture, economic structure, energy, transport, and development management.

¹⁷Zhu, Guangbin. "Feasibility Research into a Single Use Coal Highway from Yanquan City," Proceedings. p. 47-50. (in Chinese).

¹⁸McGurk. 29p

There are six appendices attached to the final report.¹⁹ Two of the six appendices, Energy Sector and Transport Sector, provide detailed discussions and analyses of coal production, distribution, and consumption. According to the World Bank, there are some unique characteristics about the role of coal in the economic development of China from an international perspective. Coal dominance in China's energy production and consumption structure, based on the comparison with other developing countries (India, Brazil) and developed countries (United States, Japan), was identified as a special feature.²⁰ The relationship of coal to other economic sectors (agriculture, industry, transport) indicates that coal is essential for China's economic development in the future.²¹

The importance of coal in China is not, however, compatible with its corresponding transport network.²² Coal transport pressure due to inadequate transport capacity is, therefore, recognized by The World Bank as a serious dilemma for economic development of China. Further

¹⁹The six appendices are: China: Issues and Prospects in Education, China: Agriculture to the Year 2000, China: The energy Sector, China: Economic Model and Projections, China: Economic Structure in Industrial Perspectives, and China: The Transport Sector.

²⁰World Bank. CHINA, The Energy Sector. Washington, D.C.: World Bank, (1985). p.11-13

²¹Ibid. p. 4-6.

²²World Bank. CHINA, The Transport Sector. Washington, D.C.: World Bank, (1985). p. 53-58

study of coal transport in China possibly will lead the Bank to suggest an appropriate development process for China, a country heavily influenced by one particular energy resource in its economy.

1.2.3 Modeling Studies

Once the coal transport problem was identified, the World Bank sought to develop a model for coal transport in China. McGurk's study is the result of that effort. His modeling efforts actually initiated a new direction in coal transport studies in China. McGurk's models can be used to systematically generate and evaluate different alternatives of improving the coal transport system, including the layout of new lines or increasing the existing line capacity. In his report, McGurk proposed three models which, he feels, could be used to optimize coal distribution in China: a carrier model, a shipper model, and a production and distribution model. The shipper model is an adaptation of models created by Meeraus, Sheldrick, and McGurk for the World Bank's China Phosphate Sub-sector Study in 1987. The carrier model is a modified version of models developed by Daugherty et al.²³ The integration of

²³Daugherty, A.F., M.A. Turnquist and S.L. Griesbach. "Estimating Origin-Destination Specific Railroad Marginal Operating Cost Functions," Transportation Research. Vol.17a, No.6, (1983). p. 451-462.

these three models follows the work of Harker.²⁴

The carrier model is designed to minimize total carrier operating costs by respective carrier grid given line and yard capacities and demands for total commodity volume by line.²⁵ The shipper model, incorporating the carrier model output, minimizes coal shipper's unit coal commodity shipment costs over all possible carrier grids. The production and distribution model, which summarizes output from both the carrier and shipper models, is designed to minimize coal delivery costs given coal demands, coal mines and plant production capacities and costs, and transport costs.

In his study, McGurk has already created the carrier grid for coal transport in China. However, his models seem too theoretical to be applied in China's situation. The intensive data collection requirements of the models are difficult to fulfill. Some of the data will probably not be available at all. For example, the demand data of commodity flow by carrier line or yard will not be available, since the Chinese government does not keep such records. It is also very hard to simulate these data because the Chinese government does not have continuous census data

²⁴Harker, P.T. Predicting Intercity Freight Flows. Utrecht, The Netherlands: VNU Science Press BV. (1987).

²⁵The carrier grid is actually a graph of the transportation network which also contains information on shipping capacity, cost, flow direction, and, so on for each individual arc.

collected at regular intervals.

Some models of coal transport in the United States can be considered applicable to the Chinese situation. For example, the Generalized Spatial Price Equilibrium Model (GSPEM) of freight transportation systems incorporates the generation, distribution, and modal split of freight trips via price equilibrium mechanism, and assigns trips via the profit maximizing behavior of carriers. Harker and Friesz applied the GSPEM to analyze the entire U.S. coal market.²⁶ With the GSPEM, the effect of decisions of producers, consumers, shippers, and carriers on the price, supply, demand and regional distribution of coal are taken into account at the same time.

Other models, such as the Multimodel Intercity Freight Transportation Network Model (TNM),²⁷ and Ratick and Osleeb's Coal Logistic System (CLS),²⁸ have been used to study optimal coal transport in the U.S. TNM is used to

²⁶Harker, P.T. and T.L. Friesz. "The Use of Equilibrium Network Models in Logistics Management: With Application to the U.S. Coal Industry," Transportation Research. Vol.19b, No.5, (1985). p. 457-470.

²⁷CACI, inc-Federal. Transportation Network Models For Energy Supply Analysis. include five volume: Volume 1 -- Executive Summary; Volume 2 -- Methodology and Scenario; Volume 3 -- Transportation Network Model User's Guide and Documentation; Volume 4 -- Transportation Network Model Support Programs; Volume 5 -- Appendixes. Arlington, Virginia: Electric Power Research Institute, Inc. (1982).

²⁸Ratick, S.J. and J.P. "Optimizing Freight Transshipment: An Evaluation of East Coast and Export Options," Transportation Research. Vol.17a, No.6, (1983). p.493-504

route intercity coal movements through a multimodal transportation network composed of elements with known operating and performance characteristics. CLS is designed for minimizing systemwide costs of purchasing, handling, and transporting coal to demand sites (power plants, industrial user, export demand etc.). Since all of these models have been developed for solving the same problem, namely large scale coal transport to balance coal demand and supply, they may be useful for solving the coal transport problem in China as well.

In the Chinese literature, no modeling studies have been found thus far. Two reasons can be offered here. The first is due to the difficulties associated with data collection. In general, it is very difficult to gather data for modeling studies since the Chinese government does not conduct a systematic and regular collection of coal supply, transport, and demand data. The second is the resistance from Chinese administrators. Most of these modeling studies are still new to Chinese administrators, and they are not sure how valuable these studies will be. Some administrators are accustomed to doing their work based on qualitative studies, and they cannot accept the new results from modeling studies. Therefore, there is little support and coordination from governmental administrators to encourage such modeling studies.

CHAPTER 2

THE IMPORTANCE OF COAL IN CHINA

The importance of coal in the economic development of China can be explained in two respects: it is a dominant energy resource, and it is a major commodity flow.

2.1 Coal As A Dominant Energy Resource

Coal is the dominant energy resource in China. As Table 2-1 shows, coal has a very high percentage share in Chinese energy production and consumption. In 1986, coal comprised 72 percent of Chinese primary energy production and 76 percent of its consumption²⁹ Before the relatively recent development of China's petroleum industry, the role of coal was even larger: in 1965, it accounted for almost 90 percent of primary commercial energy use. The share of coal consumption today is high in all major economic sectors -- even in transport, where railway consumption brings the share of coal to almost one half of the sector total (Table 2-2). Without doubt, the proper balance of coal demands and supplies at a nationwide scale will be essential to accelerate China's economic development and industrialization.

China's heavy reliance on coal is due primarily to

²⁹McGurk. p. 1

TABLE 2-1

CHINA: PRIMARY COMMERCIAL ENERGY PRODUCTION AND CONSUMPTION
(Millions of tons of coal equivalent)

Year	Production			Consumption		
	Oil	Coal	Natural Gas	Oil	Coal	Natural Gas
1965	16.4	165.6	1.5	16.0	162.3	1.5
1970	44.7	252.9	3.9	44.1	250.6	3.9
1975	112.4	344.4	11.8	94.9	341.2	11.8
1976	127.1	345.4	13.4	111.9	343.1	13.4
1977	136.4	393.4	16.1	120.2	390.8	16.1
1978	151.7	441.4	18.2	132.0	438.2	18.2
1979	154.7	453.9	19.3	130.8	449.3	19.3
1980	154.3	443.0	19.0	128.8	436.9	19.0
1981	147.5	444.0	16.9	120.7	437.7	16.9
1982	148.8	475.7	15.8	118.9	469.4	15.8
1983	154.6	510.7	16.2	125.0	504.3	16.2
1984	166.8	551.4	16.5	N.A.	N.A.	16.5

Source: (1) 1965-83: State Statistical Bureau, Statistical Yearbooks of China, 1981, 1983, 1984. (2) 1984: State Statistical Bureau, Communique of China's 1984 Plan.

TABLE 2-2

PERCENTAGE SHARES OF COMMERCIAL ENERGY CONSUMPTION
IN CHINA, 1980

Sector	Oil	Coal	N.Gas	Electricity	Total
A. Energy Composition (%)					
Agriculture	28.8	47.4	0.0	23.8	100.0
Transportation	51.7	46.8	0.0	1.5	100.0
Industry	13.4	60.0	4.4	22.2	100.0
Residential	1.8	87.6	0.3	10.3	100.0
Other	38.7	49.7	0.0	11.6	100.0
Total Commercial Energy	16.3	63.0	2.7	18.0	100.0
B. Sectoral Shares (%)					
Agriculture	15.5	6.5	0.0	11.5	8.7
Transportation	24.6	5.8	0.0	0.6	7.8
Industry	49.7	57.6	97.9	74.4	60.4
Residential	2.2	27.4	2.1	11.3	19.7
Other	8.2	2.7	0.0	2.2	3.4
Total	100.0	100.0	100.0	100.0	100.0

Source: Almanacs of China's Economy, 1980.

the existence of large, high-quality, and low-cost coal reserves. It is a country rich in coal resources ranking third in the world. Its proven coal reserves of 640 billion tons are believed to be the largest in the world (Table 2-3). About 100 billion tons of these coal reserves are economically recoverable under present mining conditions, an amount sufficient to meet the projected demand for well over 100 years. Over 90 percent of the reserves are located in the northern, northwestern and northeastern parts of the country.³⁰

China has all types of coal, from lignite to anthracite. Table 2-4 shows the major types of coal reserves in China. Most of these reserves are of good quality. For example, the prominent reserves of hard coal are of bituminous rank, most of which have a sulfur content of less than 1 percent. The hard coal does, however, have a high ash content. In general, coal reserves north of the Yangtze River are of high quality. About 30 percent of the total coal reserves in China have a sulfur content greater than 2 percent, and these are mostly located in the southwest area.

³⁰ In Chinese regional division, the Northern region includes three provinces, Shanxi, Nei Monggol, and Hebei, and two municipalities, Beijing and Tianjin. The Northwestern region includes five provinces, Gansu, Shaanxi, Qinghai, Xinjiang, and Ningxia. The Northeastern region includes three provinces, Heilongjiang, Jilin, and Liaoning. The complete list of provinces in each region is shown in Table 2-11.

TABLE 2-3

COMPARISON OF COAL RESOURCES AND RESERVES
IN USSR, US AND CHINA
(billion tons)

Country	Resources	Reserves
USSR	5,920	276
US	3,600	438
China	3,200	640
World Total	13,000	2,000

Source: China Coal Industry Yearbook, 1982, and
Colliery Guardian, November, 1983.

TABLE 2-4
TYPES OF COAL IN CHINA

Type	Percent of Total Resource Tonnage
Bituminous (coking)	37
Bituminous (steam)	32
Anthracite	17
Sub-bituminous	6
Lignite	8
Total	100

Source: China Coal Industry Year Book,
1983, 1984.

Another reason for the dominance of coal in the Chinese energy structure is its low price. Table 2-5 displays the retail price comparison of major Chinese energy resources with the corresponding international prices. Coal is the least expensive energy type in China, at only Y34 or \$11 per ton.³¹ The reason for this can be explained by several advantages of coal production in China. For example, Chinese operating costs are typically Y20 per ton, while mine capital costs average approximately Y110 per ton (including mine-related infrastructure such as workshops, rail lines and welfare facilities). The average wage plus bonuses is less than Y100 per month. Therefore only countries such as South Africa and India can compete with China in coal prices (Table 2-6).

Inexpensive coal in China not only provides strong incentive for domestic utilization and consumption of coal, but also creates a competitive position for Chinese coal in the international market, particularly in the Pacific Rim. This kind of competitive capability is very strong and likely to improve with time. In early 1984, FOB prices of coal received by Chinese exporters were about \$40 per ton for thermal coal, although they averaged about \$50 per ton during the 1980 to 1983 period. FOB prices for

³¹The Chinese currency is called renimibi (RMB). The major unit of currency is the Chinese yuan (Y): 1 yuan = 10 jiao = 100 fen. In 1988, the official exchange ratio of the yuan to the U.S. dollar is: Y3.737 = \$1. In 1984 this ratio was Y2.8 = \$1.

TABLE 2-5

CHINESE RETAIL AND INTERNATIONAL ENERGY UNIT PRICES
IN EARLY 1985

	Chinese Ave. Retail Price		International price
	Yuan	US\$/ <u>a</u>	US\$/ <u>b</u>
Petroleum Product (tons)			
Gasoline	800	286	278
Kerosene	735	263	263
Diesel Oil	560	200	245
Fuel Oil			
Directly burned	155	55	179
Other	85	30	179
Crude Oil	186	65	-
Natural Gas (1000 cu m)			
Associated	100	36	-
Nonassociated	170	61	-
Coal/ <u>c</u>	34	11	34

/a Yuan are converted into US\$ at Y2.8/US\$.

/b Petroleum product prices are FOB Singapore, March 4, 1985. Coal price is for steam coal, FOB Qinhuangdao, China, late 1984, 5400 kcal/equivalent.

/c Estimated for late 1984. Actual coal prices vary substantially according to quality and type of producer supplied within the national system. Washed coal from MOCI mines may cost the end-user as much as Y70/ton, while raw coal from nearby mines may cost as little as Y15/ton.

Source: CHINA, The Energy Sector. p.76.

