ENVIRONMENTAL AND SOCIAL SUSTAINABILITY OF TRANSPORT

Comparative Study of Rail and Road

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ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT

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It is an accepted premise that economic development requires adequate and efficient transport services. However, use of transportation is not wholly a benign activity. It causes strain on nature by consuming scarce resources, emitting harmful pollutants and generating undesirable wastes. Different modes of transport cause varying levels of stress and consequential damage. Hence, there is growing recognition that the transport systems and modal choices should factor in the cost of environmental degradation and social damage, as it would promote overall sustainability and sustainable transport.

It is in this context that the Institute undertook a comparative study of rail and road modes with a focus on social sustainability. It has been a path-breaking effort in many ways. It is for the first time that such a comparative study of the two modes has been undertaken and models developed for projecting outcomes under Indian conditions. The study encompasses several areas demanding an inter-disciplinary approach, particularly because each mode of transport has its own characteristics, different capital intensities and technical and operational capabilities. It also explores the realms of the economics of environmental and social costs and attempts to monetise these costs relevant to Indian conditions.

The study has had to face difficulties in obtaining necessary data, as reliable data are not available on certain aspects. In some cases, data related to Indian conditions have not been worked out. We have, therefore, used data pertaining to other countries for constructing an Indian scenario. There has also been the problem of multiplicity of data on certain issues. In such cases, we have tried to reconcile them to the extent possible and adopt what we consider most appropriate in the situation obtaining in our country.

This study does not seek to establish whether rail is better than road or vice versa, nor to prove which mode of traction is superior. It is to bring out all aspects of the two principal modes of transport in India so that appropriate choices can be made. Rail and road, both have their own place and relevance in national transport. Their roles do not have to be adversarial. They need to be complementary, so that scarce resources are utilised to maximise overall benefits to the society. It is hoped that this study will prove useful to all the stakeholders, particularly policymakers at the national level.

K. L. Thapar
Director

May, 2002

Contents

1 Intermodal Choices

All human endeavour involves choices and nowhere is this more true than in commercial activity. Indeed, the science that formally studies such activity – economics – is the study of the choices that people, businesses and countries make in order to maximise their overall welfare.

All human endeavour involves making a choice.

Transport is an integral part of economic and commercial activity. As such, it also requires choices to be made between different modes of transport, such as rail, road, ship, air or even non-motorised transport. At the personal or firm level, the driving factor is the trade-off between price, speed, safety, reliability and convenience. However, the sum of these individual choices, even while maximising individual or firm-level welfare, may not maximise social welfare.

This becomes obvious when intermodal choices are examined. Choices that maximise profits, utility or welfare in the short run do not necessarily do so in the long run. In other words, short-run choices between different modes of transport, based on trade-off mentioned above, can lead to outcomes that are unsustainable in the long run in a variety of ways. The intermodal choices have far-reaching economic, social and environmental implications which are not reckoned in individual choices but affect the overall sustainability and efficiency of transport systems.

Individual choices, while maximising personal welfare, may not maximise social welfare.

An analysis of road and rail, the two dominant modes of transport in the country, reveals that, over the years, these modes have undergone vast changes both in terms of their growth and respective modal shares. The share of rail has fallen steeply, while that of road has gone up sharply. The share of goods traffic carried by road is now estimated to be as high as 76%, and of passenger traffic 79%.

There has been a modal shift in favour of road both for passenger and freight traffic.

The elasticity of road transport with respect to gross domestic product of the country has been substantially higher than that of rail transport. During the three decades ending the year 2000, while the gross domestic product (GDP) grew at an average of 4.8% annually, the railways recorded a growth of 4.6% for passenger traffic and 3.1% for freight traffic. On the other hand, road freight traffic grew at the rate of 10.3% and passenger traffic at 7.4%.

The modal shares of the two modes during the period 1970-2000 are shown in Table 1.1 below:

Table 1.1 : Modal Shares of Rail and Road Traffic

Year	RLFRT BTKM	RLPAS BPKM	RDFRT BTKM	RDPAS BPKM	TLFRT BTKM	TLPAS BPKM	Share of RLFRT in TLFRT	Share of RDFRT in TLFRT	Share of RLPAS in TLPAS (%)	Share of RDPAS in TLPAS (%)
1970-71	127	118	57	210	184	328	69.02	30.98	35.98	64.02
1971-72	133	125	62	225	195	350	68.21	31.79	35.71	64.29
1972-73	137	134	51	223	188	357	72.87	27.13	37.54	62.46
1973-74	122	136	54	257	176	393	69.32	30.68	34.61	65.39
1974-75	134	126	56	293	190	419	70.53	29.47	30.07	69.93
1975-76	148	149	59	308	207	457	71.50	28.50	32.60	67.40
1976-77	157	164	65	318	222	482	70.72	29.28	34.02	65.98
1977-78	163	177	68	397	231	574	70.56	29.44	30.84	69.16
1978-79	155	193	76	409	231	602	67.10	32.90	32.06	67.94
1979-80	156	199	84	421	240	620	65.00	35.00	32.10	67.90
1980-81	159	209	98	543	257	752	61.87	38.13	27.79	72.21
1981-82	174	221	113	595	287	816	60.63	39.37	27.08	72.92
1982-83	178	227	129	597	307	824	57.98	42.02	27.55	72.45
1983-84	178	223	145	674	323	897	55.11	44.89	24.86	75.14
1984-85	182	227	161	739	343	966	53.06	46.94	23.50	76.50
1985-86	206	241	193	850	399	1091	51.63	48.37	22.09	77.91
1986-87	223	257	210	893	433	1150	51.50	48.50	22.35	77.65
1987-88	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
1988-89	230	264	420	765	650	1029	35.38	64.62	25.66	74.34
1989-90	237	281	453	835	690	1116	34.35	65.65	25.18	74.82
1990-91	243	296	503	859	746	1155	32.57	67.43	25.63	74.37
1991-92	257	315	567	956	824	1271	31.19	68.81	24.78	75.22
1992-93	258	300	610	1003	868	1303	29.72	70.28	23.02	76.98
1993-94	257	296	646	1086	903	1382	28.46	71.54	21.42	78.58
1994-95	253	319	672	1192	925	1511	27.35	72.65	21.11	78.89
1995-96	274	342	762	1322	1036	1664	26.45	73.55	20.55	79.45
1996-97	280	357	807	1427	1087	1784	25.76	74.24	20.01	79.99
1997-98	284	380	863	1498	1147	1878	24.76	75.24	20.23	79.77
1998-99	282	404	923	1573	1205	1977	23.40	76.60	20.43	79.57
1999-2000	305	431	987	1659	1292	2090	23.60	76.40	20.62	79.38

Note: RL : Rail; RD : Road; TL : Total (RL + RD); FRT : Freight; PAS : Passengers. BTKM : Billion Tonne Kilometres; BPKM : Billion Passenger Kilometres; NA : Not available

* For the years 1997-98 to 1999-2000, the data has been estimated on the basis of past trends.

As would be seen from the above table, during this period, the share of rail in case of freight traffic declined from 69% to 24%, while that of road went up from 31% to 76%. In case of passenger traffic, while the share of rail declined from 36% to 21%, that of road went up to 79%.

Shift in favour of road is not just due to modal attributes, but also because of the distorted nature of relative pricing structures.

Such a shift in favour of road is the result of the pricing regimes prevailing in the two modes. This, combined with non-price related factors, such as door-to-door service and response to customer requirements provided by road transport, has resulted in such a large reduction in the railway's share. There are two components that distort the structure of relative prices of rail and road. Rail transport, in its pricing, covers all costs, including that of the fixed infrastructure, whereas road pricing does not reflect the full normative cost of ground infrastructure and its maintenance. Moreover, the road and fuel taxes have little or no relation with the true resource cost of various inputs.

Besides the larger problems of pricing, as mentioned above, the railway's skewed pricing policy has also led to diversion of traffic to road. The rail freight rates have invariably been kept at higher levels in order to cross-subsidise passenger traffic. The profits generated from freight traffic have been used to cover the losses from passenger services.

The intermodal choice of transport has been a matter of concern.

The intermodal choice of transport, particularly between rail and road, has been a matter of concern to the government. The National Transport Policy Committee (NTPC), 1980 and the Steering Committee on Perspective Planning for Transport Development, 1988, studied optimal intermodal division of freight traffic between rail and road keeping in view past trends, resource cost estimates, break-even points and increase in oil prices, etc. NTPC visualised a modal share of 72% for rail and 28% for road transport in the case of freight traffic. They further observed that 60% of passenger traffic, particularly for short distances, would have to be carried by road services. They also visualised that in the years to come long-distance inter-city and heavy metropolitan commuter traffic would be carried by the railways. In actual practice, however, the traffic trend has been in the reverse direction with the railway's share sliding down and the share of road transport going up.

The principal policy issues addressed in most of the past studies related to rail and road modes were financial and economic. Environmental and ecological concerns, which have assumed increasing importance lately, were generally overlooked or referred to only peripherally. The tendency on the whole was to take environmental and social sustainability for granted. However, there is now a growing concern globally about environmental and ecological sustainability of economic development in general and infrastructure development (especially transport development) is particular. In addition, social sustainability has also become a matter of concern in most countries, in view of the growing realisation of the need to serve larger public interests of the communities.

Past studies largely addressed financial and economic issues.

Economic and financial sustainability of the transport system requires that resources be used efficiently and economically. Environmental and ecological sustainability requires that the external effects of transport be taken into account fully when decisions are made in respect of the sector's future development. Social sustainability requires that social costs (like loss of life or property) are reduced to the minimum and benefits of transport reach all sections of the society.

In this context, it may be pointed out that the United States Intermodal Surface Transportation Efficiency Act 1991 required intermodal transport planning in order to reduce energy consumption and air pollution while promoting economic development. This was to be achieved by developing a national intermodal transportation system which is economically efficient and environmentally sound, which provides the foundation for the nation to compete in global economy, and which moves people and goods in an energy-efficient manner.

Following on this, the United States Transportation Equity Act 1998 requires that indicators of economic, social and environmental performance of transportation system be developed to facilitate analysis of potential alternatives. It further requires study of the relationship between highway density and ecosystem integrity, including the impacts of highway density on habitat integrity and overall health of the ecosystem. Besides, the Act also requires the development of a rapid assessment methodology for use by transportation and regulatory agencies in determining the relationship between highway density and ecosystem integrity.

The future approaches to the development of various transport modes in India, particularly rail and road, must necessarily be guided by the broader policy goals of ensuring their environmental and ecological sustainability besides economic and social viability. The overall objective of the present study is to examine how these broad policy goals can be achieved.

Energy has a special significance in the transport sector not only because this sector is one of the major users of energy, but also because different modes of transport use different forms of energy, with varying efficiency and intensity. Again, this is the sector where at present there are few substitutes for oil. Therefore, fuel economy emerges as the most effective means of preserving the country's capacity for sustainable development. The study aims to present an up-to-date in-depth analysis of energy usage in rail and road modes of transport, its efficiency and environmental and ecological impacts, taking into account the emerging technological advances. The study also aims at evolving approaches to ensure optimum balancing of the country's transport system with the national economy, on the one hand, and between different modes of transport, on the other, having regard to the competing usages of energy which will become an increasingly scarce resource in the foreseeable future.

The study examines how transport can serve the larger goal of social sustainability.

With the emerging market-orientation of the national economy, there is a growing emphasis on leaving future development in transport, as far as possible, to market forces as is being done in the case of other sectors of the national economy. In this perspective, national concerns about safeguarding the country's environment and ecology as well as conservation of scarce natural resources assume greater importance. How best to address these concerns in a manner that does not inhibit or decelerate growth, would be one of the most difficult challenges for policy makers and planners of transport at all levels, both public and private, in the years to come. The study aims at analysing the issues involved, based on a realistic assessment of prospective developments in the country's transport system and their economic, social, environmental and ecological implications. The emerging environmental situation in the country calls for a better understanding of the railway's role, particularly as a major national carrier. The study would in all probability lead to a discussion of policy options for an optimum development of the various constituents of the country's transport system with a view to enhancing the efficiency of the system as a whole.

The ultimate objective of transport planning must necessarily be to develop a system that ensures economic efficiency of services, optimising usage of resources in general and minimising economic and social costs to the national economy, taking into account not only the economic and financial costs, as has been done traditionally, but also the environmental and ecological costs to the society as a whole.

The scarcity value of natural resources used and the external costs involved in the transportation activity due to pollution and degradation of environment thus need to be built into the social cost of transport services. The socially optimal resource allocation rule warrants prices to be equalised with the long-run marginal social cost of supply and use of transport services. Only such allocation of resources would correctly identify the socially optimal modal choice of transport.

The study focuses mainly on the relative contribution of the two principal modes of transport to environmental and social costs of spatial transformation of critical material resources. Although the share of transport in the existing costs of final goods and services may not always be very large, the various impacts of transport on the environment assume significance in the light of the already degraded nature of air, land and water in many areas. Significant changes may, therefore, be called for in the location of economic activities and modal choice if the costs of environmental damage are internalised by introducing appropriate market-based policy instruments as per the dictates of Pareto-optimal resource allocation.

Socially optimal resource allocation would induce optimal modal choice.

The broad policy goals behind internalisation of external effects, *inter alia*, are: optimal use of existing capacity; abolishing subsidies not justified by public good characteristics of the transport system; allocation of costs to the agent responsible for their production; achieving long-term environmental/safety standards; better balancing of regional and social development; and developing new markets and new technologies with lower consumption of natural resources.

The study analyses the problem of modal choice of transport with reference to:

(i) a comparison of the physical effects of development and operation of the rail and road modes of transport on natural environmental conditions, human health as well as the safety of human life; and

(ii) a comparison of the socio-economic and financial resource cost of rail transport with that of road transport.

Assuming that the projections of population, urbanisation, transport and associated requirements, as made by the Planning Commission, India, up to the year 2010, will hold, and that the prevailing trends of globalisation, urbanisation and economic reforms will not only continue but will accelerate, the study focuses on the intermodal choices between rail and road for the movement of people as well as goods.

An important objective of the study was to find out if there was an optimum modal choice and, if so, how to induce the transport user to move towards such optimal modes. There are three types of issues to be considered in the context of the intermodal choice – economic, environmental and social. Policy measures have to take care of these diverse concerns. Transport users will, however, be primarily concerned with the first one even at the expense of the other two.

A major task of this study was to determine the various elements of social, environmental and financial costs of the two modes and evaluate the effects of intermodal substitution in order to arrive at an optimal choice on an objective basis. This exercise posed a major challenge to develop a methodology to quantify and monetise all elements of costs and benefits in order to be able to compare or integrate them. While determining direct financial costs in construction and manufacture was relatively easy, it was difficult to determine and assign values to externalities, such as health hazards and accidents or pollutants in the atmosphere. Some selective elimination of items was, therefore, inevitable.

In a free market economy, price is a major instrument for directing economic activity into the desired channels. However, due to the 'public good' character of several transport activities, pricing policy has been unable to prevent certain undesirable outcomes. Chief among these is the shift of loads, whether of freight or passengers, from rail to road. This has largely been due to the fact that the prices charged for these modes do not reflect the real integrated social, environmental and financial costs for the individual modes.

The study evolves guidelines for price setting based on empirical results.

An important task of the study was to evolve guidelines for price setting. Ideally, the user should pay for all costs in proportion to usage. But, in practice, this may not work equitably, because of two important factors: one is the 'public good' character of the fixed assets where usage is often indivisible, and the other is the question of equity arising out of the vast differentials in income distribution between various users of transport services. An attempt has, however, been made to evolve guidelines for price setting. The theoretical framework for arriving at policy conclusions on pricing is discussed in Appendix 5.1.

The broad coverage of the chapters in the report is as follows: Chapter 2 discusses issues of environmental concerns in transport. Chapter 3 gives details of the methodological framework of the analysis of modal choice and the development of a database for alternative transport scenarios, including parameters of energy consumption. Chapter 4 examines energy consumption and the emissions of different pollutants on the rail and road modes. Chapter 5 considers the financial costs of the two transport modes. Chapter 6 looks at the material resource requirements in transport and their environmental impact. Chapter 7 discusses the external costs of transport relating to health damage costs and accident costs. Chapter 8 deals with the social costs of transport and integrates the results of the previous chapters. Chapter 9 discusses the policy implications related to sustainable modal choice and transport pricing.

2 Environmental Concerns

It is now widely recognised that thoughtless expansion of economic activities is causing a strain on the nature's functional system. Indeed, there is a growing apprehension that too much tilting of the balance would cause ecosystems to flip over to new regimes involving vast uncertainties. The sustainability of the present global pattern of growth or development process has, therefore, become an issue of serious concern, more so, in view of the uncertainty regarding human ability to adapt to the changing environmental conditions. Therefore, in order to arrive at the right policy approach for sustainable development of any economy, it has become imperative to take cognisance of the interactive relationship between nature and economic development.

Sustainability of the present pattern of growth has become an issue of serious concern.

Nature and Economy

According to the value system of a market-driven society, the economic well-being of its members depends on the flow of consumption goods and services, which are produced by using natural resources. On their conversion into products and the consumption of these products, the basic elements constituting these resources emerge in a transformed state and flow back to nature as high-entropy valueless waste. The overall material balance, however, ensures that the molecular weight of all material resources drawn from nature is equal to the molecular weight of wastes plus that of durable goods and recyclable waste added as inventory to the economic system. Nature is, thus, used as a source for material resources and also as a sink for dumping wastes.

Changing environmental conditions have necessitated a reappraisal of interaction between nature and economy.

The ecological processes of the flow of solar energy and biogeochemical cycles regenerate resources as well as degrade wastes. However, the time rates of regeneration of resources and degradation of wastes have upper bounds and vary from one type of resource/waste

Nature is a source for material resources as also a sink for dumping wastes.

to another. Biotic resources like forest biomass are regenerated faster than abiotic resources, some of which take millions of years like fossil fuel. The biodegradable wastes can similarly be degraded faster than abiotic wastes, some of which like hard chemicals or radioactive wastes may take hundreds of years to decay.

The flow of resources from nature to the economic system and the reverse flow of wastes into nature is a direct function of economic activity. Any excess of resource withdrawal over the rate of regeneration (like groundwater lifting at a rate higher than that of recharging of water) would be a cause for the depletion of that resource. Similarly, any excess of waste arisings over its absorption would lead to the deposition of unabsorbed wastes in the sink of nature as pollutant. This stock of pollutant as a load entering the airshed, waterbody or landfill harmfully affects human health and health of other biotic species. It also adversely affects the productivity of the resource base of nature.

Time rates of resource regeneration and degradation of wastes have upper bounds in an ecosystem and vary from one type of resource/waste to another.

The production processes of an economic system use the services of nature as stock, like those of land, forest, waterbodies, atmosphere, etc. Such use brings about changes in the landscape of the ecosystem. A high level of undegraded or unabsorbed pollutant stock would degrade the quality of nature as an asset. It would also reduce its ability to regenerate resources and provide support service to the economic system. For example, sulphur oxides or nitric oxides cause acid rain which destroys the photosynthetic ability of plants and the fertility of soil and thus reduces agricultural or forestry productivity. Since air, water and soil provide basic life support to all species by supplying oxygen, energy and nutrients, their qualitative degradation would threaten the very quality of life by increasing morbidity and mortality.

The concept of sustainable development which is based primarily on the consideration of intergenerational equity, requires that the economic activities of the present generation should leave behind such stocks of natural, man-made and human capital that the level of well-being of the future generations does not decline. It also requires that the various types of natural capital stocks should be so maintained that the present equivalent of the totality of their value for inter-temporal utilisation does not go down over time. It is, therefore, important to assess the environmental impact of economic activities and work out social costs of its deleterious effects.

A high level of undegraded or unabsorbed pollutant stock degrades the ability of nature to regenerate resources.

Transport and Environment

Economic processes of production and use of commodities and services involve transformation of resources into products and wastes. Such transformation generally takes place over time and space, and not instantaneously at one locational point. The spatial transformation of inputs from one location to another is brought about by the activity of transportation. This activity, however, causes stress on nature by:

(i) consuming scarce resources – fossil fuel, various metallic and non-metallic minerals and other materials like sand, stones, etc. and by the use of land;

(ii) producing wastes like pollutant gases, solid wastes, noise, etc., all of which flow back to nature that acts as a sink to absorb them;

(iii) partitioning or destroying the ecosystem in the neighbourhood of transport operation, such as farmland, wildlife habitats, etc.

Inter-generational equity requires that the various types of natural capital stocks are so maintained that their use value for inter-temporal utilisation does not go down over time.

The delivery of transportation service involves three kinds of activities:

(i) construction of ground-fixed infrastructure, including roads or railbed, signalling system, terminals, ports, etc., and their maintenance.

(ii) manufacture of rolling stock – automobiles, wagons, coaches, railway engines, aircraft, ships, etc.

(iii) operation of the rolling stock using ground-fixed infrastructural facilities to provide the final service.

Transport activity stresses nature in multiple ways – consuming scarce resources, emitting pollutants and generating harmful wastes.

Each of these components involves entropic use of increasing amounts of a large number of material resources drawn from nature. For example, fuel is burnt to generate the energy required to operate motor vehicles; steel goes into the body of the rolling stock; and materials like cement, sand, bitumen, gravel, etc. are used for the construction of roads.

The sourcing of hydrocarbons, metallic or non-metallic minerals and other material resources causes change of land-use which, in turn, leads to destruction of farmland, forests, wildlife habitats, and disturbs the integrated ecosystem of the neighbourhood. The waste arisings in the form of gaseous emissions, liquid effluents and solid wastes damage human health, economic productivity of natural resources and even the regenerative capacity of the ecosystem.

The pollution arisings damage human health, economic productivity of natural resources and regenerative capacity of the ecosystem.

The diversion of land-use from agriculture to road or rail also has an important opportunity cost and causes physical loss to the neighbouring ecosystem. The arisings of noise, heat, dust and congestion due to transport activities are expressions either of the byproduct waste resulting from the transformation process of the material and energy throughput into transportation service, or of the degradation of land, airshed, water body and immediate ambience which provide support to this service.

The quality of the ecosystem and its ambience is, thus, affected by transport activities. This involves costs to society. A transport user generates externalities which may involve costs for others and possibly for himself as well. The pollution or degraded environment often has the character of 'public bad'. The monetised value of the damage caused to other persons or other economic activities would constitute external cost of transport service. Since the environmental service is not a marketed product and one is, therefore, not required to pay for the use of nature as a sink, the private cost of transportation activity does not include this cost. This omission often leads to unsustainable use of transport service. Transport policy needs to address the issue of internalising such external social costs for a sustainable transport system. The modal choice will certainly make a difference in respect of stresses on nature in the form of resource depletion, shifts in land-use based on partial pattern of ground infrastructure, and degradation of the ecosystem of the neighbourhood due to transport operations. The social costs of such externalities need to be worked out for evaluating optimal modal choice and for formulation of transport policy just as similar environmental economic analysis is required for attaining optimal resource allocation in the production system and for evolving policies for industry and other sectors.

Damage effects of transport activities are costs to the society and are termed as external costs in economic terms.

A sustainable transport policy means such intervention into the market system which would ensure the fulfilment of the following two conditions:

The external costs need to be built into the cost of transport service.

(i) The direct or indirect use of natural resources should be such that they can be replenished by:

- natural regeneration (e.g. hydroelectric energy used for electric traction), or
- discovery of new deposits of the currently used exhaustible resource (e.g., oil or natural gas reserves used for driving of automobiles), or
- use of a new renewable resource like hydroelectric or solar power in place of fossil fuel used for generating motive power in transport, or
- conservation of the use of resources per unit of transportation, or
- a combination of the above.

(ii) The damage of the environment should be controlled in such a way that the productivity of various economic activities and the quality of human life in terms of health and security do not deteriorate over time.

Internalisation of social costs would induce rational modal choice.

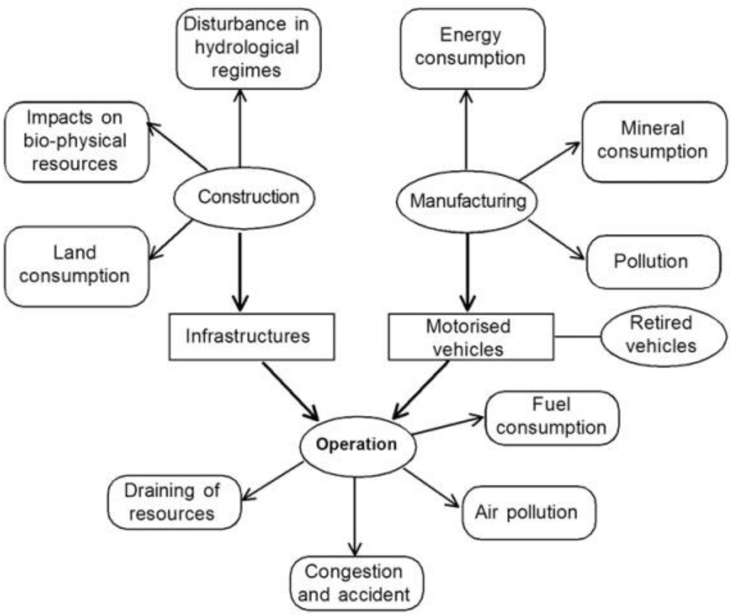
The large-scale expansion of the transport sector during the twentieth century has created a host of environmental problems. Among these are: consumption of non-renewable resources; adverse impacts on land-use; emission of air pollutants; oil slicks in marine environment; and growing congestion on urban roads. Noise, heat, dust and accidents are among the dangerous effects of urban transport. The construction of infrastructure, such as roads and rail lines has caused serious encroachment of scarce agricultural, forest and urban land resources.

While urban transport largely represents road mode of transport by automobiles, the inter-city transportation represents a modal mix of rail, road, air and marine or inland water transport. While the rail and road modes carry both passenger and freight traffic, airlines predominantly carry passengers, and coastal shipping mainly moves bulk commodities over long distances. Inland water transport carries little traffic in India because of the neglect of the riverways due to construction of dams on several major rivers, overall low harvesting rate of the flow of fresh water and lack of maintenance activity for ensuring requisite navigability of the rivers. The environmental impacts of the transportation system are depicted diagrammatically in Figure 2.1.

Different modes of transport have different types of environmental effects.

Different modes of transport have different types of environmental effects. Table 2.1 shows the important effects of four major modes of transport, namely, rail, road, air and water. Since water and air transport constitute a small share in the total passenger and freight movement, they cause damage of a lower order. It is, in fact, the rail and road modes which are responsible for the depletion of

Figure 2.1: Environmental Impacts of the Transportation System



natural resources like fossil fuel and other exhaustible materials as well as for environmental degradation.

The problem of sustainable resource supply is most acute in the case of fossil fuel which can have only entropic use in combustion. A large number of materials, such as steel, cement, ballast, bitumen, etc., flow as a throughput to the systems of different transport modes. However, a large portion of withdrawn or scrapped rolling stock like cars, buses, ships, railway wagons, trucks and aircraft are disassemblable and recyclable. Similarly, some of the replaceable portions of the ground-fixed infrastructure have recyclable components. The economics of industrial ecology will indicate the economically cut-off grade of recyclable material and the economically viable extent of recycling. The net pressure on the resource system will be the flow of virgin resources which are required to sustain the level and growth of

Resource scarcity of fossil fuel and other materials.

Table 2.1: Selected Environmental Effects of Principal Transport Modes

	Marine and Inland Water Transport	Rail Transport	Road Transport	Air Transport
Air		Air pollution in populated areas; global pollution from thermal generating stations for electric traction.	Air pollution (CO, HC, NOX, particulates & fuel additives, such as lead); global pollution (CO_2, CFCs).	Air pollution; greenhouse & ozone depletion effects at higher altitudes due to NOX emissions.
Water Resources	Discharge of ballast water, oil spills, etc.; modification of water systems during port construction & canal cutting and dredging.		Pollution of surface and ground water by surface run-off; modification of water system by road building.	Modification of water tables, river courses and field drainage in airport construction.
Land Resources	Land taken for infrastructure; dereliction of obsolete port facilities & canals.	Land taken for right-of-way and terminals; dereliction of obsolete facilities.	Land taken for infrastructure; extraction of road building materials.	Land taken for infrastructure; dereliction of obsolete facilities.
Solid Waste	Vessels and craft withdrawn from service.	Abandoned lines, equipment and rolling stock.	Abandoned spoil tips and rubble from road works; road vehicles withdrawn from service; waste oil.	Aircraft withdrawn from service.
Noise		Noise & vibration around terminals and railway lines.	Noise and vibration from cars, motorcycles & lorries in cities & along main roads.	Noise around airports
Risk of Accidents	Bulk transport of fuels and hazardous substances.	Derailment or collision of freight trains carrying hazardous substances.	Deaths, injuries & property damage due to road accidents; risk in the transport of hazardous substances; risk of structural failure in old or worn-out road facilities.	Deaths, injuries property damage, due to aircraft accidents.
Other Impacts		Partition or destruction of neighbourhoods, farmland and wildlife habitats.	Partition or destruction of neighbourhoods, farmland and wildlife habitat; congestion.	

Source: State of the Environment in Asia and the Pacific (1995), UN-ESCAP/ADB; ST/ESCAP/1585; p.289.

transport output. In view of this, it is the fossil fuel (which is entirely non-recyclable) that deserves serious policy attention for conservation through technological upgradation of transportation.

It may also be noted that all modes of transport involve the use of land to a large or small extent. The diversion of land-use is, however, substantive in the case of road and rail modes as land is required for the right-of-way and the construction of ground-fixed infrastructure of railbed or road in addition to terminals and stations. Since the availability of land is fixed, its use for any one purpose needs to take into account its social opportunity cost correctly.

The sustainable use of fossil fuel, other material resources and land in the transportation sector needs to be ensured through appropriate pricing of these resources which should be inclusive of the scarcity premium or optimal resource rent. The materials which are outputs of other industries and are used in transport should also ideally reflect the true value of raw materials entering as throughput in the making of those products as well as the costs of environmental externalities like those of steel making, automobile manufacture, cement making, etc. However, the externalities that are generated by the transport activity itself have to be internalised in the costs and prices of transportation in an explicit manner. In respect of rail and road modes, the significant physical environmental effects are: air and noise pollution, risk of accidents, congestion and ecosystem degradation (i.e., deforestation, destruction of wildlife habitat and biodiversity, etc.). There are, however, serious difficulties in the assessment of environmental impact and its valuation due to the problem either of measurability or of monetisation in the absence of any suitable surrogate market.

Transport costs should reflect the scarcity value of land and other scarce resources.

While the progress of science and technology has led to increasingly precise and reliable, the valuation of environmental service is still far from perfect. Research in environmental economics is trying to grapple with the problem of such valuation in the vastly differing

The valuation of environmental service has to be in the context of ecological, social and institutional perceptions and relevance.

ecological, social and institutional context. The methods of hedonic pricing, travel costs and contingent valuation through stated preferences of individuals in response to interviews have been evolved and are being applied in various case studies. However, the reliability of estimates using such methods would depend on the perception of the people of an environmental damage and their preferred structure for environmental service and non-environmental goods. The latter would determine how importantly the environmental considerations would figure in their individual and collective choices.

Poorer countries have low social preference for environmental effects like noise pollution.

Environmental service is supposed to be an income-elastic item. In an economy with a large proportion of population below the poverty line, it would not be surprising if there is relatively low social preference for environmental service and, accordingly, low value is imputed to it. The lack of stringency in environmental laws and regulations in underdeveloped economies is indicative of such low valuation. It is not surprising that a poor villager considers noise pollution, biodiversity loss or global warming quite remote issues to affect his well-being. Besides, the waste absorptive capacity of nature or an ecosystem differs from region to region depending on the agro-ecological conditions implying differential impact in the form of change in physical environment at different places. The same level of waste or pollution arisings may, therefore, be valued quite differently in different countries. The high preference for non-environmental goods of an essential nature (such as, food, energy, etc.) in poorer countries has led to choice in favour of growth of income and employment whenever there has been a conflict between conventional development and conservation of environmental quality.

This study analyses only those factors which are of greater damage value in developing economies, such as air pollution, congestion and accidents.

In view of such perception about the impact and damage value of various pollution arisings as is prevailing in developing economies like India, it is mainly the local air pollution from automobile emissions, congestion and accidents which have been considered of greater damage value and have, of late, attracted public attention. As these three factors are having perceptible physical impact in the form of higher morbidity, death, permanent disability and time cost, we shall confine our analysis to the internalisation of cost externalities of air pollution, congestion and accidents in costs and prices of rail and road transport. Before analysing the details of such internalisation of social costs, we give below an overview of the physical effects of transport which are not monetisable, with special reference to India.

Effects on Natural Resources

The consumption of forest, agricultural and urban land by transport infrastructure causes stress on already scarce land resources. Such loss of precious land is accompanied by the danger of soil erosion and adverse impact on water tables, river courses, field drainage, flora and fauna. Evidence suggests that in the construction of transport infrastructure due consideration is presently not being given to the adverse effects of the removal of topsoil and nutrients on fragile ecosystems. In addition, the obstruction and restriction of the free flow of streams and rivers resulting from such construction have serious environmental and ecological consequences. Landslides and soil instability result from soil cutting and filling in the process of building roads, rail lines, etc., as also from deforestation for clearing land.

Degradation of environmental and ecological resources during the construction phase of transport infrastructure has a major adverse effect on natural resources.

Manufacturing and use of transport vehicles involves energy and mineral consumption, emission of pollutants and generation of waste. A study in Japan shows that for an average-sized passenger car with 1 tonne weight, 12 km per litre fuel efficiency and 100,000 km life-span, carbon dioxide emission from lifetime fuel consumption is expected to be around 5.3 tonnes of carbon, of which 86.6 % is due to locomotion, 8.7% from material processing and 4.7% from assembling.

Transport sector is a major consumer of fossil fuel, reserves of which are becoming increasingly scarce and on which various sectors make competing demands. The share of this sector in domestic energy consumption is greater in the developing countries than the developed ones. In India, the share is around 25%, while the share of transport

Transport sector is a major consumer of fossil fuel.

fuel consumption [motor spirit and high-speed diesel (HSD)] in total consumption of petroleum products is nearly 50%. In 1998-99, transport consumed about 32 million tonnes of HSD, which was 87% of the total HSD consumption in India. Besides the main petroleum fuels like gasoline, diesel and jet fuels, the share of coal, which is the most polluting fuel, is significant in both China and India. However, in the case of Indian Railways, there is a shift away from conventional fossil fuel towards electricity. While coal-based steam traction has almost been phased out, diesel traction is also being gradually replaced by electric traction.

Effects on Urban Air Quality

The stupendous growth in the number of motor vehicles, over the years, means a greater discharge of polluting emissions into the atmosphere. Although every mode of transport causes some form of air pollution, the road vehicles are responsible for maximum pollution. Railways and maritime transport are not generally associated with serious problems of air pollution, since their pollution loads are spread over wide areas. Road vehicle movement is usually confined to urban centres, which are densely populated and congested. The nature of vehicles in use and the quality of fuel contribute further to the intensity and severity of pollution.

The burning of fossil fuels in combustion engines results in the emission of a host of pollutants, such as carbon monoxide, lead, nitrogen oxides, sulphur dioxide, hydrocarbons, photochemical oxidants responsible for the production of ozone, suspended particulate matter and other toxic substances as well as carbon dioxide and methane.

Emissions from combustion engines result in a host of pollutants.

High lead concentrations in urban centres are primarily the result of vehicles using gasoline with lead content. Lead is emitted along with exhaust gases and contaminates the atmosphere causing potential health risks. Hydrocarbons released by motor vehicles, such as benzene are human carcinogens. Emissions of nitrogen oxides irritate lungs and aggravate respiratory diseases like asthma. Additionally, they inhibit crop growth and contribute to acid rain. The combination of hydrocarbons and nitrogen oxides in the presence of sunlight forms ozone, a key ingredient of urban smog and a danger to both human health and local vegetation. Particulate matter, profusely emitted by diesel-driven vehicles, impairs respiration and visibility and acts as a vector for airborne carcinogens into the lungs. Sulphur dioxide seriously affects human respiration, besides causing acid rain. Carbon monoxide, lead and hydrocarbons are mostly emitted by gasoline engines, particulate matter and sulphur dioxide by diesel engines, and nitrogen oxides by both types of engines. Table 2.2 at the next page summarises the health effects of major pollutants from motorised engines.

