Determining the least cost method of transporting bulk commodities with competing road and rail possibilities

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Abstract:

A mixed integer linear programming model was developed to determine the least social cost method of transporting bulk commodities. The model was applied to the problem of transporting export coal from the Hunter and Newcastle Coalfields to the Port of Newcastle. Transport options included road and rail or a road/rail combination. The results illustrated the comparative advantage of rail in transporting bulk commodities. The approach used in this analysis has application to other problems involving determination of the least social cost method for transporting commodities.

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Introduction

Bulk commodities such as wheat, coal or minerals usually have to be transported long distances from their point of production (farm or mine) to a port for export or to a processing plant. Usually there are competing modal possibilities for the transportation of these commodities, with modal choice being determined by lower freight charges reflecting lower private costs. However, least private costs are not necessarily the most acceptable solution from a social point of view.

Efficiency of transportation has important implications for resource use and, in the case of exports, for maintaining Australia's competitiveness on international markets. Hence, reform of transport is an important component in the Federal Government's overall approach to economic reform. The development of models and their application to problems constraining the efficient transportation of goods provides policy-makers with an important tool to address issues associated with reform.

The problem reported in this paper is that of transporting coal from the Hunter and Newcastle Coalfields to the Port of Newcastle. The investigation has two aims. The first is to develop a model to determine the least cost method of transporting bulk commodities where some transport modes involve substantial fixed costs. The second aim is to apply the model to select the least social cost method of transporting export coal from those coalfields.

A mixed integer linear programming model was developed to determine the least social cost combination of transport modes. The method involves estimating the costs of competing road and rail transport options over a selection of routes to estimate the optimal modal configuration in social cost terms. Account is taken of the fixed costs of transport infrastructure maintenance required to keep railway lines open. Added to this are road and rail operating costs (which vary with the tonnages of coal transported), the costs of reloading of coal between minesite and port and the costs of road accidents.

Background

Federal and State Governments have in place a series of reform measures to improve the efficiency of transportation. These measures are part of governments' aims to improve efficiency of resource use through economic reform. However, this process of economic reform places additional pressure on the transport sector as a service industry responsible for the movement of freight and people across sectors.

Railway efficiency has national, as well as State implications. All public railway systems are operating in deficit, with the States using rail subsidies to cover the costs of urban and passenger services and, to a lesser extent, the unprofitable areas among freight activities. Cost recovery rates for non-urban rail at the national level in 1986-87 ranged from 24 per cent for LCL freight to 140 per cent for coal and minerals (Railway Industry Council 1990).

Restructuring of the rail industry is being pursued through Federal and State government initiatives. The objective of such restructuring is to develop medium and long term strategies to improve the competitiveness of rail.

The road freight industry is also under continuing review by Federal and State governments. For example, the Federal Government is pursuing the issue of greater uniformity of regulations across States. Recently, the Inter-State Commission (1990) released a series of recommendations for road cost recovery in a report on the road freight industry which, if adopted, will affect the relative cost efficiency of road freight transport.

The coal industry plays an important role in the Australian economy, with black coal accounting for 15.2 per cent of Australia's export earnings in 1986-87. Given the economic significance of black coal, it is important to maintain its export share in an increasingly competitive world market. Because the costs of handling and transporting export coal are prominent in the supply chain, amounting 30 to 45 per cent of the f.o.b. trimmed cost of delivery, it is appropriate to examine the transport configurations which minimise total cost.

The Port of Newcastle accounted for approximately 30 per cent of total Australian coal exported in 1987-88. The Hunter Region's coal transportation network is sufficiently complex, with its numerous road, rail and reloading alternatives, to demonstrate the methodology for determining the least cost.

Export rather than domestic coal has been chosen for the analysis because it offers more scope for modal transfer. Domestic coal is typically short-hauled by road or taken by conveyor from minesite to consumer (such as a power station). The volumes of export coal from the region are substantial, providing measurable externality effects arising from modal shifts.

The Hunter Valley coal transportation network

Description

The Hunter and Newcastle Coalfields are served by the Port of Newcastle, the largest coal port in New South Wales (see Appendix Figure 1). A total of 16 export mines is under review in this paper, 12 in the Hunter Coalfield and four in the Newcastle Coalfield. Total coal deliveries from these mines to the Port of Newcastle in 1988-89 are estimated to be 21.0 million tonnes. Total exports from the Port of Newcastle in 1988-89 were actually 29.2 million tonnes, including the production from Ulan mine in the Western Coalfield, from Gunnedah Coalfield and from Wallarah mine to the south of Newcastle (whose output is transported by sea to Newcastle).