TABLE 2-6
AVERAGE MINE-MOUTH COAL PRICES FOR
SELECTED COUNTRIES, 1982

Countries	Prices (in 1982 US\$/million kcal)
China/a	2.0
United States	4.8
Fed. Rep. Germany	15.8
France	15.2
United Kingdom	15.5
Japan	15.2
Brazil	7.1
Colombia	3.2
Philippines	8.0
India	3.2
South Africa	2.0
Zimbabwe	2.0

/a At the official exchange rate in early 1984,
Y2.00=US\$1.00.

Source: World Bank estimates.

coking coal and anthracite are \$5 to \$10 higher. Long-Run Marginal Cost (LRMC)³² of export-quality coal of China is about Y50 per ton for the North. Because railway costs are estimated (on a LRMC basis) at just over Y0.02 per ton-kilometer, coal in North China can be delivered to coastal ports for about Y70 per ton, including railway charges of about Y20 per ton, which is low by international standard ($\$34 \times 3.737 = Y126$). Moreover, given the proximity to Japan and other regional markets, ocean freight rates for China are generally lower than those paid by other coal exporters. Coal is an important resource for China to raise foreign exchange. For example, China's coal exports have increased from 7 million tons in 1985 to 13 million tons in 1987. In 1987, foreign exchange gained from exporting coal was the equivalent of about 464 million US dollars.³³

2.2 Coal As An Important Commodity Flow

Coal transport places a heavy demand on the transport system of China. The transportation of coal contributes almost 40 percent of the total freight transportation in

³²Long-Run Marginal Cost (LRMC) is a very important index adopted by World Bank study of Chinese economic development. LRMC is particularly useful for comparing investment proposals characterized by widely different conditions, such as the life of mines and time of construction.

³³Chinese government. China Daily. Feb 25, (1988). p.1

China by weight (Table 2-7). Tables 2-8 and 2-9 give further indication of how important coal transport is as a commodity. It is obvious that rail dominates China's freight transportation. Coal ranked as the first commodity in terms of billions of ton-kilometers transported, and has the largest percentage share in total freight transported by rail. In recent years the average transport distance for coal by rail has been increased from 360 kilometers in 1978 to 460 kilometers in 1983.

There are two basic reasons for the heavy pressure of coal on the transport network. The first reason, which is fundamental, is the uneven distribution of coal reserves in China. The second is the differential production costs among different regions which encourage regional transshipment of coal.

The uneven distribution of coal reserves in China brings about the large scale transportation of coal. Since most coal deposits are located in China's North, Northwest and Northeast, the major coal producing centers such as Datong, Yangquan, and Kailuan, also are concentrated in the areas (Figure 2-1). The major coal-producing centers with production exceeding 10 million tons per year are listed in Table 2-10. Figure 2-2 shows the coal supply and demand provinces in China. The major coal supply provinces are Shanxi and Nei Monggol in the North, Xinjiang, Ningxia, and Shaanxi in the Northwest, and Heilongjiang in the

TABLE 2-7

COAL AS A PERCENTAGE OF TOTAL FREIGHT TRANSPORTATION

Years	Proportion of Coal Freight in The National Total Freight (%)
1959	22.2
1980	38.2
1983	39.6
1990 (estimate)	42.0

Source: Jia Yunzhen. Transportation of Coal in China. p.132

TABLE 2-8

FREIGHT TURNOVER BY MODE OF TRANSPORT IN CHINA

Years	Rail	Road	Water	Pipeline	Air	Total
<u>A. Billion Ton-Km</u>						
1950	39.40	2.70	5.10	0.0	0.0	47
1955	98.20	10.20	23.40	0.0	0.01	132
1960	276.70	39.60	65.00	0.0	0.03	381
1965	269.80	28.50	43.30	0.0	0.03	342
1970	349.60	41.40	51.20	0.0	0.04	442
1975	425.60	60.60	81.80	26.20	0.06	594
1976	386.90	63.00	85.50	35.70	0.07	571
1977	456.80	75.30	102.10	38.70	0.08	673
1978	534.50	82.20	129.20	43.00	0.10	789
1979	559.80	74.50	139.00	47.60	0.12	821
1980	571.70	76.40	152.30	49.10	0.14	850
1981	571.20	78.00	152.80	49.90	0.17	852
1982	612.00	94.90	170.80	50.10	0.20	928
<u>B. Percentage Share</u>						
1950	83.47	5.72	10.81	0.00	0.00	100
1955	74.50	7.74	17.75	0.00	0.01	100
1960	72.56	10.38	17.05	0.00	0.01	100
1965	78.97	8.34	12.67	0.00	0.01	100
1970	79.05	9.36	11.58	0.00	0.01	100
1975	71.69	10.11	13.78	4.41	0.01	100
1976	67.74	11.03	14.97	6.25	0.01	100
1977	67.88	11.19	15.17	5.75	0.01	100
1978	67.74	10.42	16.38	5.45	0.01	100
1979	68.18	9.07	16.93	5.80	0.01	100
1980	67.29	8.99	17.93	5.78	0.01	100
1981	67.04	9.15	17.93	5.86	0.02	100
1982	65.95	10.23	18.41	5.40	0.02	100

Source: Chinese Statistical Yearbooks. (1981). p.279

TABLE 2-9
RAIL FREIGHT BY COMMODITY IN CHINA

Commodity	1970		1980	
	Bil.Tkms	Mil.Tons	Bil.Tkms	Mil.Tons
Coal	96	254	177	415
Petroleum	35	37	30	56
Timber	32	29	51	42
Iron&Steel	26	31	47	61
Cons.Mater.	16	89	33	159
Metal.Ores	15	41	19	59
Nmetal.Ores	12	32	25	60
Grain	10	21	22	32
Cement	8	13	9	24
Salt	6	9	5	9
Fertilizer	6	10	16	22
Others	87	101	108	119
Total	350	666	571	1086

Commodities	1970		1980	
	Ranking	% Share	Ranking	% Share
Coal	1	27.43	1	30.95
Petroleum	2	10.00	5	5.27
Timber	3	9.26	2	8.97
Iron & Steel	4	7.51	3	8.20
Cons. Materials	5	4.63	4	5.83
Metallic Ores	6	4.23	8	3.29
Nonmetallic Ores	7	3.51	6	4.31
Grain	8	2.83	7	3.87
Cement	9	2.23	10	1.58
Salt	10	1.77	11	0.89
Fertilizer	11	1.69	9	2.75
Total		75.09		75.86

Source: Ministry of Railways.

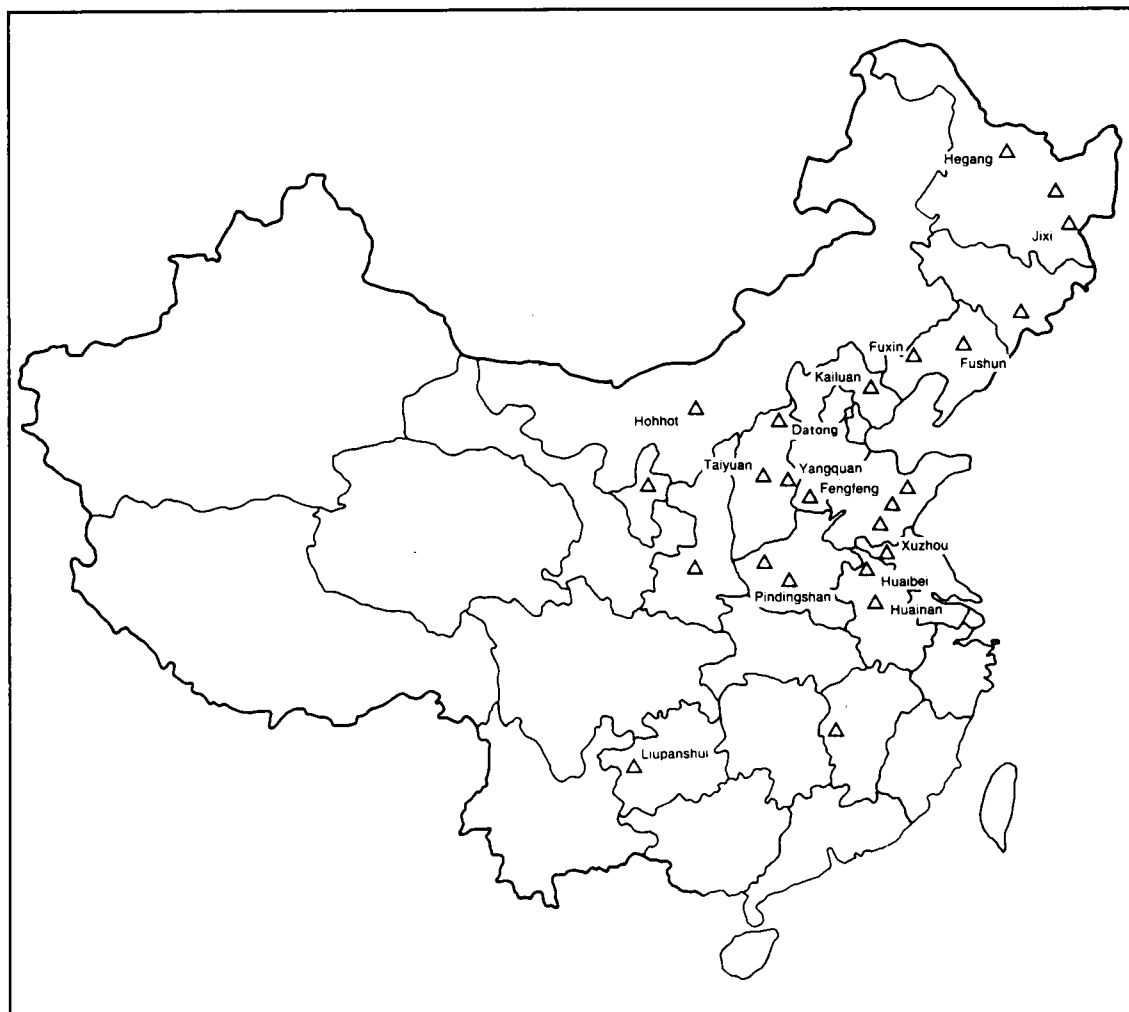


Figure 2-1

The Locations of Major Coal Mines in China

TABLE 2-10

MAJOR COAL PRODUCING CENTERS IN CHINA

Province	Centers
Shanxi	Datong, Yangquan
Hebei	Kailuan, Fengfeng
Liaoning	Fuxin
Heilongjiang	Hegang, Jixi
Jiangsu	Xuzhou
Anhui	Huaibei, Huainan
Henan	Pingdingshan

Source: Jia Yunzhen, Transportation of Coal In China. p.131

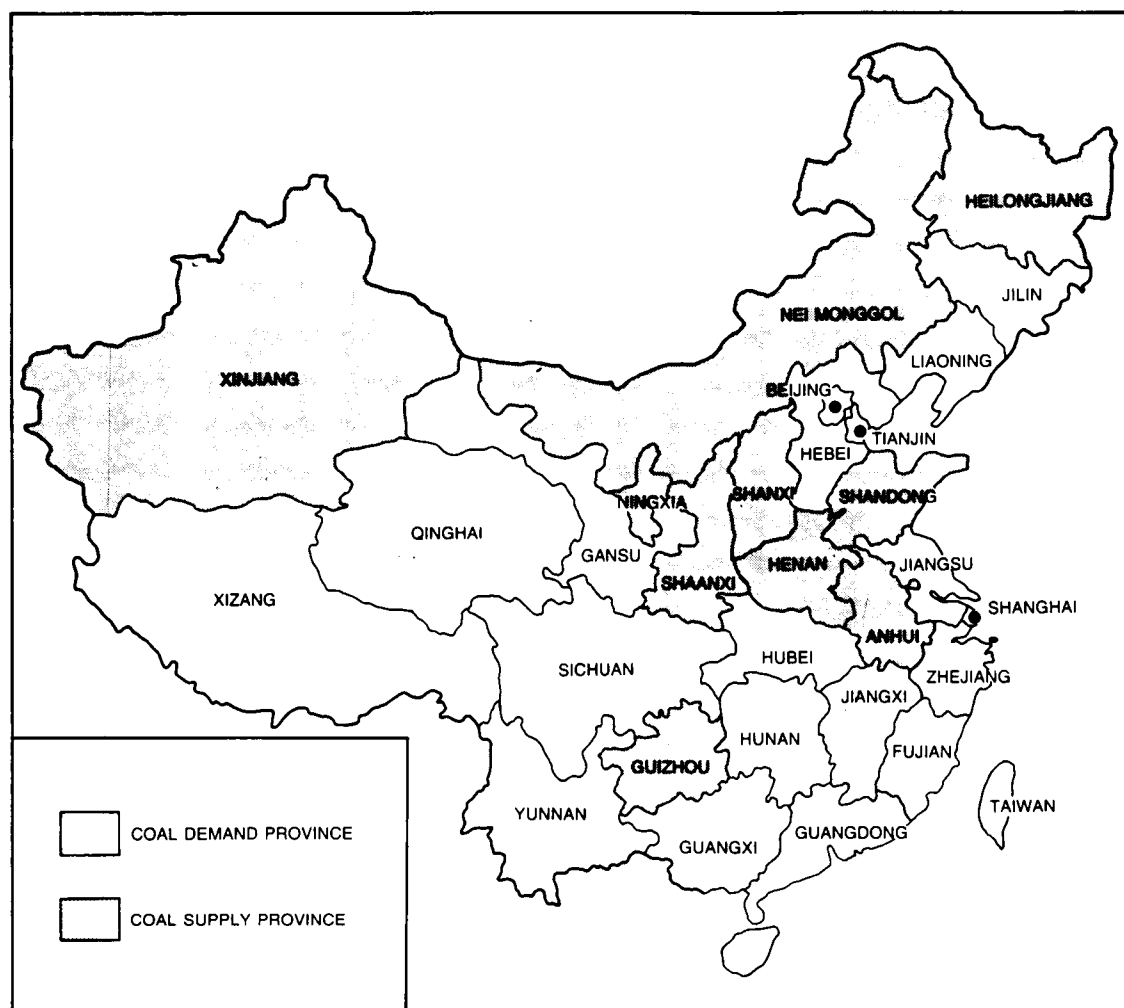


Figure 2-2

The Spatial Distributions of Coal Surplus and
Deficit Provinces in China

Northeast. Among these coal supply provinces, Shanxi is the largest coal producer and supplier to the national coal market: 180 million tons were produced in 1985, of which 135 million tons were shipped out. Regions of the South Central, the East, and the Southwest are generally coal deficit areas, but some provinces, such as Shandong and Anhui in the East, Henan in the South Central, and Guizhou in the Southwest, have surplus coal which can be supplied to neighboring provinces.