Pollutants have serious health effects.

In cities of developed, newly industrialised and rapidly developing countries, where the density of private passenger vehicles, mostly operated with gasoline, is rapidly growing, gasoline-based pollutants are dominant. On the other hand, in cities of developing countries, the most common form of air pollution is suspended particulate matter and sulphur dioxide emitted mainly by poorly maintained diesel vehicles. In most of the large cities of the developing world, road transport accounts for a major share of air pollution load; in Delhi, the figure is around 60%. It was estimated in 1995 that by 2000-01 the amount of pollutant discharge (in tonnes/year) in Delhi would be as follows:

Effects on the Global Environment

Carbon Monoxide	286.33 tonnes	Nitrogen Oxides	25.70 tonnes
Hydrocarbons	116.39 tonnes	Sulphur Dioxide	3.63 tonnes
Lead	0.17 tonne	Suspended Particulate Matter	0.58 tonne

Source: State of the Environment in Asia and the Pacific (1995), UN-ESCAP/ADB, ST/ESCAP/1585.

Emissions from motor engines have their impact not just on the local environment and economies, but also on the global ecosystem. In 1995, motor vehicles accounted for 14% of the world emissions of carbon dioxide – the primary greenhouse gas contributing to global

Table 2.2 : Health Effects of Automobile Pollution

Pollutant	Health Effects
Lead	Affects circulatory, reproductive, nervous and kidney systems; is suspected of causing hyperactivity and lowered learning ability in children; is hazardous even after exposure ends (Lead gets injected through the lungs and gastrointestinal tract).
Particulate matter	Irrigates mucous membranes and may lead to a variety of respiratory diseases; fine particles may cause lung cancer and exacerbate morbidity and mortality from respiratory dysfunctions. A strong correlation exists between suspended particulates and infant mortality in urban areas. Suspended particulates have the ability to adhere to carcinogens emitted by motor vehicles.
Carbon monoxide	Interferes with absorption of oxygen by haemoglobin (red blood cells); impairs perception and thinking, slows reflexes, causes drowsiness, brings on angina, and can cause unconsciousness and death. It affects foetal growth in pregnant women and tissue development of young children and has a synergistic action with other pollutants to promote morbidity in people with respiratory or circulatory problems. It is also associated with reduced worker productivity and general discomfort.
Sulphur dioxide	A harsh irritant, it exacerbates asthma, bronchitis and emphysema; causes coughing and impaired lung functions.
Nitrogen oxides	Can increase susceptibility to viral infections, such as influenza; irritate the lungs and cause oedema, bronchitis and pneumonia; and results in increased sensitivity to dust and pollen in asthmatics. Most serious health effects result from combination with other air pollutants.
Hydrocarbons	Low molecular weight compounds lead to unpleasant effects, such as eye irritation, coughing and sneezing, drowsiness and symptoms akin to drunkenness. Heavy molecular weight compounds may have carcinogenic or mutagenic effects. Some hydrocarbons have a close affinity for diesel particulates and may contribute to lung disease.
Ozone precursors (hydrocarbons and nitrogen oxides)	Irrigate mucous membranes of respiratory system causing coughing, choking and impaired lung function; cause eye irritation, headaches and physical discomfort; reduce resistance to colds and pneumonia; can aggravate chronic heart disease, asthma, bronchitis, and emphysema.
Toxic substances	Are suspected of causing cancer, reproductive problems, and birth defects. Benzene and asbestos are known carcinogens linked to leukemia and lung cancer; aldehydes and ketones irritate the eye, cause short-term respiratory and skin irritation and may prove to be carcinogenic.

Source: State of the Environment in Asia and the Pacific (1995), UN-ESCAP/ADB, ST/ESCAP/1585.

Emissions have their impact not only on the local environment but also on the global ecosystem.

warming. Nitrogen oxides and hydrocarbons act together to from ozone, also a greenhouse gas. The presence of carbon monoxide, a significant motor vehicle emission, can lead to a longer lifetime and a higher ambient concentration of methane, another greenhouse gas. Finally, chlorofluorocarbons (CFCs) that leak from air conditioners used in transport are not only greenhouse gases but are also the main cause of atmospheric ozone depletion.

In recent years, increasing attention has been focused on environmental pollution due to civil aviation, particularly the high altitude air pollution. Significant amounts of carbon dioxide, water vapours, nitrogen oxides and sulphur dioxide are produced in the burning of aviation fuel. Apart from contributing significantly to stratospheric ozone depletion, it has also been found that the emissions of nitrogen oxides from air traffic raise tropospheric level ozone and are responsible for 8% of global warming potential of greenhouse gases.

Effects on Coastal and Marine Environments

Port and harbour projects have their impact on sensitive coastal ecosystems. Their construction significantly affects hydrology and surface water quality in the coastal zones. Developing countries are rapidly expanding their port capacities and undertaking dredging operations for the maintenance of the existing port facilities. These activities are expected to create a host of impacts on the coastal environment of these countries.

Shipping is a major contributor to the pollution of the open seas. Surveys of oil spills and tar balls on the oceans indicate concentrations occurring along the routes of heaviest tanker traffic. In addition to petroleum and refined oil products, hazardous cargos transported via sea include sulphur, fertilisers, petrochemicals, caustic soda, acids, various pesticides, and weed killers, all of which pose serious threats to the marine environment as a result of shipwrecks and collisions. It is estimated that globally around 3.2 million tonnes of oil reaches the sea annually as a result of human activity, of which 47% comes from marine transportation. When large tanker spills take place on or near the coast, the resulting extensive oil slicks destroy sea birds and marine mammals and cause immense damage to shell fisheries and coastal amenities. Tar is deposited along the west coast of India at the rate of 1000 tonnes a year. The frequency of shipping accidents causing large-scale oil spills is increasing along major shipping routes especially in Asia.

Transport activities endanger fragile coastal and marine environment.

Effects related to the Disposal of Wastes

Transportation creates problems related to the disposal of wastes from a variety of sources.

Transportation creates problems related to the disposal of wastes from a variety of sources. Though not a major issue in terms of magnitude in developing countries, this can have serious implications especially in view of the increasing practice of replacing traditional metals in the manufacture of vehicles with composite materials. A 10% plastic content is common in cars, though some estimates suggest a figure of 25%. The large variety of chemicals involved in the production of composite materials makes their recycling impossible, leaving large-scale polluting incineration as the only means of their disposal. Air-conditioning is now becoming an increasingly standard equipment. Chlorofluorocarbons in air conditioners are released when vehicles are destroyed. The waste-managing capabilities of most developing countries are inadequate to handle the complexities involved in the disposal of a vehicle. Abandoned infrastructure facilities, such as rail lines and obsolete ports, though partly recyclable, generate solid wastes, besides affecting the aesthetics of local environment. Airports and harbours often have inadequate waste reception and treatment capacities and this, together with poor environmental monitoring and management, contributes to the waste disposal problem.

3 Empirical Model for Modal Choice

In any analysis involving the use of extensive data, choice of the empirical model is of critical importance. In what follows, a model for analysing the intermodal choice between rail and road transport is developed. The key objective of the model is to permit and enable substitution of the effects of shifts of given volumes of traffic from one mode to the other. The driving variables are environmental stress and cost.

The empirical model simulates the effects of intermodal substitution.

Empirical Model

The first step is to choose representative sections which are typical of alternative transport situations and in which the road and rail modes are in competition. The characteristics of the sections are further identified by terrain, railway traction and category of road, i.e. national or state highway. In the subsequent steps, environmental stress and social cost implications of carrying a given volume of passenger kilometers or net tonne kilometers of freight traffic for a given period by the two alternative competing modes on these representative sections are worked out.

The impacts in terms of energy consumed and polluting emissions with resultant health impacts and social costs for the two modes are worked out. From this data, the implications of intermodal shifts are derived. The equivalent volumes of traffic form the basis for the construction of alternative scenarios of traffic growth. These are designed to bring out the relative merits and demerits of alternative intermodal shifts of traffic over a ten-year period (2000-2010).

The model works out financial and social cost implications.

Essentially, we simulate the substitution of a fixed volume of traffic of one mode for an equivalent volume of traffic of the other mode throughout the given time horizon for our analysis and assess the implications of such substitution in terms of variables of costs and environmental externalities. In order to work out this basic model, we have to generate future growth profiles of traffic on the selected sections.

Traffic projections in case of road have been made on the basis of expected growth in vehicle numbers and likely changes in their composition over the given time horizon. In case of rail, the passenger kilometers and net tonne kilometers on each section have been projected on the basis of past growth in these indicators. In the next step, estimates of increases or decreases at the margin in all the impact variables for the intermodal substitution are worked out, while simultaneously observing the absolute levels of these variables as a result of the intermodal shifts.

The estimates of energy consumed for any selected volume of road traffic have been derived using the estimated vehicular composition and empirical relations between fuel consumption and its determining factors like speed, distance, incline of road, roughness of surface, etc. for each type of vehicle. The energy consumed by the given volume of rail traffic could be in the form of diesel or electricity. Diesel consumption is estimated by simulating train runs on a special software programme 'RUNTRAIN' described on page 39. Electricity consumption (in kWh) per 1000 GTKMS has been obtained from the Indian Railways Annual Statistical Statements.

Once the energy consumption estimates on both the modes are worked out, the estimates of emissions are derived on the basis of coefficients applicable to the units of energy consumed. The emissions generated, in turn, help in making an assessment of the costs to human health attributable to alternative modes of transport. The operating costs, which include the fuel cost, are worked out by using widely accepted norms and made comparable for the two modes, incorporating infrastructure maintenance cost in the case of road transport and value of passenger time and cost of commodities in transit in the case of railways. In case of road transport, the latter component is included in the overall operating costs.

The other areas covered in this study, namely, material resource inputs and accident costs, are based on the estimates of equivalent traffic volumes on selected road and rail sections.

Representative Sections

To undertake detailed case studies on road-rail substitution, eight sections have been selected where the rail and road modes are operating side by side. The sections vary with regard to the type of terrain (plain or rolling), type of rail traction (electric or diesel) and the type of road (national or state highway). Together, they may be deemed to be representative of the characteristics of transport situation on most of the road and rail sections in the country.

The selected sections broadly represent characteristics of transport situation in the country.

The sections chosen with portions of national highways running alongside railways are: New Delhi-Mughal Sarai, Jalandhar-Jammu, Lucknow-Gorakhpur, and Jabalpur-Allahabad. The remaining four sections, namely, Secunderabad-Wadi, Gudur-Renigunta, Bhopal-Ujjain, and Ratlam-Godhra, have state highway segments as a competitive challenge to the railways. The selected sections along with their main characteristics are set out in Table 3.1.

Table 3.1 : Selected Sections for Comparative Road-Rail Study

Section / Sub-section	Terrain	NH/ SH	2L/ 4L	Rail track	Traction	Total rail route length (km)	Total length of urban rail route (km)	Total road length (km)	Total length of urban road section (km)
New Delhi - Mughal Sarai	Level	NH	2/4L	Double line	Electric	780	75	825	85
New Delhi-Agra (Sub)	Level	NH	4L	–	–	–	–	200	15
Agra-Mughal Sarai (Sub)	Level	NH	2L	–	–	–	–	625	70
Jalandhar - Jammu	Rolling	NH	2L	Single line	Diesel	216	30	240	37
Jalandhar-Pathankot (Sub)	Level	NH	2L	–	Diesel	116	15	115	27
Pathankot-Jammu (Sub)	Rolling	NH	2L	–	Diesel	100	15	125	10
Jabalpur - Allahabad	Rolling	NH	2L	Double line	Diesel	367	30	353	55
Lucknow - Gorakhpur	Level	NH	2L	Single line	Diesel	277	30	265	45
Secunderabad - Wadi	Rolling	SH	2L	Double line	Diesel	194	25	200	25
Gudur - Renigunta	Rolling	SH	2L	Double line	Electric	83	10	75	15
Bhopal - Ujjain	Plain	SH	2L	Double line	Electric	183	15	190	25
Ratlam -Godhra	Rolling	SH	2L	Double line	Electric	185	10	285	25

NH : National Highway, SH : State Highway, 2L: two- lane, 4L: four-lane; Sub: Sub-section

Note: The Bhopal-Ujjain section has a rolling terrain in some parts and, besides, has a few running diesel trains. We have thought it advisable to work on the assumption of a plain terrain throughout and electric trains only, since this simplifies the analysis and does not essentially distort our estimates.

The combined route length of the rail sections is 2285 km of which 1231 km is under electric traction and the balance 1054 km under diesel traction. The total length of the road sections is 2433 km of which 1683 km are categorised as national highways and the balance 750 km as state highways. The length of the urban stretches is 312 km on road and 225 km on rail.

Road Traffic Flows

Estimates of road traffic flows and their composition on national highways are based on road census data.

The estimates of road traffic volumes on the selected sections have been made by using the data of road surveys periodically carried out on the national highways by the Ministry of Road Transport and Highways (MORTH). Counting stations set up along these highways provide estimates of the number of cars, buses and trucks passing through the stretch of road on a given day. For a typical stretch of national highways, vehicle counts of sub-sections making up the stretch are given. The data given in the MORTH surveys has been smoothed out to remove some seeming anomalies of vehicle count. In addition, the traffic counts for different stretches and sub-sections belong to different years. In order to update them for the year 2000, certain growth rates have been used in accordance with the past growth of traffic and likely future growth, as indicated in Table 3.2.

Table 3.2 : Growth Rates used to Estimate Road Traffic Volumes

Type of Vehicle	1990-95	1995-2000	2000-05	2005-10
Car	7%	8%	8.5%	8%
Bus	6%	7%	6.5%	6%
Truck	5%	7.5%	6.5%	6%

The above methodology provides estimates of vehicular traffic in the year 2000 for different sub-sections included in the selected highway sections. To arrive at estimates of average daily road traffic for the entire selected stretch, the estimated vehicular counts have been weighted for each sub-section by its length and the average count derived for each type of vehicle applicable to the entire stretch.

Unlike the national highways, proper estimates of vehicular traffic flows are not available for the state highways. The estimates on these sections are, therefore, based on informed discussions with the state governments and their planning agencies. While doing so, the location of a state highway, its importance as a link and its proximity to the national highway have also been factored.

The car population on both national and state highways has been divided into cars using old technology and those with new technology in the ratio of 1:5. It is assumed that this position will remain unchanged till 2010. The population of trucks in the year 2000 has been divided into light, heavy and multi-axle vehicles (MAVs). MAVs are further sub-divided into three-axle rigid vehicles, three-axle semi-truck trailers, four-axle semi-truck trailers and truck trailers. This composition has been used to estimate the number of trucks needed to carry a certain tonnage.

Projections of multi-axle vehicle population are based on a recent study of the Asian Institute of Transport Development.

The percentage share of different types of trucks has been separately calculated for the northern and southern regions of the country on the basis of a recent study of the Asian Institute of Transport Development (AITD). Table 3.3 shows the region-wise position.

Table 3.3 : Shares of Different Truck Types in Road Freight Population (2000)

	LCV	HCV	MAV
Northern region	15%	77%	8%
Southern region	15%	75%	10%

It is expected that during the period 2000-2010, the share of multi-axle and light commercial vehicles in the total population of trucks will increase, while the share of two-axle trucks will decline (AITD, 2000). These shares have accordingly been modified for the years 2005 and 2010, as given in Table 3.4. Estimates of truck population for the intervening years have been worked out by appropriate interpolation.

Estimates relate to the 10-year period ending 2010.

Table 3.4 : Likely Future Composition of Truck Population (all-India)

Year	LCV	HCV	MAV
2005	20%	65%	15%
2010	23%	55%	22%

The final estimates of road vehicular traffic for the years 2000-2010 are presented in Tables A1.1.1 to A1.1.8 of Appendix 1.1. Table 3.5 gives the estimates of road traffic for a typical section – New Delhi-Mughal Sarai – for the years 2000, 2005 and 2010.

Table 3.5 : Estimates of Road Traffic on the New Delhi-Mughal Sarai Section (number of vehicles)

Year	Car	Bus	LCV	HCV	MAV	PCUs	V/C (1)	V/C (2)
2000	4019	1123	974	4998	519	26859	1.47	1.47
2005	6044	1539	1778	5780	1334	37337	2.04	2.04
2010	8881	2059	2677	6604	2618	50757	2.77	0.85

Note: V/C (1) – volume-to-capacity ratio without road widening.
V/C (2) – volume-to-capacity ratio with road widening.

Road capacity has been normatively chosen and traffic volumes in excess of this capacity represent congestion levels.

The daily road capacity has been normatively chosen. Traffic volumes in excess of this capacity represent congestion levels. For a two-lane road, the daily capacity has been taken as 15000 passenger car units, and for a four-lane road 60000 units. Most of the sections considered in this study carry large volumes of traffic. Road improvement works have been planned on heavily congested sections. These include New Delhi-Mughal Sarai and Jalandhar-Jammu sections where four-laning job is expected to be completed by the year 2006 and 2005, respectively. On the remaining sections, pavement overlay with the provision of paved shoulders, has been planned for the year 2005.

Road improvement has considered options of four-laning and provision of paved shoulders.

Scenarios of Shifts of Traffic: In order to analyse the implications of shifts of passenger and freight traffic, two scenarios have been constructed. One relates to shift of traffic from road to rail, and the other from rail to road. Intermodal shifts of 10,000 passengers and 10,440 tonnes of freight per day have been considered for national highways. This quantum would translate into traffic volumes which are considered appropriate for the purposes of comparative analysis. It may be pointed out that 10,440 tonnes of freight is equivalent to 3 train loads of heavy box wagons. In the case of state highways, where traffic densities are generally low, shifts of 5,000 passengers and 5,220 tonnes of freight have been considered.

The number of vehicles required to carry the determinate number of passengers and tonnage on a section is calculated by keeping intact the composition of traffic as estimated for the base year 2000. The average occupancy in inter-city journeys is taken to be 4 for a car and 40 for a bus. The payloads for a light/heavy commercial vehicle are taken to be 5 tonnes and 9 tonnes, respectively. In the case of MAVs, a composite average of 18 tonnes is considered in view of the mix of rigid and semi-articulated vehicles in the multi-axle vehicles population.

Intermodal shifts of 10,000 passengers and 10,440 tonnes of freight per day have been considered for the national highways. Shifts of one half of these volumes have been considered for the state highways.

Following the 1991 Road User Cost Study, we have assumed that 80% of the trucks plying on national highways and 70% on state highways are loaded with freight. From the surveys of gross vehicular weight (GVW) of trucks on national highways, the average load factor is found to be 100% for heavy/light commercial vehicles and 90% for multi-axle vehicles. In case of state highways, a reduced load factor of 80% has been taken for multi-axle vehicles and 90% for light and heavy commercial vehicles.

Vehicular payloads are based on surveys of gross vehicular weights.

The above indices of occupancy factors and payloads are used to work out the number of vehicles required to carry the determinate volumes of traffic, both passenger and freight. These numbers are used to work out the traffic volumes in case of shifts of traffic from one mode to another (Tables A1.1.1 to A1.1.24 of Appendix 1.1). Tables 3.6 and 3.7 below show the position for a typical section (New Delhi-Mughal Sarai) for a two-way modal substitution for the years 2000, 2005 and 2010.

Estimates of number of road vehicles required to carry substitution traffic.

Table 3.6 : Road Vehicular Traffic on the New Delhi-Mughal Sarai Section in the Scenario of Shift from Road to Rail

Year	Car	Bus	LCV	HCV	MAV	Total Trucks	PCUs	V/C (1)	V/C (2)
2000	3361	939	755	3878	403	5036	21287	1.16	1.16
2005	5385	1354	1560	4661	1218	7438	31764	1.73	1.73
2010	8222	1875	2459	5485	2502	10446	45184	2.46	0.75

Table 3.7 : Road Vehicular Traffic on the New Delhi-Mughal Sarai Section in the Scenario of Shift from Rail to Road

Year	Car	Bus	LCV	HCV	MAV	Total Trucks	PCUs	V/C (1)	V/C (2)
2000	4678	1307	1192	6117	636	7944	32432	1.77	1.77
2005	6703	1723	1997	6899	1450	10346	42910	2.34	2.34
2010	9539	2243	2896	7724	2734	13354	56330	3.07	0.94

Working with fixed traffic composition on rail and road keeps the analysis tractable.

In the above exercise, we are, in effect, assuming a constant daily intermodal shift from the base year 2000 onwards for all the years till 2010, while keeping the composition of vehicles in total traffic at the level of the year 2000. It is recognised that the traffic composition representing the incremental or decremental traffic should strictly vary with changes in vehicle composition in each year. The same should be the case with the composition of matching rail traffic. Working with fixed traffic composition on rail and road, however, helps to keep the analysis tractable by avoiding the need to go into unnecessary details. The estimates of the current study would not have differed substantially if we had incorporated all the details of varying traffic composition over the given years on both the modes.

We have also developed a set of additional scenarios of intermodal switches based on road improvements – four-laning of the New Delhi-Mughal Sarai and Jalandhar-Pathankot sections, and provision of pavement overlay along with paved shoulders in the case of other sections.

Thus, we have an array of scenarios incorporating variables of traffic growth under normal conditions and intermodal switches of determinate volumes of traffic, and road capacity enhancement measures. These would lead to an estimation of various factors that impact energy consumption, pollution loads and operating costs.

Estimates of rail traffic flows and their composition.

Rail Traffic Flows

The traffic flows on the rail sections and their composition, carrying capacity, lead of travel, etc. have been obtained from the concerned zonal railways. This data has been used for selection of the number and type of trains required to match the determinate volumes of traffic carried by road transport. For this purpose, three scenarios have been considered: business as usual, shift of traffic from road to rail, and shift of traffic from rail to road.

For business as usual scenario, the traffic projections are based on growth rates witnessed in the past: 4% for passenger and 3% for freight traffic. In the case of intermodal shifts, it is assumed that the passengers travel the full distance of the section. Tables A1.1.25 to A1.1.32 of Appendix 1.1 give the details of the traffic volumes on rail under the three scenarios referred to above. Table 3.8 shows traffic volumes on rail for a typical section under the three scenarios.

The analysis retains rail sectional characteristics.

Table 3.8 : Rail Traffic Volumes on the New Delhi-Mughal Sarai Section (in million PKMS and million NTKMS)

Year	Business-as-usual		Shift from road to rail		Shift from rail to road	
	Passenger	Freight	Passenger	Freight	Passenger	Freight
2000	31.06	86.62	39.32	94.70	22.79	78.54
2005	37.79	100.42	46.05	108.50	29.52	92.34
2010	45.97	116.41	54.24	124.49	37.70	108.33

It is ensured that to the extent possible the trains match the road service closest in terms of transport output while retaining the sectional characteristics. This includes empty to loaded ratio for each section. The composition of equivalent volumes of road and rail traffic for each section and for both passenger and freight traffic is presented in Tables A1.2.1.1 to A1.2.8.2 of Appendix 1.2. Tables 3.9.1 to 3.9.4 show the equivalent volumes of traffic on both modes for a typical section. It may be mentioned that a fixed composition of trains has been retained for the entire period 2000-2010, as has been done in the case of road transport. Although passenger trains are expected to have additional coaches in the future, it is difficult, at the present stage, to estimate the extent of bias as a result of this development. However, the overall effect of longer trains with more coaches may not lead to significant changes in energy consumption and operating costs for equivalent volumes of rail and road traffic.

The rail sample matches the road service closest in terms of transport output.

Equivalent Daily Passenger Traffic on Both Modes on the New Delhi-Mughal Sarai Section

Table 3.9.1 : Rail passenger traffic (one direction)

S. No	Train no. & type	Frequency	Lead (km)	Carrying capacity	Gross Tonnage	PKMS	GTKMS	TKMS/ EKMS
1	5622	Daily	780.00	1319.00	1258.30	1028820.00	981474.00	780.00
2	4084	Daily	780.00	1290.00	1072.80	1006200.00	836784.00	780.00
3	2310	Daily	780.00	426.00	757.90	332280.00	591162.00	780.00
4	5208	Daily	435.00	1260.00	857.40	548100.00	372969.00	435.00
5	4308	Daily	153.00	784.00	699.60	119952.00	107038.80	153.00
6	2418	Daily	627.00	1583.00	1520.88	992541.00	953592.12	627.00
7	DD2	Daily	35.00	1080.00	715.20	37800.00	25032.00	35.00
8	DK2	Daily	63.00	1080.00	715.20	68040.00	45057.60	63.00
	Total		3653.00	8822.00	7597.28	4133733.00	3913109.52	3653.00
Total (both directions)			7306.00	17644.00	15194.56	8267466.00	7826219.04	7306.00

Table 3.9.2 : Road passenger traffic (both directions)

Vehicle	Number	Passengers	PKMS
Car	659.00	2636.00	2174563.41
Bus	184.00	7364.00	6075436.59
Total	843.00	10000.00	8250000.00

Equivalent Daily Freight Traffic on Both Modes on the New Delhi-Mughal Sarai Section

Table 3.9.3 : Rail freight traffic

S. No	Rake	Frequency	Lead (km)	Effective Daily Net Tonnage	Gross Tonnage	Effective Daily NTKMS	Effective Daily GTKMS
Down movement							
1	BCN L	6/7	780.00	1982.00	3473.00	1324917.55	2321948.57
2	BOXN L	Daily	780.00	3480.00	4979.00	2714400.00	3883620.00
3	BOXN E	Daily	780.00	-	1499.00	-	1169220.00
	Total		2340.00	5461.71	9951.00	4039317.55	7374788.57
Up movement							
S. No	**Rake**	**Frequency**	**Lead (km)**	**Effective Daily Net Tonnage**	**Gross Tonnage**	**Effective Daily NTKMS**	**Effective Daily GTKMS**
1	BCN L	6/7	780.00	1982.00	3473.00	1324917.55	2321948.57
2	BOXN L	Daily	780.00	3480.00	4979.00	2714400.00	3883620.00
3	BCN E	Daily	780.00	-	1161.00	-	905580.00
	Total		2340.00	5461.71	9613.00	4039317.55	7111148.57
	Total (both directions)		4680.00	10923.43	19564.00	8078635.10	14485937.14

Table 3.9.4 : Road freight traffic (both directions)

Vehicle	Number	Net Tonnage	NTKMS
LCV	218.00	872.33	719669.12
HCV	1119.00	8060.29	6649742.65
MAV	116.00	1507.38	1243588.24
Total	1453.00	10440.00	8613000.00

Estimates of energy consumption relate to requirements of hydrocarbons and electricity.

Energy Consumption

To quantify the energy and environmental implications of a shift of traffic from one mode to the other, it is necessary to work out petrol, diesel and electricity consumption for road and rail modes under the concerned scenario. The estimates of energy consumption, in turn, form the basis for the derivation of estimates of air pollutants and resulting costs of externalities.

The energy consumption of road transport has been worked out using empirical equations specially developed by the Indian Roads Congress for different types of vehicles, the power-to-weight ratio of engines, and varying road conditions. Table 3.10 shows these equations.

Estimation of fuel consumption is based on 'Study for Updating Road User Cost Data' and 'Manual on Economic Evaluation of Highway Projects in India', Indian Roads Congress.

Table 3.10 : Equations for Estimation of Fuel Consumption derived from the "Study for Updating Road User Cost Data" and used in the current study

S. No.	Vehicle	Fuel Equation
1.	New-technology car	FC = 21.85 + (504.15/V) + 0.00495 V^2 + [17.09] [13.25] 0.000652 RG + 1.06945 RS – 0.36845 FL [1.70] [25.14] [-8.46] {R^2 = 0.84}
2.	Old-technology car	FC = 10.31 + (1675.52/V) + 0.0133 V^2 + + 1.3879 RS – 1.0322 FL
3.	Bus	FC = 32.97 + (3904.64/V) + 0.0207 V^2 + 0.0012 RG + 3.3281 RF – 1.7769 FL
4.	LCV	FC = 63.245 + (1615.327/V) + 0.0245 V^2 + [20.17] [18.54] 0.001525 RG + 5.377 RS – 0.8268 FL – [2.16] [52.27] [-7.15] 3.6336 PW [-14.26] {R^2 = 0.89}
5.	HCV	FC = 85.07 + (3904.64/V) + 0.0207 V^2 + 0.0012 RG + 3.3281 RS – 1.7769 FL - 6.2396 PW
6.	MAV	FC = 340.33 + (2695.79/V) + 0.0517 V^2 + [7.40] [4.44] 0.0035 RG + 17.75 RS – 5.40 FL – [0.90] [36.11] [-9.06] 51.467 PW [-13.95] {R^2 = 0.88}

FC : fuel consumption (in c.c. per km)
V : speed (in km/hr)
RG : roughness (in mm/km)
RS : rise of road (in m/km)
FL : fall of road (in m/km)
P : engine power (in kilowatts)
W : gross vehicular weight (GVW) in tonnes
PW : power-to-weight ratio

Note : The t-statistic values are given within square brackets. The R^2 and t-statistic values for the other equations are not available.

The parameters adopted for the roughness of road surface and gradients – plain and rolling – have been described in detail in

Fuel consumption takes into account variables of speed, gradients, roughness of surface and power-to-weight ratio of engines.

Chapter 5. The gross vehicular weights have been derived from the results of three surveys conducted over national highways as reported in the Indian Roads Congress Journal, 1998 (Koul and Chakrabarti). These surveys broadly covered two categories of trucks, namely, 'multi-axle vehicles' and 'other vehicles'. The sections of the national highways surveyed included Ahmedabad-Mumbai and Delhi-Gurgaon. In terms of sectional characteristics, these sections are nearest to the selected road sections considered in the present study.

The analysis incorporates results of surveys of gross vehicular weight.

Since the surveys did not cover state highways, we have assumed for these highways a lower percentage of gross vehicular weight (GVW) distribution – 5-10% towards the lower end of the scale for each quantile of the reported distribution. Since the surveys had not separately worked out gross vehicular weight for two-axle heavy vehicles, we have suitably modified the reported results relating to the category of 'other vehicles' for application to heavy commercial vehicles (HCVs). Tables A1.3.1 to A1.3.4 of Appendix 1.3 give the GVW distributions used in the present study.

As the speed of a vehicle is directly related to fuel consumption, we have assumed a range of speeds for multi-axle and heavy commercial vehicles. For each level of speed, we have worked out fuel consumption in respect of these two types of vehicles, using their gross vehicular weight distribution and engine power. The engine power has been taken to be 100.7 KW for multi-axle vehicles, 85 KW for heavy commercial vehicles and 69 KW for light commercial vehicles.

The speed of travel of a vehicle varies on a stretch of road depending on the road and traffic conditions. Having derived a weighted fuel consumption for each level of speed, we have tried to find weightages for the various speeds for each type of vehicle so that an appropriate estimate of fuel consumption could be made. The selected road sections pass along both urban and non-urban stretches indicated in Table 3.1. The speeds on urban stretches of roads have been assumed to be 17.5 km/h for heavy vehicles (buses and trucks) and 30 km/h for cars. Specific values of speed are not available for non-urban stretches of roads. As such, to work out the speeds on these stretches, we have made use of the data generated by the Transportation Research and Injury Prevention Programme (TRIPP), Indian Institute of Technology, Delhi, in their report titled 'Traffic Related Data Analysis', 1998.

Specific values of speed on non-urban road sections are based on the report, 'Traffic Related Data Analysis', TRIPP, 1998.

This report is based on the observations of road traffic speeds for intervals of 15 minutes along selected non-urban sections varying in pavement width and design. The results have been applied for constructing distributions of distance travelled against speeds applicable to the selected sections. In the absence of any other evidence, we have made a major assumption that the proportion of distance travelled at a particular speed by a particular vehicle over the entire stretch of a non-urban road section may be deduced from the time spent at a given speed over all the 15-minute intervals of observations for the given type of vehicle.

We have made use of the speed data on the Hodal-Kosi national highway and the Pondicherry-Tindivanam state highway for our calculations, since these sections come closest to matching our selected road sections in terms of pavement geometry. The share of distance corresponding to a given speed as calculated in the above manner for these sections is given in Tables A1.3.5 and A1.3.6 of Appendix 1.3. When the option of road widening is considered, the distribution of proportion of distance travelled against speed for the major and minor directions of traffic flow on a four-lane road (Delhi-Palwal) are taken into account for arriving at estimates of fuel consumption. Tables A1.3.7 and A1.3.8 of Appendix 1.3 give the distributions for major and minor directions of the four-lane road.

Given the fuel consumption for each level of speed, as obtained from the equations for fuel consumption, a weighted average of fuel consumption based on speed distributions is calculated for the non-urban stretches. The time-bound nature of the current study has led us to assume that the speed distribution with respect to distance on a road is invariant with respect to increasing congestion. Hence, the fuel consumption estimates on road derived on the basis of the relevant distribution will indicate symmetrical increases or decreases in the two-way shifts of traffic – rail to road and road to rail. A more detailed exercise would be required to take account of different distributions for different road traffic volumes in working out still more refined estimates of changes in fuel consumption for the substitutions in the two-way shift of traffic, which would be asymmetric in nature.

With regard to the equations for fuel consumption in the 'Study for Updating Road User Cost Data', 1992, the values for such parameters as payload and tare weight, as given in the study, have been used in our exercise. The final estimates of fuel consumption on road for each category of vehicle and for each speed are given in Appendix 1.4.

'RUNTRAIN' software has been used for simulating train runs to determine diesel fuel consumption, while published data has been used to estimate electricity consumption.

Fuel and Electricity Consumption on Rail: In the case of electrified rail sections, the data on electricity consumption (in kWh) per 1000 GTKMS has been obtained from the Indian Railways Annual Statistical Statements (Table 3.11). On the basis of this data, the energy consumption for the estimated traffic volumes on the electrified sections has been worked out.

Table 3.11 : Electricity Consumption (kWh per 1000 GTKMS)

Railway	Passenger	Freight
Northern	19.00	6.45
Western	20.90	8.62
South Central	18.90	7.96
All-India	20.60	8.13

In the case of rail sections with diesel traction, the fuel consumption has been worked out by simulating the train runs on a software programme (RUNTRAIN) developed by the Railway Design and Standards Organisation (RDSO). The programme considers several variables, such as the type of the rolling stock, the trailing loads, the engineering profile of the section, speed restrictions en-route, the hauling capacity of the locomotive, the maximum sectional speed and the booked speed of the trains. The inputs to the programme have been provided by the concerned zonal railways.

Emission Factors: The fuel burned in the engines of the road vehicles and rolling stock of the railways emits pollutants: lead (Pb), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOX), sulphur dioxide (SO_2), sulphur oxides (SOX), total suspended particulate matter (TSP), non-methane volatile organic compounds (NMVOCs), methane (CH_4), nitrous oxide (N_2O) and ozone. Nitrogen oxides are formed by reaction with atmospheric nitrogen and oxygen. Carbon dioxide is the most important greenhouse gas and its emissions crucially depend on fuel efficiency.

Particulate matter is emitted both directly and as a secondary pollutant caused by transformation processes. The respirable part of such particulate matter, especially the ultra-fine particles, is very important in terms of public health. Diesel particles also produce polyaromatic hydrocarbons, which are only partially volatile. Ozone is a secondary pollutant formed due to a complex reaction involving both nitrogen oxides and volatile organic compounds. Its effects are dependent on the time and position of the emissions and have an element of high uncertainty.

In transport operation, air pollution results not only from the emission of pollutants caused by the direct combustion of hydrocarbons – petrol and diesel – in transport operation, but also from the process of refining the crude oil and from the use of fuel in the thermal generation of electricity, which is partly used in rail electric traction. In the present study, most of the emission coefficients we have used for the direct or indirect use of fuel as power for transport have been taken from the documents of the Inter-governmental Panel for Climate Change (IPCC). The IPCC Inventory Update for India (1996) deals

Most emission coefficients have been derived from the studies of Intergovernmental Panel for Climate Change (IPCC).

specifically with the Indian scenario and considers the emission of four pollutants per unit of energy consumption in transport, namely, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOX) and non-methane volatile organic compounds (NMVOC).