The main transport links for all Hunter Coalfield mines 1 to 12 and two Newcastle Coalfield mines 13 and 14 are either the Newcastle-Werris Creek main railway line or the New England Highway. The railway line also carries export coal from Ulan and from Gunnedah. Ulan and Gunnedah rail movements are not directly considered because both are sufficiently distant from port for rail to be clearly the optimal mode. However, the use of road transport from the nearby mines has important implications for funding construction and maintenance of road infrastructure.

Coal-induced infrastructure demands and their funding are leading concerns of the Association of Coal Related Councils and the Hunter Regional Association of Councils. Community concerns regarding the high incidence of heavy vehicles travelling through towns in the Hunter Region have been identified by the Associations and by Jakeman and Simpson (1987). Lower Hunter councils have voiced specific concerns about the rates of road deterioration arising from truck haulage of coal and the potentially adverse impacts this haulage may have on tourism.

A number of road and rail transport options have been identified for each of the Hunter and Newcastle Coalfields' export mines. These include road options which could be regarded as unacceptable from the community viewpoint, but are assessed (below) to be sub-optimal. The transport alternatives are shown schematically at Appendix Figure 2. Although reloading costs at rail terminals may prevail in a modal choice, it is not expected that these costs represent a high proportion of total transport costs.

The current transport arrangements are shown in Appendix Figure 2 as option 'a' except for mines 1 and 2. These mines use both options 'a' and 'b' as the current arrangements. Thus, 1a, 1b, 2a, 2b and 3a represent current transport arrangements for mines 1, 2 and 3. Alternative transport options for the mines are indicated as 2c and 3b. As may be seen, a number of collieries do not have adjacent road-to-rail reloading facilities. Consequently, two inland coal loaders serve as focal points for a number of export mines.

The Mount Thorley Coal Loader (MTCL) is the largest rail loading terminal handling some 25 per cent of Newcastle's coal exports from four mines in the surrounding area, with capacity for higher throughput. The Liddell coal loader, at point C in Figure 2, while smaller than MTCL, transfers to rail export coal from five mines. Conveyor belts or road are used to deliver coal to rail loading facilities.

Social versus private costs

Failure to develop freight services in response to a changing economic environment, or to provide a regulatory framework which allows adjustments to occur will inevitably reduce efficiency of resource use with subsequent costs to the economy. Transport, like any other sector of the economy, competes for resources within competitive capital and labour markets. Failure to achieve efficiency gains in one sector has important implications for resource use by other sectors of the economy, and for overall economic performance.

In some cases, market failure may result in society bearing part of the economic costs causing a divergence between the private and social costs associated with the provision of such services. For example, the inability of the road transport sector to be self regulating in the areas of load limits, design standards and safety provisions provides an indication of areas of market failure which contribute to such divergence. Similarly, externalities such as local air and noise pollution, accidents and environmental impacts, although incurred by users of transport services, are costs borne by society.

Another area which illustrates divergence between private and social costs in freight transport is that of road damage. For the most part, road damage costs are borne by other road users. Failure to have markets allocate costs to private individuals means that, unless other correcting mechanisms are introduced, some misallocation of resources is likely to occur, resulting in a less efficient combination of transport services to meet the freight task.

In the analysis undertaken here, private and social costs incurred by transport activities were included where possible. For some variables such as quality of life, it was not possible to obtain an estimate of the reduction in utility resulting from trucks or freight trains passing through urban areas. However, the linear programming approach does provide scope for sensitivity analysis to be conducted on the shadow prices relevant to such externalities. The purpose of using a total cost objective function was to estimate the impact of transportation activities on overall efficiency of resource use.

Research Method

The existing transport system was modelled using mixed integer linear programming. The existing transport system included the routes and modes currently used to transport coal, together with alternative routes and modes that could be used, without the construction of new roads, railways, conveyor belts, slurry pipes or coal loading facilities. The effect of constructing such new facilities can be included in the model relatively easily, but data collection and the calculation of the present value of costs and returns associated with these investment alternatives is quite demanding.

Mixed integer LP model

Mixed integer linear programming was chosen because of its ability to model the fixed cost of the maintenance of rail lines. The linear programming model can be stated algebraically (see Lee, Moore and Taylor (1985) for details) as

Minimise (or maximise)

$$Z = c_1x_1 + c_2x_2 + \dots + c_jx_j + c_{j+1}x_{j+1} + \dots + c_nx_n \qquad (1)$$

subject to

$$a_{i1}x_1 + a_{i2}x_2 + \dots + a_{ij}x_j + a_{ij+1}x_{j+1} + \dots + a_{in}x_n \ (\leq, =, \geq)\ b_i \quad \text{for} \quad i=1,2,\dots,m \qquad (2)$$

$$x_1, x_2, \dots, x_j = 0 \text{ or } 1 \qquad x_{j+1}, x_{j+2}, \dots, x_n \geq 0 \qquad (3)$$

