Chapter 6

Break-Even Distances and Analysis of Optimal Transport Flows

6.1 INTRODUCTION

The preceding chapter dealt with the various components of modal transport cost (operator & user cost) in terms of their definitions and the process adopted for their estimation. In addition, the resultant modal transport cost estimates in respect of freight and passenger movement by Railways, Highways and Airways, and freight transport by Coastal Shipping have also been presented.

As a natural sequence to the above, this chapter presents an attempt to identify the Break-Even Distances between rail and road transport, the two major modes, based on their comparative cost of transport. The objective behind the exercise is to identify commodity specific operational region of cost advantage of either mode for the purpose of optimal distribution of traffic amongst them. It would be pertinent to mention that the exercise has been limited to 11 important commodity groups viz. food grains, fruits & vegetables, coal and other minerals, fertilizers, sugar, POL products, cement, livestock, iron & steel, containers and miscellaneous or other commodities. Furthermore, keeping in view the relevance for planning at national level, economic/resource costs have been adopted for the purpose of determining the Break-Even Distances.

6.2 CONCEPTUAL FRAMEWORK

Essentially, Break-Even Distance (BED) or Break-Even Point (BEP) represents the cut off point between comparative distance based modal transport costs (total of operator & user costs) of the two modes in movement of a commodity. Break-Even point defines the limit up to which movement of a commodity by a mode is cost effective and beyond which cost advantage shifts to the other mode. Break-Even point thus defines optimal area of operation for the movement of a commodity by a particular mode. Commodity specific Break-Even Distances thus provide the basis for optimal allocation of traffic amongst modes.

6.2.1 Critical Components

As the determination of Break-Even Distances (BEDs) involves the ratio of fixed and variable costs, elements that constitute the variable and fixed costs become critical for analysis. Variable costs in terms of per tonne kilometre costs include modal operator costs and, in the case of user cost, the transit inventory cost which varies with transit time, local cartage cost which varies with vehicle lead and is relevant in the case of transport by rail and handling costs which are (in general) comparatively high in case of rail transport. Packing costs in any case are invariant in the case of transport by rail or road. The process adopted for calculation of Break-Even Distances is given in the Box 6.1 below.

Box 6.1: Illustration of Break-Even Distance Calculations

Break-Even Distance depends on the relative ratios of fixed and variable costs of two different choices. The case is illustrated with two modes; mode 1 (say road) has a high variable cost but low fixed cost and mode 2 (say rail or coastal shipping) has low variable cost but high fixed costs. For obvious reasons for short distances mode 1 would be preferred and preference would shift to mode 2 in the case of long distance.

Mathematically it can be illustrated as follows.
At a Break-Even Distance D total cost incurred by both the two modes of transport are equal.

$$FC1 + VC1 * D = FC2 + VC2 * D$$

Where FC is the fixed cost and VC is the variable cost of a mode.

6.2.2 Estimates of Break-Even Distances

The details of modal costs and user costs for various operating situations of different modes are presented in the chapter on costs (Chapter 5). Modal costs of rail and road vary with sectional type and in addition road modal costs also vary with length of haul. To capture the heterogeneity of the sectional characteristics, and the cost variations thereof, the first step was to assess the various sections used in moving different types of commodities by different modes of transport. The proportion of different types of road sections for movement of different commodities is given in **Appendix-1** at the end of the chapter. Similarly, different types of rail sections involved in moving different commodities are indicated at **Appendix-2** at the end of the chapter. The proportions were used to arrive at the weighted average cost for each commodity.

The user cost for each mode was estimated through sample surveys, the details are explained in user cost section of the earlier chapter. The user cost and weighted average of modal costs were used to calculate the individual Break-Even Distances which are given in **Table-6.1.** While assessing them for Other Commodities, cost of container transport is considered as these commodities have high propensity for containerisation.

TABLE - 6.1: BREAK-EVEN DISTANCES

SN	COMMODITY	BREAK-EVEN DISTANCE (KM)
1	FOOD GRAINS	222
2	FRUITS & VEGETABLES	313
3	COAL & OTHER MINERALS	188
4	FERTILIZERS	167
5	SUGAR	372
6	POL PRODUCTS	126
7	CEMENT	160
8	LIVESTOCK	162
9	IRON & STEEL	173
10	CONTAINERS	307
11	OTHERS	307

The above table shows that the highest Break-Even Distance is in the case of sugar followed by fruits & vegetables, containers, etc. Similarly the lowest Break-Even Distance is observed in the case of POL products. As envisaged, Break-Even Distances clearly show the impact of terminal costs for each commodity. Break-Even Distance in the case of sugar, since there are hardly any sugar sidings inside the sugar factories as well as sugar is required to be stored outside the station limits/Railway sidings, the overall terminal costs are much higher in the case of Railways, thereby making the commodity dearer to Highways. Same remarks hold good for fruits and vegetables. In the case of containers, the commodity suffers on account of heavy handling charges at either end. POL products fall at the other end of the spectrum, because of low terminal charges, as it does not require packaging costs, handling costs and local cartage.

The methodology followed for calculating the break even distances for rail and road was adapted for estimating the break even distances between coastal shipping and rail. The break even distances for coal, cement and containers works out to 459, 230, and 141 kilometres respectively. However, in case of POL products, as the terminal costs of rail are slightly more than those of coastal shipping, it is advisable to move them by coastal shipping for all distances.

It may, however, be noted that Break-Even Distances are sensitive to changes in modal costs, user costs and social costs. All these costs in turn depend on inherent assumptions germane to estimation process. Thus, it is useful to treat Break-Even as a distance range than as a fixed point.

6.2.3 Comparative Analysis

For validation of Break-Even Distances, results have been compared with the outcome of earlier studies. Break-Even Distance for various commodities as estimated in the current study vis-à-vis the Total Transport System Study conducted by RITES in 1986-87 is compared in Table 6.2:

TABLE 6.2: COMMODITY WISE BREAK-EVEN DISTANCES 1986-87 VS. 2007-08

SN	COMMODITY	BREAK-EVEN DISTANCE (KM)	
		1986-87	2007-08
1	FOOD GRAINS	280	222
2	FRUITS & VEGETABLES	380	313
3	COAL & ORES	232	188
4	FERTILISERS	184	167
5	SUGAR	324	372
6	POL PRODUCTS	67	126
7	CEMENT	193	160
8	LIVESTOCK	328	162
9	IRON & STEEL	220	173
10	CONTAINERS	NA	307
11	OTHERS	NA	307

The above table shows that the Break-Even Distance in the current study has shifted in favour of Railways in almost all commodities except, sugar and POL. On close examination it is revealed that the shift is predominantly on account of fuel efficiency of Railways. Since, fuel prices have drastically increased during the period under reference the shift is justified. Further, in the present study the environmental and accident costs have also been accounted for.

In the case of sugar, increase in Break-Even Distance is accountable to the local cartage involved at either end in the case of Railways. Because of higher impact of road transport at lower leads, terminal costs of sugar have gone up resulting in shift of BED in favour of Highways.

In the case of POL products, on close scrutiny of data it has been established that in the earlier Report siding costs at destination were not appropriately considered. Because POL siding is exclusively provided to handle POL traffic and the entire development and maintenance costs are apportioned to the quantity handled, in the current study changes have accordingly been worked out. This has shifted the Break-Even Distance from 67 km in 1986-87 to 126 km in the current study.