Table 2-11 shows the coal production and consumption of 25 provinces and 3 municipalities in 1980. From these basic data, a new table has been created (Table 2-12) which clearly shows the areas of net coal supply and demand. Table 2-12 is simply a result of coal production minus coal consumption in each of the 25 provinces and 3 municipalities. Shanxi has the largest coal surplus. Henan, Heilongjiang, Ningxia, Shangdong, Anhui, Guizhou, Shaanxi, Neimong follow Shanxi in surplus coal production. The remaining provinces are all coal deficit areas. Thus, it is necessary for the national transport system to balance the coal surplus and deficient areas. The populous and industrial East, South, and Southcentral provinces should be particularly emphasized since these are the areas that have the largest demand for coal as a raw material and power resource. These same areas contribute to the largest percentage share of China's GNP as well.

TABLE 2-11
COAL PRODUCTION AND CONSUMPTION SUMMARY
BY PROVINCE, 1980

Province	Production	Consumption
<u>North</u>	<u>204.6</u>	<u>154.0</u>
Beijing	7.9	19.7
Tianjin	0.0	9.3
Hebei	53.5	56.4
Nei Monggol	22.1	19.9
Shanxi	121.0	48.7
<u>Northeast</u>	<u>97.8</u>	<u>114.0</u>
Liaoning	37.3	56.5
Jilin	18.1	23.9
Heilongjiang	42.5	33.6
<u>East</u>	<u>106.1</u>	<u>136.9</u>
Shanghai	0.0	11.8
Jiangsu	18.1	35.7
Zhejiang	1.4	12.1
Anhui	24.1	18.4
Jiangxi	14.9	15.4
Fujian	4.6	6.7
Shangong	42.9	36.9
<u>Southcentral</u>	<u>98.0</u>	<u>109.2</u>
Henan	56.2	42.2
Hubei	3.8	18.5
Hunan	24.0	27.4
Guangdong	8.0	12.8
Guangxi	5.9	8.3
<u>Southwest</u>	<u>64.7</u>	<u>62.2</u>
Sichuan	39.0	39.8
Yunnan	11.7	12.0
Guizhou	14.0	10.3
<u>Northwest</u>	<u>48.8</u>	<u>43.6</u>
Shaanxi	17.9	15.3
Gansu	7.7	11.4
Qinghai	2.2	3.2
Xinjiang	11.4	10.1
Ningxia	9.7	3.6
Total	620.1	620.0/a

/a About 0.1 million tons of coal was wasted for various reasons, such as transport waste.

Source: Ministry of Coal Industry.

TABLE 2-12
COAL DEMAND AND SUPPLY NODES
(Million Tons)

Deficit		Surplus	
Nodes	Coal	Nodes	Coal
A (Beijing)/a	11.8	J (Baotou)	2.2
R (Tianjin)	9.3	K (Taiyuan)	72.4
B (Shijiazhuang)	2.9	I (Harbin)	8.9
G (Shenyang)	19.2	Z (Hefei)	5.7
H (Changchun)	5.8	S (Jinan)	6.0
V (Shanghai)	11.8	C (Zhengzhou)	14.0
U (Nanjing)	17.6	O (Guiyang)	3.7
W (Hangzhou)	10.7	Y (Xian)	2.6
T (Nanchang)	0.5	L (Yinchuan)	6.1
X (Fuzhou)	2.1		
D (Wuhan)	14.7		
E (Changsha)	3.4		
F (Guangzhou)	4.8		
Q (Liuzhou)	2.3		
N (Chengdu)	0.8		
P (Kunming)	0.4		
M (Lanzhou)	3.4		
Total	121.6		121.6

/a All the node names are represented by letters for simplicity in processing. For example, the letter 'A' represents the Beijing node in the input data file.

Source: Table 2-11.

Production cost is another important factor that promotes the interregional coal flow in China. Although China, as a whole, is a low-cost coal producing country, the production costs still vary among regions. Cost are mainly affected by mining conditions. The North, which contributes the largest share of production, enjoys the lowest costs, as reserves lie in thick, gently-dipping coal seams, usually less than 300 meters deep. Average operating costs in Shanxi in 1983 varied between Y10 per ton for small-scale mining of outcrops to about Y18 per ton for large mechanized mines. Average investment costs (including, in the case of large mines, related infrastructure and social services, such as housing, schools, and hospitals) varied between Y60 to Y70 per ton for small mines and Y120 to Y140 per ton for large mechanized underground mines. Costs in other regions are normally higher because mining conditions are less favorable.

Even when the total cost (coal production cost and transport cost) is considered, coal from the North is still very competitive nationwide. In the World Bank's study (Table 2-13), it is shown that Shanxi coal is very competitive in the Northeast despite the need for long-distance transport. Deposits in large seams are easily accessible and both investment and operating costs are lower. Coal in Northern China is generally of higher

TABLE 2-13

COMPARISION OF TOTAL COST FOR COAL IN SHANXI AND
NORTHEAST CHINA (Y/ton)

Area	Production Cost	Transport Cost to Liaoning	Total
Shanxi	36-44	25	61-69
Northeast	60-70	5	65-75

Source: CHINA: Energy Sector, p.102. World Bank estimates.

quality and calorific value than in other regions. Therefore, further development and out-transport of Northern coal appears to make good economic sense.

In summary, the advantages of Northern coal determine that the existing coal flow direction from the North to the Northeast, the East, and the South Central will not change; rather, these flows will increase. The demand for coal as a primary commercial energy resource is great and continually growing. The pressure of coal distribution on existing transport networks will keep increasing. Unless proper solutions are developed to relieve these pressures, the imbalance of coal supply and demand by constrained transport capacities will seriously hurt the economic development of China in the near future.

CHAPTER 3

COAL TRANSPORTATION BY MAJOR MODES

Coal transport in China is provided by three chief modes: railway, highway, and waterway. At present, the railways are heavily loaded with coal, while highways and waterways are less utilized for coal transport. A study of individual characteristics of the three modes is, therefore, necessary in order to properly allocate coal flows on the three modes.

The three coal transport modes are managed by several governmental agencies. The Ministry of Railway is the authority responsible for railway coal transport while the Ministry of Communication is in charge of highway and waterway coal transport. The State Planning Commission and the State Economic Commission are the top decision-making bodies authorized to review, coordinate, formulate, and supervise the national transportation plans.

Descriptions of the three transport modes, railway, road, and waterway, and implications for coal shipment, are presented here.

3.1 Railway Transport of Coal

The railway network used for coal transport is shown on Figure 3-1. The railway lines handling the largest

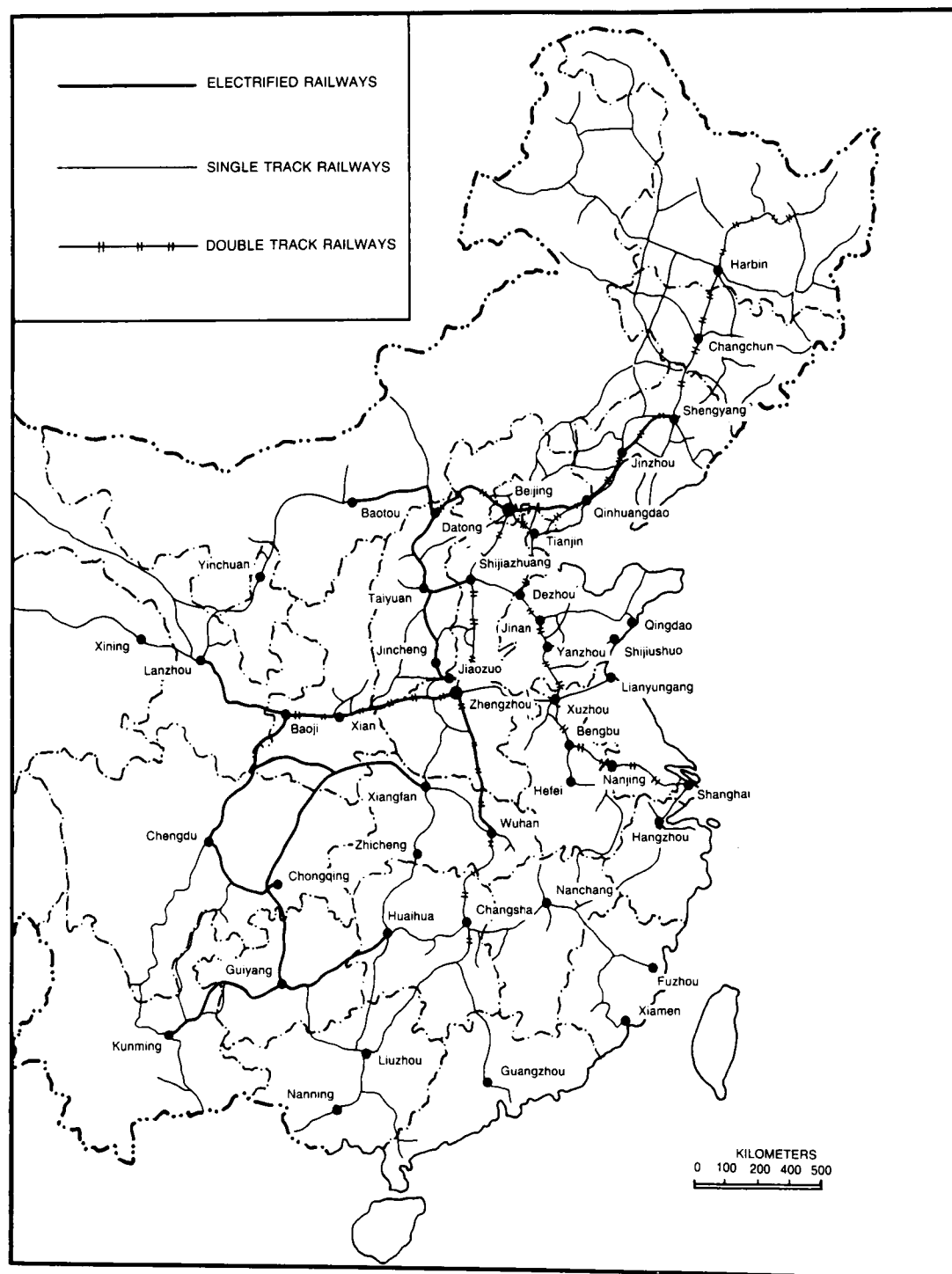


Figure 3-1

Railways for Coal Transport

amount of coal now are: Datong-Beijing-Qinghuangdao line, Beijing-Shanghai line, Beijing-Shenyang line, and Lanzhou-Lianyungang line.

The most serious coal transport problem is located within Shanxi province. Over the past years, most increments in coal output in Shanxi were used to supply the demands for other provinces. In 1962, only 20 million tons of coal were taken out of the province. This figure went up to 70 million tons in 1980, and 100 million tons in 1985. Most of this coal is moved by five key railway lines, namely the Beijing-Baotou line, the Datong-Puzhou line, the Beijing-Taiyuan line, the Shijiazhuang-Taiyuan line, and the Taiyuan-Jiaozhou line.

China plans to annually produce 1 billion tons of coal by the year 2000. The realization of this target will rely largely on the increased production of Shanxi province and other areas in the Northern China. It has been planned that, by 1990, Shanxi's yearly output should be raised to 300 million tons, with 250 million tons to be taken out of the province, and, by the year 2000, 400 million tons of production, with 300 million tons being shipped out of the province. All of the rail lines listed above are operating at full capacities and, therefore, need to expand their shipping capacities, if projected coal production levels are to be realized.

Due to its unique position of supplying coal for the

national market, coal transport in Shanxi province gets special attention from the central government of China. The review of coal transport studies in China (Chapter 1) provides such evidence. In a sense, the administrators of the Chinese government are more interested in increasing both the output of coal production and shipping capacities of Shanxi province, while the systematic balance of coal supplies and demands at nationwide scale is of less concern. For example, in order to diminish the constraints of coal production in Shanxi province, a series of upgrades and new construction of railways has been proposed to focus on increasing the coal-shipping capacities out of Shanxi province. These projects, some of which have already been finished, are detailed in the following sections.

North Line: The Datong-Beijing-Qinghuangdao line has been doubled, electrified, and equipped with unit trains. This upgrading was finished in 1987. Its shipping capacity has been increased from 40 million tons per year to 60-70 million tons per year.

A special coal shipping line directly from Datong to Qinghuangdao has been proposed. This line is going to be doubled, electrified, and equipped with unit trains. The yearly projected shipping capacity will be 100 million tons.

When the two projects are finished, the total capacity

of North Line will reach 150 million tons per year.

Central Line: The Taiyuan-Shijiazhuang line will be doubled and electrified. This project is presently under way, and its completion will provide an increase of 50 million tons capacity. Yet, it still cannot meet the increasing demand in that area. Therefore, there are plans to connect that line with the Dezhou-Jinan-Qindao line and equip the connected line with 500 ton capacity unit trains.