Since it has not been possible in the Indian context to find emission coefficients for methane (CH_4) and nitrous oxide (N_2O), we have used the coefficients for the emission of these pollutants from the data for European light-duty vehicles, heavy-duty vehicles and three-way catalyst engines of gasoline cars published by the IPCC in Greenhouse Gas Inventory Reference Manual, Volume 3 (1995). The coefficients for sulphur dioxide (SO_2) and lead (Pb) in respect of petrol-driven cars have been taken from the study conducted by the Tata Energy Research Institute, 1992. In respect of heavy duty and light duty trucks plying in the country, the emission coefficients in respect of TSP and SO_2 have been worked out on the basis of a study carried out by the World Bank on Air Pollution from Motor Vehicles, 1996.

Emission factors are worked out for road and rail in grams per litre.

For rail, no specific emission factors are available for the Indian situation. As such, the relevant data have been taken from the estimated factors for diesel locomotives used by the railways in United States and given in the IPCC Greenhouse Gas Manual, 1995. Since rail emission factors for SO_2 and TSP are not given in the IPCC Manual, we have worked them out on the basis of comparative position relating to pollutant emissions from heavy duty road vehicles. The emission factors for road and diesel rail used in this study are given in Tables 3.12 and 3.13.

Table 3.12 : Emission Factors for Road (grams per litre)

Vehicle Type	CO_2	CO	NOX	N_2O	CH_4	NMVOCs	SO_2	TSP	Pb
Car	2394.71	135.68	15.37	0.03	0.72	25.51	0.58	-	0.123
HCV/Diesel Bus	2764.44	145.17	186.63	0.11	0.22	36.29	8.25	16.50	-
LCV	2764.44	43.06	90.40	0.15	0.04	45.92	3.90	20.00	-

Table 3.13 : Emission Factors for Rail (grams per litre)

Mode	CO_2	CO	NOX	N_2O	CH_4	NMVOCs	SO_2	TSP
Rail	2735.56	22.77	67.18	0.07	0.19	4.85	1.38	2.75

It may be noted in this context that the estimates of CO_2 emissions are based on the assumption of full carbon combustion. In other words, the total carbon content of the fuel is accounted for as CO_2 emissions, even though a portion of the carbon in the fuel is released as CH_4, CO and NMVOC emissions. IPCC has established the standard that CO_2 emissions be reported as if all the carbon that is oxidised produces CO_2. The main reason is that the carbon emitted as CH_4, CO or NMVOCs eventually gets converted to CO_2 in the atmosphere. The conversion occurs over a relatively short time compared with the lifetime of CO_2 in the atmosphere, which is more than 100 years.

The transfer effect of the emissions at the thermal power plants for generation of electricity used in electric rail traction has been duly accounted for.

The electrical energy that is consumed in rail traction may come from a variety of sources, such as hydel power, nuclear power, and thermal generation (with use of coal, gas, diesel). The environmental impact of generation of electricity is most pronounced in the case of thermal generation, while it is minimal or absent for other sources of electricity.

The environmental impact arising out of the use of electricity in rail traction has, therefore, been studied from the point of view of transferability of polluting effects from thermal power stations to the specific transport activities. In general, transport and electricity sector emissions occur at different locations. Ideally, exact calculations should be undertaken of pollution dispersion and chemical transportation between each source and the various potential receptors. In practice, however, this is not possible and, as a result, approximate methods have to be used. We have, therefore, assumed that only 25 per cent of the electricity supplied for rail traction is sourced from thermal power plants located in urban areas. The quantum of energy input in terms of coal or gas as feedstock, relevant for the electricity generated, is determined by an empirically valid conversion factor of 33 per cent.

The emissions from thermal power plants are treated as equivalent to emissions from motorised engines while working out the health damage costs. For emissions due to the use of coal and gas at electricity-generating stations, we have made use of the emission factors for the operations of gas turbine combined cycle and pulverised coal given in the IPCC Greenhouse Gas Manual, 1995. In the case of emission factors of sulphur oxides (SOX) and TSP, we have relied on the studies of emissions from thermal power plants in India. These factors are given in Tables 3.14 and 3.15.

Table 3.14 : Emission Factors for Pulverised Coal Utility (kg per terajoule of energy input)

CO	NOX	NMVOCs	CH_4	N_2O	SOX	TSP
14	857	n.a	0.6	0.8	619.09	17368.87

Table 3.15 : Emission Factors for Gas Turbine Combined Cycle Utility (kg per terajoule of energy input)

CO	NOX	NMVOCs	CH_4	N_2O	SOX	TSP
32	187	n.a	6.1	n.a	0.24	5.02

n.a. – not available

CO_2 emissions are estimated on the basis of data of the Central Electricity Authority.

Carbon dioxide (CO_2) emissions from thermal power plants are worked out on the basis of the net calorific value (NCV) of the specific fuel (coal/gas). Given the total energy input, the NCV helps in determining the amount of fuel consumed. The NCVs of coal and gas are obtained from the published data of the Central Electricity Authority (CEA). The amount of carbon (C) present in the determined amount of fuel is then worked out on the basis of data in the IPCC Greenhouse Gas Manual. Data from the same source is used to obtain estimates of the fraction of carbon oxidised. Finally, the amount of total carbon oxidised is multiplied by the molecular weight ratio of CO_2 to C (44/12) to find out the quantity of total CO_2 emitted from fuel consumption. The NCV, carbon content and proportion of carbon oxidised for coal and gas are given in Table 3.16.

Table 3.16 : Parameters Relating to Different Fuels

Fuel	NCV (k. cal per kg)	Carbon (wt percent)	Fraction of carbon oxidised
Coal	3230	87.0	0.98
Gas	7830	70.6	0.995

Similarly, the transfer effect of energy consumption and emissions at oil refineries attributable to the use of liquid fuels – petrol and diesel – in road transport has been examined. Recent studies show that from the stage of extraction to processing, petrol production typically uses 8% of its own energy output compared to 4% for diesel (Eyre, N. J., et al – Fuel and Location Effects on the Damage Costs of Transport Emissions, Journal of Transport Economics and Policy, XXXI (1), January 1997). It is further seen that distribution of liquid fuels requires less than 1% of their energy content. The implications of upstream energy consumption at the thermal plants and oil refineries are discussed in the following chapter.

The transfer effect of energy use and emissions at oil refineries and steel plants have also been considered.

We have also studied the environmental impact arising out of the production of steel used in the manufacture of rolling stock and related ground infrastructure. This aspect has been duly analysed in a separate chapter and the resultant health hazard costs monetised for rail and road to reflect their impact in a total cost comparison.

Having derived equivalent volumes of vehicular traffic on the two modes of rail and road, profiles of growth in road traffic under normal and alternative scenarios, estimates of road fuel consumption for different levels of speed, and estimates of other relevant variables for energy and environment for each of the selected sections, we, in the next chapter, compare the two modes in terms of energy efficiency and environmental pollution and make projections till the year 2010.

It would be evident from the above that we have developed a comprehensive empirical model and database that facilitates the determination of a rational modal choice between rail and road modes of transport. The model permits the simulation of shifts of traffic from one mode to the other and enables analysis of resulting changes in variables of energy consumption, pollutant emissions, financial costs and externalities relating to health damage and accident costs.

4 Energy Consumption and Pollutant Emissions

The nexus between transport and energy is as old as the first use of steam locomotives for haulage of goods and commodities in 1829. Till then, energy, as we understand it today, had no role in the transport sector. Transportation was primarily through the sea route with the help of non-motorised boats and vessels. On land, transportation of goods was restricted to short haulage through non-motorised means like animal-driven carts.

However, in 1900, road transport made its debut and within a short span of time became the next best-preferred mode for carriage of passengers and goods. This brought about a change in the quality of nexus between energy and transport. The main source of energy for steam locomotives was coal. But with motor transport gaining popularity, the use of diesel and motor spirit (petrol) increased at a rapid pace. The railways also began using diesel as a source of energy for running its locomotives.

Comparison of relative energy consumption and air pollution levels has been made for equivalent volumes of traffic on the rail and road modes.

In this chapter, we analyse the energy consumption on rail and road modes of transport and its impact on environment taking into account equivalent volumes of passenger and freight traffic on the two modes. On similar parameters, the analysis also compares the performance of cars and buses on road and electric and diesel trains on rail.

Comparison has been made in respect of energy consumption and pollution levels for 10,000 passengers or 5,000 passengers for the entire stretches of the selected sections, depending on whether the road competing with rail is a national or a state highway. Similarly, the energy consumption and pollution emissions are compared for 10,440 tonnes or 5,220 tonnes of freight movement over the entire stretches of the selected sections depending on whether it is a national or a state highway competing with rail.

The fuel consumption and emissions of air pollutants have been worked out per passenger kilometer (PKM) in case of passenger traffic and per net tonne-kilometer (NTKM) in case of freight traffic for the selected sections of road and rail to facilitate comparison between the two modes.

Energy Consumption

The fuel consumption on the rail sections with diesel traction has been worked out by simulating train runs on a special software, RUNTRAIN, as described in the previous chapter. The RUNTRAIN programme is not designed to estimate energy consumption on electrified routes. In the case of these routes, the electricity consumption has been calculated by using the available statistical data which shows the energy consumption per 1000 GTKMs. The details of the calculations are given in Appendix 2.1.

Fuel consumption on road for different types of vehicles has been worked out by making use of empirical relationships between fuel consumption and influencing variables like conditions of terrain, etc., as described in the previous chapter. The analysis has been further refined by using recent research on speeds attained by different types of vehicles on representative road sections under varying traffic conditions. The details of the calculations are given in Appendix 1.4.

It would be seen that while estimating the energy consumption on the two modes, slight modifications have been made in the approach followed for calculating the operating costs which include the cost of energy consumption. The modified approach has given better estimates of energy consumption specific to the selected sections. It may be pointed out that energy consumption is a critical component for determining health damage costs arising from air pollution.

Energy consumption is expressed in a common unit – joules.

Energy consumption is expressed in a common unit – joules. Megajoules is equivalent to one million joules (10^6) and terajoules is equivalent to one thousand billion joules (10^{12}). The rates of energy consumption are baseline estimates relating to the year 2000, relevant for purposes of intermodal comparison. However, in Tables A2.2.1.1 to A2.2.8.8 of Appendix 2.2, the section-wise estimates of total energy consumption are presented on the assumption that these rates are by and large valid for the period 2000-2010.

Table 4.1 presents the rates of energy consumption in megajoules per passenger kilometer or net tonne-kilometer for the selected sections. The relative energy consumption i.e. the ratio of rail to road rates is given in Table 4.2. The sections marked with an asterisk are those with electric rail traction. Energy consumption on both modes is inclusive of the energy used at thermal power plants and oil refineries in the production of electrical energy and fuel for locomotion.

Estimates made of rates of energy consumption for passenger and freight traffic on selected sections.

Table 4.1 : Rates of Energy Consumption (in megajoules per PKM/NTKM) for Equivalent Volumes of Rail and Road Traffic

Section	Road				Rail	
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	0.29	0.19	0.32	1.13	0.18	0.12
Jalandhar-Jammu	0.28	0.21	0.32	1.27	0.18	0.21
Jabalpur-Allahabad	0.33	0.22	0.36	1.34	0.19	0.18
Lucknow-Gorakhpur	0.28	0.20	0.31	1.15	0.16	0.19
Secunderabad-Wadi	0.36	0.22	0.40	1.55	0.17	0.39
Gudur-Renigunta*	0.34	0.22	0.38	1.58	0.20	0.23
Bhopal-Ujjain*	0.38	0.20	0.40	1.28	0.19	0.19
Ratlam-Godhra*	0.36	0.21	0.40	1.52	0.18	0.17

Note: All the figures are rounded off to two decimal places.

Table 4.2 : Relative Energy Consumption for Equivalent Volumes of Rail and Road Traffic

Section	Ratio of rail to road rates				Ratio of bus to car rates
	Pass. (car & bus on road)	Pass. (only bus on road)	Pass. (only car on road)	Freight	
New Delhi-Mughal Sarai*	62.33%	92.99%	57.03%	10.28%	61.33%
Jalandhar-Jammu	62.77%	84.59%	55.97%	16.40%	66.17%
Jabalpur-Allahabad	58.35%	86.88%	53.13%	13.47%	61.16%
Lucknow-Gorakhpur	56.99%	79.10%	51.65%	16.16%	65.30%
Secunderabad-Wadi	47.37%	78.77%	43.08%	25.01%	54.69%
Gudur-Renigunta*	57.80%	87.15%	51.97%	14.51%	59.64%
Bhopal-Ujjain*	49.51%	94.91%	46.21%	14.96%	48.69%
Ratlam-Godhra*	49.48%	83.23%	44.93%	11.19%	53.98%

** denotes electrified sections*

An analysis of the data presented in the above tables brings out the following important conclusions:

Rail consumes much less energy than road and has maximum advantage in respect of freight traffic.

(i) Rail consumes less energy than road and has maximum advantage in respect of freight traffic. Energy consumption on rail in the case of freight traffic varies between 0.12 and 0.39 megajoules (Mj) per NTKM, while in the case of road, it varies between 1.13 and 1.58Mj per NTKM. For passenger traffic, energy consumption on rail varies between 0.16 and 0.20 Mj per PKM, while in the case of diesel bus, it varies between 0.19 and 0.22 Mj per PKM.

(ii) In the case of freight traffic, energy consumption on different rail sections varies between 10.28 and 25.01% of the energy consumed by road transport. In other words, rail consumes 75 to 90% less energy as compared to road.

Diesel bus is the most energy-efficient amongst different options of road vehicles.

(iii) In the case of passenger traffic, the gap in energy consumption between rail and diesel bus narrows down considerably. The energy consumption on rail varies between 78.77 and 94.91% of the energy consumed by road transport. In other words, rail consumes 5 to 21% less energy as compared to road transport.

(iv) The wide range of the above ratio in case of passenger traffic is on account of the vehicular options available – car, diesel bus or a combination of car and diesel bus.

(v) The diesel bus option is the most energy-efficient among the above three vehicular options for transporting passengers.

(vi) The range of variation in the rate of energy consumption in the case of rail passenger traffic is comparatively less than that of rail freight traffic. This is due to differences in the ratio of empty to loaded freight rakes in the various selected sections.

(vii) The higher rates of energy consumption in the case of rail passenger traffic is due to the proportionately higher tare weight of passenger coaches as compared to road vehicles.

Proportionately higher tare weight of rail passenger coaches as compared to road vehicles results in higher energy consumption.

The rates and levels of energy consumption on road and rail for the equivalent volumes of traffic are shown graphically in Figures 4.1 to 4.6 placed at the end of this chapter.

Pollutant Emissions

The rates of energy consumption of motorised engines for locomotion and of thermal power plants for generation of electricity for use in electrified rail sections along with their emission coefficients as given in Chapter 3, enable us to determine the rates of different types of pollutant emissions. The analysis is confined to major pollutants, namely, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOX), non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), sulphur oxides (SOX) and total suspended particulate matter (TSP).

The rates of emissions are expressed in units of grams per passenger kilometer or net tonne kilometer. It may be recalled that emissions from motorised engines and thermal utilities have been taken to be comparable to each other. The same has been assumed to be the case with SO_2 and SOX emissions attributable to road sections and corresponding electric rail sections, respectively.

Upstream emissions from refineries and thermal power plants duly accounted for in the analysis.

The emissions of the thermal power plants attributed to electricity used in electrified rail sections have been included in the analysis. With regard to the emissions at refineries in the process of production of petrol and diesel, the same have also been considered, but being insignificant their transfer effect has been ignored for end-results in the analysis of health damage costs.

Carbon Dioxide

Table 4.3 gives the rates of CO_2 emissions for equivalent volumes of rail and road traffic, while the relative position i.e. the ratio of rail to road is given in Table 4.4.

Table 4.3 : Rates of CO_2 Emissions (in grams per PKM/NTKM) for Equivalent Volumes of Rail and Road Traffic

Section	Road				Rail	
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	21.86	15.03	23.78	87.40	24.26	15.60
Jalandhar-Jammu	21.55	16.29	24.02	98.40	13.64	15.97
Jabalpur-Allahabad	24.89	17.14	27.21	104.03	14.74	13.87
Lucknow-Gorakhpur	21.04	15.49	23.10	89.50	12.12	14.32
Secunderabad-Wadi	27.32	16.93	29.92	120.21	13.19	29.75
Gudur-Renigunta*	25.67	17.46	28.41	122.55	23.09	26.98
Bhopal-Ujjain*	28.07	15.21	30.00	99.28	28.00	28.81
Ratlam-Godhra*	27.20	16.67	29.83	117.97	26.91	25.61

Table 4.4 : Relative CO_2 Emissions for Equivalent Volumes of Rail and Road Traffic

Section	Ratio of rail to road rates				Ratio of bus to car rates
	Pass. (car & bus on road)	Pass. (only bus on road)	Pass. (only car on road)	Freight	
New Delhi-Mughal Sarai*	111.01%	161.44%	102.02%	17.85%	63.19%
Jalandhar-Jammu	63.29%	83.70%	56.77%	16.22%	67.82%
Jabalpur-Allahabad	59.20%	85.97%	54.16%	13.33%	63.00%
Lucknow-Gorakhpur	57.60%	78.27%	52.47%	16.00%	67.04%
Secunderabad-Wadi	48.30%	77.94%	44.10%	24.75%	56.58%
Gudur-Renigunta*	89.94%	132.27%	81.27%	22.02%	61.44%
Bhopal-Ujjain*	99.74%	184.12%	93.34%	29.02%	50.70%
Ratlam-Godhra*	98.92%	161.45%	90.19%	21.70%	55.86%

The analysis brings out the following:

CO_2 emissions attributable to freight traffic on rail are invariably less as compared to road transport.

(i) CO_2 emissions attributable to freight traffic on rail are invariably less as compared to road transport. The advantage is more in the case of diesel traction and less in the case of electric traction.

(grams/NTKM)

Section	Rail	Road
Jabalpur-Allahabad (diesel)	13.87	104.03
Bhopal-Ujjain (electrified)	28.81	99.28

(ii) The emissions attributable to passenger traffic on rail present a mixed picture. As compared to road transport, the emissions are less in case of diesel traction and higher in case of electric traction.

CO_2 emissions attributable to passenger traffic on rail present a mixed picture.

(iii) The relatively higher emissions from electric traction are due to the use of coal – a heavily polluting fuel – for electricity generation at thermal power plants.

(iv) Emissions from diesel bus are lower than those from passenger car run on petrol or a combination of car and diesel bus.

Carbon Monoxide

Table 4.5 gives rates of CO emission for road and rail traffic, and Table 4.6 presents the ratios between the two modes.

Table 4.5 : Rates of CO Emissions (in grams per PKM/NTKM) for Equivalent Volumes of Rail and Road Traffic

Section	Road				Rail	
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	1.09	0.77	1.18	4.14	0.002	0.001
Jalandhar-Jammu	1.07	0.83	1.18	4.62	0.110	0.130
Jabalpur-Allahabad	1.24	0.88	1.35	4.84	0.120	0.110
Lucknow-Gorakhpur	1.05	0.79	1.14	4.25	0.100	0.120
Secunderabad-Wadi	1.36	0.86	1.49	5.53	0.110	0.240
Gudur-Renigunta*	1.28	0.89	1.41	5.65	0.002	0.002
Bhopal-Ujjain*	1.41	0.78	1.50	4.63	0.002	0.002
Ratlam-Godhra*	1.36	0.85	1.49	5.41	0.002	0.002

Table 4.6 : Relative CO Emissions for Equivalent Volumes of Rail and Road Traffic

Section	Ratio of rail to road rates				Ratio of bus to car rates
	Pass. (car & bus on road)	Pass. (only bus on road)	Pass. (only car on road)	Freight	
New Delhi-Mughal Sarai*	0.20%	0.28%	0.18%	0.03%	65.13%
Jalandhar-Jammu	10.31%	13.27%	9.33%	2.80%	70.34%
Jabalpur-Allahabad	9.63%	13.63%	8.85%	2.32%	64.95%
Lucknow-Gorakhpur	9.38%	12.41%	8.61%	2.73%	69.39%
Secunderabad-Wadi	7.83%	12.35%	7.17%	4.35%	58.04%
Gudur-Renigunta*	0.16%	0.22%	0.14%	0.04%	63.33%
Bhopal-Ujjain*	0.16%	0.29%	0.15%	0.05%	51.61%
Ratlam-Godhra*	0.16%	0.26%	0.15%	0.04%	57.28%

CO emissions in case of rail are negligible.

The following conclusions emerge from the above data:

(i) There are insignificant CO emissions in case of rail sections with electric traction, both for passenger and freight traffic. Even on sections with diesel traction, the levels of emission are negligible.

(ii) In case of road transport, the emissions of CO from diesel bus are far less as compared to passenger car.

Nitrogen Oxide

NOX emissions on different sections are shown in Table 4.7, while the ratios of rail to road emission rates are shown in Table 4.8.

Table 4.7 : Rates of NOX Emissions (in grams per PKM/NTKM) for Equivalent Volumes of Rail and Road Traffic

Section	Road				Rail	
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	1.09	1.04	1.10	5.75	0.13	0.08
Jalandhar-Jammu	1.23	1.13	1.28	6.43	0.34	0.40
Jabalpur-Allahabad	1.25	1.19	1.27	6.74	0.37	0.35
Lucknow-Gorakhpur	1.15	1.07	1.18	5.89	0.31	0.36
Secunderabad-Wadi	1.22	1.17	1.23	7.73	0.33	0.75
Gudur-Renigunta*	1.29	1.21	1.32	7.90	0.11	0.13
Bhopal-Ujjain*	0.98	1.05	0.97	6.45	0.14	0.14
Ratlam-Godhra*	1.20	1.16	1.21	7.57	0.13	0.13

Table 4.8 : Relative NOX Emissions for Equivalent Volumes of Rail and Road Traffic

Section	Ratio of rail to road rates				Ratio of bus to car rates
	Pass. (car & bus on road)	Pass. (only bus on road)	Pass. (only car on road)	Freight	
New Delhi-Mughal Sarai*	11.73%	12.24%	11.60%	1.43%	94.73%
Jalandhar-Jammu	27.93%	30.45%	26.89%	6.27%	88.30%
Jabalpur-Allahabad	29.75%	31.27%	29.33%	5.19%	93.78%
Lucknow-Gorakhpur	26.55%	28.47%	25.91%	6.14%	90.99%
Secunderabad-Wadi	27.37%	28.35%	27.14%	9.71%	95.71%
Gudur-Renigunta*	8.80%	9.38%	8.62%	1.68%	91.83%
Bhopal-Ujjain*	14.13%	13.17%	14.28%	2.22%	108.43%
Ratlam-Godhra*	11.12%	11.55%	11.02%	1.68%	95.44%

NOX emissions are lower on rail than on road.

The above data brings out the following:

(i) NOX emissions are lower on rail than on road for both freight and passenger traffic. In case of freight, the emissions are as low as 1.43 to 9.71% of road transport.

(ii) The level of emissions somewhat increases in case of passenger traffic – 9.38 to 29.33% of road transport.

(iii) Diesel bus accounts for higher emissions than passenger car run on petrol or a combination of car and diesel bus.

Non-methane Volatile Organic Compounds

The rates of NMVOC emissions for equivalent volumes of rail and road traffic are given in Table 4.9 and the ratios of rail to road rates of these emissions are given in Table 4.10. In the case of electrified rail sections, the NMVOC emission coefficients are not available.

Table 4.9 : Rates of NMVOC Emissions (in grams per PKM/NTKM) for Equivalent Volumes of Rail and Road Traffic

Section	Road				Rail	
	Pass. (car & bus)	Pass. bus only)	Pass. (car only)	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	0.58	0.19	0.69	1.12	n.a.	n.a.
Jalandhar-Jammu	0.55	0.20	0.71	1.27	0.02	0.03
Jabalpur-Allahabad	0.66	0.21	0.79	1.35	0.02	0.02
Lucknow-Gorakhpur	0.55	0.19	0.68	1.15	0.02	0.02
Secunderabad-Wadi	0.73	0.21	0.86	1.56	0.02	0.05
Gudur-Renigunta*	0.68	0.22	0.83	1.59	n.a.	n.a.
Bhopal-Ujjain*	0.76	0.19	0.84	1.28	n.a	n.a
Ratlam-Godhra*	0.73	0.21	0.86	1.53	n.a	n.a

n.a – not available

Table 4.10 : Relative NMVOC Emissions for Equivalent Volumes of Rail and Road Traffic

Section	Ratio of rail to road rates				Ratio of bus to car rates
	Pass. (car & bus on road)	Pass. (only bus on road)	Pass. (only car on road)	Freight	
Jalandhar-Jammu	4.20%	11.30%	3.24%	2.13%	28.66%
Jabalpur-Allahabad	3.78%	11.61%	3.14%	1.74%	27.06%
Lucknow-Gorakhpur	3.73%	10.57%	3.01%	2.10%	28.48%
Secunderabad-Wadi	3.05%	10.53%	2.59%	3.22%	24.65%

The analysis reveals that NMVOC emissions are almost negligible on rail as compared to road for both passenger and freight traffic. Further, these emissions are lower in case of diesel bus as compared to passenger car.

NMVOC emissions are almost negligible on rail.

Other Pollutants

The rates of emissions of methane (CH_4) and nitrous oxide (N_2O) are negligible for both modes of transport, although it is found that rail emits lower amounts of these pollutants than road. In view of the uniformly small rate of emission of methane, the rates of emissions of NMVOCs have been treated as identical with those of volatile organic compounds (VOCs), which are also known as hydrocarbons (HC).

So far as lead (Pb), sulphur dioxide/sulphur oxides (SO_2/SOX) and total suspended particulate matter (TSP) emissions are concerned, the emission rates have been worked out where applicable. Lead emissions are applicable to car only, where the rate of emission is found to be about 0.001g/PKM. Thus, in respect of this pollutant, car is at a disadvantage as compared to bus. The rates of TSP and SO_2/SOX emissions for road and rail are shown in Tables 4.11 and 4.12.

Table 4.11: Rates of SO_2/SOX emission (in grams per PKM/NTKM) for equivalent volumes of rail and road traffic

Section	Road				Rail		Ratio of car to bus rates
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight	
New Delhi-Mughal Sarai*	0.03	0.087	0.012	0.507	0.087	0.056	13.80%
Jalandhar-Jammu	0.04	0.095	0.012	0.571	0.013	0.016	12.79%
Jabalpur-Allahabad	0.03	0.100	0.014	0.604	0.014	0.014	13.84%
Lucknow-Gorakhpur	0.03	0.090	0.012	0.519	0.012	0.014	12.96%
Secunderabad-Wadi	0.03	0.098	0.015	0.698	0.013	0.029	15.47%
Gudur-Renigunta*	0.04	0.101	0.014	0.711	0.081	0.095	14.19%
Bhopal-Ujjain*	0.02	0.088	0.015	0.576	0.100	0.103	17.38%
Ratlam-Godhra*	0.03	0.097	0.015	0.685	0.096	0.092	15.68%

Note: For road and diesel loco, SO_2 emission factors are used, while for power plants supplying energy for electric locos, SOX emission factors are used.

Table 4.12: Rates of TSP emission (in grams per PKM/NTKM) for equivalent volumes of rail and road traffic

Section	Road				Rail		Ratio of car to bus rates
	Pass. (car & bus)	Pass. (bus only)	Pass. (car only)	Freight	Pass.	Freight	
New Delhi-Mughal Sarai*	0.02	0.083	0.001	0.483	2.440	1.569	1.20%
Jalandhar-Jammu	0.03	0.090	0.001	0.544	0.013	0.015	1.11%
Jabalpur-Allahabad	0.02	0.095	0.001	0.575	0.014	0.013	1.05%
Lucknow-Gorakhpur	0.02	0.086	0.001	0.495	0.011	0.013	1.17%
Secunderabad-Wadi	0.02	0.094	0.001	0.665	0.012	0.028	1.07%
Gudur-Renigunta*	0.02	0.097	0.001	0.678	2.285	2.670	1.04%
Bhopal-Ujjain*	0.01	0.084	0.001	0.549	2.816	2.897	1.19%
Ratlam-Godhra*	0.02	0.092	0.001	0.652	2.706	2.575	1.08%

The above tables bring out the following:

(i) TSP emissions attributable to both passenger and freight traffic on rail are substantially higher in case of electric rail traction as compared to road transport. This is due to high TSP emission factor at thermal power plants using coal. The position reverses if the passenger and freight traffic on rail is carried by diesel traction, which means the emissions in this case are less as compared to road transport.

TSP emissions are lower on rail with diesel traction than on road. The position reverses in case of electric traction.

(ii) SO_2/SOX emissions attributable to freight traffic are invariably lower on rail as compared to road transport. In case of passenger traffic, the rail emissions are lower than road transport in case of diesel traction, while for electric traction, the emissions of both modes are almost equal.

(iii) Diesel bus has higher rates of SO_2 and TSP emissions than car.

Diesel bus emits much higher levels of SO_2 and TSP as compared to petrol-driven car.

The absolute levels of emissions for the above-mentioned pollutants for equivalent volumes of traffic are given in Appendix 2.2. The rates and levels of total emissions for rail and road modes are shown diagrammatically in Figures 4.7 to 4.30 placed at the end of this chapter.

Intermodal Substitution and its Effects

The profiles of growth in traffic for the period 2000-2010, as worked out in the previous chapter, and the rates of energy consumption and emissions as now derived for the base year 2000, have been used to determine aggregate estimates of these variables for each of the selected sections for the given period. Tables A2.3.1 to A2.3.72.2 of Appendix 2.3 give the energy consumption and emission profiles on both the modes for the period 2000-2010 for all the selected sections. It may be recalled that the baseline rates have been taken to be valid for the entire period.

In working out energy consumption of road transport, the effect of road widening on fuel consumption (and the resulting emissions) has been taken into account in the year of road widening. The particular sections where road widening is expected to take place are the New Delhi-Mughal Sarai and Jalandhar-Jammu sections.

The detailed exercise relating to energy consumption and resultant emissions has enabled us to work out the implications of substitution of road traffic by rail. Table 4.13 presents daily overall changes (savings) in energy consumption, as a result of intermodal substitution in the base year 2000. The figures for passenger traffic relate to movement by bus only on road.

Table 4.13: Daily changes in energy consumption levels due to substitution of road by rail (in terajoules)

Section	Passenger	Freight
New Delhi-Mughal Sarai*	-0.08	-8.76
Jalandhar-Jammu	-0.07	-2.55
Jabalpur-Allahabad	-0.11	-4.10
Lucknow-Gorakhpur	-0.11	-2.59
Secunderabad-Wadi	-0.05	-1.31
Gudur-Renigunta*	-0.01	-0.52
Bhopal-Ujjain*	-0.01	-1.10
Ratlam-Godhra*	-0.04	-2.01

The following conclusions can be drawn from the above data:

Substitution of road traffic by rail results in substantial savings in energy consumption.

(i) There are substantial savings in energy consumption across all the sections with maximum savings in the case of freight traffic.

(ii) The daily savings on different sections range from 0.01 Tj to 0.08 Tj for passenger traffic and from 1.10 Tj to 8.76 Tj for freight traffic.

(iii) These savings amount to 614522.32 litres of diesel per day for freight traffic alone.

The daily overall changes in polluting emissions as a result of substitution of road traffic by rail in the base year 2000 are shown in Tables 4.14 and 4.15 separately for freight and passenger traffic.

Table 4.14: Daily changes in emission levels (in tonnes) due to substitution of road by rail - freight traffic

Section	CO_2	CO	NOX	NMVOC	SO_2/SOX	TSP
New Delhi-Mughal Sarai*	-626.75	-35.65	-48.88	-	-3.91	8.52
Jalandhar-Jammu	-205.88	-11.24	-16.01	-3.11	-1.39	-1.32
Jabalpur-Allahabad	-330.75	-17.42	-23.51	-4.90	-2.17	-2.07
Lucknow-Gorakhpur	-208.24	-11.43	-15.31	-3.13	-1.40	-1.33
Secunderabad-Wadi	-96.81	-5.54	-7.35	-1.58	-0.70	-0.67
Gudur-Renigunta*	-36.85	-2.21	-3.04	-	-0.24	0.84
Bhopal-Ujjain*	-72.26	-4.59	-6.27	-	-0.48	2.09
Ratlam-Godhra*	-137.82	-8.05	-11.07	-	-0.88	2.82

Table 4.15: Daily changes in emission levels (in tonnes) due to substitution of road by rail - passenger traffic

Section	CO_2	CO	NOX	NMVOC	SO_2/SOX	TSP
New Delhi-Mughal Sarai*	76.57	-6.34	-7.51	-	0.00	19.49
Jalandhar-Jammu	-6.52	-1.73	-1.90	-0.43	-0.20	-0.18
Jabalpur-Allahabad	-8.61	-2.68	-2.90	-0.67	-0.30	-0.29
Lucknow-Gorakhpur	-9.60	-1.83	-2.03	-0.45	-0.21	-0.20
Secunderabad-Wadi	-3.74	-0.75	-0.84	-0.19	-0.08	-0.08
Gudur-Renigunta*	2.01	-0.33	-0.41	-	-0.01	0.81
Bhopal-Ujjain*	11.80	-0.74	-0.87	-	0.01	2.56
Ratlam-Godhra*	15.00	-1.21	-1.47	-	0.00	3.77

The analysis of the above data related to the effects of substitution of road by rail leads to the following broad conclusions:

(i) There is substantial reduction in polluting emissions with the railways having greater advantage in case of freight traffic as compared to passenger traffic.

(ii) The railways, however, lose this advantage in case of electric traction used for carrying passenger traffic. This is due to the accountal of upstream emissions at thermal power plants.

Substitution leads to substantial reduction in overall pollutant emissions.

It would be seen that the substitution of road by rail mode generally leads to substantial reduction in overall pollutant emissions. The advantage of rail is more in case of freight traffic as compared to passenger traffic. The transfer effect of upstream emissions at thermal power plants places the railways in a slightly disadvantageous position in case of passenger traffic.

It is evident from the foregoing that railways account for significantly less energy consumption than road transport. The railways also generally cause less environmental damage as compared to road transport and this position remains valid both in the case of freight as well as passenger traffic, though the advantage is more marked in the case of freight traffic.

The railways cause less environmental damage as compared to road.

As seen from the above intermodal analysis, the diesel bus emerges as a close energy-efficient option when compared to rail, in case of passenger traffic. It is also far more energy-efficient than a passenger car. It also scores over car in case of CO_2 and CO emissions, but suffers disadvantage in respect of NOX, SO_2 and TSP emissions. This clearly brings out the need for providing alternative cleaner fuels for bus transport, which is the mainstay of public transport system in the country.

Comparison of diesel and electric traction in terms of environmental impact shows that electric traction accounts for higher CO_2, SO_2/SOX and TSP emissions if the polluting effect of the use of coal for power generation at thermal plants located in urban areas is transferred to the transport sector. This effect gets neutralised if gas is used as fuel for generating power. The electric traction is, however, much cleaner than diesel traction when other noxious pollutants, such as CO and NOX are considered.