Alternatively, Break-Even Distance of livestock has shifted in favour of Railways because in the earlier study local movement of livestock up to railhead was considered against the assumption of road transport. Based on the detailed field investigation it has been established that no local mode of transport is used at either end for rail handling.

6.3 OPTIMAL ANALYSIS

6.3.1 Model Description

The optimisation module is the heart of the study as it integrates the cost and flow data on the transport network of the country. The model was built with two objectives in view. The first objective is to model the current flows as they are flowing in the base year. The second objective is to assess how the modes respond after the traffic is assigned to rail and road by applying Break-Evens. This integration of cost and flow data on a real time network will throw up challenging issues to assess the relative strengths of different modes of transport in an integrated manner.

To develop optimal models two methods were followed. In the first case the problem was addressed as a simultaneous allocation and route-mode mix problem. In this scenario the total demand (or supply) from a region is the difference of supply and demand of the region. Thus, if a region has more supply than demand it becomes a net supplier, and if a region has more demand than supply it becomes a net consumer. Given the potential of supply and demand for each commodity for each O-D pair, this Model calculates least-cost O-D flow allocation and route mix for transporting commodities for each O-D pair. A brief description of the TAROP (Transport Allocation and Route-mode mix Optimisation) model is given in Box 2 as **Appendix-3**, and mathematical formulation of the TAROP model is given in **Appendix-4** at the end of the chapter.

TAROP model assumes inherent homogeneity of commodities under consideration and the approach is valid for number of bulk cargoes, which are generally homogeneous. However, in practice the condition of homogeneity is violated in a large number of situations. This could include cross movement of branded products from place to place, seasonal fluctuations in production and consumption, and taste or price variations across the regions. Thus, TAROP model underestimates the total transport demand. To remedy the situation another approach is to model the flows as noticed in the base year. In this approach every flow is modelled as it is without netting at the regional level. Thus, if regions A and B have two-way flows both are modelled as it is, for example cars moving from Gurgaon to Chennai and from Chennai to Gurgaon are treated separately. This model captures the empirically observed flows. Thus, given the flows of commodities for O-D pairs, this Model calculates least cost route mix for transporting those commodities for each O-D pair. The model is named Transport Route-mode mix Optimisation (TROP) model. A brief description of the TROP model is given in Box 3, and mathematical formulation of the TROP model is given in **Appendix-5** at the end of the chapter.

Both the models have two internal stages. In the first stage the model decides the candidate routes to be included in the optimisation model. The candidate routes are selected based on the cost but it is also feasible to select distance based routes. The candidate routes and the quantity of cargo flows are then fed into optimisation module. The optimisation module decides the optimal routes and quantities subject to the constraints specified in the model.

6.3.2 Model Inputs

The model inputs are:

- Information on Transport Network
- Cargo Flows
- Costs

Network

A critical component of the model is the transport network. The network should be sufficiently large for a realistic capture of all practical realities of transportation but not be too unwieldy for a reasonable implementation of the model. Based on this links and nodes for Road, Rail, Coastal Shipping and Airways were decided. A summary of the number of nodes and links in each mode of transport are presented in Table 6.3. The reasons for the network configurations are discussed for each mode separately.

Indian road network, with a length of 3.3 million kilometres, is second largest in the world. However, majority of the inter-regional flows of the country move on the National Highways and State Highways. Thus, the network is so made that it captures the National Highways (NH), important State Highways (SH) and Major District Roads (MDR). Length of different roads captured in the network is given in **Table 6.3**. Further, as the cost of transport is dependent on the road characteristics, these are captured in the network. The characteristics captured are:

- Type of road: NH, SH or MDR
- Number of lanes: Single, double or more
- Gradient: Plain, rolling & hilly

As transport networks of other modes are much simpler compared to road, they are fully captured. Rail links are categorised based on three characteristics:

- Traction: Diesel and electric
- Track: Single, double or more
- Gradient: Plain and hilly

In the case of Airways as every point can be connected to other point, all routes that are currently covered in 2007-08 flow data are considered. In addition some potential routes are also included in the network. In Coastal Shipping all the 49 ports and 95 routes appearing in the 2007-08 flow data are considered for the network.

TABLE 6.3: NUMBER OF LINKS AND NODES INCORPORATED IN THE MODEL FOR EACH MODE

SN	Mode	Network Type	No. of Nodes	No. of Links	Length (Km)
1	Road	NH		1548	52822
		SH		2924	94141
		MDR		217	7781
		Total	**3026**	**4689**	**154744**
2	Rail	BG		1662	52031
		MG		247	11203
		NG		62	2690
		Total	**1666**	**1958**	**65924**
3	Airways		95	3509	NA
4	Coastal Shipping		49	95	NA

Flows

Commodity movement data is categorised into 11 commodity types. For each of the commodity type base year flows data were generated for both the TAROP model and TROP model.

Cost

The costs are broadly categorised as link level costs and route level costs. The route level costs are all fixed costs and are expressed per tonne, while link level costs are variable and are expressed per tonne-kilometre. Route level costs are user costs including handling and related costs. The link level costs are the operator costs and infrastructure costs. Details of costs used in the model are described in **Appendix-3** and **Appendix-4.**

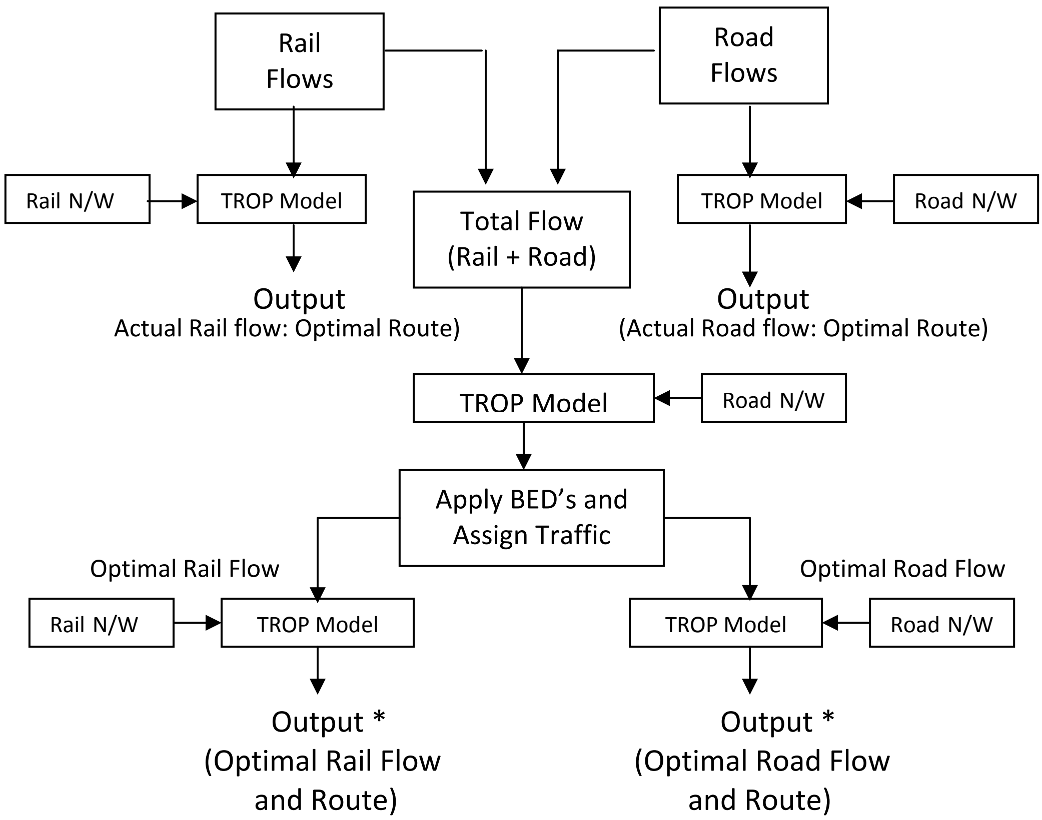
Optimal models were run for resource costs as they represent total cost to the nation. . These models were used for two types of analysis. The first is made on rail and road flows after considering the break even distances, and the analysis plan is discussed in section 6.3.3 and results are summarised in sections 6.3.4. The second type is an integrated analysis combining rail, road and coastal cargo movement with provision for transhipment across different modes. The model and results are discussed in section 6.3.5.