The x's in all the above equations, represent the value of the various activities specified in the model. The integer variables (represented by $x_1, x_2, \dots, x_j$) are, in this case, the segments of the main and branch rail lines. Each segment is either maintained at a given fixed cost and therefore usable having a value of 1 in the linear programming solution, or it is not maintained and is therefore unusable, and has a value of 0 in the solution. The maintenance of segments is defined in such a way that if, for example, the segment from Singleton to Antiene junction is maintained and therefore usable, all other segments from Antiene to Port Waratah must also be maintained. In the model, the inclusion of an activity in the optimum solution provided for an arbitrarily high volume of coal to be carried. This was reflected in the a_{ij} coefficients in the model which were negative to provide transport capacity in the right hand side of the equation system, the b coefficients in equations (2).

The fixed costs associated with the maintenance of mainline and branch line segments were calculated using various assumptions detailed in Table 1 and amplified in the discussion of results. The fixed costs are specified in the linear programming model as the $c_1, \ldots, c_j$ coefficients in equation (1).

The free variables $x_{j+1}, \ldots, x_n$ represent the transport activities. The costs of these activities are calculated by multiplying the variable cost by the distance of each of the transport methods used for each segment of the trip. Provision was made for the use of different loaded and unloaded variable costs for each transport method. Alternatively, average variable costs may be used for both the forward and return trip for each transport segment. Where coal had to be transshipped from road to rail, a reloading cost of $0.60 to $1.00 per tonne was used in the cost calculations. The $c_{j+1}, \ldots, c_n$ coefficients in equation (1) are the variable costs associated with each transport activity. Each transport activity was specified in 1000 tonne units. Transport of coal was represented by a series of ones and minus ones in the $a_{ij+1}, \ldots, a_{mn}$ coefficients in the equations labelled (2).

The constraint relationships and the right hand side coefficients b ensured that the assumption that the rail lines were maintained, if they were to be used, was enforced. The other significant set of constraints in the model was that all coal produced had to be transported to Port Waratah. A diagram of the completed model is shown in Appendix Figure 3.

The linear programming model was constructed in a computer spreadsheet which allowed the calculation of the fixed line maintenance costs and the variable transportation costs based on the distances and costs outlined in Tables 1 and 2. This approach provides flexibility to allow additional activities to be incorporated into the model (eg specification of investment activities) and for data to be updated in an efficient manner.

Data requirements

Definitions

In this analysis, private costs included direct road and rail transport costs from mine to port and transfers from conveyor or truck to rail. The analysis excluded costs which hold constant regardless of the transport options examined. Hence, the analysis excluded the costs of coal preparation and conveyors at the minesite, and the costs which follow the discharge of coal at the port, namely stacking, blending and reclaiming.

Social costs included costs of road damage arising from coal trucks and costs of fatal accidents involving the trucks. These costs were ascribed a monetary value in this analysis.

Classification of railways: For costing purposes railways were classified as mainline and branch line. Mainlines referred to are the Werris Creek and Gosford railway lines. Branch lines included all rail loops and rail sidings, and the private South Maitland Railway, extending from East Greta junction to the vicinity of Pelton/Ellalong mine.

Classification of roads: For the purpose of road damage costing roads were classified into two categories, viz highways and arterials, and local roads (BTCE 1988a; D P Luck, pers. comm., 1989).

The first category included the New England Highway and the highly-trafficked sections of other roads, termed arterial. The second category included all remaining roads with low traffic volumes, and were termed local. The traffic counts for arterials in the Hunter Region, selected for coal transport options, were in excess of 3000 Average Annual Daily Traffic (AADT). Traffic counts for locals were less than 1000 AADT, with no counts encountered between 1000 and 3000 AADT (RTA 1988).

Road damage costs were computed in terms of damage estimates per Equivalent Standard Axle Load kilometre (ESAL km). All road transportation was assumed to be carried out by six-axle articulated trucks of 40 tonne Gross Vehicle Mass (GVM). It was assumed that there is no backloading of freight by these trucks. Estimated ESALs for loaded and empty 40 tonne GVM trucks were 3.73 and 0.21 respectively. Computation of axle loads of loaded and empty trucks and the resulting damage factors was consistent with National Association of Australian State Road Authorities practice (NAASRA 1976a; 1976b).

Road accident costs were derived from the rates of fatal accidents in terms of vehicle-kilometres travelled by heavy vehicles and the average number of fatalities per accident (Federal Office of Road Safety, pers. comm., 1990). These rates were then converted into costs using estimates developed by the Bureau of Transport and Communications Economics (1988b).

Noise and air pollution costs for trucks were estimated for the Hunter Region, based on rural and urban cost estimates in ISC (1990). However, these costs were not included in the model in the absence of similar estimates for rail. The analysis did not attempt to estimate the time costs of congestion.