South Line: The Datong-Puzhou line will be doubled, electrified, and equipped with unit trains. The shipping capacity is expected to reach 50 million tons per year.

Southeast Line of Shanxi: The Taiyuan-Jiaozhou line will be upgraded by constructing two tributary lines. One will go through Henan province from Jiaozhou to Zhicheng on the downstream Yangze Valley, and the other is from Jiaozhou through Jining, Yanzhou, to Shijiushuo port. The combined capacity of the two tributaries will reach 45 million tons per year.

Most projects stated above have the common purpose of easing coal transport on railways by increasing shipping capacities, but they all are based on qualitative analyses by disparate governmental agencies. These project evaluations do not employ accurate cost-benefit analyses.

They also do not show clearly the goal capacity which should be reached at the end of the projects. This projected goal capacity should be the value determined by the conditions of coal production and coal consumption over the entire network. Instead, most of the above project evaluations only show the capacities that can be accomplished by new investment, and do not consider if the accomplished capacities (actual capacities after the upgrades are finished) are the same as the projected goal capacities. Therefore, even if upgrades are finished, the question of whether the increased shipping capacities can accommodate the projected demands of coal shipment of Shanxi Province may still remain unanswered.

3.2 Road Transport of Coal

China has a network of roads totaling about one million kilometers in length with Beijing at the center, connecting all the large and medium-sized cities of other provinces (Figure 3-2). Although the major roads are parallel with the rail lines, they are rarely utilized for shipping coal over long distances. The road network, however, has been widely used for shipping coal over short distances, such as from coal mines to railway stations, or from rail stations to consumers in the nearby cities and rural areas.

In China, trucks used for transporting coal generally

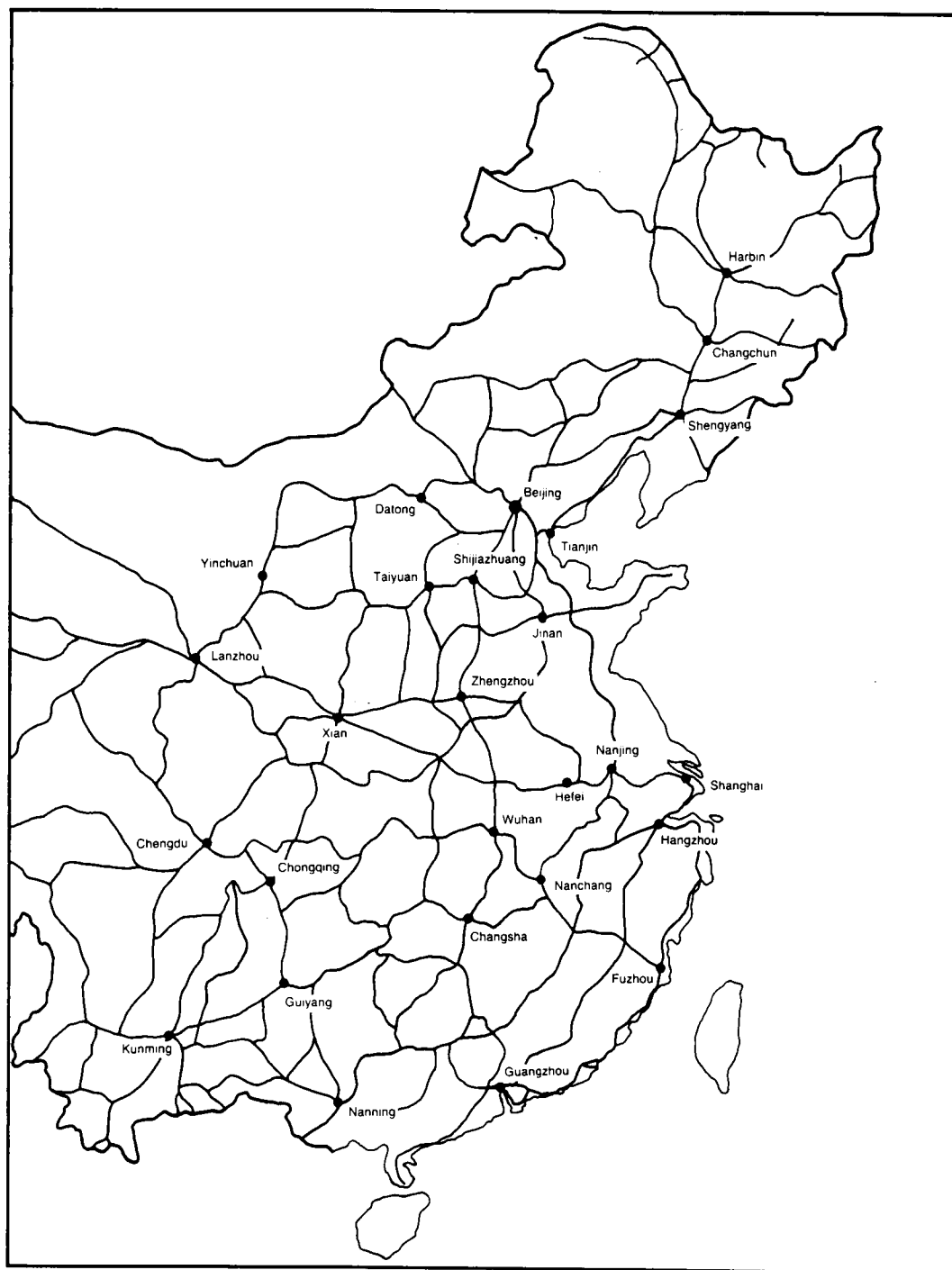


Figure 3-2
Roads for Coal Transport

have a capacity of 3 to 5 tons. In Shanxi, however, a number of larger trucks have been assigned as a supplementary solution for relaxing the coal transport pressure on railways. The capacity of these trucks is 25 tons, and their hauling distance can reach 700 kilometers. There are two major roads for transporting coal out of Shanxi province. The Northern road is from Datong, through Beijing, to Tianjin. The Central road is from Taiyuan to Shijiazhuang.

In principle, the marginal distance of shipping coal by trucks is 300 kilometers. Beyond this distance, road transport of coal is generally considered uneconomical.³⁴ However, since the road networks are less than fully utilized, the available shipping capacities provide strong incentive for using trucks to assemble coal flows at the origins and distribute coal flow around the destinations.

Proper allocation of coal flows on the road system can also save some capacities on railways for shipping coal over long distances. This is specially important in or around major metropolitan areas of China. As Yenny and Uy identified in their study of the transport system in China, short distance movements by rail have placed burdens on the

³⁴Coyle, J.J., E.J. Bardi and J.L.Cavinato.
Transportation, St. Paul: West Publishing Company, (1986).
p. 47-73.

Chinese railways.³⁵ Hauls shorter than 100 km for all commodities accounted for 23 percent of total rail freight traffic and amounted to 250 million tons in 1980. Hauls shorter than 50 km accounted for 14 percent of all rail traffic. Many of these shipments occurred in and around the large metropolitan areas of Beijing, Tianjin, Shanghai, and Taiyuan. For example, 49 percent of the 30 million tons loaded in the Beijing urban area in 1980 were moved over distances of less than 50 Km. Comparable percentages are 33 and 25 for Tianjin and Taiyuan respectively. Major commodities in this short haul metropolitan rail transport consist of construction materials, coal, ores, oil, and steel generally moving from sidings to sidings. If these commodities can be properly allocated on the road network, then the congested rail freight traffic can be reduced to some extent.

3.3 Waterway Transport of Coal

China has about 100,000 kilometers of inland waterways and 180,000 kilometers of coastline. The inland waterways running south of the Qinling Mountain and Huaihe River do not freeze in winter, and are navigable throughout the whole year. In the more northerly areas, there are some

³⁵Yenny, J. and L.V. Uy. Transport in China, A Comparison of Basic Indicators with Those of Other Countries. World Bank Staff Working Papers, No.732, Washington, D.C.: World Bank. (1985). p. 16.

freezing months. The total navigable distance is 18,000 kilometers. China also has more than 2800 large lakes (i.e. with an area of over 1 square kilometer each). Most of these inland waterways, coastlines, and lakes are located in east and south China, and these areas are generally considered to be the largest coal demand areas of China. Therefore, water transport of coal offers special advantages in these areas.

Coastal shipping can be divided into two broad regions, the South and the North. North from Xiamen (Fujian Province) to the mouth of Yalujiang river (the river bounding China and North Korea) is the North shipping region, which is operated by Shanghai Coastal Shipping Administration. South from Xiamen to the mouth of Beitsangho River is the South region, which is operated by Guangzhou Coastal Shipping Administration. Both administrations are under the control of the Ministry of Communications. Besides these two central governmental agencies, each coastal province and municipality may have its own coastal shipping operations to take responsibility of the local coastal shipping business.

As Figure 3-3 shows, there are three major waterways for transporting coal on a nationwide scale: the North-South sea line, the Yangtze River line, and the Grand Canal.

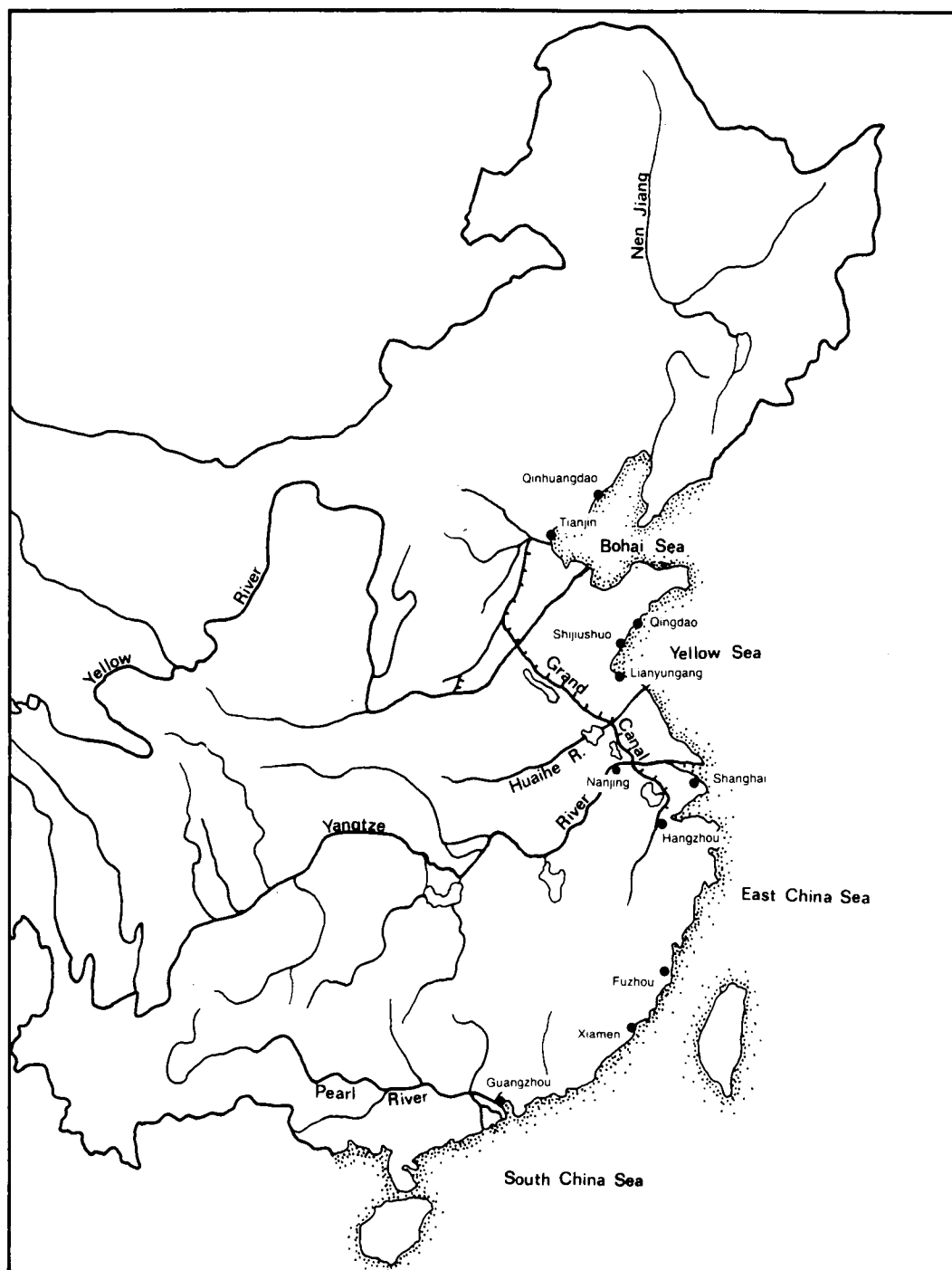


Figure 3-3

Waterways for Coal Transport

North-South Sea Line: Coal coming from Northern China and Shandong province is loaded at eastern sea ports, and then shipped to the south and the southeast along the coast. The large coal handling ports are: Dalian, Qinhuangdao, Tiajing(Xingang), Qindao, Shijiushuo, Lianyungang, Shanghai, Xiamen, Huangpu, and Zhanjiang. Qinhuangdao and Shijiushuo are specialized in coal exporting. With upgrading work completed at these two ports, berthing space will be added and cargo liners with a capacity of over 100,000 tons can be received.

Yangtze River Navigation Line: The Yangtze River is the most important inland waterway for coal transport in Central China. Its middle and low sections have a year-around navigable distance of 2958 kilometers. Coal is transported from the north down to the Yangtze River ports of Zhicheng, Wuhan, and Pukou (Nanchang), and then it is delivered to consumers by river boats or barges. In recent years, the largest dam of China, the Gezhouba Dam, has been built across the Yangtze River at Yichang in Hubei Province. There are two ship docks around the dam, one of which can pass ships of 10,000 deadweight tons and the other, 3000 deadweight tons.