6.3.3 Analysis Plan: Based on Break even distances for Rail and Road Cargo Movement

The model was used to analyse the interaction between costs, flows and the network. The plan of analysis is presented in the flow chart attached. The modal was used to size up the actual system performance by running rail flows through rail network and road flows through road network. Further analysis was undertaken by combining the rail and road flows and running the model with road network. On the outputs so obtained the Break-Even Distances were applied to segregate rail and road flows.

The O-D pairs with cargo flows more than the Break-Even Distances were assigned to rail flow and those less than the Break-Even Distances were assigned to road.

FIGURE 6.1: ANALYSIS PLAN BASED ON BREAK EVEN DISTANCES



* Model Output gives TKMs, System Cost and Section Loadings.

6.3.4 Results

Table 6.4 compares the change in transport system parameters in actual conditions and after assigning the Break-Evens.

TABLE 6.4: SYSTEM OVERVIEW: ACTUAL & OPTIMAL

MODE *	ACTUAL			OPTIMAL		
	FLOW (Million Tonne)	COST (Billion Rs)	TKMs (Billon Tkms)	FLOW (Million Tonne)	COST (Billion Rs)	TKMs (Billon Tkms)
Railways	736.2	497.3	498.6	1,704.18	1,423.4	1,168.7
Highways	1,558.9	1,555.6	692.3	590.86	244.8	66.5
Coastal Shipping	59.7	34.0	90.0	59.72	34.0	90.0
TOTAL	**2,354.8**	**2,086.9**	**1,280.9**	**2,354.8**	**1,702.2**	**1,325.2**

* Only Rail flows were subjected to Break-Even Distance Analysis. Hence, no change in values of Coastal Shipping.

The table indicates that total throughput increased by 44.3 (around 3 %) million tonne- kilometres while cost decreased by Rs.38, 470 crores (around 16 %). The throughput increased slightly as rail distances are usually longer compared to road distances for a large number of O-D pairs. The cost reduction under optimal assignment of traffic is substantial. Though some of the assignments may not meet the ideal conditions assumed in Break-Even Distance calculation, it does show the scope for readjustment of traffic.

Table 6.5 compares the rail and road actual flows with flows in optimal conditions. From the table it is seen that a total of 1000 million tonnes (45 % of the total flows) are assigned from road to rail. The highest quantity is in Other & Misc. commodities, accounting for 50 per cent of the quantity undergoing modal shift. This is also the cargo which is amenable for containerisation.

TABLE 6.5: COMMODITY WISE ACTUAL AND OPTIMAL FLOWS

SN	COMMODITY	ACTUAL		OPTIMAL	
		RAIL	ROAD	RAIL	ROAD
1	COAL	451.50	223.07	480.86	193.70
2	CEMENT	78.80	75.98	128.68	26.13
3	FOOD GRAIN	38.50	149.14	122.54	65.11
4	OTHER & MISC.	37.60	629.45	554.70	112.35
5	FERTILIZERS	36.40	18.19	44.88	9.69
6	POL PRODUCTS	36.20	153.40	149.60	40.02
7	IRON & STEEL	27.83	141.22	127.16	41.89
8	CONATINERS	20.87	56.60	35.69	41.78
9	SUGAR	5.98	18.86	13.19	11.64
10	FRUITS & VEG	1.89	69.93	39.55	32.26
11	LIVESTOCK	0.12	8.10	4.94	3.27
	TOTAL	**735.73**	**1543.94**	**1701.81**	**577.85**

The quantity shifting from road to rail and rail to road is given in the Table 6.6 along with number of O-D pairs involved in the shift and percentage of cargo shifting modes as a per cent of the total cargo.

Out of 75.5 thousand O-D pairs, cargo shifts from road to rail and in 1625 O-D pairs cargo shifts from rail to road, as would be seen from Table 6.6.

TABLE 6.6: QUANTITIES OF CARGO CHANGING MODES AFTER APPLYING BREAK EVENS (SUMMARY)

SN	COMMODITY NAME	TOTAL FLOWS (IN MILLION TONNES)	SHIFT FROM ROAD TO RAIL			SHIFT FROM RAIL TO ROAD		
			FLOW IN MILLION TONNES	O-D PAIRS (IN NUMBERS)	TONNES (IN %)	FLOW IN MILLION TONNES	O-D PAIRS (IN NUMBERS)	TONNES (IN %)
1	Coal	674.6	105.3	4,676	15.6	75.9	167	11.3
2	Other &	667.1	520.1	28,377	78.0	3.0	331	0.5
3	POL	189.6	115.8	5,692	61.1	15.5	255	8.2
4	Food Grain	187.7	86.4	10,182	46.1	2.4	243	1.3
5	Iron & Steel	169.1	103.3	10,091	61.1	4.0	141	2.4
6	Cement	154.8	55.1	5,029	35.6	5.2	159	3.4
7	Containers	77.5	15.8	689	20.4	1.0	84	1.3
8	Fruits & Veg	71.8	37.7	6,460	52.5	0.0	4	0.0
9	Fertilizer	54.6	10.4	1,668	19.0	1.9	169	3.4
10	Sugar	24.8	8.6	1,794	34.5	1.3	70	5.4
11	Livestock	8.2	4.8	810	58.8	0.003	2	0.0
	TOTAL	**2279.8**	**1063.3**	**75,468**	**46.6**	**110.203**	**1625**	**4.8**

A further break-up of quantities shifting from road to rail is given in Table 6.7 and that shifting from rail to road is given in Table 6.8. The tables also indicate the number of O-D pairs (Routes) categorised into three groups based on annual tonnage moved; O-Ds with greater than 1 lakh tonnes, those with 1 lakh to 50,000 tonnes, those with 50000 to 25000 tonnes and those less than 25000 tonnes.