Data inputs to model

The main inputs to the linear programming model were the total distances by railway and road types between mine and port and the tonnages transported. For most mines, saleable coal production figures for 1988-89 were used as a proxy for tonnes transported in that year.

These figures are presented in Table 1. The cost data inputs to the model are itemised in Table 2, including the fixed and variable costs of road transport, variable costs of road transport, reloading costs and externality costs.

Table 1 Transport Task Data Inputs to Linear Programming Model

			Rail (km)		Road (km)	
Mine	Tonnes 1988-89[a] ('000)	Transport option[b]	Mainline	Branch line	Highway/ arterial	Local
Mine 1[c]	500	1A	-	-	127	4
	250	1B	101	6	22	7
Mine 2[c]	400	2A	-	-	118	7
	250	2B	101	6	10	7
		2C	113	8	-	2
Mine 3[c]	2 250	3A	113	8	-	-
		3B	-	-	111	5
Mine 4	320	4A	101	6	-	-
		4B	-	-	105	3
Mine 5[c]	760	5A	101	6	-	4
		5B	75	11	28	21
		5C	-	-	102	4
Mine 6	3 930	6A	101	6	-	-
		6B	75	11	21	12
		6C	-	-	98	10
Mine 7	1 520	7A	75	11	17	-
		7B	-	-	93	9
Mine 8	940	8A	75	11	13	4
		8B	-	-	86	13
Mine 9	1 980	9A	75	11	-	-
		9B	-	-	76	9
Mine 10	3 060	10A	75	11	-	-
		10B	-	-	74	9
Mine 11	830	11A	75	14	-	-
		11B	-	-	70	16
Mine 12	360	12A	57	-	-	28
		12B	-	-	57	26
Mine 13	960	13A	27	3	4	-
		13B	-	-	32	-
		14B	-	-	54	-
Mine 14	1 370	14A	34	32	-	-

Table 1 (Cont.) Transport Task Data Inputs to Linear Programming Model

			Rail (km)		Road (km)	
Mine	Tonnes 1988-89[a] ('000)	Transport option[b]	Mainline	Branch line	Highway/ arterial	Local
Mine 15	580	15A	17	-	-	6
		15B	-	-	18	8
Mine 16	750	16A	17	-	-	-
		16B	-	-	18	2

(a) Saleable coal production, rounded to nearest 10 000 tonnes.

(b) Options 'A' plus 1B and 2B represent current transport arrangements.

(c) Saleable coal transported.

Source: BTCE estimates.

Table 2 Cost Data Inputs to Linear Programming Model

Type	Description	Mainline	Branch line	Highway /arterial	Local
Rail	Maintenance ($/km)	9 200	9 200	-	-
	Operating (c/tonne km)[a]	4.14	4.14	-	-
Road[b]	Damage (c/tonne km)	-	-	1.8	7.7
	Accidents - fatal (c/veh km)	-	-	0.3	0.3
	Operating (c/tonne km)	-	-	8.33	8.33
Reloading	Conveyor or truck to rail ($/tonne)	range 0.60 to 1.00			

(a) Excludes SRA's rail infrastructure investment costs, estimated to be 2 to 3 c/export tonne or less than 0.1c/tonne km.

(b) Noise and air pollution costs for road in the Hunter Region, estimated to be 0.38c/tonne km, are not included in the model.

Source: BTCE estimates.

Sources of data

Information on current transport arrangements, coal production, export and transported tonnages was derived from a number of sources including the Joint Coal Board (JCB 1989; priv. comm., 1990), the Department of Primary Industries and Energy (DPIE, 1990; C Brown, pers. comm., 1990) and the New South Wales Department of Minerals and Energy (M&E 1989).

Estimates of rail operating costs were based on Monash University, Centre of Policy Studies investigations by Freebairn and Trace (1988), incorporating work by Easton (1988). Supplementary information was obtained from the Industries Assistance Commission (1988; 1989), Booz Allen and Hamilton consultants to State Rail Authority (Booz 1989) and the BTCE submission to the Royal Commission on Grain (BTCE 1987). Estimates of road operating costs were sourced from BTE (1984) and Luck and Martin (BTCE 1988a).

Results

Initially, the analysis was to be based on three assumptions: rail transport incurs the total fixed cost of maintenance, rail transport incurs part of that cost, and rail transport does not contribute to maintenance cost.

The empirical results generated from the mixed integer linear programming model are presented in Table 3. The table shows the optimum transport modes and the social marginal costs of transporting an extra tonne of coal from each mine by the optimal modes. The calculations hold for one thousand tonnes of coal only, but they may be assumed to hold, in this case, for tonnages up to the capacity of the rail lines, coal loaders, and similar equipment. The optimum transport modes are derived under the assumption that coal transport is required to pay the entire fixed cost of rail mainline maintenance, as well as the same cost for the "coal only" branch lines. Table 3 also shows the social opportunity cost of transporting coal using any sub-optimal mode. The opportunity cost quantifies the cost of not using resources in their best use.