In South China, there are two other important waterways besides the Yangtze River. Located south of Yangtze River is the Zhujiang (Pearl) River, with a total

length of 2152 kilometers. The main navigable section is 1074 kilometers long and does not freeze in the winter. Another important river, the Huaihe, is located north of Yangtze. Its total length is 1094 kilometers, 474 kilometers of which are navigable and do not freeze in the winter. The Huaihe River connects with the Grand Canal at Huaina in Jiangsu province.

The Grand Canal: The Grand Canal runs 1747 kilometers from Beijing to Hangzhou in Zhejiang province. At present, its south section, from Hangzhou to Xuzhou, is navigable. The central government has approved a dredging project for this canal, which is being carried out. After the project is completed, the Grand Canal will be capable of transporting 15 to 20 million tons of coal.

3.4 Other Modes of Coal Transportation

Slurry pipelines have considerable potential for moving coal over long distances. However, in the north, particularly in Shanxi Province, the difficulty of securing the necessary water supply has hampered the potential for slurries. Three to four slurry pipelines are under consideration to transport coal to power stations in Shanxi Province. Owing to budget constraints and other factors, no final decision has been made.

Conversion of coal into electricity, gas, and liquid

fuels is one solution to ease the pressure of inland coal transport. However cost-benefit analyses are needed. Currently, there is a strong argument in favor of conversion of coal into electricity at mine mouth. This will be discussed further in the next chapter.

In summary, the three major coal transport modes, railway, highway, and waterway, have their own advantages and disadvantages for coal shipment. The layout of these three modes are complementary to each other. In future coal transport planning, proper allocation of coal flows on the three modes is very important to ease coal transport pressures on railways. Waterways should be considered at least as important as railways for coal shipment, and short-distance transport of coal should be allocated to highway systems as much as possible.

CHAPTER 4

STRATEGIES OF RELIEVING COAL TRANSPORT PRESSURE

There are three major strategies for reducing coal transport pressure, namely (1) direct investment in the transport network to increase shipping capacity; (2) more coal production in the less advantageous south and east of China; (3) transporting coal energy in the form of electricity generated at the mine mouth.

4.1 Direct Investment

Since shipping capacities are perceived to be the primary constraints to coal transport, increasing investments to improve saturated transport networks provides one solution for dealing with the pressures of coal supply and demand in the country. The spatial separation of coal supply and demand areas argues for railways and waterways as the most efficient ways to transport coal on a nationwide scale.³⁷ Therefore, high priority should be given to railways and waterways in order to boost shipping capacities substantially.

The present governmental policy for railway investment emphasizes increasing capacity on existing lines and general improvement in the efficiency of freight traffic,

³⁷Coyle, Bardi and Cavinato. P. 48-70 and P. 98-111.

rather than expansion of the networks. Massive investments in increased line capacity (electrification, station and yards lengthening, and double tracking) as well as in increased locomotive power and rolling stock will continue to be needed well into the future. The shortages of freight cars seems to be particularly acute. Although the production of such cars is increasing, only 10,000 cars per year were produced in the early 1980s. On a thirty-year life cycle, renewals alone would require over 8,000 cars per year while additional traffic, projected to grow at five percent per year, would require at least an additional 20,000 cars per year, a total well above the present output.³⁸

The combined use of rail and water transport may be an important alternative to investment solely on railways. An analysis of this option needs to be performed before investment is put into any particular combined rail and water route. For instance, it appears that coastal shipping from northern ports is more attractive than the use of Yangtze river to deliver coal to Shanghai. The World Bank estimates that for the distance between Datong and Shanghai, combined rail and water transport (through Qinhuangdao port) could be 20 percent cheaper than rail haulage alone.³⁹ Table 4-1 presents results from the

³⁸World Bank. CHINA, The Transport Sector. P.42

³⁹Ibid. P. 57.

TABLE 4-1
COMBINED RAIL-WATER ROUTES FOR COAL

Routes	Rail (Km)	Water (km)	Total (Km)
Datong--Shanghai	1,840		1,840
Datong--Qinghuangdao--Shanghai	620	1,350	1,970
Taiyuan--Shanghai	1,500		1,500
Taiyuan--Qingdao--Shanghai	920	750	1,670
Taiyuan--Nanjing	1,190		1,190
Taiyuan--Wuhan--Nanjing	1,180	800	1,980

Source: World Bank estimates.

recent study by the World Bank. This table shows three different rail-water routes for coal transport to south and east China. The first two routes involve solely coastal shipping, while the third case considers shipping coal along the Yangtze river. The reductions of rail distance for the three rail-water routes are 1220km, 580km, and 10km, respectively. The greater the reduction of rail distances, the greater will be the relief provided for general coal transport pressure in China.

The amount of coal that can be economically transported to eastern and southern China by a combination of rail and water transport is estimated to be around 100 million tons by the year 2000. Both coal sending ports in the north and receiving ports in the south will need to be upgraded in order to do so. Northern ports such as Qinghuangdao, Qindao, Shijiusuo, and Lianyungang are being developed with specialized facilities for shipping coal. When these developments are completed, capacity for shipping coal from the north to the south by coastal line will be increased from 40-50 million tons to about 60 million tons by the year 2000. Development of receiving ports in the south will be much easier if self-unloading ships are used to simplify the coal unloading process. The use of self-unloading ships can save costly port infrastructure such as berths for along-side mooring, shore equipment, and dredging. Turnaround time in ports can also

be reduced greatly with self-unloading ships, thus allowing more efficient use of ships.

4.2 More Coal Production in South and East China

Chinese planners have long faced a choice between (1) concentrating coal production in the north where costs are low and (2) developing more costly coal reserves closer to the consumption areas of the south and the east in order to reduce transport costs and pressures. In the past, emphasis was given to producing coal near consumption centers. Coal producing provinces in the east, the south central and southwest, such as Anhui, Hanan, and Guizhou were given special attention. Current plans, however, emphasize the concentration of coal production in the North, which is expected to produce some 60 percent of incremental production needed by the year 2000.⁴⁰

It is difficult to establish whether the planned regional distribution of coal production conforms to a least-cost development program because the goals and objectives of planners are not completely specified. On the basis of current LRMC, there appears to be hardly any difference in cost for coal delivered, say, to the Northeast between projects located in the North and those located closer to the market. The production of coal in the North is stressed by the central government because the

⁴⁰World Bank. CHINA: The Energy Sector. p.98

comparative advantages of coal production in the North are likely to grow over time. Coal production costs in the South, on the other hand, are almost twice as high as in the North.⁴¹ Both low production cost of coal in the North and low transport cost on the national railway network make the northern coal more competitive in East and South China.

The concentration of coal production in the North will inevitably increase coal transport pressure. The recent study by McGurk revealed that some of the advantages of concentrating coal production in the North have resulted from misleading price distortions, particularly the extremely low price of rail transport.⁴² The cost compensation by the distorted price system leads to the continuous increase of average distance for coal transport, and, therefore, adds more pressure to the existing transport system. China's domestic literature also pointed out that the existing coal pricing and regulation structure have given rise to non-optimal spatial pattern of coal production and distribution.

4.3 Transport of Coal as Electricity

Mine-mouth power generation and long distance transmission of electricity to users is an important

⁴¹Ibid. p.92-93.

⁴²McGurk. p. 2.

alternative to reduce coal pressure on the transport system. A study by the World Bank reveals some important findings on this issue.⁴³

In a World Bank study, two options are compared and analyzed. The first option involves transport, by a new single rail line, of 5000 kcal/kg coal from Shanxi to the Northeast power grid to generate electricity at the load center. This is a relatively unfavorable assumption since most proposed investments to transport coal out of Shanxi are more likely to be for electrification of existing lines or for additional double-track electrified lines, both with considerably lower (about one half) investment cost per ton capacity than constructing a new single rail line. The second option involves mine-mouth electricity generation in Shanxi and transmission of electricity to the Northeast.

The conclusion is that for coal above 5000 kcal/kg, rail transport of coal will be more economical than transmission of electricity, even if rail transport involves the relatively expensive option of construction of a new single-track line. Since Shanxi coal is generally of high calorific value (6000 kcal/kg), mine-mouth power generation and long distance transmission of electricity are likely to be justified only in the case of use of middlings, which should be increasingly available as a by

⁴³World Bank. CHINA, The Transport Sector. p.211-215

product of coal washing.

Preliminary plans by the Ministry of Water Resource and Electric Power envisage the development of 45,000 to 60,000 megawatts of thermal capacity at mine-mouth (of which 25,000 to 35,000 megawatts would be in North China, i.e. Shanxi and adjacent areas of Nei Moggol and Shaanxi provinces), and 50,000 to 60,000 megawatts at load centers in Northeast, East, and South China. Increased capacity at load centers would require transport of some 150 to 200 million tons of coal annually (calculated on the basis of 3 tons of coal per installed kilowatt), of which the Northeast, East and South China would account for 60 to 80 million tons, mostly from North China.

There may be significant constraints to locating power plants at the mine-mouth. Water availability is a potential problem. The cost of transporting coal from mine-mouth to a nearby location with a guaranteed water supply might have to be added to the mouth-power generation option. More comprehensive analysis should include consideration of a variety of additional costs or benefits for locating power plants, such as land use implications, or in the case of power transmission, possible additional benefits resulting from increased grid generation.

4.4 The Need for Comprehensive Planning

The above three strategies, however, have limited effectiveness for relieving coal transport pressure in China because of two reasons. First, they all involve some kind of investment which appears either as improving shipping capacities of transport networks, increasing coal production in consumption regions, or building new power plants near major coal mines. The realization of these strategies is largely dependent on funding resources. This is the most difficult problem in China right now. For example, China only has 1.1 percent of its GNP available for transport investment, which is low when compared with other countries (3.26 percent in Brazil and 4.6 percent in the US, for example). In addition, even if funds are available, it will take considerable time to finish such major construction projects. Secondly, they all deal with an individual aspect of the coal transport problem and can not by themselves solve the coal transport problem as a whole. Coal transport is not a problem merely limited to congested transport networks. Rather, it is a problem related to coal production, consumption, transport, and perhaps the transport of other commodities, too. A systematic approach to coal transport planning is necessary.

It is true that the uneven spatial distribution of coal resources and the saturated transport network account

for much of the present coal transport pressure. There are, however, additional causes of pressure. Irrational coal transport practices such as crosshauling and movements over long distance provide good examples. These irrational coal flows waste transport resources which, in turn, bring about significant coal transport pressure. The following is an example discussed by the World Bank. The Shentou power plant in the area of Datong Railway Sub-bureau does not use local coal for all of its needs, but rather imports more than 200,000 tons of coal from Songjiazhuang, and more than 200,000 tons from Yangfangkou annually. Yet, this is a coal producing area, annually shipping 740,000 tons of coal to other regions.⁴⁴ Since coal production, distribution, and consumption are managed by different governmental departments (Ministry of Coal Industry, Ministry of Railway, Ministry of Communication, National Economic Commission), the absence of well-coordinated arrangements can easily cause these irrational coal distributions.

Comprehensive optimal planning is, therefore, needed to correct these irrational coal distributions and address the coal transport problem systematically. By considering information on coal production and consumption, such as costs and market prices, and on existing transport

⁴⁴Bentjerodt, J. Coal Transport in China. World Bank Staff Working Papers. Washington, D.C.: World Bank. (1983). p.20

networks, such as shipping capacities and freight rates, an optimal coal allocation pattern for existing transport networks can be generated. If feasible, optimal planning can organize the shipment of coal out of production regions and meet all demands in consumption regions. Optimal planning, therefore, considers the three related components (production, consumption, and transportation) of the coal transport problem simultaneously. All of these ideas of optimal planning can be implanted in mathematical programming models, if sufficient information is available. The use of linear programming (LP) to address the coal distribution problem in China is the focus of the next chapter.

CHAPTER 5

LP APPLICATION OF OPTIMIZING COAL TRANSPORT IN CHINA

This chapter presents a pilot study to demonstrate the potential of a mathematical programming approach to coal transport in China. A simple linear programming model is used for illustrative purposes. The results provide an optimal coal allocation pattern as well as dual analysis which can be used to indicate where investment improvement would generate the greatest benefit. Due to data limitations, only the railway network is considered in this study.

5.1 The Coal Transport Network In China

Before using the linear programming model (LP), it is necessary to define the basic transportation network of China in terms of its topological structure (Figure 5-1). In general, the Chinese railway network can be defined in terms of nodes and arcs.

5.1.1 Nodes

Nodes are the vertices on the existing network graph which act as either supply points, transportation hubs, or demand points. These nodes correspond to the major cities in China. Among them, C1 to C6 are those cities which act

only as transportation hubs. Net demands and supplies of coal in these cities are assumed to be zero. A to Z are the capital cities for each province which are assumed to represent the aggregate demands or supplies of coal in the province as a whole. This is a reasonable assumption when one considers the coal allocation system in China.

Basically, there are two types of coal allocation: (1) a central allocation system, and (2) a provincial allocation system. Centrally distributed coal, comprising some 55 percent of output in the nation, consists of coal produced in centrally controlled mines which are directly controlled by the Ministry of Coal Industry (MOCI). Any decisions about coal production and distribution in these centrally controlled mines are solely determined by the MOCI. The management of central mines generally has no relationship with the provincial administration. The distribution of coal output from the central mines is guided by the central government's general economic plan. Under this plan, coal is supplied to both centrally controlled enterprises (mostly located in the capital cities of the provinces) and to the provincial administrations, which in turn allocate the coal to subdivisions under their control.