TABLE 6.7: CARGO SHIFTING TO RAIL AND NO OF O-D PAIRS AS PER QUANTUM OF FLOW

SN	COMMODITY NAME	TOTAL FLOW SHIFTED (MILLION TONNES)	NO OF O-D PAIRS CATEGORIZED AS PER QUANTITY OF ANNUAL FLOW (IN TONNES)				
			> 1 LAKH	50,000 TO 1 LAKH	25,000 TO 50,000	< 25 ,000	TOTAL
			O-D PAIRS *	O-D PAIRS *	O-D PAIRS *	O-D PAIRS *	
1	Other & Misc.	520.1	811 (37.7)	1200 (15.9)	2197 (14.8)	24169 (31.7)	28377 (100)
2	POL Products	115.8	150 (23.1)	356 (21.6)	1028 (30.6)	4158 (24.7)	5692 (100)
3	Coal	105.3	155 (55.0)	149 (10.1)	292 (9.7)	4080 (25.2)	4676 (100)
4	Iron & Steel	103.3	92 (21.3)	194 (13.2)	390 (13.0)	9410 (52.5)	10086 (100)
5	Food grains	86.4	52 (10.4)	136 (10.5)	348 (13.7)	9646 (65.4)	10182 (100)
6	Cement	55.1	64 (28.5)	88 (11.1)	216 (13.5)	4661 (46.9)	5029 (100)
7	Fruits & Veg.	37.7	15 (5.5)	41 (7.1)	86 (7.9)	6318 (79.5)	6460 (100)
8	Containers	15.8	29 (41.4)	22 (9.6)	41 (8.8)	597 (40.3)	689 (100)
9	Fertilizers	10.4	5 (0.3)	12 (0.7)	25 (1.49)	1626 (97.5)	1667 (100)
10	Sugar	8.6	3 (4.4)	3 (2.3)	21 (8.0)	1767 (85.3)	1794 (100)
11	Livestock	4.8	1 (2.7)	4 (6.1)	5 (3.3)	800 (87.9)	810 (100)
	TOTAL	**1,063**	**1377**	**2205**	**4649**	**67232**	**75,463**

* Figures are given in the numbers; figures in the parenthesis denote percentage to total.

TABLE-6.8: CARGO SHIFTING TO ROAD AND NO OF O-D PAIRS AS PER QUANTUM OF FLOW

SN	COMMODITY NAME	TOTAL FLOW SHIFTED (MILLION TONNES)	NO OF O-D PAIRS CATEGORIZED AS PER QUANTITY OF ANNUAL FLOW (IN TONNES)				
			> 1 LAKH	50,000 TO 1 LAKH	25,000 TO 50,000	< 25 ,000	TOTAL
			O-D PAIRS*	O-D PAIRS*	O-D PAIRS*	O-D PAIRS*	
1	Coal	75.95	80 (97.9)	8 (0.8)	14 (0.6)	65(0.7)	167 (100)
2	Petroleum Product	15.47	42 (60.7)	34 (15.2)	91 (20.2)	88 (3.9)	255 (100)
3	Cement	5.21	8 (55.4)	13 (18.6)	22 (15.2)	116 (10.8)	159 (100)
4	Iron & Steel	3.98	10 (71.1)	7 (12.9)	7 (6.4)	117 (9.7)	141 (100)
5	Other & Misc.	3.04	2 (12.4)	7 (14.5)	20 (22.3)	302 (50.8)	33 1(100)
6	Food grains	2.41	4 (32.6)	3 (9.8)	11 (16.5)	225 (41.1)	243 (100)
7	Fertilizers	1.86	0 (0.0)	5 (17.7)	18 (31.1)	146 (51.2)	169 (100)
8	Sugar	1.34	5 (48.7)	2 (10.5)	8 (21.6)	55 (19.3)	70 (100)
9	Containers	0.98	3 (73.6)	1 (8.1)	0 (0.0)	80 (18.2)	84 (100)
11	Fruits & Veg.	0.02	0 (0.0)	0 (0.0)	0 (0.0)	4 (100.0)	4 (100)
12	Livestock	0.002768	0 (0.0)	0 (0.0)	0 (0.0)	2 (100)	2 (100)
	TOTAL	**110.37**	**154**	**80**	**191**	**1200**	**1625**

* Figures are given in the numbers; figures in the parenthesis denote percentage to total.

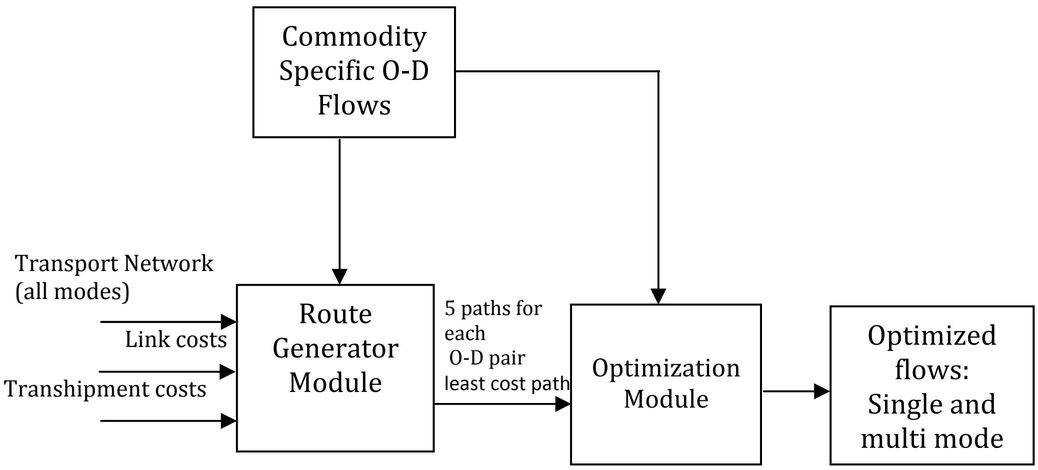
6.3.5 Analysis Plan: Rail, Road, and Coastal Cargo Movement with Transhipment

In the earlier analysis rail and road cargo movement was analysed but switching between modes was done outside the model by assigning cargo moving less than beak even distances to road and more than break even distances to rail. The models were run and results analysed based on individual networks.

In this plan the total cargo moving by all the three modes of transport is used as the flow data. This flow data was given as input to the complete goods transport network; i.e. rail, road and coastal shipping networks.

A block diagram of the steps involved in the analysis is given in Figure 6.2. The optimization involved two distinct steps. The first stage is to generate the competing routes. The model generated five different routes; a maximum of three mode specific routes; one for each feasible mode, and a minimum of two multi mode paths. In the second stage the five paths were allowed to compete with each other at the link level to arrive at optimal paths to move the total cargo. The objective function for the optimisation module was minimisation of the total system cost. The components of the system costs were transport costs, inventory cost, terminal handling costs and transhipment costs. The costs used in the module were resource costs; i.e. costs to the economy.

FIGURE 6.1: ANALYSIS USING THE CARGO MOVED BY ALL MODES AND THEIR NETWORK



To analyse the competition between modes the transhipment costs were varied. The transhipment costs were arrived at based on the user costs worked in the previous chapters. Three scenarios were simulated for the transhipment costs; efficient transhipment case; moderately efficient transhipment case and inefficient transhipment case. The transhipment costs for each of the situation are worked out based on the user costs incurred at the sample terminal locations, and the details are given in Table 6.9. While the costs would vary from place to place and from commodity to commodity, to simplify the calculations and the model results, same transhipment costs were used for all bagged and packaged goods and a different cost for loose and bulky articles.