The assumption that coal transport be required to pay all of the fixed costs of mainline maintenance is obviously unrealistic. It was used as a "higher cost" assumption. A more realistic assumption is that coal transport would pay a share of the fixed costs in proportion to the total freight volume on the various mainline segments, and that passenger services would also pay a "fair" proportion of these fixed costs. In overstating the fixed costs of rail maintenance properly attributable to coal transport, the model underestimates the opportunity costs of non-optimal road, or mixed road and rail transport modes. It proved to be difficult to collect data on the volume of coal versus other commodities transported by rail. Thus an alternative assumption that coal transport would not be required to pay any of the fixed costs of rail mainline maintenance, but would be required to pay these costs on the branch lines, was run in a modified model.

Table 3 Optimum transport modes, opportunity costs and social marginal costs

Mine	Mode (current mode in **bold**)	Optimal mode and quantity ('000 tonnes)	Social marginal costs of transporting by optimal mode 1 tonne of coal	Opportunity cost of using a sub-optimal mode ($ per tonne)
Mine 1	**RD1A**	0		$14.23
	RR1B	750	$11.86	
Mine 2	**RD2A**	0		$10.72
	RR2B	0		$0.24
	RR2C	650	$13.52	
Mine 3	**RL3A**	2250	$10.02	
	RD3B	0		$12.39
Mine 4	**RL4A**	320	$8.86	
	RD4B	0		$11.90
Mine 5	**RR5A**	0		$2.39
	RR5B	760	$8.72	
	RD5C	0		$11.72
Mine 6	**RR6A**	3930	$9.86	
	RR6B	0		$5.14
	RD6C	0		$11.70
Mine 7	**RR7A**	1520	$10.96	
	RD7B	0		$13.78
Mine 8	**RR8A**	940	$11.73	
	RD8B	0		$13.05
Mine 9	**RL9A**	1980	$7.12	
	RD9B	0		$9.05
Mine 10	**RL10A**	3060	$7.12	
	RD10B	0		$9.47
Mine 11	**RL11A**	830	$8.37	
	RD11B	0		$9.96
Mine 12	**RR12A**	360	$12.71	
	RD12B	0		$5.14
Mine 13	**RR13A**	960	$4.98	
	RD13B	0		$0.55
Mine 14	**RL14A**	1370	$5.46	
	RD14B	0		$4.83
Mine 15	**RR15A**	580	$3.91	
	RD15B	0		$1.58
Mine 16	**RL16A**	750	$1.41	
	RD16B	0		$2.58

An interesting result from the analysis is the high social opportunity costs incurred by mines 1 and 2 using a road transport mode to haul coal to port (options RD1A and RD2A in Table 3). For mine 1 they are over $14.20 per tonne, and over $10.70 per tonne for mine 2. The social costs are probably much higher than the private freight costs paid to transport coal from these mines. Unfortunately, it was impossible to collect data on the actual freight costs paid by the various mines, for the various transport modes, as this is regarded as commercially sensitive information. The development of coal loading facilities at Liddell has resulted in mine 1 phasing in rail transport at the expense of road over a three year period. Similarly, while the loop line to Drayton has been completed only recently, it appears that mine 2 is currently using rail transport through Liddell as part of a medium term goal to substitute rail for road transport of coal.

All of the other mines (with the exception of mine 5) were using transport modes that minimised net social cost. These modes were mixed road and rail (RR), or rail only (RL). Mine 5 was using a sub-optimal mixed road and rail mode with an opportunity cost of $2.39 per tonne. The optimal mode for this mine would be to transport coal to the Mount Thorley Coal Loader, for subsequent rail transport to the port.

The major result of the empirical study is quite clear. Rail transport is much cheaper than road as a means of transporting export coal in the Hunter Valley, in terms of net social cost. This result is strengthened, given that the analysis used the unrealistic assumption that coal transport using the rail mode is required to pay all of the fixed cost of main rail line maintenance. The solution to the modified model gave exactly the same transport mode choice as the original model. The only difference was in the value of the objective function. This result also strengthens the model results, as this solution is precisely as expected.

Conclusions

The analysis of transportation problems usually involves a range of options that need to be considered simultaneously. In addition, given the structure of the transport industry and possibilities for substitution and complementary relationships between transport modes, it is necessary to analyse the interactions that occur in meeting a given transportation task. Finally, given the divergence between private and social costs that arises in transportation activities, any assessment of the performance of sectors in the industry needs to evaluate the effects of their conduct on overall efficiency of resource use.