Provincially distributed coal, comprising some 30 percent of national output, consists of coal produced in most provincial mines. Coal produced in provincial mines is used mainly to supplement coal demands of each province

once the central allocations have been made. This coal is used first to meet the demands of the capital cities of the provinces. Thus, for both coal distribution systems, the capital city of each province is the largest receiver of coal. In addition, the capital city of each province is generally the major hub for the railway network within that province and, therefore, the largest origin and destination of coal flows within the province.

There are, however, some distortions in this assumption. For example, Shanxi coal production is concentrated in Datong and Yanquan. Most of the coal originates from these two cities rather than Taiyuan, the capital of the province. These possible distortions can be easily corrected by further data collection.

5.1.2 Arcs

Arc are the simplified form of the original railways. Each arc is unique and has the characteristics of (1) a single origin, (2) a single destination, and (3) distance and cost values associated with it. Because of lack of data, the allowable flow capacities of all arcs are assumed to be infinite. The length of arcs represent the actual distance between two cities connected by that railway. The LRMC cost of 0.02 Y/kmt is adopted as the average freight rate of shipping coal by rail, and it is assumed to be uniform for all railways in China. The shipping costs of

coal between any two cities are, therefore, proportional to the distance between them.

5.2 The Linear Programming Model

Linear programming has been widely used to solve problems of optimal planning such as diet problems, machine-loading problems, production-scheduling problems, and transportation problems. In general, linear programming tends to be associated with complex situations, many variables, and a general objective of optimizing some criterion which measure the effectiveness of the given system, such as profit or cost.

The optimal allocation of coal flow in this study is essentially a transportation problem which was initially proposed by Hitchcock in 1941 and independently by Koopmans in 1947. The transportation problem is a classic linear programming problem. It is generally concerned with shipping a resource from a number of origins to a number of destinations at a minimal cost. The precondition, however, is to know the demands at destinations, supplies available at the origins, and cost of shipping the resource.

Linear programming models have been successfully used to study transportation problems in many developing countries. For example, Kresge and Roberts applied LP to model the commodity flows of imports and exports in Colombia, and Ralston and Ray employed LP for food

distribution planning in Africa. As Ray identified in his African food distribution study, there are many advantages of using LP to solve resource distribution problems:⁴⁵

First, if the problem is mathematically feasible, an optimal solution is guaranteed. Secondly, commercial LP codes enable large complex problems to be solved efficiently on both micro and mainframe computers. Thirdly, marginal economic information is available through interpretation of dual as a set of shadow prices. Thus, information regarding areas of greatest potential investment is readily available by examination of the dual interpreted as a set of shadow prices.

LP is, therefore, a suitable way to solve the current coal transport problem in China.

5.3 The LP Model Used In This Study

The LP model used in this study focuses on optimizing coal transport by railways. Due to data constraints, the model has been modified in order to fit the available information. The most important change is that shipping capacities have been assumed to be infinite. Before the actual formulation of the LP model is presented, it is necessary to understand the notation and meaning of variables used in the model.

⁴⁵Ray, J. A Multi-Period Linear Programming Model for Optimally Scheduling the Distribution of Food-Aid in West Africa. Knoxville, Tennessee: The University of Tennessee. (1987). p. 21-22.

5.3.1 Notation

The notation used in this study is as follows:

$\{i\}$ = an index of arcs, where $i = 1, 2, \dots, I$.

$\{j\}$ = an index of nodes, where $j = 1, 2, \dots, J$.

AF_i = the volume of coal flow along arc (i) .

CA_i = the shipping cost of coal flow along arc (i) .

A_{ij} = 1, if arc (i) enters node (j) , -1 if arc (i) leaves node (j) , and 0 otherwise.

D_j = demand of coal at node (j) .

5.3.2 Variables and Constraints

All variables and constraints can be displayed in a LP tableau. In this tableau, variables are defined in the columns while constraints are defined in rows. Variables and constraints are linked by dependency coefficients. For this study, these coefficients can be +1, -1, or 0. If any arc (i) enters a node (j) , then a coefficient value of +1 will be typed on the tableau which indicates the destination for that arc. If any arc (i) leaves a node (j) , then a coefficient value of -1 will be typed on the tableau which indicates the origin for that arc.

Each arc has two decision variables. They are twins of each other and have reversed dependency coefficients. For example, if an arc enters any node (j) , its dependency coefficient is a +1, and the dependency coefficient for its twin is -1.

There is essentially only one type of constraint in this study, a demand constraint. The demand constraints, however, can have different meanings for the nodes depending on their right hand side values. If the right hand side value is positive, node (j) is a true demand node and indicates shortage of coal in this node. If the right hand side value is negative, node (j) has surplus coal, expressed as a negative demand. If the right hand side value is zero, then node (j) has neither demand nor supply of coal. This kind of node is called a conservation of flow node. The constraint at a conservation node guarantees that every unit of coal flow entering the node will also leave it.

5.3.3 Formulation of the LP Model

The formulation of LP model used in this study can be stated as:

$$(1) \quad \text{Min } \sum_{i=1}^I CA_i AF_i$$

Subject to:

$$(2) \quad \sum_{i=1}^I A_{ij} AF_i \geq D_j \quad \text{for all nodes (j)}$$

$$(3) \quad AF_i \geq 0 \quad \text{for all arcs (i)}$$

The objective function (1) is to minimize the total cost of shipping coal along all the arcs. Constraint (2)

states that the sum of all coal flows along the arcs to node (j) has to be greater than or equal to the demand of that particular node. No coal will be left at the conservation nodes. The result is to meet demands at a minimized cost. Constraint (3) means that all the values for decision variables have to be nonnegative.

5.4 Data Input

A pre-processor written in Professional Fortran takes data from two raw data files and constructs the appropriate MPS file. The two raw data files are a node file (Appendix A) and an arc file (Appendix B). The node file consists of node names and values representing coal demand (positive) and supply (negative). The arc file consists of names of origin nodes, name of destination nodes, transport mode, shipping costs, and a flag representing whether or not the twin flow exists. The flag of 0 indicates the existence of twin flows.

For the test problem, there are 32 nodes, 42 arc flow variables, and 37 twin flow variables. LP83 was used solve the problem.⁴⁶ Results generated by LP83 are shown in Appendices C and D. The optimal allocation of coal flows on the existing transport network, based on the LP results, is displayed in Figure 5-1.

⁴⁶LP83 Version 5.00, Sunset Software, San Marino, California. (1985)

5.5 Interpretation of the LP results

There are two ways of interpreting LP results: primal interpretation and dual interpretation. In this study, the primal interpretation provides information on the optimal allocation of coal flows. We can identify three heavy flows directed towards the Northeast, the East, and the South Central parts of China, respectively. The Northeast flow is from Taiyuan, through Beijing and Qinghuangdao, to Shenyang. The South Central flow is from Taiyuan, through Zhengzhou, Wanhua, and Changsha, to Guangzhou. The East flow starts from Taiyuan, through Shijiazhuang, Dezhou, Jinan, Xuzhou, Bengbu, Nanjing, and Shanghai, and ends at Hangzhou. This East flow is shipped mostly along the coastal railway and is the heaviest coal flow. Taiyuan in Shanxi Province provides the largest coal supply for all three heavy flows.

Comparing Figures 5-1 and 5-2, some inefficient coal flows in 1980 have been identified. For example, coal flow from Taiyuan to Zhengzhou seems inefficient on Figure 5-2. Coal was first moved out of Taiyuan and then sent to a northern city--Tianjing. Then, about 5.9 million tons of coal was transported from Tianjing down to Zhengzhou, which is located to the southeast of Taiyuan. This shipment went through the busiest rail trunk line of Northern China to Southern China. The reduced costs for the three arcs connecting Tianjing and Zhengzhou are ¥6.44 (arc 10), ¥7.6

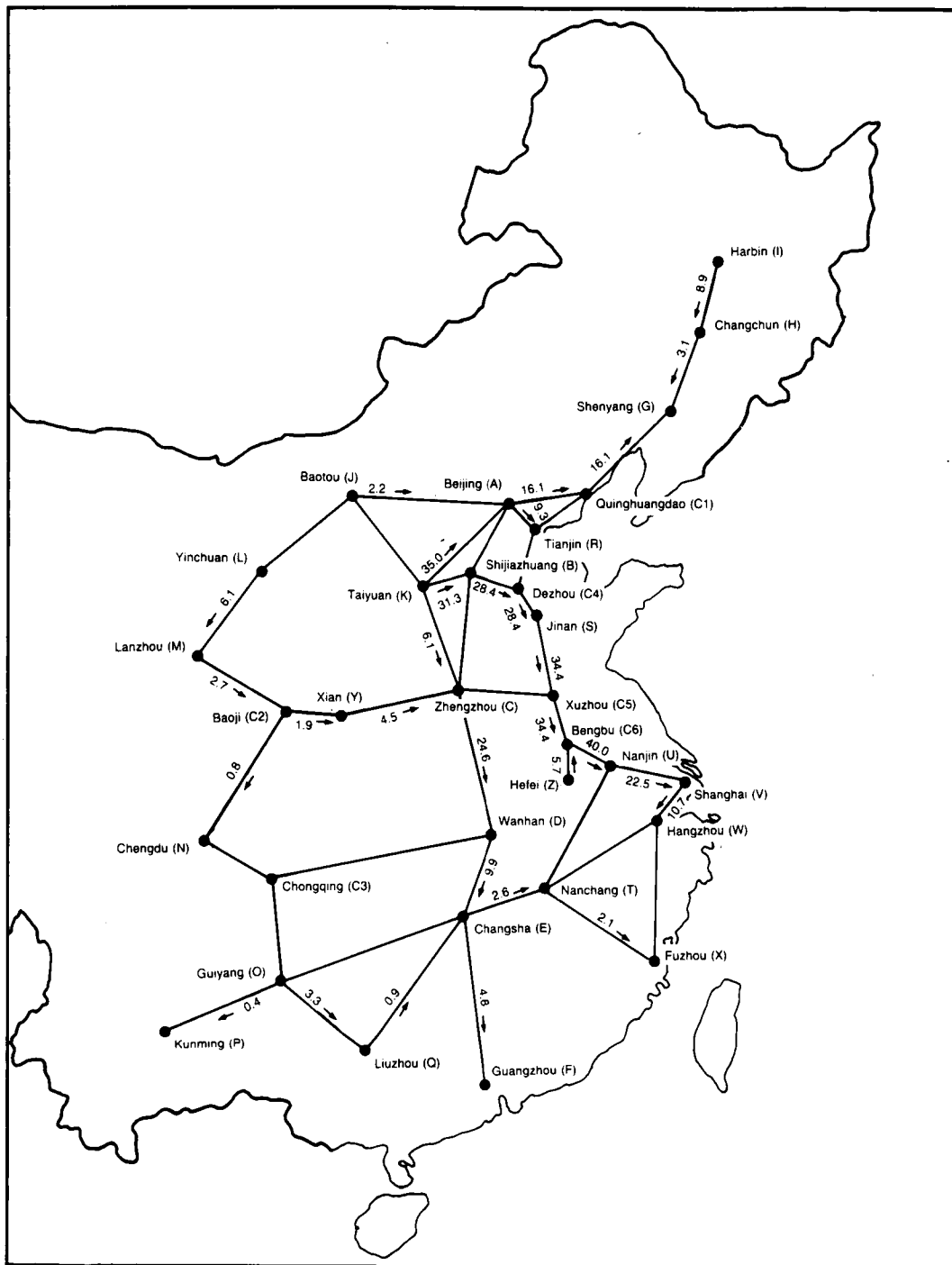


Figure 5-1

Railway Network and Optimal Allocation of Coal Flows

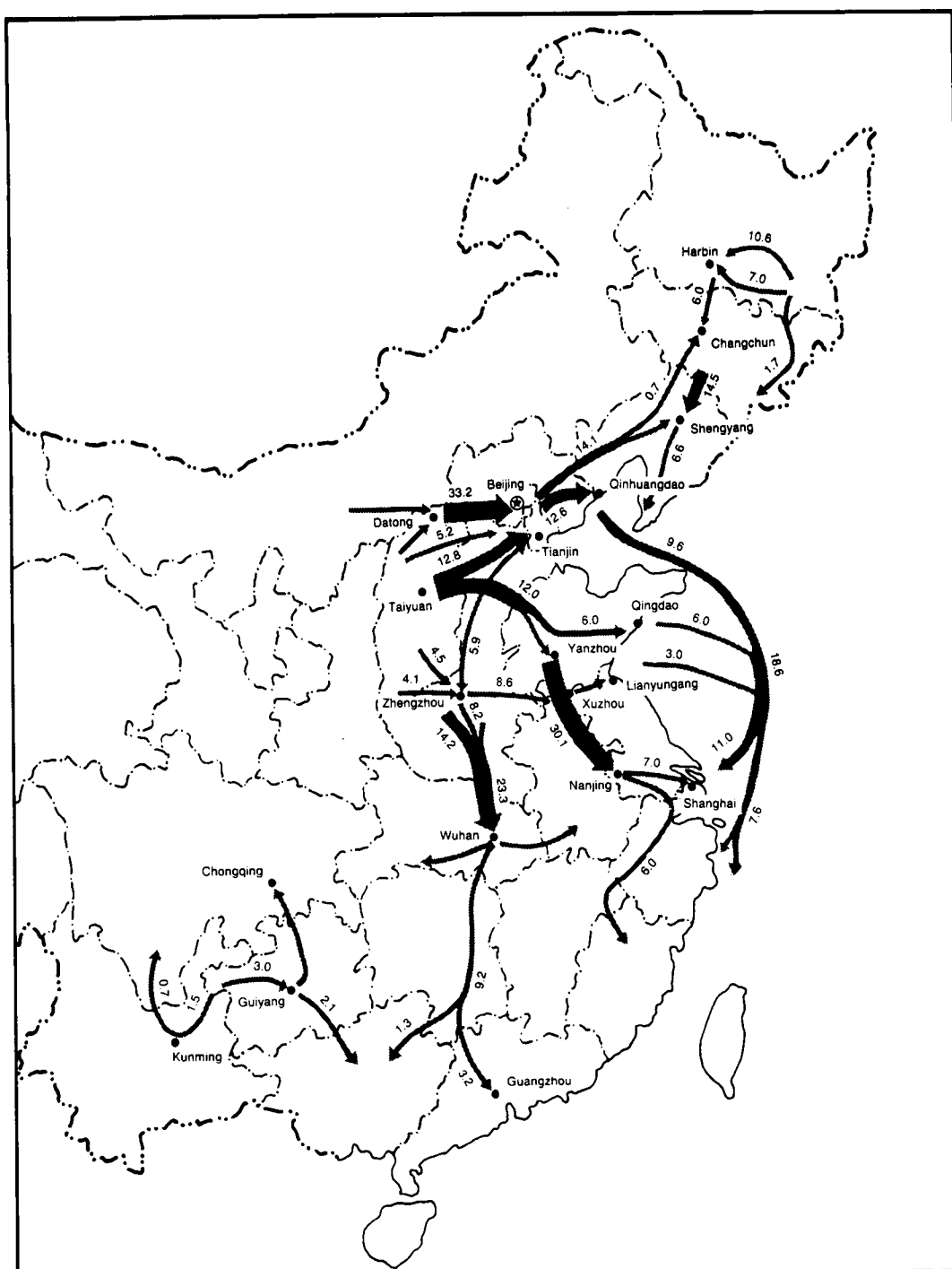


Figure 5-2

Actual Coal Flows on Railways in 1980.