TABLE 6.9: TRANSHIMENT COSTS IN DIFFERENT SCENARIOS FOR DIFFERENT COMMODITIES

SN	COMMODITY NAME	EFFICIENT TRANSHIPMENT		MODERATELY EFFICIENT TRANSHIPMENT		INEFFICIENT TRANSHIPMENT	
		BETWEEN RAIL AND ROAD RS	BETWEEN COASTAL AND RAIL OR ROAD RS	BETWEEN RAIL AND ROAD RS	BETWEEN COASTAL AND RAIL OR ROAD RS	BETWEEN RAIL AND ROAD RS	BETWEEN COASTAL AND RAIL OR ROAD RS
1	Foodgrains	40	40	40	80	80	160
2	Containers	40	40	40	80	80	160
3	Fruits and Vegetables Vegetables(80/160)	40	40	40	80	80	160
4	Fertilizers	40	40	40	80	80	160
5	Sugar	40	40	40	80	80	160
6	POL	40	40	40	80	80	160
7	Cement	40	40	40	80	80	160
8	Livestock	40	40	40	80	80	160
9	Others	40	40	40	80	80	160
10	Iron and Steel	30	30	30	60	60	120
11	Coal	30	30	30	60	60	120

The model was run for all the above three configurations for the 11 different commodities. Results of the model output in each of the transhipment cases is summarised in Tables 6.10, 6.11 and 6.12 for inefficient, moderately efficient and efficient situations respectively. The Tables give the share of different modes in moving the cargo in tonnes and tonnes kilometres. The tables also show the tonnage carried by each of the modes exclusively and also quantity carried by more than one mode – referred to as transhipped quantity in the Table.

TABLE 6.10: CHANGES IN MODAL SHARES IN INEFFICIENT TRANSHIPMENT CONDITIONS

COMMODITY	TONNAGE(MN)					TONNE KILOMETERS (TKM IN BILLION)						
	EXCLUSIVE TO ONE MODE			MORE THAN ONE MODE (TRANS HIPPED)		MODE WISE TKM				MODE WISE SHARE OF TRANSHIPPED TKM		
	RAIL	ROAD	COAS TAL		TOTAL	RAIL	ROAD	COAST AL	TOTAL	RAIL	ROAD	COAST AL
Foodgrains	106.7	64.3	0.3	16.4	187.7	104.9	9.4	1.8	116.1	9.0	1.0	1.8
Containers	42.8	36.7	1.5	4.4	85.4	47.8	2.6	1.7	52.1	2.0	0.0	1.0
Fruits n Vegetables	52.4	11.7	0.2	7.6	71.8	38.3	1.7	1.0	41.1	4.0	0.0	1.0
Fertilizers	44.4	6.2	0.2	3.8	54.6	34.2	0.6	1.5	36.3	2.0	0.0	1.0
Sugar	0.2	23.2	0.0	1.4	24.8	0.1	14.7	0.7	15.4	0.0	1.0	0.7
POL	147.3	37.9	17.1	13.9	216.2	78.8	4.9	13.0	96.6	6.0	1.0	1.0
Cement	62.4	60.8	0.0	34.7	157.9	53.2	20.3	0.0	73.5	16.0	6.0	0.0
Livestock	3.8	3.9	0.1	0.4	8.2	1.2	0.8	0.1	2.1	0.0	0.0	0.0
Others	441.0	157.0	3.0	69.0	670.0	348.0	26.0	11.0	385.0	2.0	6.0	0.0
Iron n Steel	82.6	58.2	0.5	27.8	169.1	85.6	10.2	3.5	99.3	18.0	2.0	3.0
Coal	464.0	185.1	8.9	67.8	725.7	313.8	24.4	18.1	356.2	35.0	3.0	8.0
Total	**1447.5**	**644.9**	**31.8**	**247.1**	**2371.4**	**1105.8**	**115.5**	**52.3**	**1273.6**	**94.0**	**20.0**	**18.0**
Note:*- Transhipped tonne kilometres are out of the total tonne kilometres.												

TABLE 6.11: CHANGES IN MODAL SHARES IN MODERATELY EFFICIENT TRANSHIPMENT CONDITIONS

COMMODITY	TONNAGE(MN)					TONNE KILOMETERS (TKM IN BILLION)						
	EXCLSIVE TO ONE MODE			MORE THAN ONE MODE (TRANS HIPPED)		MODE WISE TKM				MODE WISE SHARE OF TRANSHIPPED TKM		
	RAIL	ROAD	COAS TAL		TOTAL	RAIL	ROAD	COAS TAL	TOTAL	RAIL	ROAD	COAST AL
Foodgrains	101.4	60.8	0.3	25.1	187.7	102.6	9.6	3.3	115.6	12.0	2.0	3.0
Containers	41.6	36.6	1.5	5.8	85.4	47.4	2.7	1.8	51.9	3.0	0.0	1.0
Fruits n Vegetables	48.9	10.9	0.1	11.9	71.8	37.2	1.8	1.9	40.8	6.0	1.0	1.9
Fertilizers	40.9	6.0	0.2	7.5	54.6	32.6	0.7	2.6	36.0	3.0	0.0	2.6
Sugar	0.1	21.4	0.0	3.3	24.8	0.1	13.7	1.4	15.1	0.0	2.0	1.0
POL	136.7	35.8	17.1	26.7	216.2	77.2	5.2	14.3	96.7	9.0	1.0	1.0
Cement	47.6	53.7	0.0	56.6	157.9	52.7	21.0	0.0	73.7	24.0	9.0	0.0
Livestock	3.6	3.7	0.1	0.9	8.2	1.3	0.7	0.1	2.1	0.0	0.0	0.0
Others	406.0	147.0	2.0	116.0	671.0	337.0	30.0	16.0	382.0	4.0	8.0	0.0
Iron n Steel	75.5	51.0	0.5	42.0	169.1	81.7	10.6	6.6	98.9	20.0	3.0	6.0
Coal	401.3	167.3	8.6	148.5	725.7	308.8	26.3	19.0	354.2	55.0	8.0	10.0
Total	**1303.5**	**594.2**	**30.4**	**444.3**	**2372.4**	**1078.6**	**122.3**	**67.1**	**1267.1**	**136.0**	**34.0**	**27.0**
Note:*- Transhipped tonne kilometres are out of the total tonne kilometres.												

TABLE 6.12: CHANGES IN MODAL SHARES WITH IN EFFICIENT TRANSHIPMENT CONDITIONS

COMMODITY	TONNAGE(MN)					TONNE KILOMETERS (TKM IN BILLION)						
	EXCLUSIVE TO ONE MODE			MORE THAN ONE MODE (TRANS HIPPED)		MODE WISE TKM				MODE WISE SHARE OF TRANSHIPPED TKM TONNAGE KM (N)		
	RAIL	ROAD	COAS TAL		TOTAL	RAIL	ROAD	COAS TAL	TOTAL	RAIL	ROAD	COAST AL
Foodgrains	98.8	60.5	0.3	28.0	187.7	100.3	9.4	5.7	115.4	14.0	2.0	5.7
Containers	42.3	36.6	1.5	5.1	85.4	47.1	2.7	2.1	51.8	2.0	0.0	1.0
Fruits n Vegetables	47.9	10.8	0.1	12.9	71.8	36.4	1.7	2.7	40.8	6.0	1.0	2.7
Fertilizers	39.1	6.0	0.2	9.3	54.6	31.7	0.7	3.5	35.9	4.0	0.0	3.0
Sugar	0.1	19.7	0.0	5.0	24.8	0.1	12.6	2.5	15.2	0.0	3.0	2.5
POL	134.1	35.8	17.1	29.2	216.2	76.1	5.2	15.2	96.4	10.0	1.0	2.0
Cement	47.6	53.5	0.0	56.8	157.9	52.7	20.9	0.1	73.7	24.0	9.0	0.0
Livestock	3.4	3.8	0.1	1.0	8.2	1.2	0.7	0.2	2.1	0.0	0.0	0.0
Others	405.0	146.0	2.0	118.0	671.0	334.0	29.0	20.0	382.0	6.0	8.0	0.0
Iron n Steel	72.5	50.7	0.5	45.4	169.1	79.8	9.9	9.6	99.3	22.0	3.0	9.0
Coal	405.6	167.2	8.6	144.3	725.7	305.2	25.3	25.9	356.5	56.0	7.0	17.0
Total	**1296.4**	**590.6**	**30.3**	**455.1**	**2372.4**	**1064.5**	**118.2**	**87.4**	**1269.1**	**144.0**	**34.0**	**44.0**
Note:*-Transhipped tonne kilometres are out of the total tonne kilometres.												