Figure 4.1: Energy consumption on representative sections for rail (electric traction) and road

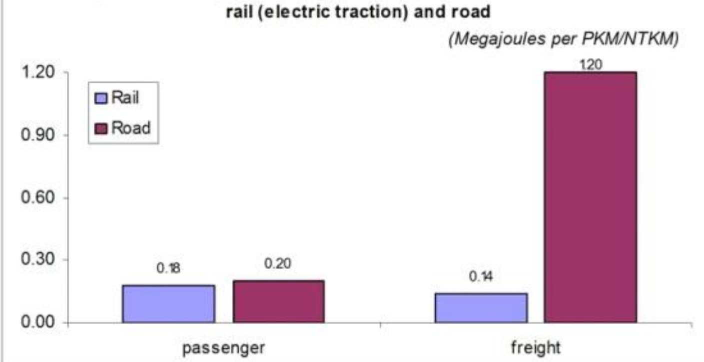


Figure 4.2: Energy consumption on representative sections for rail (diesel traction) and road

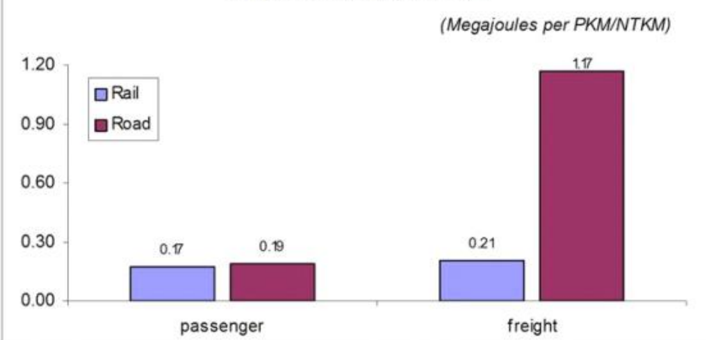


Figure 4.3: Energy consumption on rail (electric traction) and road for equivalent volumes of passenger traffic

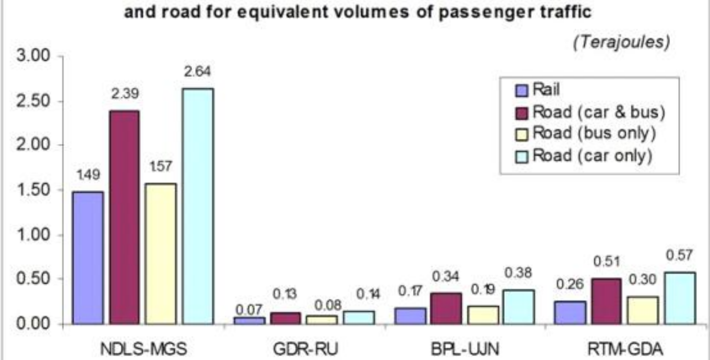


Figure 4.4: Energy consumption on rail (diesel traction) and road for equivalent volumes of passenger traffic

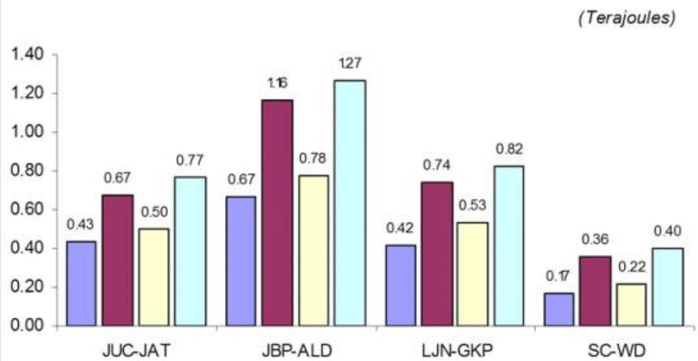


Figure 4.5: Energy consumption on rail (electric traction) and road for equivalent volumes of freight traffic

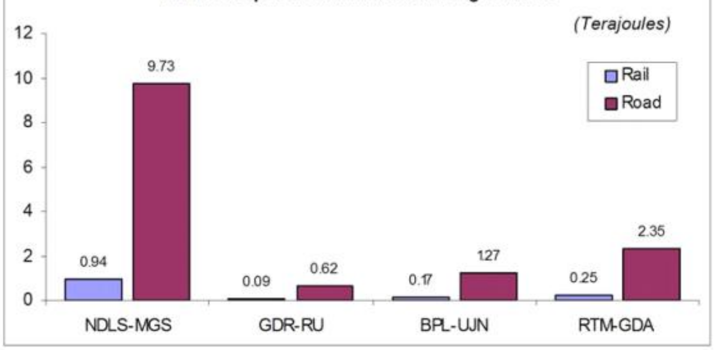


Figure 4.6: Energy consumption on rail (diesel traction) and road for equivalent volumes of freight traffic

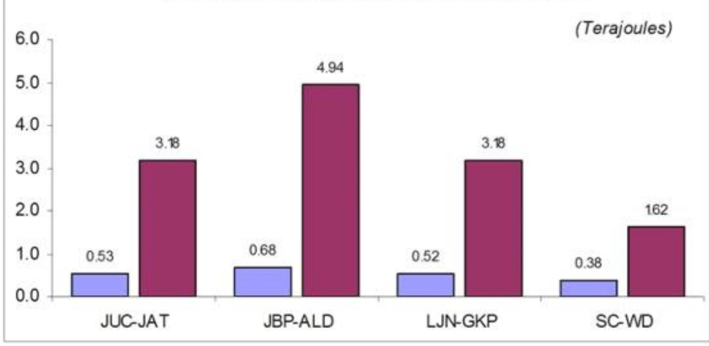


Figure 4.7: Total pollutant emissions on representative sections for rail (electric traction) and road

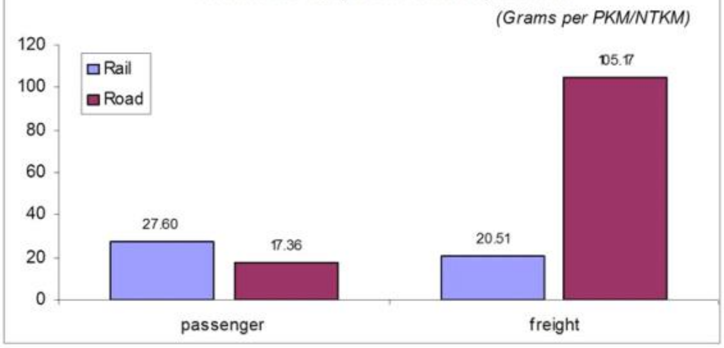


Figure 4.8: Total pollutant emissions on representative sections for rail (diesel traction) and road

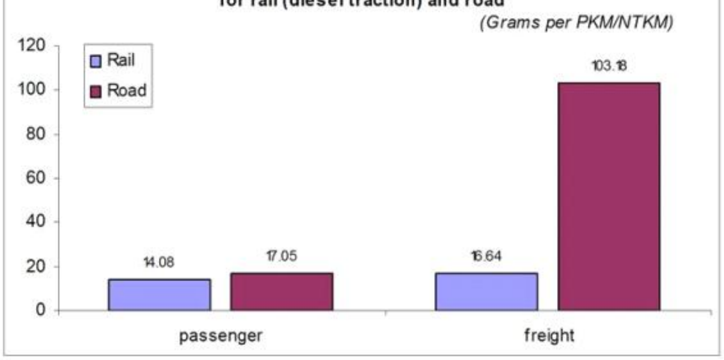
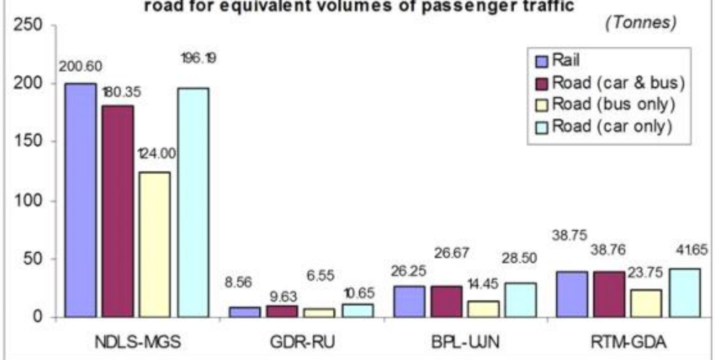


Figure 4.9: CO_2 emissions on rail (electric traction) and road for equivalent volumes of passenger traffic



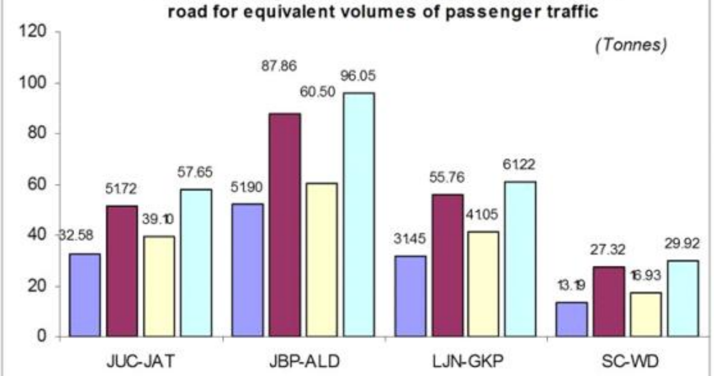


Figure 4.10: CO_2 emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

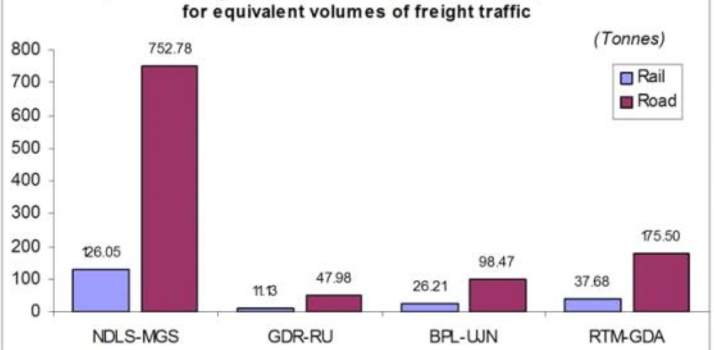


Figure 4.11: CO_2 emissions on rail (electric traction) and road for equivalent volumes of freight traffic

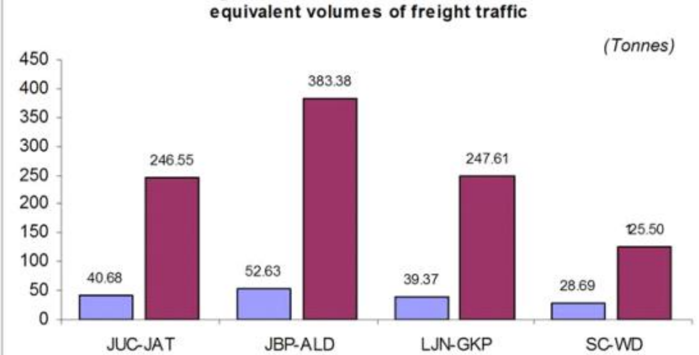


Figure 4.12: CO_2 emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

Figure 4.13: CO emissions on rail (electric traction) and road for equivalent volumes of passenger traffic

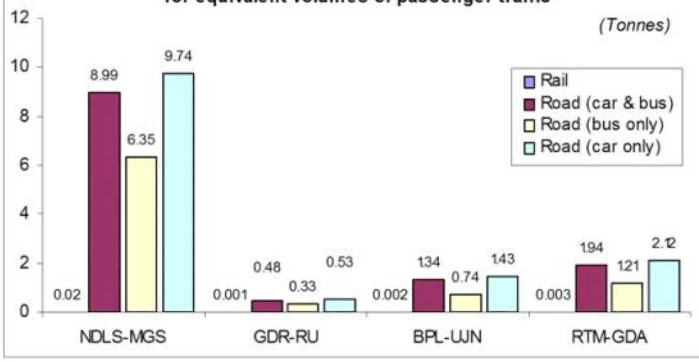


Figure 4.14: CO emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

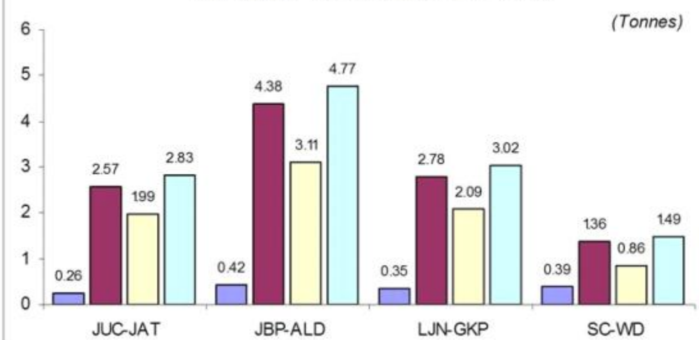
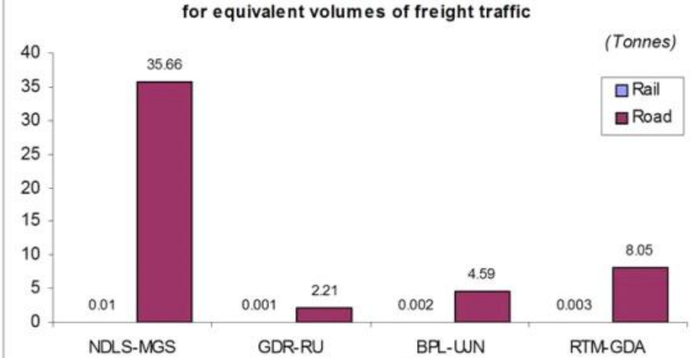


Figure 4.15: CO emissions on rail (electric traction) and road for equivalent volumes of freight traffic



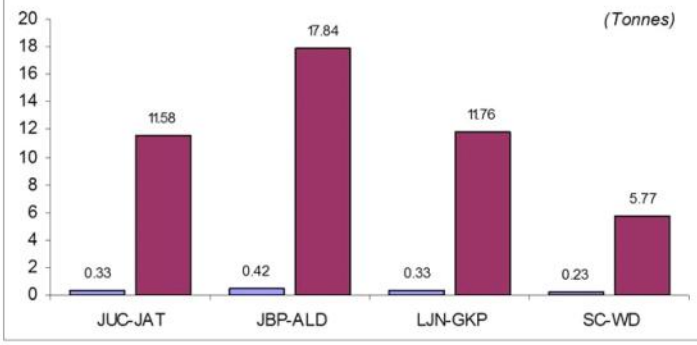


Figure 4.16: CO emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

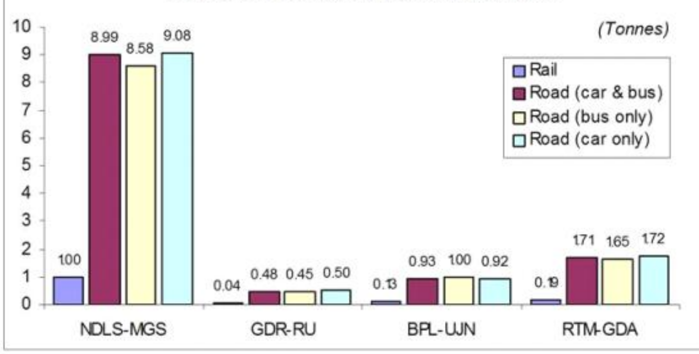


Figure 4.17: NOX emissions on rail (electric traction) and road for equivalent volumes of passenger traffic

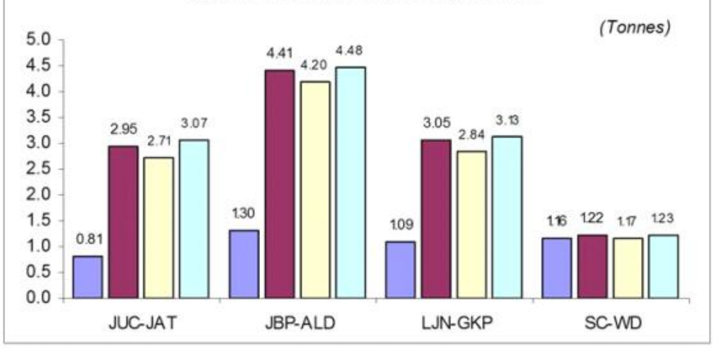


Figure 4.18: NOX emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

Figure 4.19: NOX emissions on rail (electric traction) and road for equivalent volumes of freight traffic

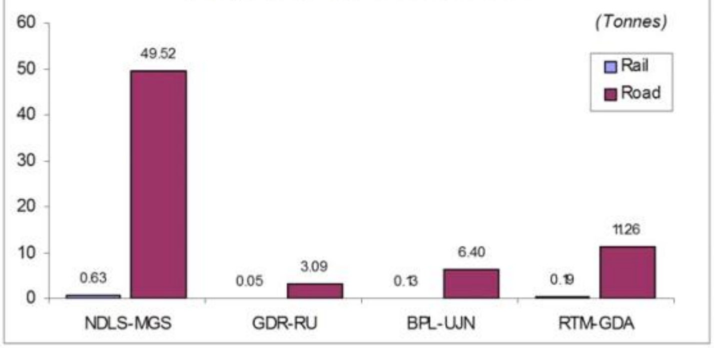


Figure 4.20: NOX emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

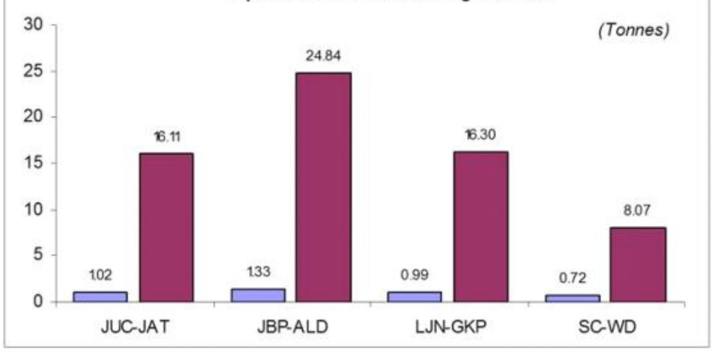


Figure 4.21: NMVOC emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

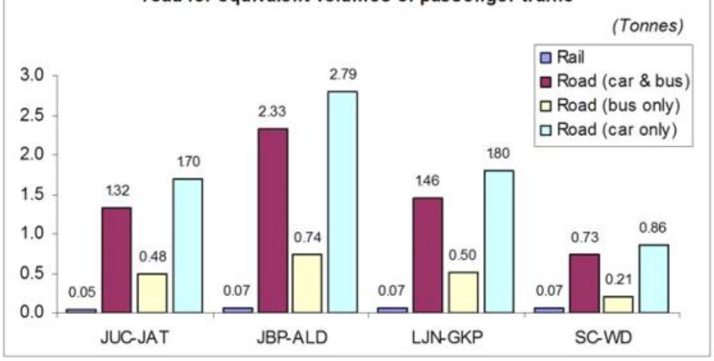


Figure 4.22: NMVOC emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

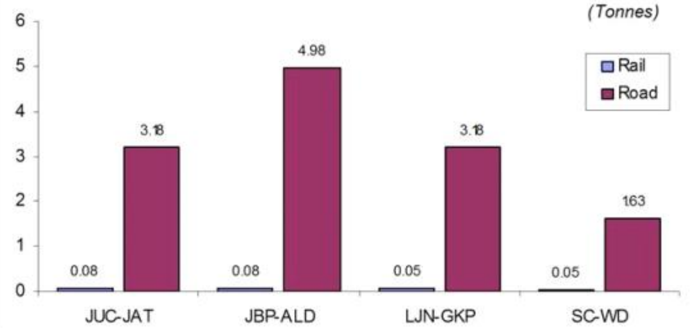


Figure 4.23: SO_2/SOX emissions on rail (electric traction) and road for equivalent volumes of passenger traffic

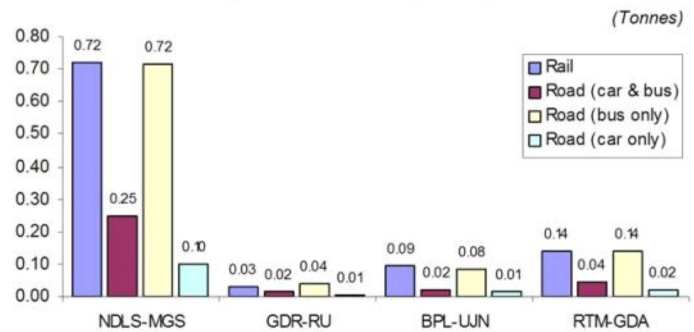


Figure 4.24: SO_2/SOX emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

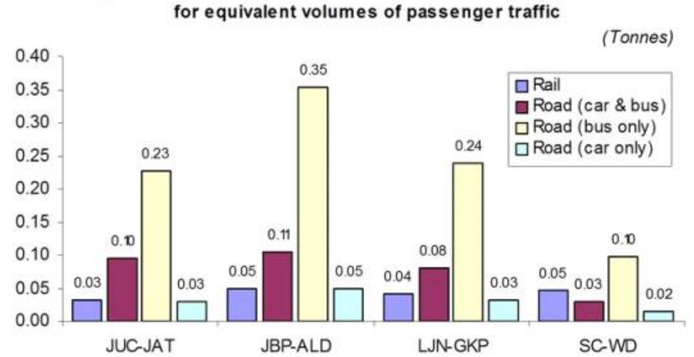


Figure 4.25: SO_2/SOX emissions on rail (electric traction) and road for equivalent volumes of freight traffic

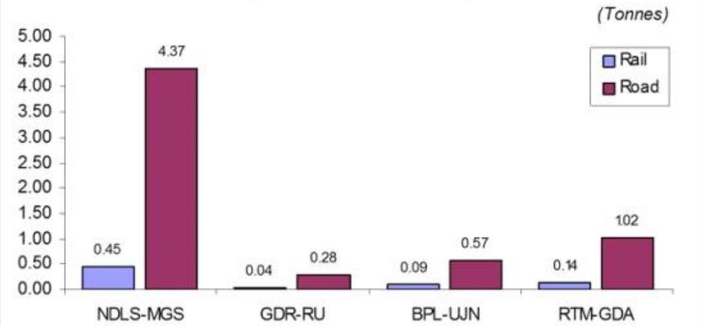


Figure 4.26: SO_2/SOX emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

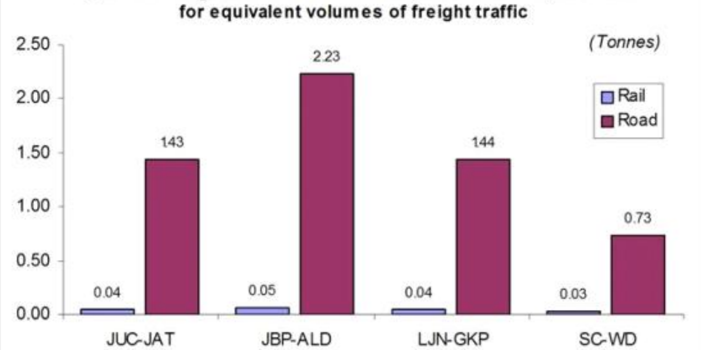
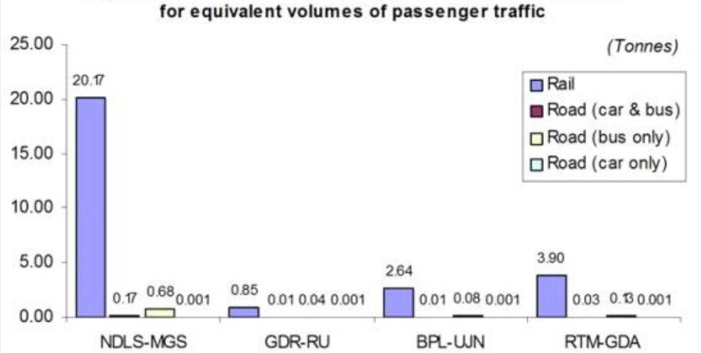


Figure 4.27: TSP emissions on rail (electric traction) and road for equivalent volumes of passenger traffic



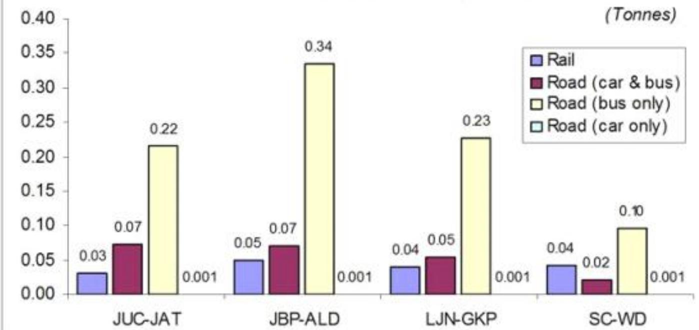


Figure 4.28: TSP emissions on rail (diesel traction) and road for equivalent volumes of passenger traffic

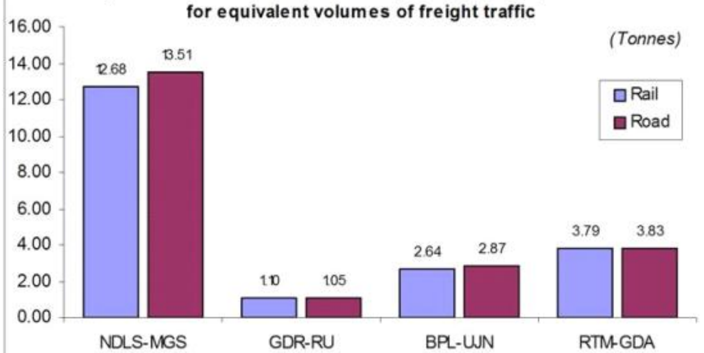


Figure 4.29: TSP emissions on rail (electric traction) and road for equivalent volumes of freight traffic

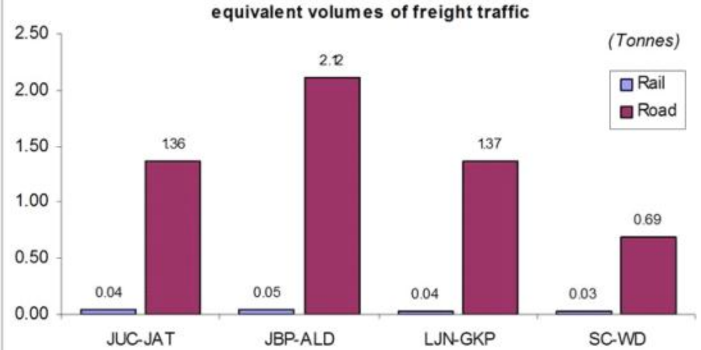


Figure 4.30: TSP emissions on rail (diesel traction) and road for equivalent volumes of freight traffic

5 Financial Costs

This chapter compares the financial costs of road and rail, on identified sections, for carrying the same volume of passenger and freight traffic. The comparison is not very easy because of the problems of comparability of the cost data of the two modes in view of their differing accounting practices. While the cost estimates published by the railways include operating costs as well as the cost of building and/or maintaining the railway infrastructure, the published road cost estimates do not reflect the cost of construction, expansion or maintenance of road infrastructure.

In addition, while in the case of rail, access to rail infrastructure is subject to the payment of a charge by the user, in the case of road, the cost of building or maintaining road infrastructure is rarely, if ever, realised from the user. Besides, road-use related taxes do not bear an identifiable relationship with the true marginal cost of supply or marginal social benefit of road service. These costs also mostly go unrequited.

There is also the problem related to taxes and subsidies. The railway costs are inclusive of all taxes and subsidies. While the railways are not required to pay duties on a large number of items, they pay a higher rate for electricity than that paid by other consumers. Since the railway cost items are grouped under such broad heads as traction cost, cost of provision and maintenance of track, it is not possible to separate each material used and examine its tax or subsidy component.

Comparison between the costs of the two modes is in financial terms.

In order to overcome this problem of comparability, separate cost estimates for road infrastructure have been worked out. The objective is to arrive at the integrated cost of road transport so that it can be compared with that of rail. The comparison between the costs of the two modes is strictly in financial rather than in economic terms. All costs are worked out at 1997-98 prices.

Road Vehicle Operating Costs

The road vehicle operating costs (VOCs) were first worked out as a part of the road user cost study carried out in 1982. The study was updated in 1991. The costs were separately worked out for different types of vehicles, roads, road surface and terrain. The vehicles covered were new and old technology cars, diesel buses and light, heavy and multi-axle vehicles (trucks). The types of the roads included were single, intermediate, two-lane and four-lane. The types of road surface took into account the roughness values as indicated in Table 5.1.

Road vehicle operating costs were first worked out as a part of the Road User Cost Study, 1982.

Table 5.1: Roughness values for roads in mm/km (towed fifth wheel bump integrator)

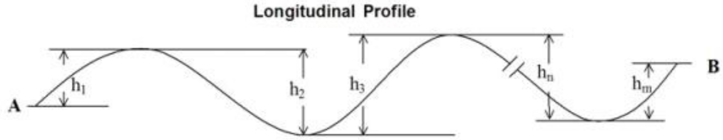
Type of Road Surface	Road Condition			
	Good	Average	Poor	Very poor
Asphaltic concrete	2000-2500	2500-3000	3500-4000	Over 4000
Premix bituminous carpet	2500-4500	4500-5500	5500-6500	Over 6500
Surface dressing	4000-5000	5000-6500	6500-7500	Over 7500
Water-bound macadam/gravel	8000-9000	9000-10000	10000-12000	Over 12000

The types of terrain covered were plain, rolling and hilly. The typical values of rise and fall for different terrains considered were as indicated in Table 5.2. The longitudinal profile measured in terms of metres of rise and fall per kilometer is shown in the figure below:

Table 5.2 : Typical values of rise and fall (RF) for various terrains

Types of Terrain	RF
Plain	0-15
Rolling	15-30
Hilly	30-50

Longitudinal Profile



Average rise of section AB, $RS = \frac{h_1 + h_3 + \ldots h_m \text{ (metres)}}{\text{Distance AB (km)}}$ expressed in m/km

Average fall of section AB, $FL = \frac{h_2 + h_4 + \ldots h_n \text{ (metres)}}{\text{Distance AB (km)}}$ expressed in m/km

Average rise and fall of section AB, $RF = \frac{h_1 + h_2 + h_3 + h_4 + \ldots + h_n + h_m \text{ (metres)}}{\text{Distance AB (km)}}$ expressed in m/km

The vehicle operating costs constituted fixed and variable costs. The fixed costs included overheads, administration charges, interest on borrowed capital, etc. The variable component covered consumables like fuel, tyres, lubricants and spares, and included cost of maintenance of the vehicle, depreciation and wages of the crew. The value of passenger time and that of commodities in transit also formed a part of the variable operating costs.

Based on the above work, Indian Roads Congress (IRC) has worked out tables for determining vehicle operating costs under different variables. These tables are included in their Manual on Economic Evaluation of Highway Projects, 1993. The tables are for uncongested traffic conditions. As traffic increases, the vehicles have to overtake, cross, accelerate and decelerate. These manoeuvres result in drop in speed and increase in fuel consumption and wear and tear of vehicles. As a consequence, the vehicle operating costs go up.

Indian Roads Congress has worked out tables for determining vehicle operating costs under different variables.

The increase in vehicle operating costs can be worked out separately for the distance-related and time-related components. The distance-related components include fuel, lubricants, spare parts, etc., while time-related components cover depreciation, fixed costs, wages of crew, value of passenger time and value of commodities in transit. The congestion factors for working out distance-related costs are given in Table 5.3. These factors relate to different types of vehicles and are indicated separately for two-lane and four-lane roads.

Table 5.3 : Congestion factors (CF) for working out distance-related costs as given in the IRC Manual

New-technology car	Two-lane	CF = 0.70 + 0.90 VCR
	Four-lane divided	CF = 0.90 + 0.90 VCR
Old-technology car	Two-lane	CF = 0.90 + 0.50 VCR
	Four-lane divided	CF = 0.90 + 0.80 VCR
LCV	Two-lane	CF = 0.90 + 1.00 VCR
	Four-lane divided	CF = 0.90 + 0.70 VCR
HCV and Bus	Two-lane	CF = 0.80 + 1.10 VCR
	Four-lane divided	CF = 1.00 + 0.75 VCR
MAV	Two-lane	CF = 0.90 + 1.40 VCR
	Four-lane divided	CF = 0.90 + 0.70 VCR

CF : congestion factor VCR : volume to capacity ratio

The effect of congestion on time-related costs is determined on the basis of the following speed-flow equation.

$$\text{Multiplying factor for determining time-related VOC Components under congested traffic conditions} = \frac{\text{Intercept given in the equation (= Free Speed)}}{\text{Speed determined from the equation under congested traffic flow}}$$

Speed-flow equations have been worked out for different types of vehicles and roads, and the nature of the terrain – plain or rolling. These equations are given in Table 5.4.

Table 5.4 : Speed-flow Equations as given in the IRC Manual

Terrain	Type of Road	Equation
Plain	Two-lane (with earthen shoulders)	VCN = 85.45 - 0.017Q VCO = 67.96 - 0.012Q VB = 66.79 - 0.013Q VLCV = 65.96 - 0.013Q VT = 58.96 - 0.008Q VMAV = 44.81 - 0.006Q
Plain	Two-lane (with paved shoulders)	VCN = 87.16 - 0.076Q VCO = 68.39 - 0.004Q VB = 69.74 - 0.0036Q VLCV = 70.06 - 0.0064Q VT = 60.35 - 0.0062Q VMAV = 45.87 - 0.0047Q
Rolling	Two-lane (with earthen shoulders)	VCN = 82.03 - 0.017Q VCO = 65.24 - 0.012Q VB = 62.78 - 0.013Q VLCV = 63.32 - 0.013Q VT = 56.01 - 0.008Q VMAV = 42.57 - 0.006Q
Rolling	Two-lane (with paved shoulders)	VCN = 83.67 - 0.0076Q VCO = 65.65 - 0.004Q VB = 65.56 - 0.0036Q VLCV = 59.55 - 0.0064Q VT = 57.33 - 0.0062Q VMAV = 43.57 - 0.0047Q
Plain	Four-lane (divided carriageway with paved shoulders)	VCN = 92.79 - 0.0075Q VCO = 68.73 - 0.0049Q VB = 74.48 - 0.0042Q VLCV = 70.94 - 0.0057Q VT = 63.25 - 0.0047Q VMAV = 48.07 - 0.0036Q
Plain	Four-lane (divided carriageway with earthen shoulders)	VCN = 66.52 - 0.0096Q VCO = 81.21 - 0.0079Q VB = 63.44 - 0.0044Q VLCV = 62.53 - 0.0039Q VT = 60.01 - 0.0086Q VMAV = 45.61 - 0.0065Q

All speeds are in km/hr

VCO : speed of old-technology car
VB : speed of bus
VT : speed of two-axle heavy truck
Q : volume of traffic in PCU/hr (both directions for two-lane and major direction for four-lane divided road)
VCN : speed of new-technology car
VLCV : speed of LCV
VMAV : speed of multi-axle heavy truck

The volume of traffic is expressed in terms of passenger car units (PCU). The same unit has been used for determining the road capacity. Capacity norms have been worked out separately for different types of roads. The maximum capacity values are given in Table 5.5.

The volume/capacity ratios (VCR), used in Tables 5.3 and 5.4, have been derived from the capacity of various types of roads measured in terms of PCUs. The peak-hour volume is assumed to be 10% of the daily volume for arriving at the values given in Table 5.5.

IRC operating costs tables are for uncongested traffic conditions.

The operating costs for different types of vehicles in respect of a two-lane and a four-lane road under uncongested conditions is given in Tables 5.6.1 and 5.6.2.

Table 5.5: Capacity values considered in the analysis for assessing the effect of congestion

S. No.	Road Details	Maximum Capacity (PCU/hr)
A. Plain terrain		
1.	Single-lane	600 (both directions)
2.	Intermediate lane	1600 (both directions)
3.	Two-lane	3000 (both directions)
4.	Four-lane	4300 (one direction, viz the major flow)
B. Hilly terrain		
5.	Two-lane	1400 (both directions)

Table 5.6.1 : VOCs in Uncongested Conditions at 1997-98 Prices for a Two-lane Road (Rs per km)

Vehicle	Terrain	Fuel Cost	Tyre Cost	EOL Cost	OOL Cost	Grease Cost	Spares Cost	Maintenance Cost	Fixed Cost	Depn. Cost	Crew Cost	Total Cost	Passenger/ Commodity Cost	Grand Total
New-Tech Car	Level	1.25	0.14	0.17	0.04	0.03	0.55	0.30	0.79	0.14	0.00	3.41	3.10	6.51
	Rolling	1.27	0.14	0.21	0.06	0.04	0.55	0.30	0.94	0.15	0.00	3.66	3.70	7.36
Old-Tech Car	Level	1.83	0.22	0.17	0.04	0.03	0.60	0.33	1.00	0.20	0.00	4.41	4.43	8.84
	Rolling	1.82	0.23	0.21	0.06	0.04	0.60	0.33	1.19	0.24	0.00	4.72	5.28	10.00
Bus	Level	1.54	1.59	0.55	0.07	0.01	0.57	0.23	2.29	0.41	1.78	9.04	39.28	48.32
	Rolling	1.66	1.90	0.57	0.07	0.01	0.63	0.25	2.58	0.47	2.01	10.16	44.31	54.47
LCV	Level	1.20	0.69	0.09	0.03	0.00	0.36	0.13	3.93	0.66	1.22	8.31	0.48	8.78
	Rolling	1.43	0.80	0.11	0.03	0.00	0.36	0.13	4.44	0.74	1.38	9.42	0.53	9.95
HCV	Level	1.64	1.67	0.21	0.09	0.03	0.49	0.19	2.71	0.50	1.32	8.84	0.58	9.42
	Rolling	1.77	1.94	0.27	0.09	0.03	0.49	0.19	3.06	0.56	1.48	9.87	0.65	10.52
MAV	Level	3.07	2.79	0.21	0.09	0.03	0.96	0.36	4.65	1.10	1.94	15.19	1.55	16.73
	Rolling	3.86	3.23	0.27	0.09	0.03	0.96	0.36	5.20	1.23	2.16	17.38	1.74	19.12

Note : EOL : Engine oil, OOL : Other oil, fixed costs include overheads, administration, interest on borrowed capital, etc.