The issue of coal transportation from the Hunter and Newcastle Coalfields is characterised by such problems. In attempting to determine the least cost combination of modes to meet the transportation task, a mixed integer linear programming model was developed. Its application to the coal transportation issue illustrates the potential use of such a technique for examining transportation problems.

The results generated by the analysis highlighted the comparative advantage of rail relative to road in transporting bulk commodities. This comparative advantage was based on a model that incorporated social costs incurred in meeting the task. While some components of social cost are difficult to quantify, the use of the approach does provide for some evaluation to be made of the impact of such social costs on the combination of modes.

Finally, while a least cost combination may be determined in a static framework, such an optimal solution does not mean that current activities are operating optimally. The technique does provide policy makers with a tool for determining current inefficiencies in the system and options for investment in infrastructure to improve efficiency. Ideally, such an extension of the current model would incorporate investment options within a dynamic framework.

However, the results do highlight the robustness of rail in performing the coal freight task. In the model, coal exporters were required to meet more than the full cost of rail freight, whereas some of the externalities incurred by road freight were not included in the road freight costs.

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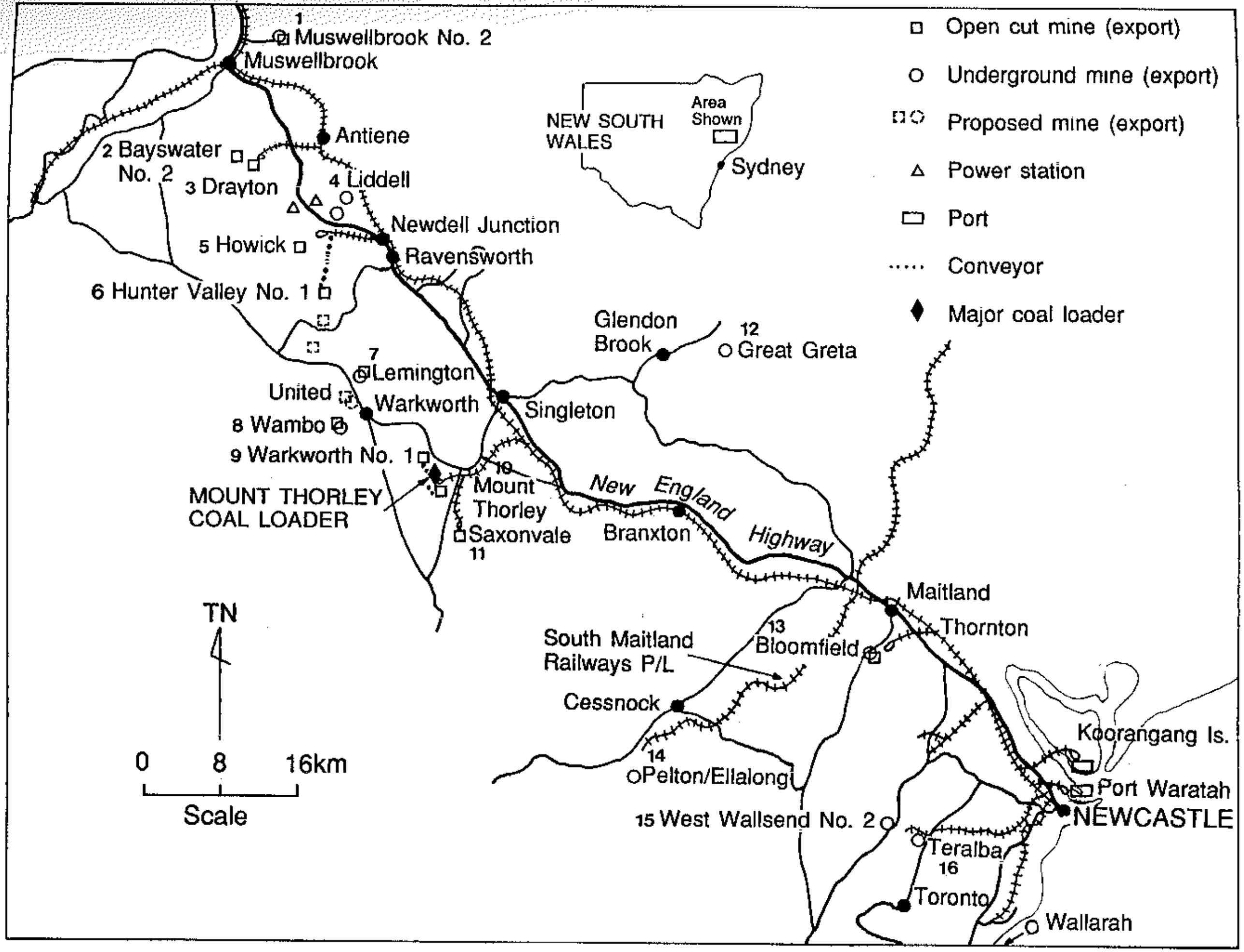
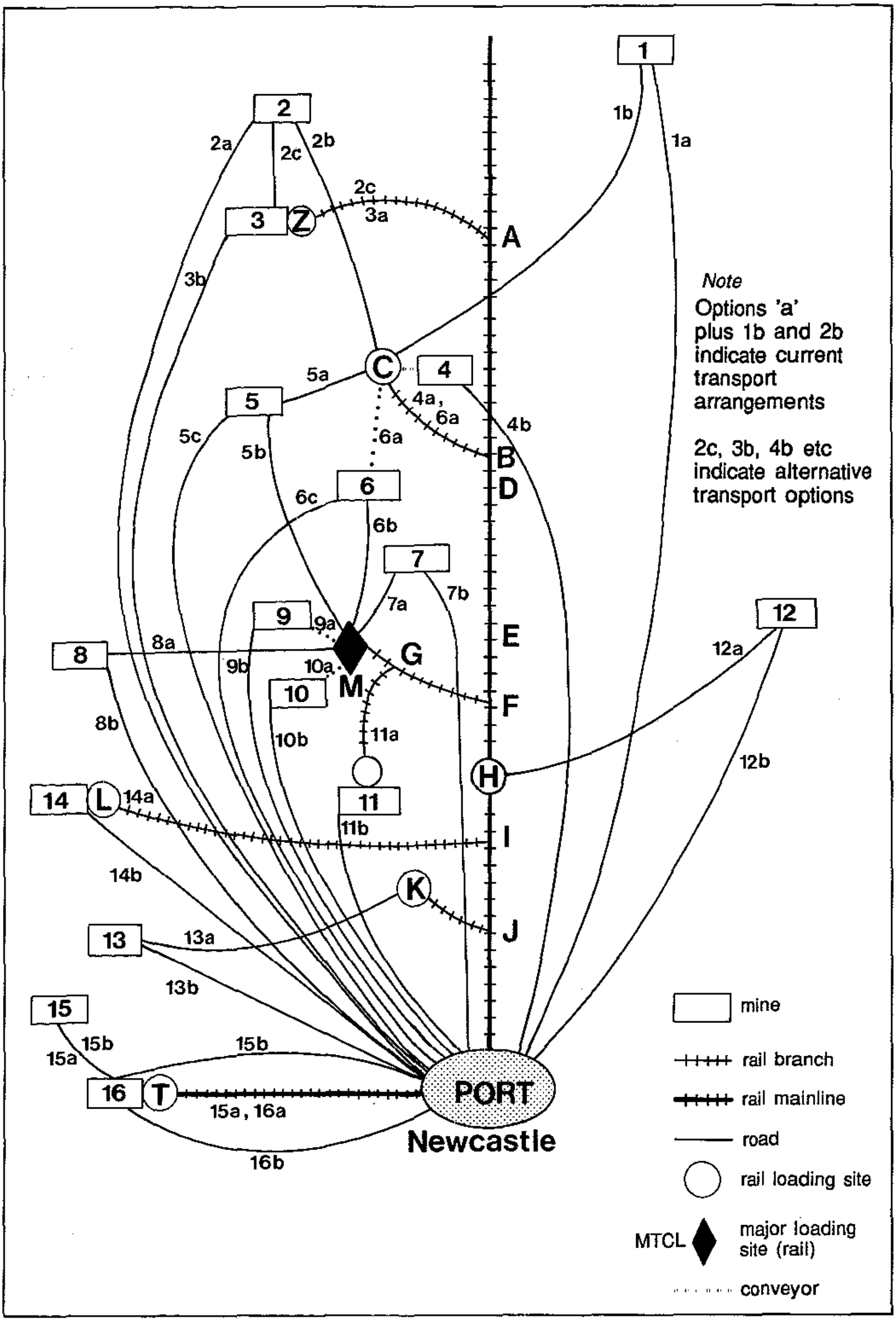


Figure 1 Hunter and Newcastle coalfields export coal mines



Note

Options 'a' plus 1b and 2b indicate current transport arrangements

2c, 3b, 4b etc indicate alternative transport options

Figure 2 Hunter and Newcastle coalfields transport schematic

HUNTER COALFIELD

Mines

1	Muswellbrook No. 2
2	Bayswater No. 2
3	Drayton
4	Liddell
5	Howick
6	Hunter Valley No. 1
7	Lemington
8	Wambo
9	Warkworth No. 1
10	Mount Thorley
11	Saxonvale
12	Great Greta

Rail Terminals

Z	Drayton loop (adjacent to 3)
C	Liddell loop
M	Mount Thorley Coal Loader (MTCL)
	Saxonvale loop (adjacent to 11)
H	Branxton siding
K	Thornton loop
L	Cessnock Coalfield (South Maitland Railway P/L)