Table 6.13 summarises the changes in the modal shares in the three scenarios. The Table is instructive in the changes noticed and the implications. Even with very inefficient transhipment conditions nearly 10 per cent of the total tonnage transhipped. As the system becomes efficient nearly 20 per cent of the cargo is transhipped. Similarly tonne kilometres of transhipped cargo increases from 10 per cent in the inefficient case to around 18 per cent in the most efficient.

TABLE 6.13: IMPACT OF DIFFERENT CONDITIONS OF TRANSHIMENT ON MODAL SHARES (TONNAGE)

TRANSHIPMENT CONDITION	TONS (MILLION)				
	RAIL	ROAD	COASTAL	TRANSHIPPED	TOTAL
Actual (no transhipment)	769	1540	59	0	**2368**
Inefficient	1448	645	32	247	**2371**
Moderately efficient	1303	594	30	444	**2372**
Efficient	1296	591	30	455	**2372**

TABLE 6.14: IMPACT OF DIFFERENT CONDITIONS OF TRANSHIMENT ON MODAL SHARES (TON KILOMETRES)

TRANSHIPMENT CONDITION	TON KILOMETRES (BILLION)							
	TON KMS BY EACH MODE				BREAK UP OF TRANSHIPPED*			
	RAIL	ROAD	COASTAL	TOTAL	RAIL	ROAD	COASTAL	TOTAL
Actual (no transhipment)	507	693	86	**1286**	0	0	0	**0**
Inefficient	1106	115	52	**1274**	94	20	18	**132**
Moderately efficient	1079	122	67	**1267**	136	34	27	**197**
Efficient	1065	118	87	**1269**	144	34	44	**222**

Note: * - Transhipped tonne kilometres are out of the total tonne kilometres.

In terms of the modal shares, as expected, the rail modal shares are increasing and the road shares are decreasing. However, a more interesting phenomenon is noticed for coastal shipping. The modal share for coastal shipping in terms of tonnage has reduced in all three cases and in terms of tonnes kilometres it has reduced in two cases. In the most efficient condition the tonne kilometres have increased marginally by around 1.6 per cent.

A closer introspection of coastal flows is warranted and Table 6.15 gives the data on coastal flows. The total tonne kilometres carried increases by 1.43 billion tonne kilometres. A commodity wise break is more instructive. The tonne kilometres carried by coastal shipping for the two commodity groups are reduced by 38 billion tonne kilometres. This, it is observed, is due to reduced leads by terrestrial modes compared to the coastal modes. The effect is mainly noticed in iron ore movement from east to west and POL products from west to east. Another phenomenon could be the high economies of scale achieved in iron ore movement which is not reflected in commodity grouping. However, given the capacity constraints by terrestrial modes and physical difficulties to organise such movement by land, iron ore and POL products including crude would continue to move by coastal shipping.

More important, however, is the shift of other cargo to coastal shipping. If the coal and POL products are excluded the coastal shipping increases from 7 billion tonne kilometres (BTKM) to 46.3 billion tonne kilometres (BTKM) an increase of 39.3 billion tonne kilometres; an astounding increase of 650 per cent. The most important increase is noticed in other goods (16 BTKM), iron and steel (9.6 BTKM) and foodgrains (5.7 BTKM). However, such an increase would not be possible unless efficient transhipment facilities are organised at the ports.

TABLE 6.15: COMPARISON OF ACTUAL AND OPTIMISED FLOWS BY COASTAL SHIPPING (CASE OF EFFICIENT TRANSHIPMENT)

COMMODITY	IN BILLION TONNE KILOMTRES		
	ACTUAL	OPTIMISED	DIFFERENCE (OPTIMISED - ACTUAL)
Foodgrains	0.00	5.69	5.69
Iron n Steel	0.00	9.59	9.59
Containers	1.00	2.06	1.06
Fruits n Vegetables	0.00	2.70	2.70
Coal	48.00	25.91	-22.09
Fertilizers	0.00	3.50	3.50
Sugar	0.00	2.52	2.52
POL	31.00	15.18	-15.82
Cement	2.00	0.11	-1.89
Livestock	0.00	0.16	0.16
Others	4.00	20.00	16.00
Total	**86**	**87.43**	**1.43**
Subtotal for coal and POL	**79**	**41.09**	**38.0**
Total without coal and POL	**7.00**	**46.33**	**39.33**

Appendix-1
Chapter 6

PROPORTIONATE SHARE OF DIFFERENT ROAD CATEGORIES

SN	ROAD CLASSIFICATION	CODE	IRON & STEEL	COAL	CONTAINERS	CEMENT	LIVESTOCK	POL	FRUITS & VEG	SUGAR	FERTILISERS	FOOD GRAINS
1	NH PL SL	111	0.21	0.1	0.12	0.24	0.24	0.28	0.13	0.19	0.64	0.21
2	NH PL DL	112	78.18	66.06	64.09	65.37	65.37	65.18	71.12	68.63	67.36	70.18
3	NH PL 4L	114	0.09	0.07	0.05	0.05	0.05	0.06	0.09	0.12	0.02	0.05
4	NH PL 4EXP	115	2.07	1.95	1.51	1.86	1.86	1.9	1.72	1.78	1.05	2.11
5	NH RL DL	122	0.03	0.33	0.95	0.57	0.57	0.93	0.51	0.38	0.27	0.41
6	NH RL 4L	124	0	0	0	0	0	0	0	0	0	0
7	NH RL 4EXP	125	0	0	0	0	0	0	0	0	0	0
8	NH HI SL	131	0.27	0.01	0	0	0	0	0.04	0	0.01	0.01
9	NH HI DL	132	1.77	2.81	3.15	2.8	2.8	3.99	2.87	2.04	3.39	2.93
10	NH HI 4L	134	0	0	0	0	0	0	0	0	0	0
11	SH PL SL	211	0	0.01	0	0.01	0.01	0	0.02	0.01	0.01	0.01
12	SH PL DL	212	16.1	25.68	28.3	26.59	26.59	24.31	20.31	23.85	25.59	21.27
13	SH PL Inter	216	0	0	0	0	0	0	0	0	0	0
14	SH RL SL	221	0	0	0	0	0	0	0	0	0	0
15	SH RL DL	222	0.03	0.05	0.28	0.12	0.12	0.2	0.12	0.04	0.1	0.08
16	SH HI SL	231	0.02	0.5	0	0.07	0.07	0.27	0.03	0.01	0.02	0.07
17	SH HI DL	232	0.57	1.49	0.1	1.69	1.69	1.7	1.89	2.07	0.99	1.8
18	SH HI Inter	236	0	0	0	0	0	0	0	0	0	0
19	MDR PL SL	311	0	0.01	0	0	0	0	0	0	0	0.01
20	MDR PL DL	312	0.64	0.88	1.45	0.54	0.54	1.04	1.07	0.86	0.51	0.81
21	MDR RL SL	321	0	0	0	0	0	0	0	0	0	0
22	MDR HI SL	331	0.02	0.03	0	0.08	0.08	0.13	0.04	0.01	0.03	0.03
23	MDR HI DL	332	0	0.02	0	0.01	0.01	0.01	0.04	0.01	0.01	0.01
24	MDR HI Inter	336	0	0	0	0	0	0	0	0	0	0.01
		Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Appendix-2
Chapter 6