Table 5.6.2 : VOCs in Uncongested Conditions at 1997-98 Prices for a Four-lane Road (Rs per km)

Vehicle	Terrain	Fuel Cost	Tyre Cost	EOL Cost	OOL Cost	Grease Cost	Spares Cost	Maintenance Cost	Fixed Cost	Depn. Cost	Crew Cost	Total Cost	Passenger/ Commodity Cost	Grand Total
New-Tech Car	Level	1.31	0.14	0.17	0.04	0.03	0.55	0.30	0.73	0.11	0.00	3.38	2.90	6.28
	Rolling	1.31	0.14	0.21	0.06	0.04	0.55	0.30	0.88	0.14	0.00	3.63	3.46	7.09
Old-Tech Car	Level	1.84	0.22	0.17	0.04	0.03	0.60	0.33	0.99	0.20	0.00	4.41	4.38	8.80
	Rolling	1.82	0.23	0.21	0.06	0.04	0.60	0.33	1.18	0.22	0.00	4.69	5.23	9.93
Bus	Level	1.57	1.59	0.55	0.07	0.01	0.57	0.23	1.92	0.35	1.50	8.37	32.96	41.33
	Rolling	1.65	1.90	0.57	0.07	0.01	0.63	0.25	2.17	0.40	1.69	9.35	37.21	46.55
LCV	Level	1.28	0.69	0.09	0.03	0.00	0.36	0.13	3.64	0.61	1.13	7.96	0.44	8.40
	Rolling	1.48	0.80	0.11	0.03	0.00	0.36	0.13	4.13	0.69	1.28	9.00	0.50	9.50
HCV	Level	1.64	1.67	0.21	0.09	0.03	0.49	0.19	2.56	0.47	1.24	8.57	0.55	9.12
	Rolling	1.75	1.94	0.27	0.09	0.03	0.49	0.19	2.89	0.53	1.40	9.56	0.62	10.18
MAV	Level	3.10	2.79	0.21	0.09	0.03	0.96	0.36	4.40	1.04	1.83	14.80	1.47	16.27
	Rolling	3.87	3.23	0.27	0.09	0.03	0.96	0.36	4.93	1.17	2.05	16.94	1.64	18.59

Note : EOL : Engine oil, OOL : Other oil, fixed costs include overheads, administration, interest on borrowed capital, etc.

It would be observed from the above that for personal vehicles and buses, the value of passenger time forms the largest share of the operating costs, whereas for commercial vehicles, the main constituents are the fixed costs.

Operating costs adjusted for traffic congestion factor.

Table 5.3 gives the congestion factors for multiplying the distance-related VOC components in order to adjust for congestion. The cost under congested conditions is, therefore, derived by applying the congestion factor for the relevant year to the cost figures of Tables 5.6.1 and 5.6.2. This methodology, however, is not applied to fuel costs, since these costs have already been worked out for congested conditions in respect of the base year 2000. Instead, these are calculated in accordance with the emerging changes in the congestion factor (CF) between the base year and each successive year. These estimates take into account variations in fuel consumption for urban and non-urban stretches for different types of terrain and for empty and loaded trucks. For detailed estimates, refer to Appendix 1.4.

The speed-flow equations given in Table 5.4 form the basis for working out cost adjustment factors for determining the time-related VOC components under congested conditions. The specific adjustment factor is derived by dividing the intercept (or free speed) of the relevant speed-flow equation by the speed determined from the equation under congested traffic flow.

The variable Q has been calculated by assuming (i) that peak-hourly traffic flow is 10% of the daily traffic flow, and (ii) that 80% of the peak-hourly traffic flow is the average traffic volume in PCU/hr (Indian Roads Congress, 1993). In the case of four-lane roads, Q refers to the number of PCUs in the major direction. It has been assumed that 55% of the traffic is in the major direction. In the absence of congestion factors and speed-flow equations for traffic in the minor direction of a four-lane road, the distance-related and time-related components of costs for traffic in this direction are adjusted in the same way as those in the major direction.

Infrastructure maintenance costs added to the vehicle operating costs to make the data between the two modes comparable.

Based on the above methodology, we have worked out vehicle operating costs in financial terms for the time horizon 2000-2010 under varying conditions of traffic and road capacity. These costs are shown in Tables A3.5.1.1 to A3.5.8.3 in Appendix 3.5. They costs do not include the cost of maintenance of road infrastructure. The maintenance cost has, therefore, been separately worked out and added to the road vehicle operating costs in order to make the data related to the rail and road modes comparable.

We have also worked out cost of different types of road improvements in the case of some of the selected sections under different conditions of soil – black cotton and red soil. This has been done to understand the implications of these improvements on the overall operational costs of road transport, since capacity of most of the roads has reached a saturation level. The cost of road improvements per kilometer for different variables of capacity enhancement and types of soil is given in Table 5.7. The details are shown in Appendix 3.2.

Table 5.7 : Cost of Road Improvements (Rs million per km) at 1997-98 Prices

Road Stretch	Cost
Jalandhar-Pathankot - four-laning with provision of paved shoulders	22.21
Pathankot-Jammu - pavement overlay with provision of paved shoulders	8.82
Lucknow-Gorakhpur - pavement overlay with provision of paved shoulders	10.24
Bhopal-Ujjain (black cotton soil area) - pavement overlay with provision of paved shoulders	7.70
Bhopal-Ujjain (red soil area) - pavement overlay with provision of paved shoulders	8.05

Road improvement costs added to understand their implications in respect of the overall operational costs.

The cost of improvements, including maintenance of infrastructure, has been amortised over a period of 10 years i.e. 2000-2010 under two scenarios – business as usual and shift of traffic from road to rail. While amortising the costs, a discount factor of 12%, as recommended by the Indian Roads Congress, has been taken. Tables 5.8.1 and 5.8.2 show the cost per vehicle kilometer separately under conditions of normal maintenance and maintenance plus improvements.

Table 5.8.1 : Cost per Vehicle of Normal Maintenance Operations from 2000 to 2010* (Rs)

Section/ Vehicle type	BAU scenario of traffic growth		Scenario of shift from road to rail	
	Entire stretch	Per km	Entire stretch	Per km
New Delhi-Mughal Sarai				
Car	32.48	0.04	37.84	0.05
Bus/ Truck	97.45	0.12	113.53	0.14
Jalandhar-Jammu				
Car	11.61	0.05	13.15	0.05
Bus/ Truck	34.83	0.15	39.45	0.16
Jabalpur-Allahabad				
Car	22.70	0.06	30.81	0.09
Bus/ Truck	68.11	0.19	92.44	0.26
Lucknow-Gorakhpur				
Car	14.38	0.06	30.81	0.09
Bus/ Truck	43.13	0.19	92.44	0.26
Secunderabad-Wadi				
Car	13.77	0.07	19.04	0.10
Bus/ Truck	41.32	0.21	57.11	0.29
Gudur-Renigunta				
Car	5.02	0.07	6.78	0.09
Bus/ Truck	15.06	0.20	20.35	0.27
Bhopal-Ujjain				
Car	10.47	0.06	11.82	0.06
Bus/ Truck	31.41	0.17	35.46	0.19
Ratlam-Godhra				
Car	26.66	0.09	44.34	0.16
Bus/ Truck	79.98	0.28	133.03	0.47

* at 1997-98 prices BAU: Business as usual

Note: For the derivation of the above results involving benefits and costs, refer to Appendix 3.3.

Table 5.8.2 : Cost per Vehicle of Road Improvement between 2000 & 2010* (Rs)

Section/ Vehicle type	BAU scenario of traffic growth		Scenario of shift from road to rail	
	Entire stretch	Per km	Entire stretch	Per km
New Delhi-Mughal Sarai				
Car	130.43	0.16	151.03	0.18
Bus/ Truck	391.30	0.47	453.10	0.55
Jalandhar-Jammu				
Car	42.26	0.18	50.98	0.21
Bus/ Truck	126.77	0.53	152.93	0.64
Jabalpur-Allahabad				
Car	59.14	0.17	88.54	0.25
Bus/ Truck	177.42	0.50	265.61	0.75
Lucknow-Gorakhpur				
Car	36.74	0.14	50.58	0.19
Bus/ Truck	110.21	0.42	151.74	0.57
Secunderabad-Wadi				
Car	42.75	0.21	58.46	0.29
Bus/ Truck	128.25	0.64	175.39	0.88
Gudur-Renigunta				
Car	15.44	0.21	21.26	0.28
Bus/ Truck	46.31	0.62	63.77	0.85
Bhopal-Ujjain				
Car	28.79	0.15	35.21	0.19
Bus/ Truck	86.37	0.45	105.63	0.56
Ratlam-Godhra				
Car	83.77	0.29	142.04	0.50
Bus/ Truck	251.31	0.88	426.12	1.50

* at 1997-98 prices

Note: For the derivation of the above results involving benefits and costs, refer to Appendix 3.3.

The amortised cost of road infrastructure has then been added to the vehicle operating costs to arrive at the total cost of freight or passenger services separately for each type of vehicle. The details are given in Appendix 3.4.

Cost of Rail Transport

The cost of rail transport has been computed on the basis of the estimates of cost of coaching and freight services worked out by the Indian Railways for the year 1997-98. These estimates take into account cost of traction, maintenance of track and signalling, terminal and transportation costs and other overheads, but do not include the value of passenger time or the cost of commodities in transit, which are included in the road transport costs. In order to make a valid comparison between the two modes, we have included these costs in the case of rail transport also.

Value of commodities in transit and passenger time included in the operational costs of rail for valid comparison between the two modes.

The values of passenger time and commodities in transit have been obtained from the study carried out by the Planning Commission in 1988. These have been updated to 1997-98 prices by using the relevant commodity price indices in case of commodities and the GDP deflator in case of passenger time. The value of passenger time has been computed under two different situations: (i) travel between two mofussil towns, and (ii) travel between a metropolitan city and a mofussil town. Among the selected eight sections, Gudur-Renigunta and Ratlam-Godhra sections are the only ones that fall in the first category. The inventory cost of the major commodities in transit is depicted in Table 5.9.1 and the value of passenger time in Table 5.9.2.

Table 5.9.1 : Transit Inventory Cost (for 650 km distance slab)

S. No.	Item	Share in Total Commodity Traffic	Inventory Cost (Rs/tonne) - 1997-98 prices
1	Coal (BL)	52.46%	0.76
2	Foodgrains (wheat)	17.12%	8.40
3	Cement	8.51%	1.87
4	Chemical Manures	8.03%	8.48
5	Mineral Oils	8.20%	8.61
6	Steel	5.68%	15.37
Total		100.00%	
Weighted average			4.25

Table 5.9.2 : Value of Passenger Time on Railways (for 50 km distance slab)

S. No.	Travel Situation	Value of Time (Rs/Pass.) 1997-98 prices
	Plains	
1.	Travel between metropolitan city and mofussil town	46.49
2.	Travel between two mofussil towns	57.11

The cost estimates of the rail services reflect the prevailing operational conditions, including the level of utilisation of the available sectional capacity. Thus, the congestion factor is built in the cost of these services. In the case of road transport, however, the cost arising due to the congestion factor has been separately estimated and added to the vehicle operating costs. This makes the data relating to the two modes comparable in all respects for the base year 2000.

Cost estimates of the rail services reflect the prevailing operational conditions.

To make the position comparable for the remaining years of the chosen period, we have attempted to work out the cost impact of the increase in traffic levels (number of trains) in the case of railways, as has been done in the case of road transport. It may, however, be clarified that the movement of trains is a planned exercise within the parameters of normative capacity. Passenger services are run according to published schedules which remain unchanged. Only in case of freight services, the transit time may show an increase with higher levels of capacity utilisation.

Notwithstanding the above explanation, it may be pointed out that the train services, both passenger and freight, are affected by unscheduled incidences, the effect of which is all the more pronounced if utilisation is close to the capacity saturation levels. In this case, the ripple effect of delays is felt across all services resulting in increase in operating costs. This impact relationship is explained, in detail, in the subsequent paragraphs.

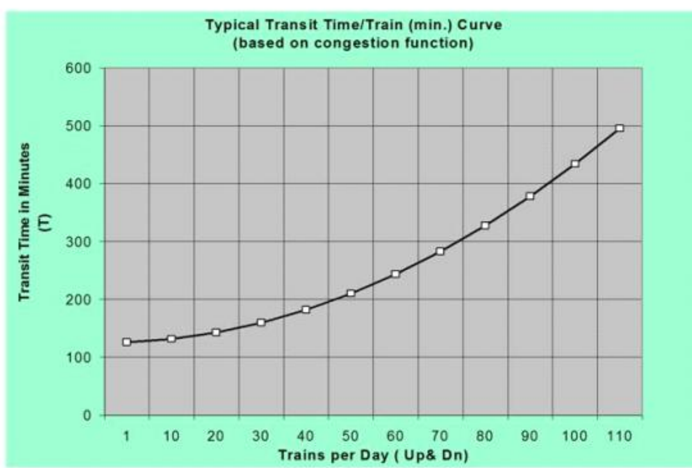
Train services are affected more by unscheduled incidences.

It is now universally acknowledged that line capacity is not so much a matter of pushing a number of trains through a section of the railways. As a matter of fact, line capacity has to be viewed in terms of the number of trains that can be run with a certain consistency over a portion of the railways within permissible transit time to be defined by the management.

Various models are available for simulating trains running over a section. In mid-nineties, Indian Railways acquired an event-based line simulation model called RAILS (Railway Analysis and Interactive Line Simulator) for train simulations. This model uses a large amount of track and signalling data related to gradients and curvatures of tracks, station layouts and index plan and inter-station distances. The technical characteristics of locomotives, wagons and coaches are fed from the rolling stock database. Operating characteristics are captured in the form of train schedules and special events related to failures, maintenance blocks, and temporary and permanent speed restrictions. The simulation model can then be used for 'running' trains, generating 'Control Charts' and a number of other useful output reports.

Simulation model – RAILS – used for train simulations.

For estimating the line capacity, the RAILS model is used to run multiple simulations over a particular section at different levels of traffic. Results thus obtained are translated into an "average" congestion curve between transit times per train and the number of trains keeping the traffic mix and other scheduled events like passenger train halts constant. In the base case, the weighted-average transit time is plotted on a graph, having average transit time on the "Y" Axis and the traffic level on the "X" Axis. Through a series of such simulations, a congestion curve can be obtained for a particular section. A sample congestion curve is shown below:



Indian Railways conducted detailed simulations on seventeen typical sections of IR in 1999-2000 for developing congestion curves representative of varying conditions of track, terrain, locomotive hauling power, wagon loads, signalling systems, type of traction, etc. These sections are representative of the entire Indian Railways, as over 80% of the network comprises similar sections. The transit times generated through simulations were compared with actual control charts for one week. The model was then calibrated to ensure that the difference in the transit times between the simulated results and the actual times taken by various trains over the selected seventeen sections is less than 5%. Thereafter, traffic in terms of trains was gradually increased and average transit time plotted on a curve, for different levels of traffic. The results were reported in "LRDSS Phase II Analysis Report".

Mathematically, the total time (T) taken by a train to cover a given length of track can be expressed as the sum of the following:

The average bare running time of a train (t_1) – This is the time taken by a single train to run the full length of the section. This is dependent on:

- Permanent speed restrictions
- Maximum sectional speed
- Maximum speed of train
- Locomotive and wagon characteristics (e.g. tractive effort/speed curve, rolling resistance, etc.)

Scheduled Delay (t_2) – This is the time lost in scheduled halts of passenger trains, maintenance blocks, etc. Since the attempt here is to fix a capacity norm, maintenance blocks are included in the simulation data in a form that actually replicates field operations.

Interference Delay (t_3) – This takes place as a result of interference with other trains running on the section. It results from meets and passes on single-line territory and multiple overtakes on double-line territory. These, in turn, are due to:

- Speed differential
- Priority differential
- Resource availability (e.g. number of loops, etc.)

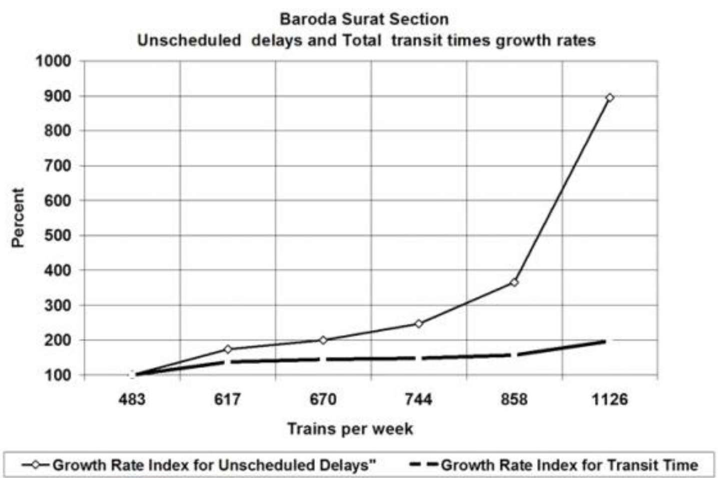
Thus, the total time (T) taken by a train to clear a section is given by $T = t_1 + t_2 + t_3$.

As the number of trains over a section increases, congestion also starts increasing. The total running time (T) for all the trains begins to rise. This is due partly to increase in unscheduled delays (t_3) and partly to scheduled delays (t_2) associated with additional trains introduced in the system as a result of increase in total traffic. The scheduled halts are not congestion-related and are related more to the operating policy issues with regard to passenger trains and the maintenance blocks. Out of the total transit time (T), two time components viz. t_1 and t_2 are not related to congestion. The rolling stock, the permanent speed restrictions and the gradient largely govern t_1, and these are in the nature of 'boundary conditions' insofar as line capacity definition is concerned. Similarly, scheduled delays t_2 are determined by extraneous factors like track maintenance and passenger trains operating policy. For a given section and at a given point of time, both these components are externally defined by safety considerations and the policy related to passenger train halts. Consequently, both are equivalent to a constraint or a 'boundary condition' within which the traffic must move over the section. The sum of t_1 and t_2 is the bare minimum time that a train would take to clear a section.

On the other hand, unscheduled delays, which are accounted for by increased meets/passes/overtakes, continue to increase with growing congestion. As such, as traffic increases, the t_3 factor also increases while t_1 and t_2 factors remain virtually static.

The t_3 component varies from day to day. It is affected by failures, the number of trains run on a day, and all the unscheduled events that take place on the section. If the traffic is low, the value of this factor is also low as a result of low interference. As the traffic grows, the interference with other trains competing for limited resources (such as permanent way, sidings, loop lines, platforms, etc.) increases, and this results in an increase in the transit time.

The growth in the unscheduled delays on the seventeen representative sections of the Indian Railways selected for simulations (mentioned earlier) was plotted for each section. One such graph is given below.

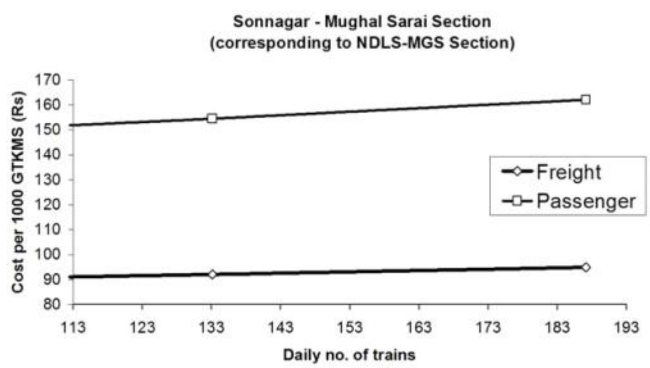


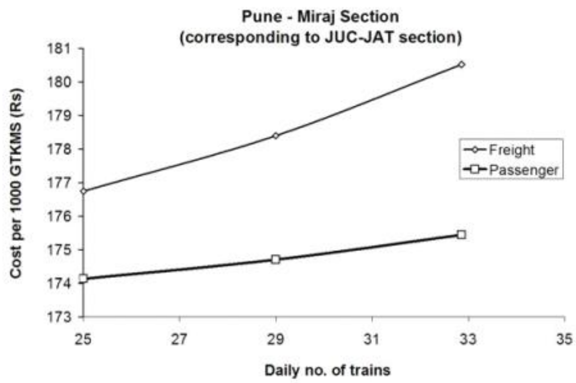
Unscheduled delays are sensitive to capacity utilisation.

The graph above shows how the total train hours lost increase with increase in traffic. It illustrates the growth rates (using base as 483 trains per week) in the unscheduled train hours as well as total train hours at different levels of traffic. At each level of traffic, points have been plotted using the product of average unscheduled delays/ transit times per train and the traffic level. It is seen that as the number of trains increases beyond the 858 trains a week mark, there is a steep rise in the percentage growth of total train hours lost due to unscheduled delays. Using a base of 453 trains a week, the unscheduled train hours grow to 370% over the base (Delays at 453 train per week = Base of 100) up to traffic level of 858 trains a week. However, beyond that, the rate of growth of train hours lost due to congestion is very sharp. In other words, when the traffic increases beyond the 858 trains per week mark, the percentage increase in the total hours lost due to unscheduled delays is very steep. Similarly, the growth rate of total transit time beyond 858 trains a week is relatively higher. This implies that any further dispatch of trains beyond the 858-trains/week point results in a sharp degradation in the section's performance.

Increase in transit time increases the cost of operations.

On the basis of the above, it can be concluded that the increase in the transit time will result in an increase in the cost of operations, more specifically the long-term line haul variable costs. This is reflected in the following graphs showing the cost per thousand GTKMS in relation to the daily number of trains on two representative sections – one level and the other rolling – out of the 17 sections selected in the LRDSS study. The graphs are based on a linear relationship between the two variables. The analysis has been done for a freight train and an express passenger train in each case.





The percentage increase in operating costs for increasing levels of traffic has been derived from the above. The rate of increase in each of the sections varies according to the base level of traffic. This derived rate has then been applied for working out costs for passenger and freight services on each of the 8 selected sections for the time horizon 2000-2010.

The rate of increase in operating costs has been applied for working out cost of services.

Comparative Costs of Road and Rail

The integrated costs in respect of road and rail modes for equivalent volumes of passenger and freight traffic are given in Tables A3.5.1.1 to A3.5.8.3 of Appendix 3.5. The cost per net tonne-kilometer (NTKM) and cost per passenger-kilometer (PKM) are given in Tables 5.10 and 5.11 for the case of no improvement in road and rail infrastructure.

Table 5.10: Financial costs for equivalent volumes of traffic on road and rail

(Rs per PKM)

Section	Passenger					
	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010	
New Delhi-Mughal Sarai*	2.312	1.294	3.399	1.360	6.674	1.430
Jalandhar-Jammu	2.891	1.271	4.482	1.303	9.779	1.336
Jabalpur-Allahabad	1.938	1.104	2.342	1.120	3.037	1.137
Lucknow-Gorakhpur	2.213	1.112	3.019	1.134	4.798	1.157
Secunderabad-Wadi	1.973	1.213	2.343	1.244	2.935	1.275
Gudur-Renigunta*	1.283	1.482	1.584	1.497	2.069	1.512
Bhopal-Ujjain*	1.951	1.110	2.447	1.121	3.336	1.132
Ratlam-Godhra*	1.043	1.346	1.199	1.387	1.431	1.429

Table 5.11: Financial costs for equivalent volumes of traffic on road and rail

(Rs per NTKM)

Section	Freight					
	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010	
New Delhi-Mughal Sarai*	2.410	0.322	3.168	0.332	4.734	0.342
Jalandhar-Jammu	2.407	0.328	3.107	0.350	4.520	0.373
Jabalpur-Allahabad	2.163	0.333	2.574	0.345	3.172	0.358
Lucknow-Gorakhpur	2.201	0.298	2.767	0.301	3.704	0.304
Secunderabad-Wadi	2.511	0.614	2.849	0.652	3.333	0.692
Gudur-Renigunta*	2.536	0.618	2.885	0.634	3.384	0.650
Bhopal-Ujjain*	2.469	0.414	2.929	0.416	3.607	0.418
Ratlam-Godhra*	2.342	0.270	2.583	0.288	2.914	0.307

Table 5.12 presents the ratios of the rail to road transport costs. It may be recalled that the figures for passenger traffic relate to movement only by bus on road.

Table 5.12: Relative financial costs for equivalent volumes of road and rail traffic

(Percentage)

Section	Ratio of rail to road cost					
	Pass.	Freight	Pass.	Freight	Pass.	Freight
	2000		2005		2010	
New Delhi-Mughal Sarai*	55.99%	13.36%	40.02%	10.47%	21.42%	7.22%
Jalandhar-Jammu	43.97%	13.62%	29.07%	11.26%	13.66%	8.26%
Jabalpur-Allahabad	56.95%	15.41%	47.84%	13.42%	37.45%	11.27%
Lucknow-Gorakhpur	50.25%	13.53%	37.58%	10.87%	24.12%	8.20%
Secunderabad-Wadi	61.50%	24.44%	53.09%	22.87%	43.46%	20.75%
Gudur-Renigunta*	115.50%	24.37%	94.48%	21.96%	73.08%	19.19%
Bhopal-Ujjain*	56.88%	16.76%	45.81%	14.20%	33.94%	11.59%
Ratlam-Godhra*	128.98%	11.52%	115.65%	11.14%	99.86%	10.53%

The following conclusions can be drawn from the above data.

(i) The rail costs are generally lower than those of road transport, though the advantage is greater for freight traffic than passenger traffic.

(ii) The differential between road and rail costs for passenger traffic in the base year 2000 is as much as Rs 2.09 per NTKM. For passenger traffic, the differential in unit costs is as much as Rs 1.62 per PKM.

The rail costs are invariably lower than those of road transport, though the advantage is greater for freight traffic than passenger traffic.

(iii) For passenger traffic, for the base year 2000, the cost on rail varies between Rs 1.10 and Rs 1.48 per PKM, while in the case of road transport (diesel bus), it varies between Rs1.04 and Rs 2.89 per PKM. The comparative advantage of rail declines in a situation where adequate road capacity is available.

(iv) For the year 2010, while there is marginal increase in the rail costs, the costs of road transport show an exponential increase. This is due to unacceptable levels of congestion on different road sections.

The daily savings in transport costs resulting from the intermodal substitution of the selected volumes of traffic when there is no road improvement are shown in Table 5.13.

Table 5.13: Daily overall changes in financial costs (Rs. million)

Section	Pass.	Freight	Pass.	Freight	Pass.	Freight
	2000		2005		2010	
New Delhi-Mughal Sarai*	-8.40	-17.99	-16.82	-24.43	-43.26	-37.83
Jalandhar-Jammu	-4.19	-5.29	-7.94	-6.99	-20.58	-10.48
Jabalpur-Allahabad	-2.79	-6.70	-4.16	-8.16	-6.55	-10.32
Lucknow-Gorakhpur	-2.78	-5.23	-4.86	-6.79	-9.51	-9.37
Secunderabad-Wadi	-0.80	-2.00	-1.14	-2.31	-1.70	-2.78
Gudur-Renigunta*	0.13	-0.73	0.03	-0.85	-0.15	-1.04
Bhopal-Ujjain*	-0.84	-2.05	-1.30	-2.51	-2.13	-3.18
Ratlam-Godhra*	0.45	-3.09	0.29	-3.42	0.02	-3.88

Substantial savings result from intermodal substitution – road by rail.

The following conclusions can be deduced from the above data:

(i) There are significant savings in transport costs as a result of shift of traffic from road to rail.

(ii) The cost savings in respect of freight traffic are generally greater than those related to passenger traffic.

(iii) The daily overall savings in respect of freight traffic in the base year 2000 range between Rs 0.73 million and Rs 17.99 million. In respect of passenger traffic, for the base year 2000, the daily savings range between Rs 0.80 million and Rs 4.19 million. The variation in savings is due to sectional characteristics, such as length of section, type of terrain, etc.

The total daily overall savings in financial costs are shown separately for electrified and dieselised sections in Table 5.14.

Table 5.14: Overall savings in financial cost with intermodal substitution

(Rs million)

Type of sections	Pass.	Freight	Pass.	Freight	Pass.	Freight
	2000		2005		2010	
Electrified sections	9.23	23.85	18.12	31.21	45.54	45.93
Dieselised sections	10.56	19.21	18.09	24.26	38.34	32.95
Total	19.80	43.07	36.22	55.47	83.88	78.88

It can be seen that in case of passenger traffic in the year 2000, the total daily overall savings on the sections with electrified rail traction are Rs 9.23 million, while for the dieselised sections, they are Rs 10.56 million. The savings in respect of freight traffic, for the same year, work out to Rs 23.85 million for the electrified sections and Rs19.21 million for the dieselised sections.

The operational costs of road transport decline significantly with road improvements.

The comparative financial costs of transport on road and rail for equivalent volumes of passenger and freight traffic (without road improvements) are shown diagrammatically in Figures 5.1 to 5.16 at the end of this chapter.

As mentioned earlier, we have also calculated the effect of road improvements on the operational costs. The improvements considered are widening of the carriageway (4-laning) and/or provision of pavement overlay with paved shoulders. The results are presented in Tables 5.15 and 5.16.

Table 5.15: Financial costs of road transport with road improvements (Passenger)

(Rs per PKM)

Section	2000	2005**	2010
New Delhi-Mughal Sarai*	2.308	1.506	1.719
Jalandhar-Jammu	2.885	1.658	1.866
Jabalpur-Allahabad	1.935	1.705	1.870
Lucknow-Gorakhpur	2.202	1.706	1.948
Secunderabad-Wadi	1.960	1.735	1.904
Gudur-Renigunta*	1.265	1.123	1.278
Bhopal-Ujjain*	1.942	1.681	1.907
Ratlam-Godhra*	1.019	0.945	1.015

*** 2006 in the case of New Delhi-Mughal Sarai*

Table 5.16: Financial costs of road transport with road improvements (Freight)

(Rs per NTKM)

Section	2000	2005**	2010
New Delhi-Mughal Sarai*	2.433	2.015	2.296
Jalandhar-Jammu	2.435	2.215	2.590
Jabalpur-Allahabad	2.178	2.426	2.872
Lucknow-Gorakhpur	2.195	2.468	3.044
Secunderabad-Wadi	2.554	2.761	3.138
Gudur-Renigunta*	2.575	2.787	3.174
Bhopal-Ujjain*	2.489	2.750	3.245
Ratlam-Godhra*	2.402	2.530	2.758

*** 2006 in the case of New Delhi-Mughal Sarai*

The following conclusions can be drawn from the above data:

(i) The operational costs of road transport decline significantly with road improvements.

(ii) Rail continues to maintain cost advantage over road except in the case of two sections where traffic volumes are low and road improvements are also carried out.

(iii) Cost efficiency of rail vis-à-vis road is greater in respect of freight traffic than in the case of passenger traffic under the scenarios of with and without road improvements.

However, the conclusions (ii) and (iii) above should be interpreted with caution as the cost of rail infrastructure improvements has not been factored in the above comparison.

It is evident from the intermodal operational cost analysis that both for passenger and freight transport, rail is generally cheaper than road. The cost efficiency is pronounced in favour of rail for freight traffic. Substantial savings in transport costs can result from intermodal substitution of road traffic by rail transport. Significant reduction in operating costs can, however, be effected by capacity augmentation and other improvements of road infrastructure. This underscores the need for investments in such infrastructure development.