NEWCASTLE COALFIELD

Mines

13	Bloomfield
14	Pelton/Ellalong
15	West Wallsend
16	Teralba

Rail Terminals

T	Teralba

PORT RAIL TERMINALS

Koorangang Island loop
Port Waratah Coal Services loop

PLACE NAMES

A	Antiene
D	Ravensworth
E	Singleton
F	MTCL branch - mainline junction
I	East Greta junction (Maitland)
J	Thornton junction
B	Newdell junction

Key to export mines, rail terminals and placenames - Transport Schematic (Figure 2)

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           M M M M M M M M B B B B B B B M R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R R   R
           N N N N N N N N R R R R R R R N D R D R R L D I D R R D R R D R D R D L D I D I D R D R D I D R D I D   H
           L L L L L L L L L L L L L L L L 1 1 2 2 2 3 3 4 4 5 5 5 6 6 6 7 7 8 8 9 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1   S
           A B D E F H I J Z C M N G I K T A B A B C A B A B A B C A B C A B A B A B 0 0 1 1 2 2 3 3 4 4 5 5 6 6
           B C E F H I J P A B G G F I J P                                           A B A B A B A B A B A B A B
--------------------------------------------------------------------------------------------------------------------
OBJ        C C C C C C C C B B B B B C B C B B B B B B B A B B A B A B B B B B B A B A B A B B B A A A B A A A A
RCAPA     -C                                      V V                                                           ≤ 0
RCAPB     -C-C                                    V V                                                           ≤ 0
RCAPD     -C-C-C                            V   V V V   V   V     V                                             ≤ 0
RCAPE     -C-C-C-C                          V   V V V   V   V     V                                             ≤ 0
RCAPF     -C-C-C-C-C                        V   V V V   V   V V   V V   V   V   V   V   V                       ≤ 0
RCAPH     -C-C-C-C-C-C                      V   V V V   V   V V   V V   V   V   V   V   V   V                   ≤ 0
RCAPI     -C-C-C-C-C-C-C                    V   V V V   V   V V   V V   V   V   V   V   V   V       V           ≤ 0
RCAPJ     -C-C-C-C-C-C-C-C                  V   V V V   V   V V   V V   V   V   V   V   V   V   V   V           ≤ 0
RCAPZ                     -A                      V V                                                           ≤ 0
RCAPC                       -A                  V   V       V   V     V                                         ≤ 0
RCAPM                         -A                              V     V   V   V   V   V                           ≤ 0
RCAPN                           -A                                                  V                           ≤ 0
RCAPG                             -A                          V     V   V   V   V   V   V                       ≤ 0
RCAPL                               -A                                                          V               ≤ 0
RCAPK                                 -A                                                    V                   ≤ 0
RCAPT                                   -A                                                          V   V       ≤ 0
MINE1                                     1 1                                                                   ≥ C
MINE2                                         1 1 1                                                             ≥ C
MINE3                                               1 1                                                         ≥ D
MINE4                                                   1 1                                                     ≥ C
MINE5                                                       1 1 1                                               ≥ C
MINE6                                                             1 1 1                                         ≥ D
MINE7                                                                   1 1                                     ≥ D
MINE8                                                                       1 1                                 ≥ C
MINE9                                                                           1 1                             ≥ D
MINE10                                                                              1 1                         ≥ D
MINE11                                                                                  1 1                     ≥ C
MINE12                                                                                      1 1                 ≥ C
MINE13                                                                                          1 1             ≥ C
MINE14                                                                                              1 1         ≥ D
MINE15                                                                                                  1 1     ≥ C
MINE16                                                                                                      1 1 ≥ C
PORT                                    -1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1 ≤ 0
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Range Table

Symbol		Value
Z	>	.0000001
Y	>	.0000010
X	>	.0000100
W	>	.0001000
V	>	.0010000
U	>	0100000
T	>	1000000
I	>	9999990
A	>	1.0000000
B	>	10.0000000
C	>	100.0000000
D	>	1000.0000000
E	>	10000.0000000
F	>	100000.0000000
G	>	1000000.0000000
H	>	10000000.0000000

Legend

Symbol	Meaning
Columns	
MNLij	Fixed cost of maintaining main line segment i to j
BRLij	Fixed cost of maintaining branch line segment i to j
RDxy	Road transport from mine x using option y
RLxy	Rail transport from mine x using option y
RRxy	Road and rail transport from mine x using option y, including a reloading charge from road to rail
Rows	
RCAPi	Rail capacity "produced" by rail maintenance and "used" by rail transport options
MINEj	Mine from which coal is required to be transported
PORT	Transport destination

Figure 3 Structure of the linear programming model matrix