COMMODITY WISE WEIGHTED AVERAGE SECTIONAL COST OF RAILWAYS

SN	Elements of Costs	SECTIONAL COST				
		Dsl. SL	Dsl. DL	Elec. SL	Elec. DL	Wtd. Avg. UC
A	**Food Grains**					
1	Unit Costs per Tonne-Km	0.677799044	0.637638576	0.56629637	0.551563112	
2	Tonne-km (Wtg.factor)	8649024495	2253920976	820782008	33970658368	45694385847
3	Total Cost (In Rupees)	5862300533	1437186962	464805869	18736962031	26501255395
4	**Average Unit Cost (In Rupees)**					**0.58**
B	**Fruits & Vegetables**					
1	Unit Costs per Tonne-Km	0.699009167	0.657536087	0.58509247	0.569606818	
2	Tonne-km (Wtg.factor)	314922506	212793249	22142379	2211118142	2760976276
3	Total Cost (In Rupees)	220133718.5	139919240.3	12955339.3	1259467969	1632476267
4	**Average Unit Cost (In Rupees)**					**0.59**
C	**Coal**					
1	Unit Costs per Tonne-Km	0.724077459	0.680543581	0.60324428	0.586518458	
2	Tonne-km (Wtg.factor)	45629958636	20014639990	2.3077E+10	1.59684E+11	248405527305
3	Total Cost (In Rupees)	33039624494	13620834775	1.3921E+10	93657602646	154239098332
4	**Average Unit Cost (In Rupees)**					**0.62**
D	**Fertilisers**					
1	Unit Costs per Tonne-Km	0.69917914	0.659018673	0.58767646	0.572943208	
2	Tonne-km (Wtg.factor)	8810700242	2925725740	1658708348	12257338395	25652472725
3	Total Cost (In Rupees)	6160257822	1928107894	974783855	7022758783	16085908355
4	**Average Unit Cost (In Rupees)**					**0.63**
E	**Sugar**					
1	Unit Costs per Tonne-Km	0.67217563	0.632015163	0.56067295	0.545939698	
2	Tonne-km (Wtg.factor)	1775781907	490263713	248664203	2242524242	4757234065
3	Total Cost (In Rupees)	1193637323	309854100.3	139419293	1224283007	2867193723
4	**Average Unit Cost (In Rupees)**					**0.60**
F	**Petroleum products**					
1	Unit Costs per Tonne-Km	0.796204979	0.745959168	0.65940689	0.639340177	
2	Tonne-km (Wtg.factor)	6223939764	2304605080	1210773007	12927539252	22666857103
3	Total Cost (In Rupees)	4955531829	1719141289	798392058	8265095229	15738160404
4	**Average Unit Cost (In Rupees)**					**0.69**
G	**Cement**					
1	Unit Costs per Tonne-Km	0.71910901	0.678948543	0.60760633	0.592873078	
2	Tonne-km (Wtg.factor)	12427907799	4875761765	1349603115	16928390723	35581663402
3	Total Cost (In Rupees)	8937020478	3310391345	820027400	10036387114	23103826337
4	**Average Unit Cost (In Rupees)**					**0.65**
H	**Livestock**					
1	Unit Costs per Tonne-Km	1.679804361	1.576972015	1.39507075	1.357175528	
2	Tonne-km (Wtg.factor)	8225602	7054721	3390286	153574801	172245410
3	Total Cost (In Rupees)	13817402.11	11125097.59	4729688.85	208427961.6	238100150.2
4	**Average Unit Cost (In Rupees)**					**1.38**
J	**Steel Products**					
1	Unit Costs per Tonne-Km	0.739902932	0.692045317	0.60899762	0.590014172	
2	Tonne-km (Wtg.factor)	3157039319	1519166050	954877790	18499830906	24130914065
3	Total Cost (In Rupees)	2335902648	1051331751	581518304	10915162419	14883915123
4	**Average Unit Cost (In Rupees)**					**0.62**
K	**Containers**					
1	Unit Costs per Tonne-Km	0.859775772	0.809151884	0.7202777	0.701473464	
2	Tonne-km (Wtg.factor)	2028150585	310790536	890838268	22357887651	25587667040
3	Total Cost (In Rupees)	1743754735	251476747.8	641650938	15683464905	18320347326
4	**Average Unit Cost (In Rupees)**					**0.72**

Appendix-3
Chapter 6

TRANSPORT ALLOCATION AND ROUTE-MODE MIX OPTIMIZATION (TAROP) MODEL

**Given the Potential of Supply and Demand for Each Commodity for Each O-D Pair,
This Model Calculates Least Cost O-D Flow Allocation and
Route Mix for Transporting Commodities for Each O-D Pair**

Input Data:
- Network data definitions – Nodes, Links
- Candidate Routes for each O-D pair (selected using 'k' shortest paths algorithm before the optimization model)
- Link type – section type, mode, etc.
- Link length (km)
- Route – Links membership
- Supply of each Commodity from each Node (in tonnes)
- Demand for each Commodity at each Node (in tonnes)
- Capacity of each Link (in Standard Vehicle Load)
- Standard Vehicle Load Conversion Factor for each Commodity (in Standard Vehicle Load per tonne)
- Route level costs:
  - Handling Cost for each Commodity (in INR per tonne)
- Link level costs (all expressed as multi-steps in INR per tonne per km):
  - Variable OM Cost
  - Fixed OM Cost
  - Variable Infrastructure Cost
  - Fixed Infrastructure Capital Cost
  - User Discomfort Cost (Congestion and Delays)
- Environmental Cost
  - Accident Related Cost
  - Other Costs
- Inventory cost (interest value of time which the commodities spend in transport, handling and waiting)

Output Variables:
- Flow of each Commodity between each O-D pair (in tonnes)
- Unused supply of each Commodity from each Node (in tonnes)
- Unmet demand for each Commodity at each Node (in tonnes)
- Flow of each Commodity on each Route (in tonnes)
- Flow of each Commodity on each Link (in tonnes)
- Flow of each Commodity on each Link (in Standard Vehicle Load)

Objective Function:
- Minimize Total System Cost (i.e. Sum of all costs)

Constraints:
- Supply Constraints: Sum of flows of a Commodity from a Node plus unused supply must be equal to Supply of that Commodity from that Node
- Demand Constraints: Sum of flows of a Commodity into a Node plus unmet demand must be equal to Demand of that Commodity at that Node
- Flow Constraints: Flow of a Commodity between an O-D pair must be equal to the sum of flows of that Commodity on all candidate Routes for that pair
- Link Capacity Constraints: Total flow of all Commodities on a Link must not exceed its Capacity
- Link-Route Flow Balance: Total flow of a Commodity on a Link must be equal to sum of flows of that Commodity on all Routes containing that Link
- Link Flow - Cost Segments Flow Balance: Total flow of a Commodity on a Link is equal to the sum of flows of that Commodity on all Cost Segments of that Link
- Link Cost Segment Flow Limit: Flow on a Cost Segment of a Link must not exceed that Segment's

Appendix-4
Chapter 6

Transport Allocation and Route-Mode Mix Optimization (TAROP) Model

Brief description:

Given the data of supply and demand of each commodity for each node, candidate routes for each o-d pair, handling cost for each route, inventory cost, variable and other section level costs and section capacities, this model calculates the optimal (least cost) o-d flow allocation of commodities and mix of routes to transport the flows.