Figure 5.1: Financial costs of equivalent volumes of passenger traffic (New Delhi-Mughal Sarai section)

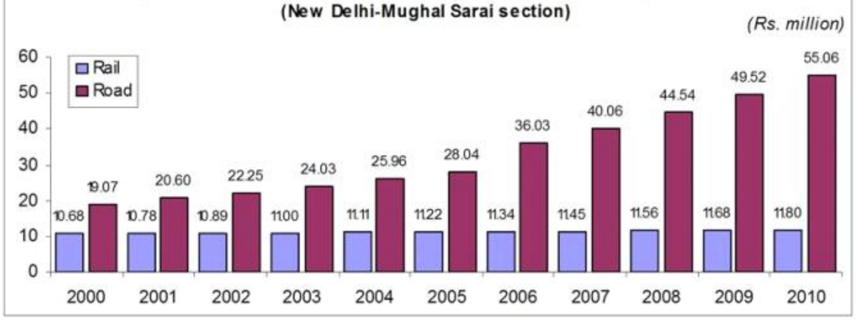


Figure 5.2: Financial costs of equivalent volumes of freight traffic (New Delhi-Mughal Sarai section)

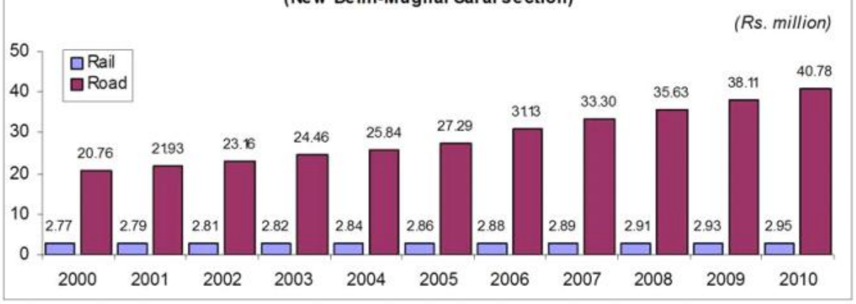
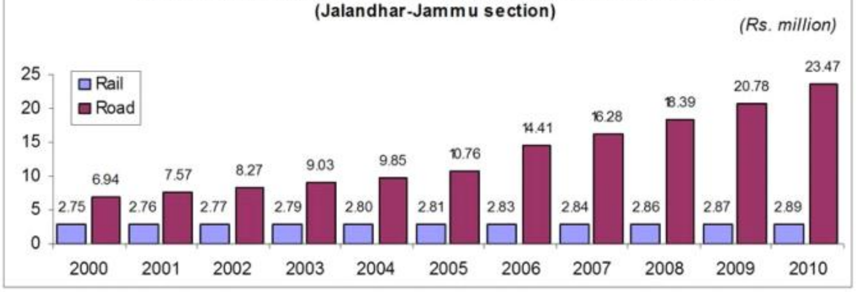


Figure 5.3: Financial costs of equivalent volumes of passenger traffic (Jalandhar-Jammu section)



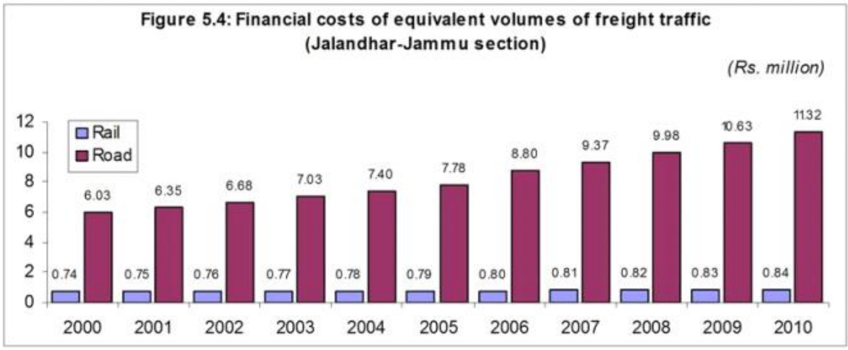


Figure 5.4: Financial costs of equivalent volumes of freight traffic (Jalandhar-Jammu section)

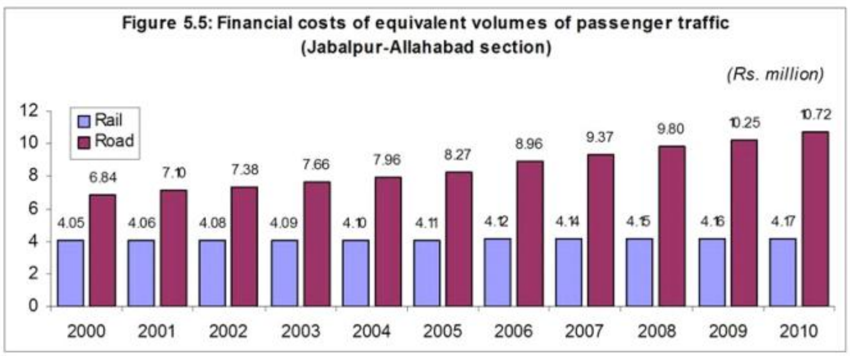


Figure 5.5: Financial costs of equivalent volumes of passenger traffic (Jabalpur-Allahabad section)

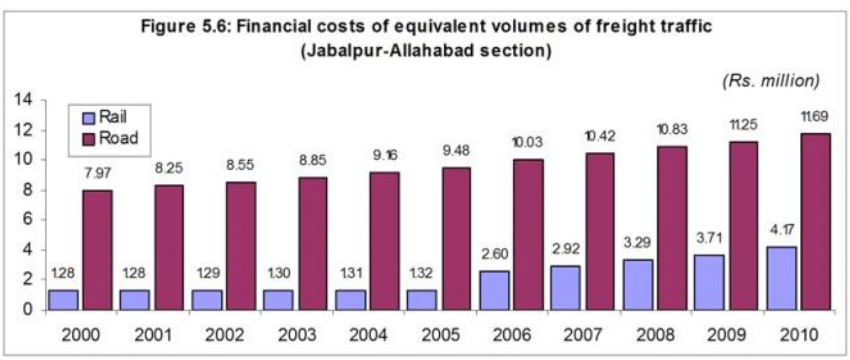


Figure 5.6: Financial costs of equivalent volumes of freight traffic (Jabalpur-Allahabad section)

Figure 5.7: Financial costs of equivalent volumes of passenger traffic (Lucknow-Gorakhpur section)

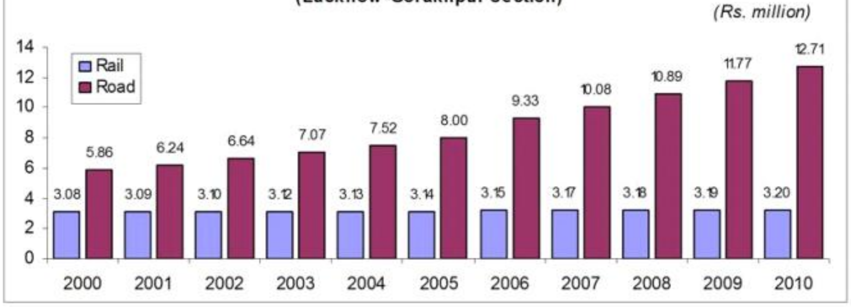


Figure 5.8: Financial costs of equivalent volumes of freight traffic (Lucknow-Gorakhpur section)

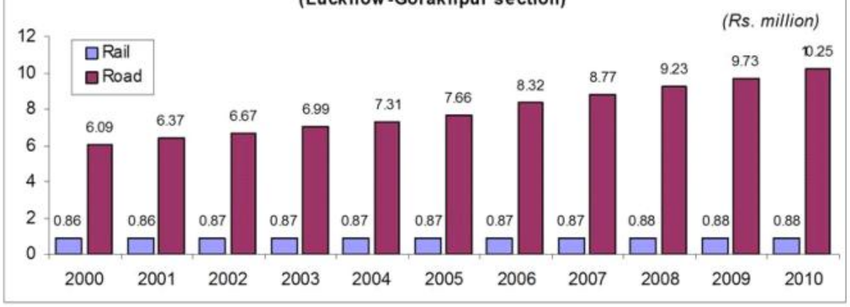


Figure 5.9: Financial costs of equivalent volumes of passenger traffic (Secunderabad-Wadi section)

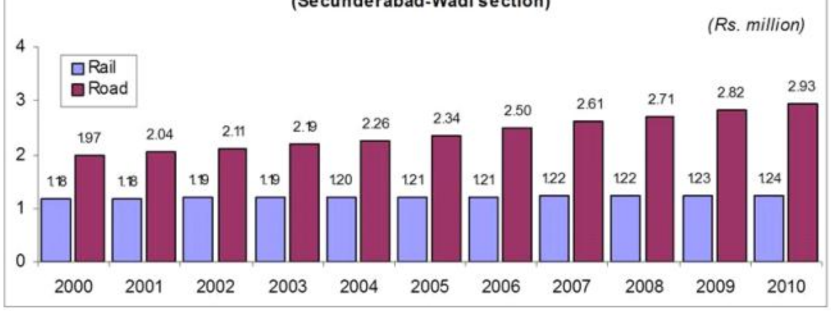


Figure 5.10: Financial costs of equivalent volumes of freight traffic (Secunderabad-Wadi section)

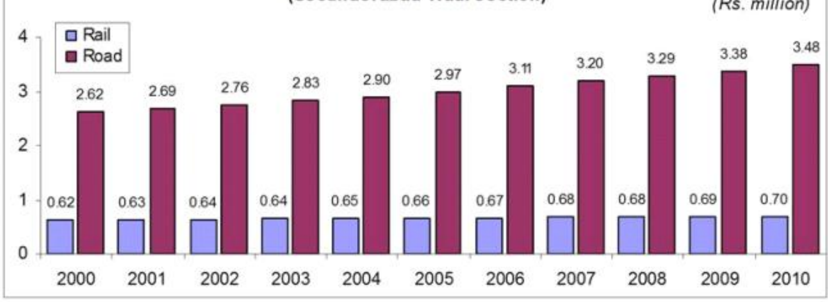


Figure 5.11: Financial costs of equivalent volumes of passenger traffic (Gudur-Renigunta section)

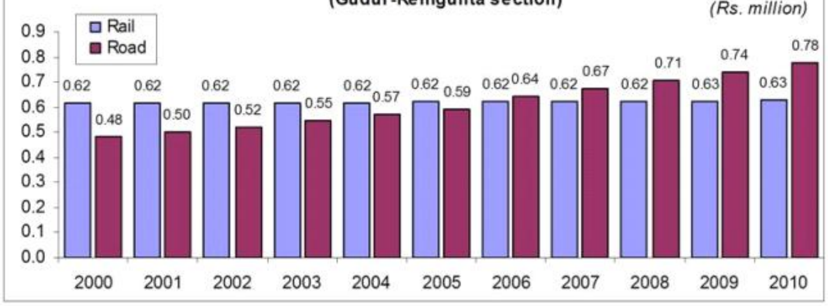


Figure 5.12: Financial costs of equivalent volumes of freight traffic (Gudur-Renigunta section)

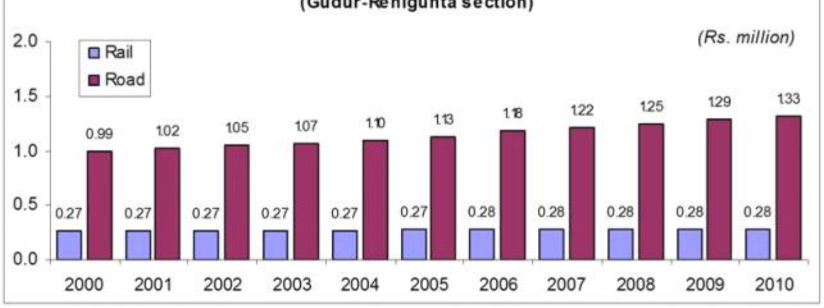


Figure 5.13: Financial costs of equivalent volumes of passenger traffic (Bhopal-Ujjain section)

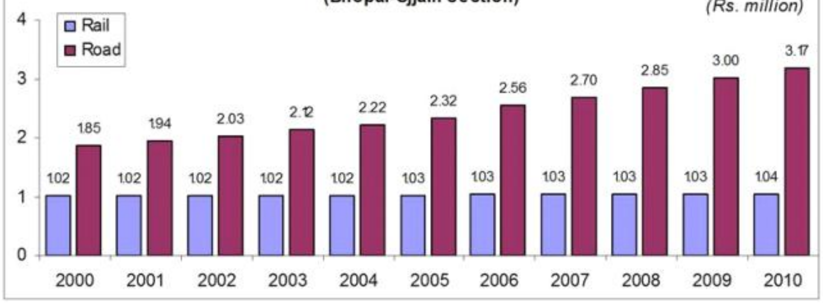


Figure 5.14: Financial costs of equivalent volumes of freight traffic (Bhopal-Ujjain section)

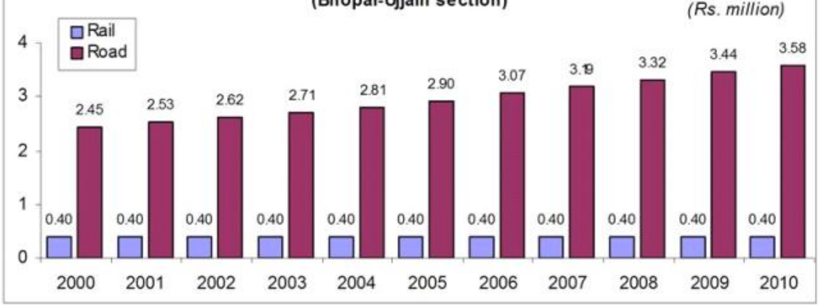
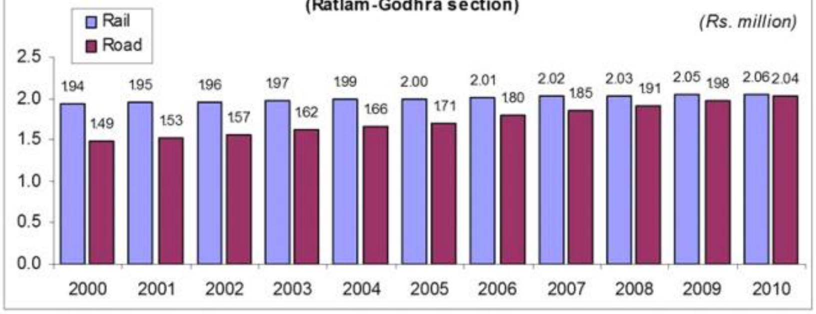


Figure 5.15: Financial costs of equivalent volumes of passenger traffic (Ratlam-Godhra section)



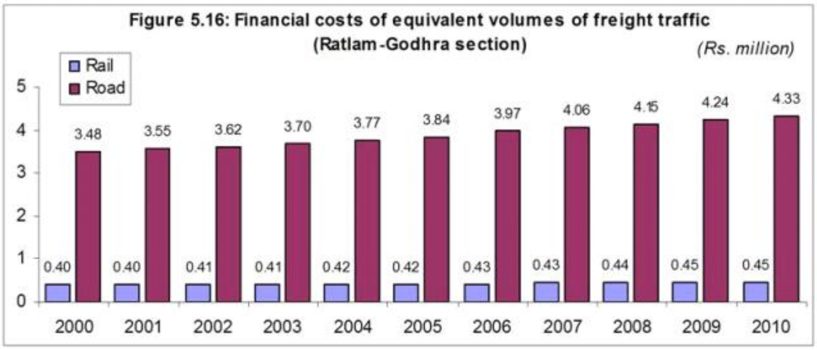


Figure 5.16: Financial costs of equivalent volumes of freight traffic
(Ratlam-Godhra section)
(Rs. million)
Rail
Road
5
4
3
2
1
0
3.48
3.55
3.62
3.70
3.77
3.84
3.97
4.06
4.15
4.24
4.33
0.40
0.40
0.41
0.41
0.42
0.42
0.43
0.43
0.44
0.45
0.45
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

6 Material Inputs and Environmental Impact

We have studied how the use of energy in transport for haulage purposes gives rise to emission of noxious pollutants which degrade environment and endanger human health. We have also attempted to monetise the resultant health hazard costs for rail and road and to reflect their impact in a total cost comparison.

Manufacturing of moveable assets and construction of ground infrastructure consumes scarce natural resources.

However, for a complete comparison, it is necessary to also consider the environmental impact arising out of the production of materials used in the manufacture of rolling stock (wagons, coaches, buses, etc.) and related ground infrastructure (rails, bridges, etc.). We have duly analysed this aspect and in this chapter we will discuss the results of our analysis and the comparative significance of such environmental impact.

Rolling Stock

Road vehicles, rail coaches and rail wagons are composed of various materials of which the principal ones are steel, ferrous and non-ferrous alloys, rubber, plastics, timber and paints. Steel, however, accounts for the largest and most significant proportion of the material resources utilised in rail locomotives and passenger coaches. For freight wagons, the tare weight of the wagon could itself be taken as a good estimate of the steel used, since the amounts of other materials used are relatively negligible. Steel is also one of the important material constituents of road vehicles. While some information is available on the amounts of different materials going into the production of rail vehicles, it has not been possible to access similar information for road vehicles. Hence, our analysis has been restricted to the comparative use of steel in road and rail. It has been assumed that none of the steel used is recycled.

Steel is the most important material used in road and rail vehicles.

for sections with competing national highways and 5000 passengers and 5220 tonnes of freight daily for sections with competing state highways).

A typical road vehicle has a life of about 10 years, whereas a rail coach or a locomotive remains in operation for about 30 years. Since the life of the rolling stock on rail is three times of that on road, we have derived the comparative requirements of steel for a time horizon of 30 years for both the modes. Table 6.3 summarises the steel requirements for each section. Based on this data, Table 6.4 has been drawn up which gives the ratio of road to rail steel requirements.

Table 6.3: Steel Requirements (in tonnes) over a 30 year period for the Selected Equivalent Volumes of Passenger and Freight Traffic on Road and Rail

Sections	Road		Rail	
	Pass.	Freight	Pass.	Freight
New Delhi-Mughal Sarai*	859.02	7605.88	10196.05	15802.20
Jalandhar-Jammu	859.02	7605.88	9706.85	12388.60
Jabalpur-Allahabad	859.02	7605.88	11380.20	10954.20
Lucknow-Gorakhpur	859.02	7605.88	7474.40	16378.35
Secunderabad-Wadi	429.51	4819.60	2104.75	8933.76
Gudur-Renigunta*	429.51	4819.60	977.70	8957.10
Bhopal-Ujjain*	429.51	4837.76	6088.30	5971.40
Ratlam-Godhra*	429.51	4837.76	6064.05	8957.10

Table 6.4: Ratio of Road to Rail Steel Requirements for the Selected Equivalent Volumes of Passenger and Freight Traffic

Sections	Pass.	Freight
New Delhi-Mughal Sarai*	8.43%	48.13%
Jalandhar-Jammu	8.85%	61.39%
Jabalpur-Allahabad	7.55%	69.43%
Lucknow-Gorakhpur	11.49%	46.44%
Secunderabad-Wadi	20.41%	53.95%
Gudur-Renigunta*	43.93%	53.81%
Bhopal-Ujjain*	7.05%	81.02%
Ratlam-Godhra*	7.08%	54.01%

A study of Tables 6.3 and 6.4 brings out the following conclusions:

(i) On sections with national highways (the first four sections in the above tables), the requirement of steel for passenger traffic on road is in around 859 tonnes, 1000 PKM varies between 10 kg to 105 kg, while the corresponding figures on rail range from 115 kg to 611 kg. For freight traffic, the steel used for road haulage varies from 81 to 1124 kg per 1000 NTKM as compared to a range of 179 kg to 1982 kg by rail. The difference in the relative positions between the two modes is the result of variations arising out of various factors, such as train composition, etc.

On an average, passenger coaches require 7 times more steel, while freight wagons require almost 2 times more as compared to road vehicles.

Table 6.5: Steel-haulage indices (intensities of steel use) in rolling stock of the selected equivalent volumes of passenger and freight traffic on road and rail

(grams per PKM/NTKM)

Sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.010	0.081	0.115	0.179
Jalandhar-Jammu	0.033	0.277	0.348	0.444
Jabalpur-Allahabad	0.022	0.188	0.274	0.264
Lucknow-Gorakhpur	0.030	0.251	0.248	0.544
Secunderabad-Wadi	0.039	0.422	0.199	0.846
Gudur-Renigunta*	0.105	1.124	0.216	1.982
Bhopal-Ujjain*	0.041	0.445	0.611	0.599
Ratlam-Godhra*	0.028	0.297	0.376	0.556

Infrastructure

Besides rolling stock, steel is also used in the infrastructure required for rail and road i.e. rails, bridges, etc. We have, therefore, considered the use of steel not only for rolling stock but also for various items of infrastructure and worked out the resultant steel-haulage index. Table 6.6 gives the steel-haulage index for infrastructure only, while Table 6.7 gives the index for total steel representing the combined figures of infrastructure and rolling stock.

Table 6.6: Steel-haulage indices (intensities of steel use) for infrastructure only

(grams per PKM/NTKM)

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.005	0.008	0.398	0.174
Jalandhar-Jammu	0.021	0.037	0.565	0.339
Jabalpur-Allahabad	0.037	0.063	1.186	0.482
Lucknow-Gorakhpur	0.007	0.012	0.396	0.256
Secunderabad-Wadi	0.050	0.098	2.168	0.344
Gudur-Renigunta*	0.042	0.945	1.418	0.603
Bhopal-Ujjain*	0.013	0.020	1.343	0.391
Ratlam-Godhra*	0.070	0.141	0.782	0.174

Capacity Expansion

Besides rolling stock, infrastructure for rail and road also requires materials – both for fresh construction as well as capacity expansion. We would, therefore, discuss the requirements of materials for capacity enhancement, as it would be relevant to any decisions involving rail or road options.

In the sections being studied, Jalandhar-Jammu rail section is scheduled for doubling. The Jalandhar-Pathankot road, which is a sub-section of Jalandhar-Jammu section, is scheduled for capacity enhancement through widening from two-lane to four-lane by 2010. We have, therefore, worked out estimates of materials and cost per km for such capacity expansion on the Jalandar-Pathankot sub-section and the same are given in Tables 6.8 and 6.9.

For comparative analysis, material resources for capacity expansion are considered.

Table 6.8: Estimates of Materials and Costs per km for the Four-laning of Jalandhar-Pathankot Road Section

Material	Quantity per km	Unit	Cost per km (Rs thousand)*
Earthwork	18066.75	cu.m.	2548.43
Land	15000.00	sq.m.	724.52
Gravel	2523.92	cu.m.	936.13
Stone aggregate (ordinary and graded)	6720.31	cu.m.	2505.55
Cement	455.26	tonne	1180.94
Steel	19.77	tonne	610.65
Sand	4469.01	cu.m.	1531.00
Bricks	17886	no.	23.66
Bitumen	495.98	tonne	4090.24
All (inclusive of labour and other costs)			22208.44 (22.20 million)

Table 6.9: Estimates of Materials and Costs per km for Doubling of Jalandhar-Pathankot Rail Section

Material	Quantity per km	Unit	Cost per km (Rs thousand)*
Earthwork	1830.00	cu.m	138.34
Land	6100.00	sq.m	294.64
Ballast	880.00	cu.m	540.53
Stone aggregate (bridges)	79.48	cu.m	34.92
Concrete	533.34	tonne	3702.87
Steel	155.57	tonne	3702.87
Sand	262.42	cu.m	106.63
Bricks	20921	no.	28.53
All (inclusive of labour and other costs)			12457.00 (12.45 million)

* at 1997-98 prices

Note: (1) Except for earthwork in major bridges, the quantities of materials required in the construction of bridges and culverts on this section are included in the above items.

(2) The cost per km is an average across different varieties of the same item

(3) Welding joints, glued joints and switch expansion joints on rail track are taken to be made entirely of steel.

(4) Estimates of rates and quantities of items used in major bridges are made on the basis of information in the project report of the doubling of the Jalandhar-Jammu rail section. These estimates are taken to be applicable to road bridges on the section.

The salient features that emerge from the above tables are:

(i) The land requirement (per km) for doubling a rail section is about 40% less than for road and the earthwork required is only 10% of that needed for four-laning a road.

available. Among the different materials making up the capital stock, it is only for steel that we have satisfactory data for estimating the pollution intensity per unit of the service rendered by the capital stock. We would, therefore, indicate here the extent of comparative pollution responsibility for rail and road only in respect of steel. It would be based on the assumption that the present steel plant technology and pollution abatement technologies would not undergo any major changes.

The environmental impact of the use of steel has been examined from the point of view of energy consumption and emissions due to such consumption which occur at steel plants. For the purpose of our analysis, we consider the coefficients of energy use and emissions/ discharges in a typical steel plant which have been related to the steel input going into the manufacture of rolling stock and creation of infrastructure for rail and road. Energy used in the production of steel is assumed to come from the burning of coal.

Environmental impact of the usage of steel are analysed.

Table 6.10 gives the energy consumption at steel plants attributable to the production of steel needed for the manufacture of rolling stock and creation of infrastructure after amortisation over their life span expressed as kilojoules per PKM/NTKM traffic carried by road and rail.

Table 6.10: Intensity of energy consumption at steel plants (in kilojoules per PKM/NTKM)

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.49	3.06	17.65	12.21
Jalandhar-Jammu	1.86	10.87	32.38	27.09
Jabalpur-Allahabad	2.04	8.70	51.22	25.80
Lucknow-Gorakhpur	1.25	9.11	22.79	27.68
Secunderabad-Wadi	3.07	17.98	81.63	41.15
Gudur-Renigunta*	5.06	42.15	57.36	89.42
Bhopal-Ujjain*	1.89	16.08	66.94	34.24
Ratlam-Godhra*	3.36	15.14	40.36	25.26

Higher usage of steel in rail requires higher levels of energy inputs at steel plants.

Following salient points emerge from the above table:

(i) The energy consumption for road transport ranging from 0.49 to 3.07 kilojoules (Kj) for passengers and from

Table 6.13: Intensity of NOX emission at steel plants imputable to steel use in transport infrastructure (in milligrams per PKM or NTKM)

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.42	2.62	15.13	10.46
Jalandhar-Jammu	1.59	9.32	27.75	23.21
Jabalpur-Allahabad	1.75	7.45	43.90	22.11
Lucknow-Gorakhpur	1.07	7.81	19.53	23.72
Secunderabad-Wadi	2.63	15.41	69.96	35.26
Gudur-Renigunta*	4.33	36.12	49.16	76.63
Bhopal-Ujjain*	1.62	13.78	57.37	29.34
Ratlam-Godhra*	2.88	12.97	34.59	21.65

Table 6.14: Intensity of TSP emission at steel plants imputable to steel use in transport infrastructure (in milligrams per PKM or NTKM)

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.04	0.23	1.36	0.94
Jalandhar-Jammu	0.14	0.84	2.49	2.08
Jabalpur-Allahabad	0.16	0.67	3.93	1.98
Lucknow-Gorakhpur	0.10	0.70	1.75	2.13
Secunderabad-Wadi	0.24	1.38	6.27	3.16
Gudur-Renigunta*	0.39	5.49	4.40	6.87
Bhopal-Ujjain*	0.14	1.23	5.14	2.63
Ratlam-Godhra*	0.26	1.16	3.10	1.94

Table 6.15: Intensity of SOX emission at steel plants imputable to steel use in transport infrastructure (in milligrams per PKM or NTKM)

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.30	1.89	10.93	7.56
Jalandhar-Jammu	1.15	6.73	20.05	16.77
Jabalpur-Allahabad	1.26	5.39	31.71	15.97
Lucknow-Gorakhpur	0.77	5.64	14.11	17.13
Secunderabad-Wadi	1.90	11.13	50.54	25.47
Gudur-Renigunta*	3.13	26.09	35.51	55.36
Bhopal-Ujjain*	1.17	9.96	41.44	21.20
Ratlam-Godhra*	2.08	9.37	24.99	15.64

An examination of the above tables brings out the following significant points:

(i) The intensity of CO_2 emission at steel plants ranges from about 85 to 874 milligrams (mg) per PKM for passenger traffic by road and about 3050 to 14098 mg/PKM for such traffic by rail. For freight traffic, the

Table 6.16: Total cost of health damage (paise per PKM/NTKM) at steel plants in urban areas

Transport sections	Road		Rail	
	Passenger	Freight	Passenger	Freight
New Delhi-Mughal Sarai*	0.00	0.01	0.07	0.05
Jalandhar-Jammu	0.01	0.04	0.13	0.11
Jabalpur-Allahabad	0.01	0.03	0.20	0.10
Lucknow-Gorakhpur	0.00	0.04	0.09	0.11
Secunderabad-Wadi	0.01	0.07	0.32	0.16
Gudur-Renigunta*	0.02	0.18	0.22	0.35
Bhopal-Ujjain*	0.01	0.06	0.26	0.13
Ratlam-Godhra*	0.01	0.06	0.16	0.10

A study of the above table brings out the following facts:

(i) Health damage costs in case of rail, both for passenger and freight traffic, are higher as compared to road transport.

(ii) For passenger traffic, the cost per PKM ranges from 0.01 to 0.02 paise in the case of road transport as compared to 0.07 to 0.32 paise for rail.

(iii) For freight traffic, the cost per NTKM on road varies from 0.01 to 0.18 paise, while the corresponding figures for rail range from 0.05 to 0.35 paise.

Health costs due to pollution from steel usage are much less as compared to such costs attributable to energy requirements for motive power.

We have analysed in the previous chapter the health damage costs arising from the use of energy in motive power for purposes of haulage of passengers and goods. If we compare these costs with the costs of pollution due to usage of steel for rail and road modes, the latter costs are insignificant. These costs further decline with greater utilisation of ground infrastructure. The energy source for providing motive power, therefore, remains the predominant factor in determining the results of a comparative assessment of the environmental damage between rail and road modes.

7 External Costs

This chapter deals with costs of externalities relating to air pollution and accidents arising from the operations of rail and road. Air pollution has a direct link with public health and is a major cause for respiratory and various other diseases. These diseases result in premature deaths, hospitalisation, prolonged treatment and consequent loss of wages. Table 2.2, given in Chapter 2, summarises the health effects of major pollutants from motorised engines.

External costs considered in the study relate to health damage and accident costs.

As is widely known, urban population is the worst sufferer because of its maximum exposure to the polluting environment with the exposure levels varying according to the concentration of pollutants. It is for this reason that the analysis in the present study is confined to the urban stretches of the selected sections.

Safety has always been an important consideration in transport operations, but until recently it has not been a significant issue in the economics of transport. The major economic concerns have been pricing, subsidies and the regulatory regimes. However, it is now widely recognised that safety should also be regarded as an economic attribute of transport.

Accidents lead to fatalities, injuries to people and damage to property. All of these cause economic loss to the society due to output lost by the deceased or injured victims; expenses incurred on medical treatment; administrative costs of police, insurance companies, accident claims tribunals; and damage to vehicles. Accidents also cause intangible damage, such as pain, grief and suffering to the victims and their families.

Here, the two subjects of health and accidents have been dealt with separately. While Section I deals with health damage costs from air pollution, Section II deals with cost of accidents arising from transport operations.

Section I: Health Costs

In Chapter 4, we have worked out the emission rates of various kinds of polluting emissions from road and rail modes of transport, including emissions from power plants supplying energy for electric traction. These pollutants include lead (Pb), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOX), sulphur dioxide (SO_2), sulphur oxides (SOX), total suspended particulate matter (TSP), non-methane volatile organic compounds (NMVOCs), volatile organic compounds/hydrocarbons (VOCs/HC), methane (CH_4) and nitrous oxide (N_2O). Of these, CO_2, CO, NOX, NMVOCs, CH_4 and N_2O are greenhouse gases that contribute to global warming and climatic change over a long period.

The focus is on direct effects of noxious air pollutants on human health.

The present study focuses on direct effects of air pollutants on human health. As such, greenhouse gas emissions have not been considered. Only such pollutants that are particularly noxious to human beings, namely, CO, NOX, SO_2/SOX, TSP and NMVOCs have been taken into consideration. The rates of emissions of sulphur dioxide (SO_2) and sulphur oxide (SOX) have been treated as identical in their effect on human health. Similarly, the rates of emissions of NMVOCs have been treated as the same with those of volatile organic compounds (VOCs) since they include only a minuscule component of methane.

The analysis of health damage costs is confined to the use of diesel fuel on rail and road and of electricity on rail. Hence, lead emissions from the use of petrol have not been considered in the present health analysis. However, while studying the comparative advantages of petrol-driven car vis-à-vis diesel bus in Chapter 4, the emissions of lead have been taken into account.

There are several methods of determining the health impacts of air pollutants. These methods draw heavily from epidemiological studies conducted around the world, mostly in developed countries. In India, a study was attempted in 1995 to estimate the health damage costs of major air pollutants arising from a number of sources in 36 cities. It was based on exposure-impact (dose-response) functions relating changes in the concentration of noxious pollutants to changes in premature deaths (mortality) and sickness (morbidity). The value of premature deaths was based on the value of statistical life, as determined by using a human capital approach which values an individual's life according to the net present value of his/her productivity. In valuing the costs of morbidity, three types of costs were considered: (i) medical expenses; (ii) lost wages; and (iii) individual disutility (discomfort, suffering, and the opportunity cost of time). Only the first and second categories were estimated since they were more easily monetised than the third.

Epidemiological studies conducted mostly in developed countries.

In this study, the dose-response functions are described in terms of relationship between change in the concentration level of a pollutant and change in the mortality or morbidity of the exposed population. For example, in the case of particulate matter (PM) of diameter 10 microns or less, the dose-response functions are as follows:

- Premature mortality: change in mortality = 0.096 * change in PM_{10} * (1/100) * crude mortality rate * exposed population
- Respiratory hospital admissions: change in respiratory hospital admissions per 100,000 = 1.20 * change in PM_{10}
- Emergency room visits: change in emergency room visits per 100,000 = 23.54 * annual change in PM_{10}
- Restricted activity days: change in restricted activity day per person per year = 0.0575 * change in PM_{10}
- Lower respiratory illness in children: change in bronchitis = 0.00169 * change in PM_{10}
- Asthma attacks: change in asthma attacks = 0.0326 * change in PM_{10}
- Respiratory symptoms: change in symptom days per year per person = 0.183 * change in annual PM_{10}
- Chronic bronchitis: change in chronic bronchitis = 6.12×10^{-5} change in annual PM_{10}

Dose-response functions relate changes in concentration level of pollutant to mortality or morbidity.

The above methodology requires detailed monitoring of the concentration levels of air pollutants over a long period. It also requires detailed site-specific information on several factors, including weather conditions, industrial activity, population density, etc. Its use is, therefore, limited to estimations concerning total pollution levels arising from multiple sources like refuse burning, fuel burned by households, vehicle exhausts, fuel burned by industry and power plants, etc.

Emission factor model duly adjusted for Indian conditions used in the present study.

In the present study, the objective is to estimate health impact cost of pollutants from motorised vehicles and thermal power plants relevant for traction in the transport sector. The emissions from both these sources have been taken to be identical in their effect on human health. Further, the study deals with rates of emission and not changes in the concentration levels of emissions. As such, the above-mentioned methodology has not been found helpful for our analysis. We have, therefore, chosen to follow another methodology specifically developed for motor vehicle-related air pollution where rates of emissions have been correlated with health damage cost. This work was carried out in the United States in 1999 by the well-known researchers, Donald R. McCubbin and Mark A. Delucchi* .

The model developed by these researchers constitutes the following four steps:

(i) estimating emissions related to motor-vehicle use;

(ii) estimating changes in exposure to air pollution;

(iii) relating changes in air pollution exposure to changes in physical health effects;

(iv) relating changes in physical health effects to changes in economic welfare.

In the first step, the emissions are estimated by using an emission factor model (MOBILE 5) developed by the Environmental Protection Agency of the United States. Under this model, the individual pollutants are estimated in mass (gm/kg) per distance

* Donald McCubbin is with Abt Associates Inc., Bethesda, MD 20814, USA. Mark Delucchi is at the Institution of Transportation Studies, University of California, Davis, California 95616, USA.

travelled as a function of variables, such as types of vehicles, fuels, trips, etc.

In the second step, changes in exposure to air pollution are estimated by taking the initial air pollution level to be the actual level as reported by air quality monitors. The air quality, after change in motor vehicle emissions, is estimated on the basis of the motor vehicle contribution to ambient pollution relative to the contribution of other sources. With this method, there is no need to estimate the absolute pollution level (in, say, parts per million), and hence there is less need for sophisticated air quality models. Instead, a simple dispersion model, with highly simplified atmospheric chemistry, is used to estimate the relative effect of motor vehicles on air quality.

In the third step, an exposure-impact (or dose-response) function is constructed by relating a change in the impact of interest (in this case, impact on human health) to exposure variables, such as air quality. The function is constructed for each pollutant and each health impact (e.g. asthma, headache, chronic illness, or death) after a review of clinical and epidemiological studies of the health effects of various pollutants. The analysis is confined to the health impacts of carbon monoxide (CO), nitrogen oxides (NOX), ozone, and particulate matter (including sulphate particulate matter from sulphur oxide (SOX) emission).

In the last step, the economic value of the health effects is estimated. The health effects include acute morbidity, chronic morbidity, mortality and cancer. Acute and chronic morbidity broadly cover respiratory diseases. Mortality has been divided into identified types mainly for the purpose of estimating the statistical value of life. For example, the statistical value of life of the elderly is less than the range of values typically applied in the case of middle-aged working males.

The US study has worked out health costs separately for rural and urban areas and metropolitan towns. It has also considered emissions from upstream sources as well as road dust. The emissions considered include ozone, volatile organic compounds and particulate matter of diameter 10 microns or less.

Health damage costs worked out for motor vehicle related emissions.

The health costs relevant to the types of emissions considered in our study are presented in Table 7.1.

Table 7.1: The Health Cost per Kg of Motor-Vehicle-Related Emissions (1990 Emissions, 1991 \$/Kg Emitted)

Emission	Ambient Pollutant	All Urban Areas		Cost (Rs/Kg) at 1997-98 prices
		Low	High	
CO	CO	0.01	0.10	0.09
Total for NOX	Nitrate PM_{10} & NO_2	1.59	23.34	13.80
Total for PM_{10}	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	13.74	187.48	119.29
SOX	Sulphate PM_{10}	9.62	90.94	83.52
VOCs/HC	Organic PM_{10}	0.13	1.45	1.13

CO = Carbon monoxide; NOX = nitrogen oxides; PM_{10} = particulate matter of aerodynamic diameter of 10 microns or less; $PM_{2.5}$ = particulate matter of aerodynamic diameter of 2.5 microns or less; $PM_{2.5\text{-}10}$ = particulate matter of aerodynamic diameter between 2.5 and 10 microns; SOX = sulphur oxides; NO_2 = Nitrogen dioxide; VOCs = volatile organic compounds; HC = hydrocarbons

In this table the estimates of health damage cost per kilogram of each pollutant (in 1991 dollars) have been suitably adjusted to take account of temporal variation as well as differences between the US and India in such factors as purchasing power, population density, state of human health and per capita real incomes. It is sad but true that a large segment of Indian urban population, particularly the slum dwellers, live in conditions which are in no way comparable with the conditions in the cities of United States. Most of them suffer from malnutrition and are in a marginal state of health; hence they have pronounced susceptibility to polluting emissions in terms of higher morbidity and mortality.

The most important result in the above table is the high cost of particulate matter pollution and the potentially large contribution of motor vehicles to ambient particulate levels. Particulates are known to cause a number of respiratory ailments, including chronic illness and mortality. Motor vehicles contribute the smaller, more dangerous particulates directly from tailpipe emissions and indirectly from the large amounts of ‘precursor’ gases that they emit, such as nitrogen dioxide. CO, NOX and SOX appear to have minor effects as compared to particulate matter. Aside from their contribution to particulate formation, emissions, of NOX, SOX and VOCs are relatively unimportant.