(arc 15), and Y2.56 (arc 16), respectively.

In fact, there is a direct rail line between Taiyuan and Zhengzhou. In the optimal coal allocation pattern of Figure 5-1, this line is assigned a coal flow of 6.1 million tons (assuming unlimited shipping capacity). Obviously the potential advantages of this rail line have been realized by the Chinese government. The electrification project, which is highly selective, has been adopted on this line to increase its shipping capacity.

The interpretation of dual values from LP solutions may provide valuable economic information on the marginal costs of decision variables and constraints. The dual values for constraints (also called shadow prices) indicate the savings which would accrue from altering the right hand-side values of the constraints. For example, the shadow prices for supply constraints will indicate the increased earning revenue, or location rent, per ton of coal increase at production points. The highest value of this shadow price will signify the best coal production point with the highest location rent. As Appendix D shows, the location of coal production in the North generally has a lower location rent than the locations of coal production in the Northeast, East, and South Central regions. The location rents for coal mines in Harbin, Jinan, Guiyang, and Zhengzhou are Y25.44, Y24.52, Y25.30, and Y24.36, respectively, which

indicates the savings for locating per ton of coal production in these areas. The coal production in Hefei has the highest location rent which means it is the most favorable location to increase coal production and investment. The location rent for Taiyuan, on the other hand, is only Y14.76 which is much lower than the coal productions in those coal demanding areas. The interpretation of location rent, therefore, provides some support to the strategy of increasing coal production in coal deficit area wherever the mining conditions are favorable. This conclusion, however, is based on a problem with no production costs. If the data for production costs are available, the location rents derived in this study would undoubtedly be different. Since coal production costs in the Southeast are generally higher than those in the North, the location rents for coal production in the Southeast may be lower than what were derived from this study.

The shadow prices for demand constraints will indicate the delivered prices per ton increases of demand at the consumption points. The highest value of shadow prices will signify the most expensive coal demand point. As Appendix D shows, most demand points along the Southeast coast have high delivered costs of coal by rail when compared to those inland points. For example, the delivered prices for Shanghai, Hangzhou, Fuzhou and

Guangzhou are Y41.52, Y45.30, Y61.08, and Y51.44, respectively. Among them, Fuzhou has the highest delivered price.

Among all the shadow prices, it is those associated with shipping capacity constraints that would provide the most valuable and accurate information on potential investment selections. In general, those arcs having high shadow prices on shipping capacity constraints should be given high priority in terms of investment. Unfortunately, this study cannot provide such information. There are no data available for shipping capacity on the railway network of China. These data have to be collected through field work.

The lack of shipping capacity data does not mean that this study reaches a dead end. We are still able to find alternative ways to yield similar information on investment potential of railway arcs. This can be done by comparing the optimal coal allocation map (Figure 5-1) with the actual characteristics of the transportation network (Figure 3-1).

In Figure 5-1, there are three major railway arcs used to ship coal out of Shanxi province to the Northeast, the East, and the South Central parts of China: Taiyuan--Beijing, Taiyuan--Shijiazhuang, and Taiyuan--Zhengzhou. All these arcs have been, or will be, electrified. A potential problem exists for the railway arc from

Shijiazhuang to Dezhou. This arc is part of the heavy coal flow path. We can see that west of this arc is the electrified railway arc of Taiyuan to Shijiazhuang. There will be a large amount of coal (31.3 million tons as indicated on Figure 5-1) shipped along the Shijiazhuang--Dezhou rail line from the west. East of this arc, coal flows can be diverted along several paths: from Dezhou to the port of Qingdao, or from Dezhou down further south along the coastal railways. The Shijiazhuang--Dezhou arc has the potential of becoming a 'bottleneck' due to limited shipping capacity. Based on this preliminary analysis, investment in this arc seems warranted.

CHAPTER 6

CONCLUSION AND PROBLEMS FOR FURTHER STUDY

Constrained coal transport has been identified as a serious problem in China. It has substantially affected coal production, consumption, and the balance of coal supply and demand nationwide. The foreseeable negative effect of constrained coal transport on the economic development of China is considerable because of its pressures on both the transport and energy sectors.

Many intelligent suggestions have been presented to relieve the coal transport pressure in China. Highways and waterways are believed to have great potential for diverting heavy coal flow from railways, since both are not yet fully utilized. Mine-mouth power generation and transmission of electricity will be an alternative economic strategy, avoiding the transport of low quality coal. In any event, the concentration of coal production in Northern China will not change for the foreseeable future due to the enormous quantity and high quality of its coal reserves. Coal from the Northern mines will continue to provide the largest supply to the national coal market. The coal flow volume from Northern mines to the Northeast, the East, and the Southcentral regions will be further increased in the future. The large-scale transport of coal will persist,

and the average transport distance of coal will become greater. It is the efficient long distance transport modes that provide the ultimate solution for balancing coal production and consumption in China. Rail is still the dominant transport mode for coal. However, it will be very difficult to accommodate large-scale coal transport by railway alone. Having similar characteristics for long distance coal transport, waterways or rail-water combinations provide promising alternatives.

Even with limited data, the interpretation of LP results suggests that transporting coal by waterways or by a water-rail combination are viable options. The heavy coal flow along coastal railways and the high delivered prices for most coastal cities by rail alone support the notion of coastal shipping of coal. The southeast coastal areas are the most developed industrial and agricultural regions of China. The transport of raw materials, industrial and agricultural products as well as passenger flows to this region already has caused enormous pressure on the coastal railway. Further development of coastal shipping can divert some coal flows from the coastal railway and, therefore, relieve pressures on the coastal railway.

In fact, there are advantages to develop coastal shipping of coal in this area. Most rail nodes have easy access to ports, and some nodes, such as Nanjing and

Shanghai, are actually functioning as both rail yards and ports. If the savings from increasing coal shipments by waterway is greater than the cost of transshipment from rail cars to ships, coastal shipping of coal should be greatly increased. Further study is necessary in order to provide complete assessment of the rail-water combination.

Direct investment on a rail or rail-water combination may provide a solution for increasing shipping capacities, thus relieving the current coal transport pressure. Electrification, double-tracking, more powerful steam and diesel locomotives, and self-loading ships are suitable methods to reach this objective. A priority selection of the most urgent steps is necessary in order to invest the limited financial resources of China more effectively and productively.

Linear programming could provide a means for priority selection. The interpretation of dual values gives valuable information on which arcs are constrained and what the savings should be for investment on constrained arcs. In addition, dual analysis will also indicate the best places to locate coal production, and the most expensive places to deliver coal.

The primary purpose of using LP in this study, however, is to demonstrate its potential utility for optimal planning of coal transport in China. Coal transport in China is not a problem merely limited to a

constrained transport network. It encompasses problems associated with coal production, consumption, and the characteristics of the existing transport network, and the competition of numerous commodities vying for railway attention. In the review of Chinese literature on the subject, several different opinions for solving the coal transport problem in China were presented. The ideas of either limiting coal production to transportable capabilities or only focusing on increasing shipping capacities will not fundamentally resolve the coal transport problem in China. To effectively solve the problem, it is necessary to conduct systematic planning which will include all sectors related to coal transport. Optimal planning of coal flows supported by LP modeling is such a systematic approach.

Optimal planning actually considers many of the related aspects of the coal transport problem. In an actual planning context, coal flows must be allocated to the existing railway network and various investment strategies must be considered based on more complete LP results. In the short run, results from the simple transportation problem can be used to highlight irrational coal flows such as those which occurred in 1980, providing immediate relief of present coal transport pressure.

At present, the lack of sufficient data is a pressing problem, inhibiting further study of coal transport

considerations in China. This study was limited by such data constraints. For example, the freight rate for coal was assumed to be uniform for all railway arcs in China. This obviously is not true. The actual rates may vary considerably across the country because of economies of scale. The lack of coal production costs forces the LP model to calculate optimal coal allocation solely on the transportation costs. Although waterways and highways are recognized as important alternatives to divert coal flows from railways, they were not considered in the model because there were no data available. Other assumptions for using the LP model were made under similar circumstances. For example, all the railways are assumed unconstrained because of lack of data on shipping capacities. Dual analysis for investment priority selection was, therefore, impossible. But it could be done if the data were available.

There is still much to be done in studying coal transport in China. This study can be viewed as a preparation for more complex modeling study of coal transport in China. My intention is to carry this study further on a more detailed level, using additional nodes rather than simply capital cities of each province. It will also include modes of waterway and highway transport in addition to railway transport. The overall direction of further study should focus on the following problems:

intensive data collection needs, transshipment consideration, locational studies and the effect of price distortion. Each of these problems is discussed briefly in turn in the following subsections.

6.1 Intensive Data Collection

Data required for further study can be assigned to two categories: coal data and transport network data. The coal data include coal production, storage, consumption, production cost, and retail pricing; transport network data include shipping capacity, freight rate, distance, network layout, transshipments, and modal combination of railways, highways and waterways. Among these data, coal production, consumption, and shipping capacity data are most urgently required for the purpose of optimal planning.

6.2 Transshipment

Transshipment refers to the situation in which coal is loaded from one type of transport mode (such as rail) to another (such as river barge). This is a very common phenomenon in the coal distribution system of China. Since rail only connects the major cities, most small scale coal distributions have to be accomplished by truck, which involves unloading the coal from trains and loading it on trucks. At present, the most interesting coal transshipment problem is with combined rail-water coal

transport. As we saw in the previous chapters, there may be, indeed, advantages of a combined rail-water transport system in the eastern coastal areas. However, a detailed analysis which includes transshipment cost is necessary to make the final decision.

6.3 Location Studies

Some location studies are necessary for relieving coal transport pressure. Location of mine-mouth power plants and industries relying heavily on coal are particularly important. Optimal location of power plants and industries could reduce considerably the amount of coal movements on the transport network and, therefore, greatly reduce present transport pressures. In locating both power plants and industries in the major coal producing areas, water availability is a common constraint to which should be paid particular attention.

6.4 Price Distortion

Price distortion has been identified as an important factor that induces increased coal transport pressure. The direct effects of distorted coal prices are that they increase average coal transport distances and reduce the incentives of developing coal production at favorable consumption areas. For the purpose of optimal planning, realistic estimates of coal production costs, freight

rates, and delivered prices are very important.

6.5 Summary Remarks

The ultimate goal of coal transport studies for China is to provide a comprehensive plan of investment and coal transport which relieves the current coal transport pressure, and balances coal production and consumption on a nationwide scale. The LP model used in this study is very simple. In reality, the Chinese coal transport problem is further complicated by differing scales of analyses, coal varieties, distorted prices, economies of scale in transport and production, seasonal changes in coal demands, and the possible lack of cooperation among different governmental agencies. For accurate planning, more complex models should be developed.

The requirements of a linear objective function and constraints for LP models limit their ability to include behavioral considerations and economies of scale. Decision-making entities, such as shippers and carriers, are very important in the planning of coal transport system since their cooperation directly affects the success of coal transport. The influence of carriers and shippers may be presented as a nonlinear arc or node cost function. In addition, transport costs will not be linear functions of distances if the economies of scale are considered. Instead, transport cost will be a nonlinear function of

both distance and freight volumes. The objective function of this modeling, therefore, may become nonlinear. When this type of modeling study is completed, the results of optimal planning will, it is hoped, provide valuable information for coal transport planning in China.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Bradley, S. P., A. C. Hax, and T.L. Magnanti. Applied Mathematical Programming. Reading, Massachusetts: Addison-Wesley Publishing Company. (1977).
- CACI, Inc. Transportation Network Models for Energy Supply Analysis. Vol. 3-4. Arlington, Virginia: Electric Power Research Institute, Inc. (1982).
- Chinese Government. Proceedings of the Academic Conference on the Shipment of Shanxi Coal. Beijing: Documents of Chinese Government. (1985). (in Chinese)
- Coyle, J. J., E. J. Bardi, and J.L. Cavinato. Transportation. St. Paul, Minnesota: West Publishing Company. (1986).
- Daughety, A. F., M. A. Turnquist, and S. L. Griesbach. "Estimating Origin-Destination Specific Railroad Marginal Operating Cost Function," Transportation Research, Vol.17A, No.6, (1983). p. 451-462.
- Elmes, G. "Coal Transportation: An Undervalued Aspect of Energy Modeling?" Transportation Research, Vol.18A, No.1, (1984). p. 13-23.
- Friesz, T. L., R. L. Tobin, P. T. Harker. "Predictive Intercity Freight Network Models: the State of the Art," Transportation Research, Vol.17A, No.6, (1983). p. 409-417.
- Friesz, T. L. "Transportation Network Equilibrium, Design and Aggregation: Key Developments and Research Opportunities," Transportation Research, Vol.19A, No.5/6, (1985). p.413-427.
- Friesz, T. L., J. Gottfried, and R. L. Tobin. "Analyzing the Transportation Impacts of Increased Coal Haulage: Two Case Studies," Transportation Research, Vol.17A, No.6, (1983). p.505-525.
- Gass, S. I. Linear Programming. New York: McGraw-Hill, Inc. (1985).
- Hadley, G. Linear Programming. Readings, Massachusetts: Addison-Wesley Publishing Company, Inc. (1962).
- Harker, P. T. Predicting Intercity Freight Flows. Utrecht, The Netherlands: VNU Science Press BV. (1987).