Sets:

I	:	Centroid nodes (i1, i2, ...)
L	:	Links or Sections (l1, l2, ...)
LT	:	Type of link (lt1, lt2, ...)
R	:	Routes (r1, r2, ...)
K	:	Commodities (k1, k2, ...)
CT	:	Link related cost types (ct1, ct2, ...)
OD_Ri, j, r	:	Valid set of o-d pairs and routes for each pair
R_Lr, l	:	Valid set of links belonging to each route
LT_Llt, l	:	Set of links belonging to a type of link

Parameters:

a	:	Annual rate of interest (in fraction)
SUPPLYi, k	:	Supply of commodity k from node i (in tonnes / year)
DEMANDj, k	:	Demand of commodity k at node j (in tonnes / year)
pricek	:	Price of commodity k (Rs./ tonne)
speedlt	:	Average distance travelled per day on link type lt (km / day)
caplt	:	Capacity of link type lt (in maximum standard vehicle loads / year)
linklenl	:	Length of link l (in km)
stdloadl, k	:	Factor for converting standard vehicle load to tons for link l and commodity k (in tonnes / standard vehicle load)
hcr, k	:	Handling cost or user cost incurred due to handling and cartage at terminals for route r for commodity k (in Rs./ tonne)
lcct, lt, k	:	Link level cost ct for commodity k and type of link lt (in Rs./ tonne-km)

Variables:

FLOWi, j, k	:	Flow of commodity k from node i to node j (in tonnes)
R_FLOWr, k	:	Flow of commodity k on route r (in tonnes)
L_FLOWl, k	:	Flow of commodity k on link l (in tons)
STD_FLOWl	:	Flow on link l (in standard vehicle loads)
EXCESS_SUPPLYi, k	:	Surplus supply of commodity k at node i (in tons)
EXCESS_DEMANDj, k	:	Excess demand of commodity k at node j (in tons)

Model Description:

Minimize HANDLING COST + INVENTORY COST + LINK COST
Where,

HANDLING COST = $\sum_{r,k}\left(hc_{r,k} \times R\_FLOW_{r,k}\right)$

INVENTORY COST = $\frac{a}{360} \times \sum_{k}\left\{price_k \times \sum_{(lt,l)\in LT\_L}\left(\frac{linklen_l \times L\_FLOW_{l,k}}{speed_{lt}}\right)\right\}$

LINK COST = $\sum_{(ct,lt,l,k)\in LT\_L}\left(linklen_l \times lc_{ct,lt,k} \times L\_FLOW_{l,k}\right)$

Subject to..

Supply constraints:

$$\sum_{j,r\in OD\_R} FLOW_{i,j,k} + EXCESS\_SUPPLY_{i,k} = SUPPLY_{i,k} \qquad \forall i,k$$

Demand constraints:

$$\sum_{i,r\in OD\_R} FLOW_{i,j,k} + EXCESS\_DEMAND_{j,k} = DEMAND_{j,k} \qquad \forall j,k$$

Route flow equation:

$$\sum_{r\in OD\_R} R\_FLOW_{r,k} = FLOW_{i,j,k} \qquad \forall i,j,k$$

Link capacity constraints:

$$STD\_FLOW_l = cap_{lt} \qquad \forall (lt,l) \in LT\_L$$

Route-Link flow balance:

$$\sum_{r\in R\_L} R\_FLOW_{r,k} = L\_FLOW_{l,k} \qquad \forall l,k$$

Standard vehicle load equation:

$$STD\_FLOW_l = \sum_{k}\left(stdload_{l,k} \times L\_FLOW_{l,k}\right)$$

All variables are non-negative.

Appendix-5
Chapter 6

Transport Route-Mode Mix Optimization (TROP) Model

Brief description:

Given the data of traffic flow of commodities between given o-d pairs, candidate routes for each o-d pair, handling cost for each route, inventory cost, variable and other section level costs and section capacities, this model calculates the optimal (least cost) mix of routes to meet the flows.

Sets:

I	:	Centroid nodes (i1, i2, ...)
L	:	Links or Sections (l1, l2, ...)
LT	:	Type of link (lt1, lt2, ...)
R	:	Routes (r1, r2, ...)
K	:	Commodities (k1, k2, ...)
CT	:	Link related cost types (ct1, ct2, ...)
OD_Ri, j, r	:	Valid set of o-d pairs and routes for each pair
R_Lr,l	:	Valid set of links belonging to each route
LT_Llt, l	:	Set of links belonging to a type of link

Parameters:

a	:	Annual rate of interest (in fraction)
flowi,j, k	:	Flow of commodity k from node i to node j (in tonnes / year)
pricek	:	Price of commodity k (Rs./ ton)
speedlt	:	Average distance travelled per day on link type lt (km / day)
caplt	:	Capacity of link type lt (in maximum standard vehicle loads / year)
linklenl	:	Length of link l (in km)
stdloadl, k	:	Factor for converting standard vehicle load to tons for link l and commodity k (in tonnes / standard vehicle load)
hcr, k	:	Handling cost or user cost incurred due to handling and cartage at terminals for route r for commodity k (in Rs./ tonne)
lcct, lt, k	:	Link level cost ct for commodity k and type of link lt (in Rs./ tonne-km)

Variables:

R_FLOWr, k	:	Flow of commodity k on route r (in tons)
L_FLOWl, k	:	Flow of commodity k on link l (in tons)
STD_FLOWl	:	Flow on link l (in standard vehicle loads)

Model description:

Minimize HANDLING COST + INVENTORY COST + LINK COST

Where,

HANDLING COST = $\sum_{r,k}\left(hc_{r,k} \times R\_FLOW_{r,k}\right)$

INVENTORY COST = $\frac{a}{360} \times \sum_{k}\left\{price_{k} \times \sum_{(lt,l)\in LT\_L}\left(\frac{linklen_{l} \times L\_FLOW_{l,k}}{speed_{lt}}\right)\right\}$

LINK COST = $\sum_{(ct,lt,l,k)\in LT\_L}\left(linklen_{l} \times lc_{ct,lt,k} \times L\_FLOW_{l,k}\right)$

Subject to..

Flow constraints:

$$\sum_{r\in OD\_R} R\_FLOW_{r,k} = flow_{i,j,k} \qquad \forall i,j,k$$

Link capacity constraints:

$$STD\_FLOW_{l} = cap_{lt} \qquad \forall (lt,l) \in LT\_L$$

Route-Link flow balance:

$$\sum_{r\in R\_L} R\_FLOW_{r,k} = L\_FLOW_{l,k} \qquad \forall l,k$$

Standard vehicle load equation:

$$STD\_FLOW_{l} = \sum_{k}\left(stdload_{l,k} \times L\_FLOW_{l,k}\right)$$

All variables are non-negative.