The estimates of health damage costs have been given for lower and upper bounds. For several of the emission estimates, the difference between the lower and upper bounds is roughly a factor of two. The wide range of costs reflects the complexity of the task of assigning a precise value of the damage impact of air pollution. For our analysis, we have taken the lower estimates of costs since we feel that these estimates would approximate better to the Indian conditions.

Lower estimates of costs are used since they approximate better to the Indian conditions.

It would be seen that the detailed calculations of health damage costs relate to urban sections and are based on rates of emissions in urban areas. In case of non-urban sections, the incidence of health damage will be much lower because of the lower density of population, better health condition and higher resistance to disease as compared to urban dwellers. In the absence of any specific data, we have assumed that half of the urban health damage costs are applicable to non-urban sections as well.

The health damage costs of emissions in urban and non-urban areas for the selected sections are shown, separately for passenger and freight traffic, in Tables 7.2.1 and 7.2.2.

Table 7.2.1: Health damage costs of emissions from passenger traffic (paise per PKM)**

Section	Urban			Non-urban		All	
	Rail	Road (bus only)	Road (car only)	Rail	Road (bus only)	Rail	Road (bus only)
New Delhi-Mughal Sarai*	18.07	11.61	10.11	9.04	5.81	8.81	6.41
Jalandhar-Jammu	2.64	11.87	12.15	1.32	5.94	1.50	6.85
Jabalpur-Allahabad	2.85	12.50	11.78	1.42	6.25	1.54	7.22
Lucknow-Gorakhpur	2.34	11.54	11.09	1.17	5.77	1.30	6.10
Secunderabad-Wadi	2.55	12.43	10.30	1.28	6.22	1.44	6.99
Gudur-Renigunta*	19.01	12.53	11.69	9.50	6.27	8.26	7.52
Bhopal-Ujjain*	18.66	11.67	8.23	9.33	5.83	10.17	6.60
Ratlam-Godhra*	17.94	11.69	10.24	8.97	5.85	9.78	6.36

***at 1997-98 prices*

Table 7.2.2: Health damage costs of emissions from freight traffic (in paise per NTKM)**

Section	Urban		Non-urban		All	
	Rail	Road	Rail	Road	Rail	Road
New Delhi-Mughal Sarai*	11.62	61.47	5.81	30.74	5.67	33.90
Jalandhar-Jammu	3.09	63.69	1.54	31.84	1.76	36.75
Jabalpur-Allahabad	2.68	67.93	1.34	33.96	1.45	39.25
Lucknow-Gorakhpur	2.77	61.59	1.38	30.80	1.53	32.54
Secunderabad-Wadi	5.75	81.63	2.88	40.81	3.25	45.91
Gudur-Renigunta*	22.21	83.98	11.11	41.99	9.65	50.39
Bhopal-Ujjain*	19.20	73.19	9.60	36.59	10.47	41.41
Ratlam-Godhra*	17.07	84.72	8.53	42.36	9.30	46.08

***at 1997-98 prices*

On an average, total health damage cost of rail passenger traffic in urban and non-urban areas is lower than that of road by a factor of 5, while in case of freight traffic, it is lower by a factor of 7.

The following broad conclusions emerge from the above data:

(i) The health damage cost of rail is generally lower than that of road. The advantage is more in case of freight traffic as compared to passenger traffic. The rail, however, loses the advantage when electric traction is used for passenger traffic.

(ii) In urban areas, the health damage cost of rail, in case of freight traffic is lower by as much as 76 paise per NTKM (average 62 paise), while in case of passenger traffic (diesel bus), the same is lower by 10 paise per PKM (average 9 paise).

(iii) In non-urban areas the health damage costs decline by half as compared to urban areas.

The results of our case studies point to the problem of substitution between petrol-driven personal car transport and diesel-driven public bus transport. The above data shows that, in most cases, car scores over diesel bus in terms of lower health cost in urban areas, although its advantage is not significant on account of inefficient energy consumption in urban areas. While substitution of passenger cars by diesel buses would substantially reduce congestion, conserve energy and abate greenhouse gas emission, they will inflict higher health cost on the passengers because of the emission of noxious pollutants, such as NOX, SO_2 and PM_{10}. Higher health cost of public bus transport is a pointer for the need to upgrade bus technology with cleaner fuels.

Higher health cost of public bus transport is a pointer for the need to upgrade bus technology with cleaner fuels.

Table 7.3 shows the daily increase or decrease in the total overall health costs due to the substitution of road by rail in the selected sections as a whole. In working out these estimates, we have assumed that 25% of the thermal plants supplying energy for electric rail traction are located in urban areas.

Table 7.3: Daily overall changes in health damage cost due to substitution of road by rail

*(Rs thousand)***

Section	Passenger	Freight
New Delhi-Mughal Sarai*	200.34	-2462.05
Jalandhar-Jammu	-128.62	-876.11
Jabalpur-Allahabad	-200.65	-1391.64
Lucknow-Gorakhpur	-127.89	-858.09
Secunderabad-Wadi	-55.53	-448.04
Gudur-Renigunta*	2.40	-157.43
Bhopal-Ujjain*	32.64	-315.48
Ratlam-Godhra*	50.19	-548.58
Total decrease in electrified sections	0.00	3483.54
Total decrease in dieselised sections	512.69	3573.88

*** at 1997-98 prices*

The above data leads to the following conclusions:

(i) Substitution of passenger traffic on road by rail with diesel traction results in decrease (savings) in health damage costs amounting to Rs 0.51 million per day. In case the freight traffic is substituted, the decrease in health damage costs amounts to Rs 3.57 million.

(ii) Substitution of passenger traffic on road by rail with electric traction does not result in any change. In case the freight traffic is substituted, the decrease in health damage costs amounts to Rs 3.48 million.

The comparative daily health damage costs for equivalent volumes of traffic on both modes (with diesel bus taken as the passenger option on road) are shown diagrammatically in Figures 7.1 and 7.4 at the end of this chapter.

Since gas is a cleaner fuel than coal, one has to find out whether substitution of gas for coal leads to a significant reduction in the health damage costs of rail. Accordingly, for a typical electric section, such as the New Delhi-Mughal Sarai, in Tables 7.4.1 and 7.4.2 we have worked out the changes in emissions resulting from the use of gas instead of coal at the power generating stations. The analysis is based on the rates of emission for the section as a whole. Rail emissions come down significantly when gas is substituted for coal. The reduction is particularly substantial in respect of the two most noxious pollutants, namely, SOX and TSP/PM_{10}. The total reduction in health damage cost of rail due to this substitution is of the order of 99% for passenger and freight traffic. Thus, substitution of gas for coal makes rail less damaging to human health than road traffic in all cases.

Table 7.4.1: Emissions relating to selected volumes of passenger and freight traffic with coal based thermal power plants (daily)

Section: New Delhi-Mughal Sarai		
Pollutant	Passenger traffic (g/PKM)	Freight traffic (g/NTKM)
CO_2	24.26	15.60
CO	0.00	0.00
NOX	0.12	0.08
NMVOCs	n.a	n.a
SOX	0.09	0.06
TSP	2.44	1.57

Table 7.4.2: Emissions and health damage cost relating to selected volumes of passenger and freight traffic with gas based thermal power plants (daily)

Section: New Delhi-Mughal Sarai				
Pollutant	Emissions		Health damage cost	
	Passenger traffic (g/PKM)	Freight traffic (g/NTKM)	Passenger traffic (paise/PKM)	Freight traffic (paise/NTKM)
CO_2	11.04	7.10	--	--
CO	0.00	0.00	0.000	0.000
NOX	0.03	0.02	0.043	0.028
NMVOCs	n.a	n.a	--	--
SOX	0.00	0.00	0.000	0.000
TSP/PM_{10}	0.00	0.00	0.005	0.003
Total health damage cost of rail	--	--	0.048	0.031

Section II: Accident Costs

When a driver takes a vehicle on the road, he imposes two distinct risk externalities on the rest of the society. In the first place, there is the risk that he himself may be killed or severely disabled, in which case his family and friends will experience the psychological costs of grief and suffering. Besides, society at large will bear the cost of vehicle damage and police and medical costs, and will also lose the driver's contribution to current and future output.

Accidents impose heavy social costs.

The other kind of externality is the risk that the driver may kill or injure someone else, such as a pedestrian, cyclist, or motorcyclist, or cause damage to someone else's vehicle or property. This external cost is also imposed by the operators of public transport upon non-users of the particular transport mode. In the case of rail transport, however, while risk for groups of railway users may be limited, risk for road users may be significant, as there can be serious consequences for people outside the train, e.g. car users at level crossings.

The incidence of accidents has assumed serious dimensions, particularly in developing countries. Fatality rates in these countries are much higher in comparison to those in the developed world. It is estimated that about half a million fatalities occur due to road accidents each year all over the world, of which 70% happen in developing countries.

In India, 76,732 persons were killed and 324,377 injured in road accidents alone in 1998. This is, however, an underestimate, as all cases of injuries are not reported to the police. As a matter of fact, the actual number is estimated to be in the region of 11,50,000 persons requiring hospital treatment, besides a large incidence of minor injuries. In addition to road, the railways accounted for 489 fatalities and 851 injured including 316 seriously injured during the year 1998-99.

In India, 76,732 persons were killed and 324,377 injured in road accidents in 1998.

Tables 7.5 and 7.6 show the comparative position of road and rail in respect of casualties for the period 1981-82 to 1998-99.

Table 7.5: Road transport output and casualties

Year	BPKM	BTKM	Combined transport output	Population	Casualties (in thousands)			Casualties per billion units of combined transport output	Casualties per million population
					Killed	Injured	Total		
1981-82	595	113	708	683329027	28.4	114.0	142.4	201.13	208.39
1985-86	850	193	1043	772196737	39.2	163.4	202.6	194.25	262.37
1991-92	956	567	1523	843930861	56.3	255.0	311.3	204.40	368.87
1992-93	1003	610	1613	861693859	57.2	267.1	324.3	201.05	376.35
1993-94	1086	646	1732	879279448	60.7	287.9	348.6	201.27	396.46
1994-95	1192	672	1864	897223927	64.0	310.8	374.8	201.07	417.73
1995-96	1322	762	2084	915534620	70.7	322.9	393.6	188.87	429.91
1996-97	1427	807	2234	934219000	74.7	364.2	438.9	196.46	469.80
1997-98	1498	863	2361	949200000	75.0	290.8	365.8	154.93	385.38
1998-99	1573	923	2496	965600000	76.7	324.4	401.1	160.69	415.37

Table 7.6: Rail transport output and casualties

Year	BPKM	BTKM	Combined transport output (in billions)	Casualties			Casualties per billion units of combined transport output	Casualties per million population
				Killed	Injured	Total		
1981-82	221	174	395	666	1154	1820	4.61	2.66
1985-86	241	206	447	203	653	856	1.91	1.11
1991-92	315	257	572	229	884	1113	1.95	1.32
1992-93	300	258	558	282	823	1105	1.98	1.28
1993-94	296	257	553	379	905	1284	2.32	1.46
1994-95	319	253	572	305	687	992	1.73	1.11
1995-96	342	274	616	594	935	1529	2.48	1.67
1996-97	357	280	637	363	615	978	1.54	1.05
1997-98	380	284	664	332	991	1323	1.99	1.39
1998-99	404	282	686	489	851	1340	1.95	1.39

BPKM - billion passenger kilometers
BTKM - billion tonne kilometers
Combined transport output = BPKM + BTKM

The analysis of the above data brings out the following:

(i) The incidence of casualties in case of road transport is substantially higher as compared to railways.

(ii) In case of road transport, the total number of casualties per billion units of transport output range between 154 and 204, while in case of rail, they range between 1.54 and 4.61.

(iii) Casualties per million population range between 1.05 and 2.66 in the case of rail, while for road they lie between 208.39 and 469.80.

Accidents can be classified into two categories – those involving injury to people called 'personal injury' accidents, and those causing damage to vehicles termed as 'damages only' accidents. The personal injury accidents are further classified into fatal, serious, major and minor.

The following six different methods have been identified for evaluating the cost of road accidents:

There are several methods for evaluating the cost of road accidents.

(i) *'Gross output' (or human capital) approach* – It takes into consideration the cost of a road accident as the sum of real resources costs, such as vehicle damage, medical expenditure, police costs and the discounted value of the victim's future output. The cost of pain, grief and suffering is also added.

(ii) *'Net output' approach* – It differs from the gross output approach in that the discounted value of victim's future consumption is deducted from the gross output value.

(iii) *'Life insurance' approach* – In this approach, the cost of an accident is taken as the sum of the real resources cost and the amount for which an individual is willing to ensure his life or limbs.

(iv) *'Court award' approach* – In this approach, the amount of court awards is added to the real resources cost to obtain the total cost of an accident. The compensation awarded by the court to the insured or dependents of those killed is regarded as the cost the society associates with the road accident, or the value that it would have placed on its prevention.

(v) *'Implicit public sector valuation' approach* – It is based on the costs and values that are implicitly placed on accident prevention in safety legislation or in public sector decisions taken either in favour or against investment programme involving traffic safety.

(vi) *'Willingness to pay', approach* – It assumes that the value of prevention of one accident involving one fatality is the amount that all the affected individuals in the society are willing to pay for small marginal risk reductions brought about by investment in traffic safety, both for themselves and for whom they care.

The main objective of costing road accidents are: maximisation of national output and pursuit of social welfare.

The six approaches described above produce substantially different costs and values for accidents involving fatalities. The selection of the method to be used for costing road accidents depends on the objectives being pursued in a country. The main objectives of costing road accidents are maximisation of national output and pursuit of social welfare (such as minimisation of injuries, fatalities and accidents in relation to traffic). The only accident costing/valuation methods that appear directly relevant to these two objectives are:

– 'Gross output' method, which is well suited to the objective of maximising the wealth of the country; and

– 'Willingness to pay' method (especially for social welfare maximisation and for use in cost-benefit analysis).

The gross output approach measures the cost of death or injury on the basis of current and future levels of output.

The gross output approach is an attempt to measure the impact of death or injury on current and future levels of national output, broadly construed to include various non-marketed services. A major objection to this approach is that an individual values safety principally because of his or her aversion to the prospect of death and injury *per se* rather than because of a concern to preserve current and future levels of output and income. If this is the case, then values of safety ought ideally to be defined so as to reflect the individual's preference for safety as such, rather than in terms of effects on output and income.

In order to define and estimate values of safety in this way, what is required is some means of measuring people's preferences for safety and, more particularly, the strength of their preference. A natural measure of the extent of a person's preference for anything is the maximum amount that he or she would be willing to pay for it. This amount reflects not only the person's valuation of the derived good or service relative to other potential objects of expenditure, but also his ability to pay, which in itself is a manifestation of the society's overall resource constraint.

Thus, under the willingness-to-pay approach for the valuation of safety, the amounts that those affected would individually be willing to pay for (typically small) improvements in their own and others' safety are determined in the first instance. These amounts are then aggregated across all individuals – possibly with distributional weights – to arrive at an overall value for the concerned safety improvement. Defining values of safety in this way effectively mimics the operation of market forces in circumstances in which markets do not exist.

The willingness-to-pay approach relies on the amounts that affected individuals would be willing to pay for their own and others' safety.

The willingness to pay may have large variation from person to person and, as a consequence, it would be difficult to arrive at its value for an accident. It seems unlikely that reliable willingness to pay based costs and values will be available for use in developing countries for quite some time. As such, it is our considered opinion that the gross output approach is better suited for accident costing in developing countries.

In the past, organisations like the Central Road Research Institute (CRRI) carried out studies to quantify the cost components of road user costs in India and relate them to roadway and traffic characteristics. The most recent of these studies titled 'Evaluation of Road Accident Costs – Research Scheme R-79' was conducted in 1998-99 by the Ministry of Surface Transport (MOST). Its objective was to update the data on accident costs representing the entire country.

For the purpose of evaluating the cost of damages to vehicles, the study has classified motor vehicles into 5 broad categories – truck, bus, car, three-wheeler and two-wheeler. Cost of vehicle damage is assessed on the basis of the following parameters: repair cost of vehicle, sales tax and excise duty, detention period, surveyor's fees and legal fees, wages of the crew, administrative cost of insurance companies, and other losses.

Gross output approach for accident costing moderated to capture some of the humane considerations has been adopted in the present study.

The study has generally used the gross output approach for accident costing. However, to capture some of the humane considerations reflected in the willingness to pay approach, the values derived from the gross output approach have been augmented by a further allowance of pain, grief and suffering of those involved in road accidents.

An exception to the gross output approach has been made in the case of minor injuries on the ground that the compensation awarded to the victim includes the cost incurred by him or her on medical and other expenses. The various cost components included in each accident category are summarised below:

Cost of a Fatal Accident = Gross loss of future output + notional value of pain, grief and suffering (% of gross output loss) + hospital expenditure + loss of earnings during hospitalisation + lawyers' fees + surveyors' fees + administrative expenses by police, insurance companies and courts + relatives' costs.

Cost components of various kinds of injuries include such factors as loss of future output, hospital expenditure, lawyers' fees, etc.

Cost of a Serious Injury = Gross loss of future output + notional value of pain, grief and suffering (% of gross output loss) + hospital expenditure + loss of earnings during hospitalisation and convalescence + lawyers' fees + surveyors' fees + administrative expenses by police, insurance companies and courts + relatives' costs.

Cost of a Major Injury = Gross loss of future output + notional value of pain, grief and suffering (% of gross output loss) + hospital expenditure + loss of earnings during hospitalisation and convalescence + lawyers' fees + surveyors' fees + administrative expenses by police, insurance companies and courts + relatives' costs.

Cost of a Minor Injury = Compensation awarded + notional value of pain and grief (% of gross output loss) + administrative expenses of insurance company + lawyers' fees + surveyors' fees.

Cost of Damages to Vehicles = Repair charges of the damaged vehicle + wages of the crew + surveyors' fees + administrative expenses of insurance companies.

In order to have a truly representative sample at the national level, the study collected data from different parts of India. The country was divided into 4 regions – north, south, east and west – and from each region, four cities were selected on the basis of the availability of sufficient records and the spatial distribution of cities in the region.

Based on the above methodology, the study has arrived at the following costs of injuries due to road accidents for each region and the country as a whole (Table 7.7).

Table 7.7: Region-wise costs of injuries due to road accidents

(in Rs.)

Region	Fatal injury	Serious injury	Major injury	Minor injury
North	613,194	385,528	151,168	20,077
South	527,336	230,293	108,125	21,698
West	485,201	218,011	89,932	14,678
East	567,071	269,551	118,641	23,614
National average	535,489	242,736	106,959	18,855

Region-wise costs of injuries due to road accidents.

We find that the above estimates are relevant for our study and, as such, they have been used while calculating the accident costs on the rail and road modes. Since, these estimates relate to the year 1998-99, they have been adjusted to 1997-98 prices by using the GDP deflator.

The accident costs have been estimated for the selected sections separately for passenger and freight traffic on rail and road modes. The methodology followed for this purpose has been to calculate, in the first instance, the cost of accidents including casualties and the cost of damage to vehicles by using the values indicated in the MOST study. Subsequently, the costs per PKM/NTKM have been worked out by dividing the accident costs by the intercity transport output for passenger and freight traffic.

Accident costs are estimated separately for intercity passenger and freight traffic.

In the case of road transport, in order to remove any bias resulting from the inclusion of accidents and casualties in big cities, their incidence in the four metros has been subtracted from the total numbers for the year 1998-99. Further, the numbers of accidents, fatalities and injuries have been bifurcated according to the type of vehicle in line with the proportions observed on highways in the country (D. Mohan, *Traffic Safety and Health in Indian Cities*, The Asian Journal, February 2002).

The bus passenger kilometers have been derived by using the equations for growth of traffic as given in IRC – *Time Series Data on Road Transport Passenger and Freight Movement (1951-1991)*, Special Publication 45, 1996.

In the case of rail, the cost of accidents, including casualties, has been worked out for the year 1998-99 by first dividing the number of accidents and casualties between passenger and freight traffic according to the observed proportion of passenger or goods train kilometers and then working out the costs by using the values given in the report of the Ministry of Surface Transport. The costs of damage to rail rolling stock and permanent way, as obtained from the Railways' statistical publication, are also included. These aggregated costs are then divided by the appropriate passenger kilometers or net tonne kilometers for the related year to obtain the figures per PKM or NTKM.

The accident costs for the two modes separately for passenger and freight traffic for the year 1998-99 are given in Table 7.8.

Table 7.8: Accident costs per PKM/NTKM for the year 1998-99*

(in paise)

Type of Service	Road	Rail
Passenger	1.14	0.14
Freight	5.87	0.13

** at 1997-98 prices*

The table shows that the accident costs on road are significantly higher than those on rail. In the case of passenger traffic, the costs are higher by a factor of 8, while in the case of freight traffic, it is higher by as much as 45 times.

Road accident cost is higher by a factor of 8 for passenger traffic and a factor of 45 for freight traffic.

The total accident costs on the selected sections have been worked out by multiplying the values given in the above table by the respective traffic volumes on the specific sections for the time horizon 2000-2010. Since the figures relate to the aggregate transport output in the country, there might be an understatement in the case of national highways and a marginal overstatement in the case of state highways. Tables 7.9 and 7.10 show the section-wise position of accident costs for the years 2000, 2005 and 2010.

Table 7.9: Estimates of total daily accident cost for passenger traffic (Rs thousand)**

Section	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010	
New Delhi-Mughal Sarai*	572.58	42.69	804.64	51.94	1106.54	63.19
Jalandhar-Jammu	126.09	6.75	172.77	8.21	231.23	9.99
Jabalpur-Allahabad	85.18	10.61	119.61	12.90	164.34	15.70
Lucknow-Gorakhpur	116.41	11.84	162.85	14.41	222.88	17.53
Secunderabad-Wadi	47.79	3.07	67.30	3.73	92.75	4.54
Gudur-Renigunta*	22.19	1.67	31.08	2.03	42.60	2.48
Bhopal-Ujjain*	51.88	3.30	73.97	4.01	103.25	4.88
Ratlam-Godhra*	45.40	6.14	63.93	7.47	88.11	9.09
Total	1067.52	86.06	1496.15	104.71	2051.72	127.39

*** at 1997-98 prices*

Table 7.10: Estimates of total daily accident cost for freight traffic (Rs thousand)**

Section	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010	
New Delhi-Mughal Sarai*	2257.22	111.29	3197.33	129.02	4465.03	149.57
Jalandhar-Jammu	450.94	4.95	638.76	5.74	892.01	6.65
Jabalpur-Allahabad	455.68	12.56	645.46	14.56	901.38	16.88
Lucknow-Gorakhpur	498.91	7.33	706.71	8.50	986.91	9.85
Secunderabad-Wadi	134.62	9.31	187.49	10.80	261.48	12.51
Gudur-Renigunta*	50.48	3.01	70.31	3.48	98.05	4.04
Bhopal-Ujjain*	188.89	10.59	267.17	12.28	372.61	14.23
Ratlam-Godhra*	141.67	25.74	200.38	29.84	279.46	34.59
Total	4178.42	184.78	5913.60	214.21	8256.92	248.33

*** at 1997-98 prices*

The above data brings out the following:

Total accident costs on the selected sections are estimated for both modes over the time horizon 2000-2010.

(i) In the year 2000, the total accident cost attributable to passenger traffic on road works out to Rs 1,067,520 per day as compared to Rs 86,060 for rail traffic. The difference increases over the selected period.

(ii) For the same year, the total accident cost attributable to freight traffic on road works out to Rs 4,178,420 per day as compared to Rs 184,780 for rail traffic. The difference increases over the selected period.

The detailed calculations of the accident costs for both road and rail for all the eight sections are given in Appendix 4.2. The comparative daily accident costs for equivalent volumes of traffic on both modes are shown diagrammatically in Figures 7.3.1 and 7.3.2 at the end of this chapter.

Substitution of road by rail leads to large overall decreases in total accident costs.

The substitution of road by rail in respect of the selected volumes of traffic leads to decreases in daily overall accident costs in the transport system. These are shown in Table 7.11.

Table 7.11: Overall changes in daily accident cost due to substitution of road by rail (Rs thousand)**

Section	Passenger	Freight
New Delhi-Mughal Sarai*	-82.51	-495.25
Jalandhar-Jammu	-24.02	-143.82
Jabalpur-Allahabad	-35.33	-211.47
Lucknow-Gorakhpur	-26.59	-158.88
Secunderabad-Wadi	-10.00	-60.05
Gudur-Renigunta*	-3.76	-22.45
Bhopal-Ujjain*	-9.52	-57.06
Ratlam-Godhra*	-14.23	-85.45
Total savings	205.96	1234.44

*** at 1997-98 prices*

From the above, it would be observed that:

(i) In case of passenger traffic, substitution of road by rail for the selected volumes of traffic would result in total daily savings in accident costs of Rs 205,960.

(ii) Similar substitution in the case of freight traffic would bring about total daily savings in accident costs amounting to Rs 1,234,440.

The foregoing analysis of health and accident costs shows that rail is a safer transport mode than road, and is generally less damaging to human health. Table 7.12 presents the total external costs of transport per passenger kilometer and per net tonne kilometer.

Table 7.12: External costs of transport

(paise per PKM/NTKM)

Section	Urban				Non-urban				All			
	Passenger		Freight		Passenger		Freight		Passenger		Freight	
	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail
New Delhi-Mughal Sarai*	12.75	18.14	67.34	11.68	6.94	9.25	36.61	6.01	7.54	8.95	39.77	5.80
Jalandhar-Jammu	13.01	2.77	69.56	3.21	7.08	1.46	37.71	1.67	7.99	1.64	42.62	1.89
Jabalpur-Allahabad	13.63	2.99	73.80	2.81	7.39	1.56	39.83	1.47	8.36	1.68	45.13	1.58
Lucknow-Gorakhpur	12.68	2.48	67.46	2.90	6.91	1.31	36.67	1.51	7.11	1.44	37.75	1.66
Secunderabad-Wadi	13.57	2.69	87.50	5.88	7.35	1.41	46.68	3.00	8.13	1.58	51.79	3.37
Gudur-Renigunta*	13.67	19.10	89.85	22.30	7.40	9.73	47.86	11.32	8.66	8.40	56.26	9.78
Bhopal-Ujjain*	12.81	18.72	79.06	19.25	6.97	9.53	42.46	9.78	7.74	10.31	47.28	10.59
Ratlam-Godhra*	12.83	17.97	90.59	17.10	6.98	9.17	48.23	8.72	7.50	9.91	51.95	9.43
Overall - electrified sections	12.82	18.20	72.50	13.53	6.97	9.28	38.98	6.93	7.59	9.17	42.56	6.84
Overall - dieselised sections	13.19	2.75	71.99	3.37	7.18	1.44	39.28	1.68	7.90	1.58	43.15	1.86
Overall - both	13.03	13.28	72.21	10.17	7.06	4.85	39.11	3.90	7.73	5.64	42.84	4.46

*** at 1997-98 prices*

It would be seen that:

(i) In urban areas, the external costs of rail are lower by 11 paise (average 10 paise) per PKM and 82 paise (average 68 paise) per NTKM as compared to road. The external costs are higher by 5 paise per PKM in respect of electric traction.

The external costs of rail are generally lower than those of road.

(ii) In non-urban areas, the external costs are lower by 6 paise per PKM and 44 paise (average 37 paise) per NTKM as compared to road. The external costs are higher by 2 paise per PKM in respect of electric traction.

It would be evident from the forgoing analysis that the health damage costs of rail are substantially lower than those of road *transport. In urban areas, the costs for freight traffic are lower by as much as 76 paise per NTKM, while in case of passenger traffic, the costs are lower by 10 paise per PKM. When the accident costs are computed, the railways score still better. For freight traffic, the accident costs on rail are lower by a factor of 45, while in case of passenger traffic, the costs are lower by a factor of 8.*

It may, thus, be concluded that generally the external costs of rail are significantly lower than those of road. The internalisation of these external costs is the subject matter of the next chapter where we deal with the social costs of transport.

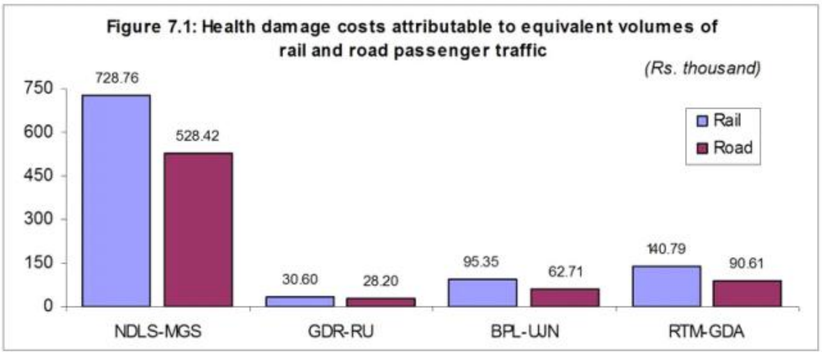


Figure 7.1: Health damage costs attributable to equivalent volumes of rail and road passenger traffic
(Rs. thousand)
750
600
450
300
150
0
728.76
528.42
30.60
28.20
95.35
62.71
140.79
90.61
NDLS-MGS
GDR-RU
BPL-UJN
RTM-GDA
Rail
Road

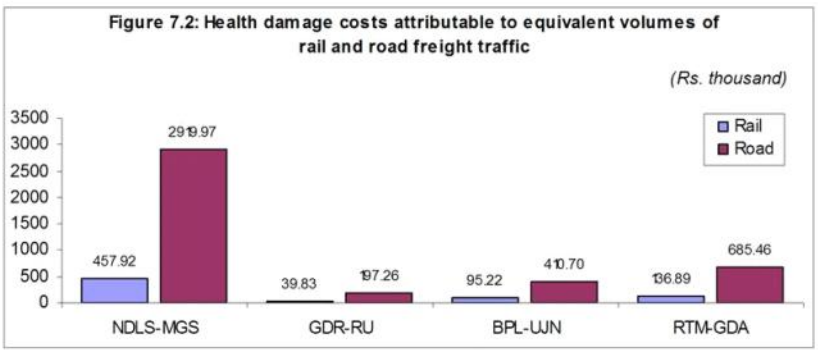


Figure 7.2: Health damage costs attributable to equivalent volumes of rail and road freight traffic
(Rs. thousand)
3500
3000
2500
2000
1500
1000
500
0
457.92
2919.97
39.83
197.26
95.22
410.70
136.89
685.46
NDLS-MGS
GDR-RU
BPL-UJN
RTM-GDA
Rail
Road

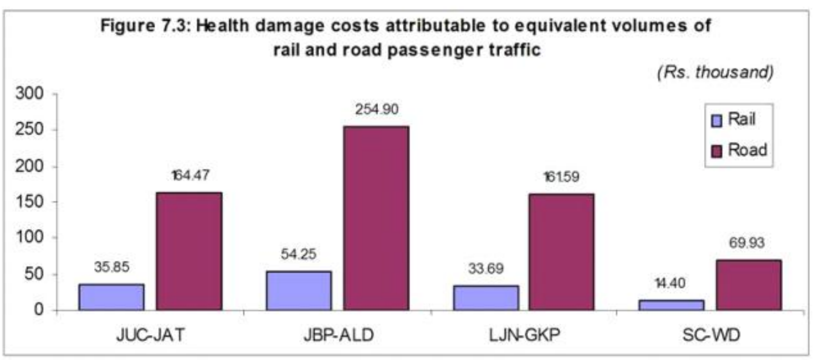


Figure 7.3: Health damage costs attributable to equivalent volumes of rail and road passenger traffic
(Rs. thousand)
300
250
200
150
100
50
0
35.85
164.47
54.25
254.90
33.69
161.59
14.40
69.93
JUC-JAT
JBP-ALD
LJN-GKP
SC-WD
Rail
Road

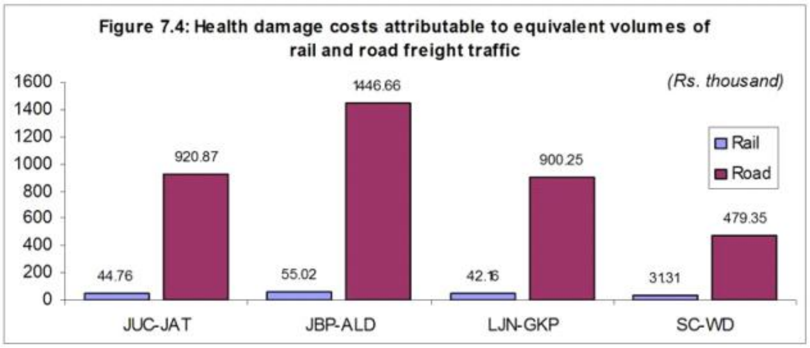


Figure 7.4: Health damage costs attributable to equivalent volumes of rail and road freight traffic

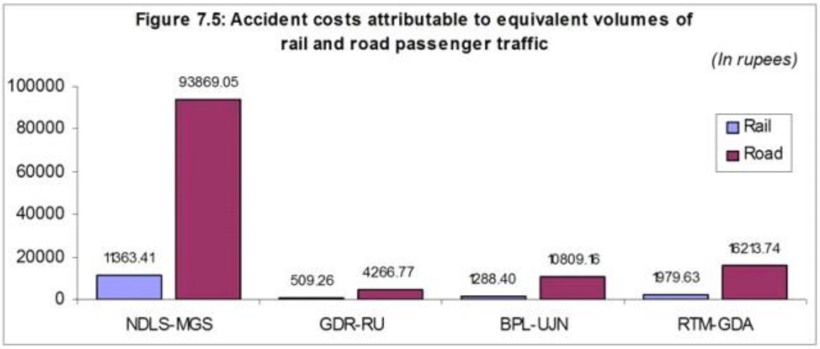


Figure 7.5: Accident costs attributable to equivalent volumes of rail and road passenger traffic

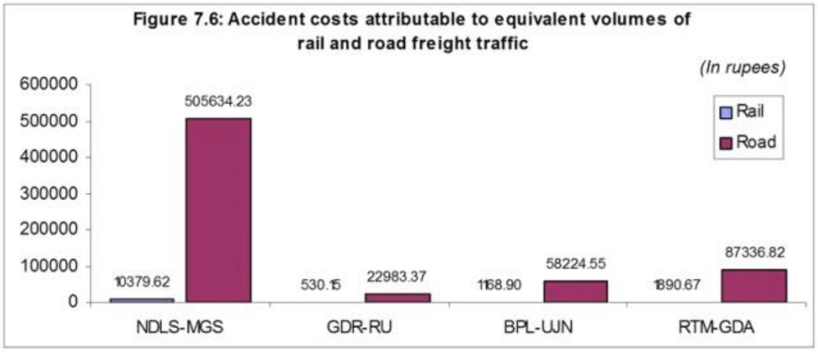


Figure 7.6: Accident costs attributable to equivalent volumes of rail and road freight traffic

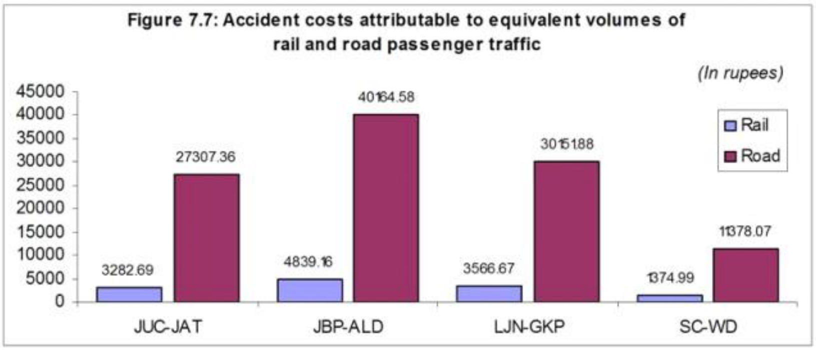


Figure 7.7: Accident costs attributable to equivalent volumes of rail and road passenger traffic
(In rupees)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
3282.69
27307.36
4839.16
40164.58
3566.67
30151.88
1374.99
11378.07
Rail
Road
JUC-JAT
JBP-ALD
LJN-GKP
SC-WD

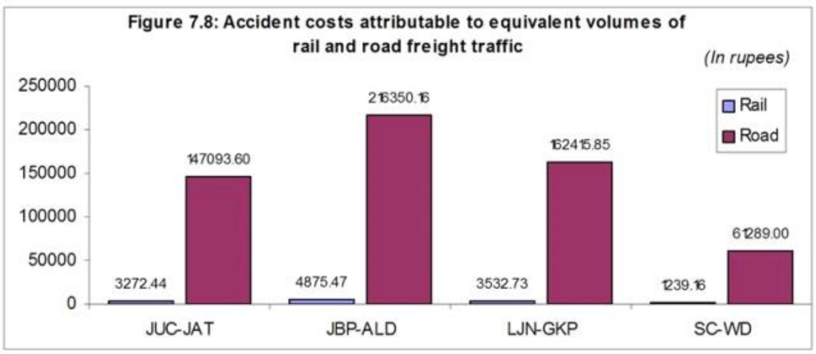


Figure 7.8: Accident costs attributable to equivalent volumes of rail and road freight traffic
(In rupees)
250000
200000
150000
100000
50000
0
3272.44
147093.60
4875.47
216350.16
3532.73
162415.85
1239.16
61289.00
Rail
Road
JUC-JAT
JBP-ALD
LJN-GKP
SC-WD

8 Social Costs – All Inclusive Costs

An evaluation or comparison of any mode of transport involves consideration of its cost structure. This is not a straightforward exercise since the cost components are varied and occur in many areas some of which are not apparent. The position is further compounded by the fact that not all costs are borne by the transport operator and paid for by the user. Some of the costs are borne by other persons or by the society as a whole. Health damage costs arising out of air pollution caused by road vehicles is an example of such costs. We may, therefore, distinguish between the internal or private costs, which are borne by the persons (or entities) engaged in transport activity and the external costs which are borne by others.