- Harker, P. T., and T. L. Friesz. "The Use of Equilibrium Network Models in Logistics Management: With Application to the U.S. Coal Industry," Transportation Research, Vol.19B, No.5, (1985). p. 457-470.
- Hoyle, B.S. Transport and Development. New York: Harper & Row Publishers, Inc., Barnes & Noble Import Division. (1973).
- Jia, Yunzhen. "Transportation of Coal in China," Coal--Trade, Transportation & Handling. Vol.4, (1986). p. 131-134.
- Kraft, G., J. R. Meyer, and J. P. Valette. The Role of Transportation in Regional Economic Development. Lexington, Massachusetts: D.C. Health and Company. (1971).
- Kresge, D. T. and P. O. Roberts. Systems Analysis and Simulation Models. Edited by J. R. Meyer: Technique of Transport Planning. Washington, D.C.: The Brookings Institution. (1971)
- Leblanc, L. J., E. K. Morlok, and W. P. Pierskalla. "An Efficient Approach to Solving the Road Network Equilibrium Traffic Assignment Problem," Transportation Research, Vol.9, (1975). p. 309-318.
- McGurk, S. J. CHINA, Coal Transport Planning Study. Washington, D.C.: World Bank, (1987).
- Ratick, S. J., and J. P. Osleeb. "Optimizing Freight Transshipment: An Evaluation of East Coast Coal Export Options," Transportation Research, Vol.17A, No.6, (1983). p. 493-504.
- Ray, J. A Multi-Period Linear Programming Model for Optimally Scheduling the Distribution of Food-Aid in West Africa. Unpublished M.S. thesis, Department of Geography, Knoxville, Tennessee: The University of Tennessee. (1987).
- World Bank, CHINA, Long-Term Development Issues and Options. Washington, D.C.: World Bank, (1985).
- World Bank, CHINA, The Energy Sector. Washington, D.C.: World Bank, (1985).
- World Bank, CHINA, The Transport Sector. Washington, D.C.: World Bank, (1985).

APPENDICES

APPENDIX A

NODE FILE

Node Name	City	Coal Demand
A	Beijing	11.80
R	Tianjin	9.30
B	Shijiazhuang	2.90
G	Shenyang	19.20
H	Changchun	5.80
V	Shanghai	11.80
U	Nanjing	17.60
W	Hangzhou	10.70
T	Nanchang	0.50
X	Fuzhou	2.10
D	Wanhan	14.70
E	Changsha	3.40
F	Guangzhou	4.80
Q	Liuzhou	2.40
N	Chengdu	0.80
P	Kunming	0.40
M	Lanzhou	3.40
J	Baotou	-2.20
K	Taiyuan	-72.40
I	Harbin	-8.90
Z	Hefei	-5.70
S	Jinan	-6.00
C	Zhengzhou	-14.00
O	Guiyang	-3.70
Y	Xian	-2.60
L	Yinchuan	-6.10
C1	Qinhuangdao	0.00
C2	Baoji	0.00
C3	Chongqing	0.00
C4	Dezhou	0.00
C5	Xuzhou	0.00
C6	Bengbu	0.00

APPENDIX B

ARC FILE

Arc	Origin	Destination	Mode	Unit Cost/ <u>a</u>	Twin flow
1	I	H	RL	4.80	1
2	H	G	RL	6.00	0
3	G	C1	RL	8.48	0
4	C1	A	RL	5.40	0
5	C1	R	RL	5.00	0
6	J	A	RL	13.20	1
7	A	R	RL	2.40	0
8	A	K	RL	7.60	0
9	A	B	RL	5.20	0
10	R	C4	RL	4.00	0
11	J	L	RL	10.72	0
12	J	K	RL	14.00	0
13	K	C	RL	9.60	1
14	K	B	RL	3.76	1
15	B	C4	RL	3.80	0
16	B	C	RL	8.40	0
17	C4	S	RL	2.20	0
18	S	C5	RL	4.80	0
19	L	M	RL	6.20	0
20	M	C2	RL	6.40	0
21	C2	Y	RL	3.20	0
22	Y	C	RL	8.56	0
23	C	C5	RL	6.98	0
24	C2	N	RL	10.40	0
25	C	D	RL	10.28	0
26	C5	C6	RL	3.20	0
27	Z	C6	RL	2.40	1
28	C6	U	RL	3.40	0
29	U	V	RL	5.60	0
30	U	T	RL	16.58	0
31	T	W	RL	12.72	0
32	T	X	RL	12.44	0
33	E	T	RL	7.20	0
34	E	F	RL	10.00	0
35	E	Q	RL	4.00	0
36	C3	O	RL	6.80	0
37	D	E	RL	6.80	0
38	O	E	RL	16.72	0
39	O	Q	RL	12.14	0
40	O	P	RL	10.60	0
41	V	W	RL	3.78	0
42	W	X	RL	19.44	0

a Unit cost = distance(km) x 0.02 Y/kmt.

APPENDIX C

OPTIMAL ALLOCATION OF COAL FLOWS

Arcs/a		Volume(mt)	Cost(Y)	Reduced Cost(Y)
"ARC 1	",	8.9000,	4.8000	0.0000
"ARC 2	",	3.1000,	6.0000	0.0000
"TARC 2	",	0.0000,	6.0000	12.0000
"ARC 3	",	0.0000,	8.4800	16.9600
"TARC 3	",	16.1000,	8.4800	0.0000
"ARC 4	",	0.0000,	5.4000	10.8000
"TARC 4	",	16.1000,	5.4000	0.0000
"ARC 5	",	0.0000,	5.0000	8.0000
"TARC 5	",	0.0000,	5.0000	2.0000
"ARC 6	",	2.2000,	13.2000	0.0000
"ARC 7	",	9.3000,	2.4000	0.0000
"TARC 7	",	0.0000,	2.4000	4.8000
"ARC 8	",	0.0000,	7.6000	15.2000
"TARC 8	",	35.0000,	7.6000	0.0000
"ARC 9	",	0.0000,	5.2000	9.0400
"TARC 9	",	0.0000,	5.2000	1.3600
"ARC10	",	0.0000,	4.0000	6.4400
"TARC10	",	0.0000,	4.0000	1.5600
"ARC11	",	0.0000,	10.7200	19.8800
"TARC11	",	0.0000,	10.7200	1.5600
"ARC12	",	0.0000,	14.0000	8.4000
"TARC12	",	0.0000,	14.0000	19.6000
"ARC13	",	6.1000,	9.6000	0.0000
"ARC14	",	31.3000,	3.7600	0.0000
"ARC15	",	28.4000,	3.8000	0.0000
"TARC15	",	0.0000,	3.8000	7.6000
"ARC16	",	0.0000,	8.4000	2.5600
"TARC16	",	0.0000,	8.4000	14.2400
"ARC17	",	28.4000,	2.2000	0.0000
"TARC17	",	0.0000,	2.2000	4.4000
"ARC18	",	34.4000,	4.8000	0.0000
"TARC18	",	0.0000,	4.8000	9.6000
"ARC19	",	6.1000,	6.2000	0.0000
"TARC19	",	0.0000,	6.2000	12.4000
"ARC20	",	2.7000,	6.4000	0.0000
"TARC20	",	0.0000,	6.4000	12.8000
"ARC21	",	1.9000,	3.2000	0.0000
"TARC21	",	0.0000,	3.2000	6.4000
"ARC22	",	4.5000,	8.5600	0.0000
"TARC22	",	0.0000,	8.5600	17.1200
"ARC23	",	0.0000,	6.9800	2.0200
"TARC23	",	0.0000,	6.9800	11.9400

(Continued)

Arc		Volume(mt)	Cost(Y)	Reduced Cost(Y)
"ARC24	"	0.8000,	10.4000	0.0000
"TARC24	"	0.0000,	10.4000	20.8000
"ARC25	"	24.6000,	10.2800	0.0000
"TARC25	"	0.0000,	10.2800	20.5600
"ARC26	"	34.4000,	3.2000	0.0000
"TARC26	"	0.0000,	3.2000	6.4000
"ARC27	"	5.7000,	2.4000	0.0000
"ARC28	"	40.1000,	3.4000	0.0000
"TARC28	"	0.0000,	3.4000	6.8000
"ARC29	"	22.5000,	5.6000	0.0000
"TARC29	"	0.0000,	5.6000	11.2000
"ARC30	"	0.0000,	16.5800	3.8600
"TARC30	"	0.0000,	16.5800	29.3000
"ARC31	"	0.0000,	12.7200	16.0600
"TARC31	"	0.0000,	12.7200	9.3800
"ARC32	"	2.1000,	12.4400	0.0000
"TARC32	"	0.0000,	12.4400	24.8800
"ARC33	"	2.6000,	7.2000	0.0000
"TARC33	"	0.0000,	7.2000	14.4000
"ARC34	"	4.8000,	10.0000	0.0000
"TARC34	"	0.0000,	10.0000	20.0000
"ARC35	"	0.0000,	4.0000	8.0000
"TARC35	"	0.9000,	4.0000	0.0000
"ARC36	"	0.0000,	6.8000	0.0000
"TARC36	"	0.0000,	6.8000	13.6000
"ARC37	"	9.9000,	6.8000	0.0000
"TARC37	"	0.0000,	6.8000	13.6000
"ARC38	"	0.0000,	16.7200	0.5800
"TARC38	"	0.0000,	16.7200	32.8600
"ARC39	"	3.3000,	12.1400	0.0000
"TARC39	"	0.0000,	12.1400	24.2800
"ARC40	"	0.4000,	10.6000	0.0000
"TARC40	"	0.0000,	10.6000	21.2000
"ARC41	"	10.7000,	3.7800	0.0000
"TARC41	"	0.0000,	3.7800	7.5600
"ARC42	"	0.0000,	19.4400	3.6600
"TARC42	"	0.0000,	19.4400	35.2200

/a "TARC" means the twin arc which has opposite flow direction from its correspondent arc flow.

APPENDIX D

BALANCE OF COAL SUPPLIES AND DEMANDS

Nodes	Activity(mt)	RHS(mt)	Dual(Y)
Beijing	11.8000	11.8000	22.3600
Tianjin	9.3000	9.3000	24.7600
Shijiazhung	2.9000	2.9000	18.5200
Shenyang	19.2000	19.2000	36.2400
Changchun	5.8000	5.8000	30.2400
Shanghai	11.8000	11.8000	41.5200
Nanjing	17.6000	17.6000	35.9200
Hangzhou	10.7000	10.7000	45.3000
Nanchang	0.5000	0.5000	48.6400
Fuzhou	2.1000	2.1000	61.0800
Wanhan	14.7000	14.7000	34.6400
Changsha	3.4000	3.4000	41.4400
Guangzhou	4.8000	4.8000	51.4400
Liuzhou	2.4000	2.4000	37.4400
Chengdu	0.8000	0.8000	23.0000
Kunming	0.4000	0.4000	35.9000
Lanzhou	3.4000	3.4000	6.2000
Baotou	-2.2000	-2.2000	9.1600
Taiyuan	-72.4000	-72.4000	14.7600
Harbin	-8.9000	-8.9000	25.4400
Hefei	-5.7000	-5.7000	30.1200
Jinan	-6.0000	-6.0000	24.5200
Zhengzhou	-14.0000	-14.0000	24.3600
Guiyang	-3.7000	-3.7000	25.3000
Xian	-2.6000	-2.6000	15.8000
Yinchuan	-6.1000	-6.1000	0.0000
Qinhuangdao	0.0000	0.0000	27.7600
Baoji	0.0000	0.0000	12.6000
Chongqing	0.0000	0.0000	18.5000
Dezhou	0.0000	0.0000	22.3200
Xuzhou	0.0000	0.0000	29.3200
Bengbu	0.0000	0.0000	32.5200

VITA

Jun Hu was born in Dunhuang City (a small town known as the "Pearl of the Silk Road"), People's Republic of China on May 20, 1965. He attended elementary school in that city and was graduated from Dunhuang High School in July 1981. He then attended Lanzhou University, People's Republic of China, and in July 1985 he received a Bachelor of Science degree in Geography. After working at Lanzhou University as a teaching assistant for one year, he accepted a graduate assistantship in the Department of Geography at the University of Tennessee, Knoxville, in 1986 and began work towards a Master's degree. He received a Master of Science degree in Geography in December 1988.

The author is currently working towards a Ph.D degree in the Department of Geography at UTK. His specialities are transportation geography, location theory, and economic development. He plans to return to People's Republic of China and teach at the university level upon graduation.