Social costs represent the true cost of transport to the community.

The sum of the internal and external costs is what is termed as social cost since it represents the true cost of transport to the community as a whole. It is important to note that this concept of social costs also includes the cost of providing and maintaining infrastructure, irrespective of the fact whether the operator undertakes this work or not. It is also not relevant whether the cost is recovered from the user or the operator. Thus, the costs of road provisioning and maintenance are elements of social cost even though they may not be borne by the user or the operator.

Relevance of Social Costs

The relevance of social costs arises from the fact that in a market economy, financial decisions are greatly dependent on market prices and profitability and often fail to reflect existing scarcities (clean air, absorptive capacity of the environment, infrastructure, etc.). Consequently, the individual decisions of consumers and producers do not add up to an outcome that provides maximum benefits to the society as a whole. Therefore, analysis based on full social costs is a valuable

Market prices often fail to reflect existing scarcities.

tool for policymakers and regulators in developing an efficient and sustainable transport system and in facilitating an optimal mix of different modes of transport.

Social cost is a valuable tool in developing an efficient and sustainable transport system.

Social costs, therefore, are useful and assist in:

- Evaluation of costs of different modes of transport.
- Conserving scarce resources and ensuring their optimal distribution.
- Framing policies that encourage efficient and sustainable transport.
- Establishing rational and efficient pricing of transport services.

Recognising the importance of social costs in any holistic comparison of rail and road modes we, in this study, have considered both internal and external costs. In the earlier chapters, we have analysed and estimated different costs that are incurred directly or indirectly in the use of these modes. In this chapter, we combine all these costs to arrive at social costs separately for each mode in order to have a comparative appreciation.

Comparative Analysis

It is well known that the costs in the transport sector vary with the flux of time. Factors like condition of infrastructure, traffic densities, growth profiles, etc. influence the costs at every stage. However, all future changes cannot be predicted nor their effects quantified. Improvement in technology, especially in motive power, is one such example. In view of these limitations, the present analysis is spread over a time horizon of 10 years i.e. from 2000 to 2010.

Tables 8.1 and 8.2 give the social costs (which include health and accident costs) in respect of road and rail both for passenger and freight traffic expressed in rupees per PKM/NTKM for the three milestone years 2000, 2005 and 2010. The costs have been computed for urban areas, non-urban areas and the sections as a whole. They are based on the assumption that no improvements or capacity additions on road and rail would take place during the period and, as a result, the 'congestion' effect of the projected increase in traffic has been duly factored into the cost calculations.

Table 8.1: Social costs of passenger traffic (in Rs per PKM)

Sections	Urban						Non-urban						All					
	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010		2000		2005		2010		2000		2005		2010	
New Delhi-Mughal Sarai*	2.44	1.48	3.53	1.54	6.80	1.61	2.38	1.39	3.47	1.45	6.74	1.52	2.39	1.38	3.47	1.45	6.75	1.52
Jalandhar-Jammu	3.02	1.30	4.61	1.33	9.91	1.36	2.96	1.29	4.55	1.32	9.85	1.35	2.97	1.29	4.56	1.32	9.86	1.35
Jabalpur-Allahabad	2.07	1.13	2.48	1.15	3.17	1.17	2.01	1.12	2.42	1.14	3.11	1.15	2.02	1.12	2.43	1.14	3.12	1.15
Lucknow-Gorakhpur	2.34	1.14	3.15	1.16	4.92	1.18	2.28	1.13	3.09	1.15	4.87	1.17	2.28	1.13	3.09	1.15	4.87	1.17
Secunderabad-Wadi	2.11	1.24	2.48	1.27	3.07	1.30	2.05	1.23	2.42	1.26	3.01	1.29	2.05	1.23	2.42	1.26	3.02	1.29
Gudur-Renigunta*	1.42	1.67	1.72	1.69	2.21	1.70	1.36	1.58	1.66	1.59	2.14	1.61	1.37	1.57	1.67	1.58	2.16	1.60
Bhopal-Ujjain*	2.08	1.30	2.58	1.31	3.46	1.32	2.02	1.21	2.52	1.22	3.41	1.23	2.03	1.21	2.52	1.22	3.41	1.24
Ratlam-Godhra*	1.17	1.53	1.33	1.57	1.56	1.61	1.11	1.44	1.27	1.48	1.50	1.52	1.12	1.45	1.27	1.49	1.51	1.53

Table 8.2: Social costs of freight traffic (in Rs per NTKM)

Sections	Urban						Non-urban						All					
	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail	Road	Rail
	2000		2005		2010		2000		2005		2010		2000		2005		2010	
New Delhi-Mughal Sarai*	3.08	0.44	3.84	0.45	5.41	0.46	2.78	0.38	3.53	0.39	5.10	0.40	2.81	0.38	3.57	0.39	5.13	0.40
Jalandhar-Jammu	3.10	0.36	3.80	0.38	5.22	0.41	2.78	0.34	3.48	0.37	4.90	0.39	2.83	0.35	3.53	0.37	4.95	0.39
Jabalpur-Allahabad	2.90	0.36	3.31	0.37	3.91	0.39	2.56	0.35	2.97	0.36	3.57	0.37	2.61	0.35	3.02	0.36	3.62	0.37
Lucknow-Gorakhpur	2.88	0.33	3.44	0.33	4.38	0.33	2.57	0.31	3.13	0.32	4.07	0.32	2.58	0.31	3.14	0.32	4.08	0.32
Secunderabad-Wadi	3.39	0.67	3.72	0.71	4.21	0.75	2.98	0.64	3.32	0.68	3.80	0.72	3.03	0.65	3.37	0.69	3.85	0.73
Gudur-Renigunta*	3.43	0.84	3.78	0.86	4.28	0.87	3.01	0.73	3.36	0.75	3.86	0.76	3.10	0.72	3.45	0.73	3.95	0.75
Bhopal-Ujjain*	3.26	0.61	3.72	0.61	4.40	0.61	2.89	0.51	3.35	0.51	4.03	0.52	2.94	0.52	3.40	0.52	4.08	0.52
Ratlam-Godhra*	3.25	0.44	3.49	0.46	3.82	0.48	2.82	0.36	3.07	0.37	3.40	0.39	2.86	0.36	3.10	0.38	3.43	0.40

The following salient points emerge from the above data:

(i) The railways have a huge comparative cost advantage over road transport; the advantage is greater in the case of freight traffic than in the case of passenger traffic.

The railways have a huge comparative cost advantage over road transport.

(ii) The cost advantage in the year 2000 is as much as Rs 1.72 per PKM and Rs 2.81 per NTKM in urban areas, and Rs 1.68 per PKM and Rs 2.47 per NTKM in non-urban areas. For the sections as a whole, the cost advantage of rail is as much as Rs 1.68 per PKM and Rs 2.50 per NTKM.

(iii) Unit freight costs on the railways are significantly lower than unit passenger costs, while the opposite is true for road transport.

(iv) The effect of congestion is more pronounced in the case of road transport as compared to rail, thereby enhancing the cost advantage of rail. It underscores the need for improvements in road infrastructure.

We have also worked out social costs in a situation where road improvement/upgradation takes place and, consequently, the effect of congestion is significantly reduced. Tables 8.3 and 8.4 indicate the social costs with road improvements in the year 2005/2006. The results emerging from these tables and any inferences drawn therefrom should, however, be viewed with caution as rail improvement has not been considered and its effect is not reflected in the tables.

Table 8.3: Social costs of passenger traffic (in Rs per PKM) – with road improvement

Section	Passenger (Road)		
	2000	2005**	2010
New Delhi-Mughal Sarai*	2.38	1.58	1.79
Jalandhar-Jammu	2.96	1.74	1.95
Jabalpur-Allahabad	2.02	1.79	1.95
Lucknow-Gorakhpur	2.27	1.78	2.02
Secunderabad-Wadi	2.04	1.82	1.99
Gudur-Renigunta*	1.35	1.21	1.36
Bhopal-Ujjain*	2.02	1.76	1.98
Ratlam-Godhra*	1.09	1.02	1.09

Table 8.4: Social costs of freight traffic (in Rs per NTKM) – with road improvement

Section	Freight (Road)		
	2000	2005**	2010
New Delhi-Mughal Sarai*	2.83	2.41	2.69
Jalandhar-Jammu	2.86	2.64	3.02
Jabalpur-Allahabad	2.63	2.88	3.32
Lucknow-Gorakhpur	2.57	2.85	3.42
Secunderabad-Wadi	3.07	3.28	3.66
Gudur-Renigunta*	3.14	3.35	3.74
Bhopal-Ujjain*	2.96	3.22	3.72
Ratlam-Godhra*	2.92	3.05	3.28

*** 2006 in the case of New Delhi-Mughal Sarai*

Social costs of road significantly decline when road improvements are carried out.

It would be seen from the above that the social costs of road significantly decline when road improvements are carried out. Still, rail retains its cost advantage over road both for passenger and freight traffic across the entire time horizon of 2000-2010.

Intermodal Substitution

We have seen that social costs of rail are significantly lower than those of road when computed in terms of per passenger kilometer/ net tonne kilometer. However, the unit social costs do not by themselves indicate the quantitative savings in case of substitution of road traffic by rail. We have, therefore, calculated the daily changes in social costs resulting from intermodal substitution of equivalent volumes of traffic with no improvement/upgradation of infrastructure. Table 8.5 reflects the daily overall changes in social costs due to substitution of road by rail.

Table 8.5: Daily overall changes in social cost of transport due to substitution of road by rail****

Rs. million

Sections	Urban						Non-urban						Both					
	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.	Pass.	Frt.
	2000		2005		2010		2000		2005		2010		2000		2005		2010	
New Delhi-Mughal Sarai*	0.31	-2.04	-0.51	-2.70	-3.18	-4.08	-10.91	-19.64	-18.64	-25.45	-42.53	-37.50	-10.60	-21.69	-19.15	-28.15	-45.72	-41.58
Jalandhar-Jammu	-0.69	-1.07	-1.27	-1.33	-3.21	-1.87	-3.37	-5.15	-6.53	-6.58	-17.22	-9.52	-4.05	-6.22	-7.80	-7.91	-20.43	-11.39
Jabalpur-Allahabad	-0.81	-1.55	-1.03	-1.79	-1.41	-2.13	-2.38	-6.76	-3.53	-7.99	-5.54	-9.81	-3.19	-8.31	-4.56	-9.78	-6.95	-11.94
Lucknow-Gorakhpur	-0.73	-1.25	-1.09	-1.52	-1.88	-1.96	-1.73	-4.33	-3.21	-5.44	-6.54	-7.29	-2.47	-5.58	-4.30	-6.96	-8.42	-9.25
Secunderabad-Wadi	-0.10	-0.36	-0.15	-0.40	-0.22	-0.46	-0.72	-2.18	-1.02	-2.46	-1.51	-2.86	-0.82	-2.54	-1.16	-2.85	-1.72	-3.32
Gudur-Renigunta*	0.00	-0.21	-0.02	-0.23	-0.06	-0.27	-0.10	-0.79	-0.19	-0.89	-0.33	-1.05	-0.10	-1.00	-0.21	-1.13	-0.39	-1.32
Bhopal-Ujjain*	0.01	-0.31	-0.05	-0.36	-0.16	-0.45	-0.93	-2.19	-1.33	-2.58	-2.06	-3.17	-0.92	-2.49	-1.39	-2.95	-2.22	-3.62
Ratlam-Godhra*	0.33	-0.28	0.33	-0.31	0.31	-0.35	-0.09	-3.49	-0.26	-3.80	-0.52	-4.23	0.24	-3.77	0.07	-4.11	-0.21	-4.58
Total savings (electrified)	0.00	2.84	0.26	3.61	3.09	5.15	12.03	26.11	20.41	32.73	45.44	45.94	11.53	28.95	20.53	36.34	48.33	51.09
Total savings (dieselised)	2.34	4.24	3.53	5.04	6.72	6.41	8.20	18.41	14.29	22.47	30.81	29.49	10.54	22.64	17.82	27.50	37.53	35.90
Total savings	2.34	7.08	4.12	8.65	10.12	11.56	20.23	44.51	34.70	55.20	76.25	75.43	22.06	51.59	38.35	63.84	85.85	86.99

*** at 1997-98 prices;* Pass. = Passenger traffic; Frt. = Freight traffic

The following conclusions emerge from the above data:

(i) Substitution of road by rail results in substantial daily savings in social costs both in urban and non-urban areas.

(ii) The total daily savings work out to Rs 51.59 million for freight traffic and Rs 22.06 million for passenger traffic for the base year 2000.

Substitution of road by rail results in substantial daily savings in social costs.

(iii) The quantum of savings increases over the selected time horizon. This is due to increasing levels of congestion on road resulting in higher operating costs.

(iv) The lower external costs of rail add to its comparative advantage over road in terms of higher daily savings in social costs.

The foregoing analysis clearly brings out the primacy of rail as a mode of transport.

The foregoing analysis clearly brings out the primacy of rail as a mode of transport. Substantial savings can result from the use of rail transport. The savings are not only in direct financial costs but also in external costs attributable to environmental pollution and accidents.

The above conclusions are broadly in line with the results of the studies carried out in France and Australia and also by OECD. These studies confirmed that rail mode was more environmentally friendly than road mode. A study commissioned by the SNCF in France found that the contribution of rail to various pollutants at the national level was less than 0.8% of total emissions from transport. Road transport contributed between 94 and 99% of total pollutants arising from transport. Rail was found to be not only more energy-efficient but also with a lower emission coefficient of CO_2 for the same quantity of energy consumed.

A French study found that substitution of road by rail will lead to reduction in overall energy usage and pollution stresses.

The study revealed that for every 100 PKMS, a high-speed train consumed the equivalent of 1.8 litres of oil as primary energy and emitted 0.4 kg of CO_2. A private car, on the other hand, carrying an average of 1.85 people, consumed 4 litres of oil and emitted 10 kg of this pollutant for 100 PKMS. The percentage share of transport in total emissions of sulphur-dioxide (SO_2) was found to be 13.5%; nitrogen oxides (NOX) 62.7%; non-methane volatile organic compounds (NMVOCs), 41.7%; carbon monoxide (CO), 59.4%; and CO_2, 39.4%. Shares of road in the total transport emissions were found to be SO_2, 94.8%; NOX, 93.9%; NMVOCs, 95.1%; CO, 99%; and CO_2, 93.6%. The rail shares in the total transport emissions were revealed to be SO_2, 0.8%; NOX, 0.8%; NMVOCs, 0.2%; CO, 0.1%; and CO_2, 0.6%.

The study also worked out hypothetical savings in pollution loads resulting from transfer of road traffic to rail. Thus, if 1 billion PKMS were transferred from private car to rail travel (taking a mean load factor of 1.8 passengers per car), the resulting reductions in pollution would be as follows: CO_2, 106860; CO, 3720; volatile organic compounds (VOCs), 620; NOX, 550; and suspended particulate matter (SPM), 55 tonnes. If 1 billion tonne-kilometers were transferred from heavy goods vehicles to rail haulage, the overall decreases in pollution levels would be as follows: CO_2, 59450; CO, 420; VOCs, 100; NOX, 580; and SPM, 65 tonnes. The study concluded that, on the whole, any shift in favour of rail at the expense of road would result in significant improvements in terms of savings in energy consumption and reductions in pollution loads.

An OECD study (Wiederkehr, P., Environmentally Sustainable Transport (EST) – International Perspectives, 1988) found that for the OECD countries, as a whole, the share of transport in polluting emissions varied from 25% for CO_2 to 90% for CO, with road transport contributing more than 80% of total transport emissions. The so-called external costs of transport arising from the health and environmental effects of air pollution, noise, congestion and time losses were estimated between 5-10% of GDP of OECD countries. Road transport and aviation were found to be primarily responsible for these costs; the rail mode contributed just less than 1% of the social cost burden. Estimates of the social costs from transport indicated that for cars the cost is almost 50 European Currency Units (ECU) per 1000 PKMS, whereas for passenger rail it was 25 ECU per 1000 PKMS. The social cost of rail freight was 30 ECU per 1000 NTKMS, in contrast to road freight average of 70 ECU per 1000 NTKM.

An OECD study (1988) revealed that the social cost of rail freight was less than half that of road freight.

The study further revealed that environmental impacts arise not only from the operation and use of the means of transport, but also from the production and maintenance of vehicles, the construction of infrastructure, the provision of energy and fuels, and the disposal and decommissioning of vehicles. Life-cycle assessments and material-balance studies showed that rail transport, including high-speed rail, caused considerably less environmental impacts than road and air traffic. Total life-cycle emission of NOX due to passenger transport was found to be about 1.1 grams per PKM for car, whereas for ordinary train the estimate was about 0.8g/PKM and for high-speed train about 0.25 g/PKM. In respect of CO_2 emissions from passenger transport, car discharged about 180 g/PKM, while ordinary train emitted about 60 g/PKM, and high-speed rail about 70 g/PKM.

An Australian study (1998) has confirmed that rail transport is twice as energy efficient as road transport even after accounting for full cycle of activities.

Studies carried out in Australia brought out that road transport consumed nearly 90% of Australia's transport energy consumption and produced 80% of the nation's transport greenhouse gas emissions. In contrast, rail transport accounted for just 3% of the nation's domestic transport energy consumption and was responsible for only 2% of transport greenhouse gas emissions. Rail freight used only one-third of the fuel required by road transport for the same freight task. Rail was twice as energy-efficient as road even after fuel use had been included for rail line haul, road pick-up and delivery from rail terminals, manufacture of transport equipment and construction of roads and railway lines. A rail line accounted for only one-third of the construction and maintenance costs of road and required one-third of road space. With regard to accidents and safety, the road transport accounted for over 90% of the cost of transport accidents, while the cost of rail accidents was just 1% of the total cost. Rail freight transport was 7 times safer than road freight transport with only 0.55 fatalities per billion tonne-kilometers of freight hauled compared with road freight's record of 3.8 fatalities per billion tonne-kilometers.

9 Findings and Policy Prescriptions

All human endeavour involves choices and nowhere is this more true than in commercial activity. Transport is an integral part of economic and commercial activity. As such, it also requires choices to be made between different modes of transport, such as rail and road. However, the sum of individual choices, even while maximising the welfare of an individual or a firm may not maximise social welfare. The findings of the present study, presented below, support this thesis.

Energy consumption

1. Rail consumes much less energy than road and has maximum advantage in respect of freight traffic. Energy consumption on rail for freight traffic varies between 0.12 and 0.39 megajoules (Mj) per NTKM, while for road, it varies between 1.13 and 1.58 Mj per NTKM. For passenger traffic, energy consumption on rail varies between 0.16 and 0.20 Mj per PKM, while in the case of diesel bus, it varies between 0.19 and 0.22 Mj per PKM.

2. In comparison to road, rail consumes 75 to 90% less energy for freight traffic and 5 to 21% less for passenger traffic. The higher rates of energy consumption in respect of rail passenger traffic can be attributed to the higher tare weight of passenger coaches as compared to road vehicles.

3. Substitution of road traffic by rail traffic results in substantial savings in energy consumption. For example, 10,000 passengers and 10,440 tonnes of freight per day carried on national highways and half of these volumes carried on state highways when shifted to rail mode result in savings of 614,522 litres of diesel oil per day.

4. Diesel bus emerges as a close energy-efficient option in comparison to rail in case of passenger traffic. It is also far more energy-efficient than passenger car.

5. For comparative analysis, energy consumption on both the modes is inclusive of the energy used at thermal power plants and oil refineries in the generation of electrical energy and production of fuel used for locomotion.

Financial costs

6. Financial costs of rail transport are generally lower than those of road transport. Advantage is, however, greater for freight than for passenger traffic. The differential between road and rail costs for passenger traffic in the base year 2000 is as much as Rs 1.62 per PKM. For freight traffic, the differential in unit costs increases to Rs 2.09 per NTKM.

7. For passenger traffic, the cost on rail varies between Rs 1.10 and Rs 1.48 per PKM, while in the case of road transport (diesel bus), it varies between Rs 1.04 and Rs 2.89 per PKM. The comparative advantage of rail declines in a situation where adequate road capacity is available and utilisation is within the normative capacity.

8. Substantial savings result from the substitution of road by rail for carrying the selected volumes of traffic mentioned above. The daily overall savings in respect of freight traffic in the base year 2000 range between Rs 0.73 million and Rs 17.99 million. For the same year, the daily savings in respect of passenger traffic range between Rs 0.80 million and Rs 4.19 million. The variation in savings is due to sectional characteristics, such as length of section, type of terrain, etc.

Environmental damage

9. The railways cause less environmental damage as compared to road; the advantage is more marked in respect of freight traffic. The railways, however, lose this advantage when electric traction is used for carrying passenger traffic.

10. Comparison of diesel and electric traction in terms of environmental impact shows that electric traction accounts for higher CO_2, SO_2/SOX and TSP emissions if the

polluting effect of the use of coal for power generation at thermal plants located in urban areas is transferred to the transport sector. This effect gets neutralised if gas is used as fuel for generating power. The electric traction is, however, much cleaner than diesel traction when other noxious pollutants, such as CO and NOX are considered.

11. Diesel bus scores over car in respect of CO_2 and CO emissions, but suffers a disadvantage in regard to NOX, SO_2 and TSP emissions. This clearly brings out the need for providing alternative cleaner fuels for buses, which are the mainstay of public transport system in the country.

Material resources

12. Manufacturing of moveable stock and construction of ground infrastructure consumes large quantities of scarce natural resources. Steel is by far the most important material used in road and rail vehicles. On an average, passenger coaches require 7 times more steel, while freight wagons require almost 2 times more as compared to road vehicles for carrying equivalent volumes of traffic. Steel requirement for rail infrastructure is also much more than that for road infrastructure.

13. Higher usage of steel in rail requires higher levels of energy inputs at steel plants. Major pollutants emitted in the production of steel are CO_2, CO, NOX, SOX and TSP. These emissions are higher when attributed to rail traffic than in case of road traffic.

14. Health costs due to pollution from usage of steel are much less as compared to such costs attributable to energy requirements for motive power. These costs further decline with fuller utilisation of ground infrastructure. The energy source for providing motive power, therefore, remains the predominant factor in determining the comparative results of the environmental damage of rail and road modes.

15. Widening of road by two lanes requires almost 2½ times the land required for rail track doubling. Cost of rail doubling is almost half of the cost of four-laning of road.

Health damage costs

16. The health damage cost of rail is generally lower than that of road. In urban areas, for freight traffic, it is lower by as much as 76 paise per NTKM, while for passenger traffic, it is lower by 10 paise per PKM. In non-urban areas, the costs decline by half as compared to urban areas. Thus, on an average, the health damage cost of rail freight traffic is lower than that of road by a factor of 7, while in case of passenger traffic, it is lower by a factor of 5. The health damage cost of rail is, however, higher if electric traction is considered for carrying passenger traffic.

17. Substitution of passenger traffic on road by rail with diesel traction results in decrease (savings) in health damage costs amounting to Rs 0.51 million per day. In case such substitution is carrying freight traffic, the decrease in health damage costs amounts to Rs 3.57 million per day. Substitution of road by rail with electric traction does not result in any change in health damage costs in the case of passenger traffic. In the case of freight traffic, however, the decrease in health damage costs amounts to Rs 3.48 million per day.

Accident costs

18. The incidence of casualties in case of road transport is substantially higher as compared to railways. The total number of casualties per billion units of transport output range between 154 and 204 for road transport, while for rail, they range between 1.54 and 4.61. Casualties per million population range between 1.05 and 2.66 for rail, while for road they lie between 208.39 and 469.80.

19. The accident costs on road are also significantly higher than those on rail. In the case of passenger traffic, the costs are higher by a factor of 8, while for freight traffic, these are higher by as much as 45 times. In monetary terms, the cost on road is 1.14 paise per PKM and 5.87 paise per NTKM, while rail costs are 0.14 paise and 0.13 paise, respectively.

20. Substitution of road traffic by rail leads to large overall decreases in total accident costs – Rs. 205,960 per day in case of passenger traffic and Rs 1,234,440 per day for freight traffic.

Social costs (all-inclusive costs)

21. In terms of social costs, also termed as all-inclusive costs, railways have a huge cost advantage over road transport. The advantage is greater in freight traffic than in passenger traffic. For urban areas, the cost advantage of rail in the base year 2000 is as much as Rs 2.81 per NTKM and Rs 1.72 per PKM, while for non-urban areas, the cost advantage is as much as Rs 2.47 per NTKM and Rs 1.68 per PKM.

22. The unit freight costs on the railways are significantly lower than the unit passenger costs, while the opposite is true for road transport. The effect of congestion is more pronounced in the case of road transport as compared to rail, thereby further enhancing the cost advantage of rail.

23. Substitution of road by rail can result in substantial daily savings in social costs. For the base year, the daily savings work out to Rs 51.59 million for freight traffic and Rs 22.06 million for passenger traffic. The lower external costs of rail add to its comparative advantage over road in terms of higher daily savings in social costs.

The above results in respect of energy intensity, pollutant emissions, health damage costs and cost of accidents for rail and road modes give us broad guidance for bringing about policy changes to induce shift of modal choice in favour of rail, particularly for freight traffic and in favour of public road transport over personalised transport. It may be noted that the costs considered in the present study relate to line-haul of traffic and do not include the shippers' costs at either end. The international experience, however, suggests that the inclusion of such costs would not alter the main findings.

Policy Prescriptions

We have seen that despite the comparative advantage of rail over road in terms of social costs, its share in both passenger and freight traffic has been declining over the years. The reasons for this decline can be broadly categorised into pricing policies and non-pricing attributes related to rail and road modes.

Of the two modes, rail is a state-owned monopoly subject to price regulation, while road transport market is privatised and competitive for freight traffic. The prices of freight transport service by trucking are determined by free market forces. However, for passenger road transport, both public sector undertakings and private operators supply the service under a regime of price regulation.

The pricing systems prevailing in the two modes are totally different. Rail transport, in its pricing, covers all costs, including that of the fixed infrastructure, whereas road pricing does not reflect the full normative cost of ground infrastructure and its maintenance. Besides, the road and fuel taxes have little or no relation with the true resource cost of various inputs.

In road transport, the freight and passenger segments operate as independent entities, while in rail, there is no such distinction. This difference in structural characteristics has critical implications in pricing of the products in the two modes. In road transport, there is no element of cross-subsidisation between the two products, while railways indulge in it with great profligacy.

Cross-subsidisation, *per se*, between the product lines within a firm is an accepted practice. Indeed, all large firms with multiple products indulge in varying degrees of inter-product cross-subsidisation. But, in the case of rail, this aspect has been carried to unsustainable extremes. This has happened because the rail being a public sector monopoly has failed to peg the differential within acceptable levels.

The rail freight rates have invariably been pegged at higher levels to cross-subsidise passenger traffic. The profits generated from freight traffic have been used to cover the losses on passenger services. In this process, the railways have outpriced themselves in the freight sector, thereby losing their competitive edge over road transport. This skewed pricing policy, in turn, has led to diversion of traffic to road.

Transport activity stresses nature in multiple ways – consuming scarce resources, emitting pollutants and generating harmful wastes. The waste arisings in the form of gaseous emissions, liquid effluents and solid wastes damage human health, economic productivity of natural resources and even the regenerative capacity of the ecosystem. The damaging effects of transport activities are costs to the society generally referred to as external costs in economic terms. These external costs need to be built into the cost of transport service.

Presently, however, the external costs are not borne by the user of the transport service. Hence, the modal choice decision is not influenced by these costs, resulting in intermodal distortions. To the extent the road transport causes more environmental and health damage without paying for it, the intermodal choices would continue to have an element of aberration.

Ideally, the user should pay the full marginal resource cost of his transport, such cost being the cost to the economy or society of actual resources utilised in its production. Pricing transport services on the basis of their comparative resource cost would lead to creation of an efficient system in which the total transport demand would be met at a minimum resource cost to the economy.

Therefore, it is necessary to seriously consider devising policies for transport sector as a whole. However, this may not be possible as long as pricing decisions are taken directly by the government. The objective could be achieved by setting up an independent and autonomous tariff regulatory authority whose recommendations should be binding on all market players and stakeholders.

Efficient instruments to internalise the external costs of road accidents should aim at reducing risk-taking in the broadest sense of the term and should, therefore, be introduced at the level of the individual motorist. This suggests that one should seriously review the existing insurance systems and ensure that the premiums, both in level and in structure, reflect risk to society as a whole. The use of insurance premiums has the additional advantage of relying on an existing instrument.

Many alternatives have been proposed over the years to internalise the environmental costs of transport – from charging of higher emission fees based on actual emission to adjustments of the level of the existing fuel, vehicle or purchase taxes to take into account an approximation of the emissions. The implementation of decisions in this regard will, however, have to be based on a trade-off between an instrument's link to emissions and its implementation costs.

The railways should consider organisational changes to market their products on commercial lines. This will help the organisation to be in the market as a competitive service provider. Time is both ripe and opportune for it to respond to the new imperatives of the market forces rather than merely stress on the virtues of the rail mode.

The political economy of the country often poses problems in translating any optimal package of policies into practice. The real problem in the Indian context has been one of lack of implementation and delivery through correct institutional choice and management. Policies for sustainable development of alternative modes of transport should, therefore, give equal attention to the task of finding out the rational modal share, on the one hand, and choosing the institutional mechanism with associated model of management, on the other. While this study has focused on the former, it is leaving the latter as a task ahead, to be taken up for a separate exercise.

Figure 9.1: Energy Consumption – Ranges in Passenger Transport

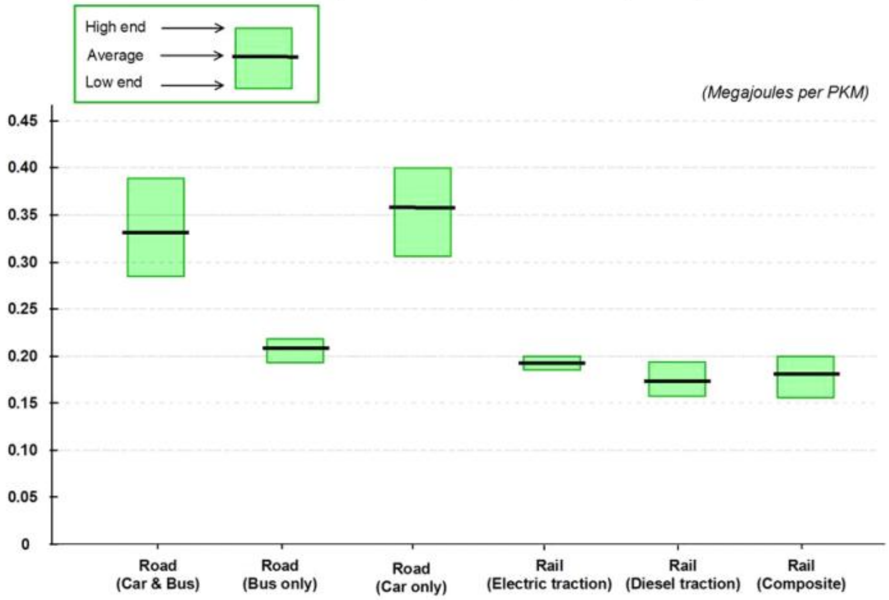


Figure 9.2: Energy Consumption – Ranges in Freight Transport

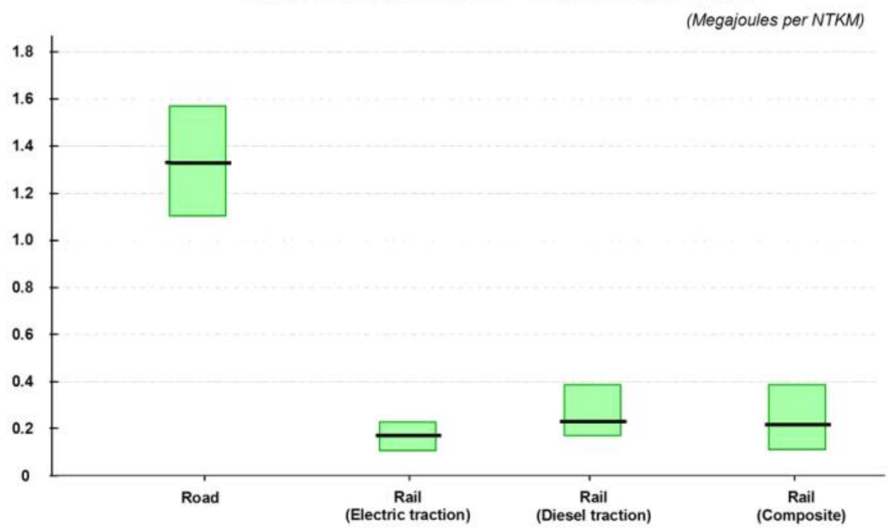
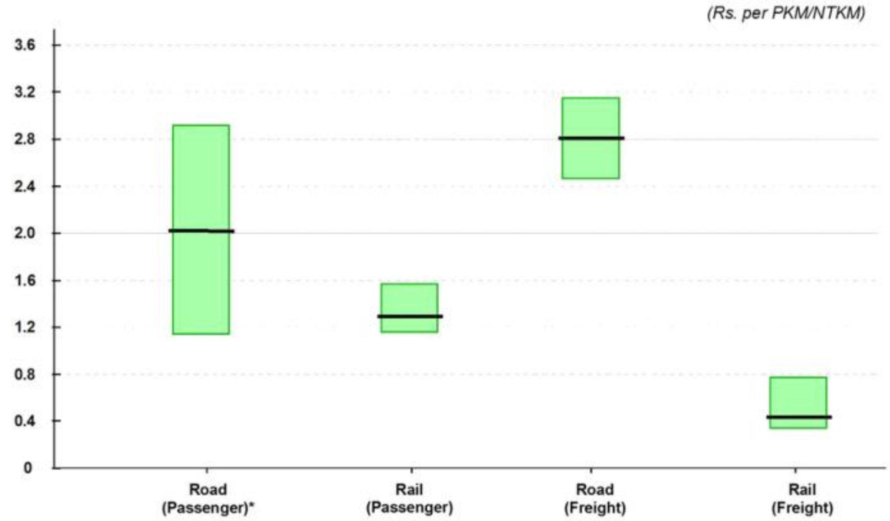


Figure 9.3: Social Cost – Ranges in Passenger and Freight Transport (Base year 2000)



** The option of 'bus only' is considered for road passenger transport.*

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