ENVIRONMENTAL ASPECTS OF TRANSPORT FOR NATURAL RESOURCE DEVELOPMENT

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The environmental problems of transport for natural resource development and utilization are highly varied, widespread, and far-reaching. Such problems include exhaust emissions; noise and vibration; waste disposal and other pollutions to land, water, and air; and hazards to human living. The precise dimensions of a particular environmental problem depend on the types of resource material to be moved, the natural conditions of the location, and the economic, social, and commercial circumstances of the nation or region, as well as the techniques and facilities of transportation to be used. To deal with the various problems, it is necessary to undertake appropriate transport planning for natural resource development and utilization from the point of view of environmental quality. This involves considerations of the economic and physical factors as well as, in each individual case, a balance between cost and benefits. Transport planning calls for the establishment of a suitable policy and a program of work with properly defined objectives and priorities. Within the scope of environmental problems themselves, standards have to be set and enforcements have to be effected. For such tasks, however, there is a conspicuous deficiency of knowledge with respect to the incidence and extent of the specific environmental problems and the technological know-how to deal with them in developing countries. Thus it is suggested that research studies be undertaken in the first instance in three areas: (a) surveys for defining the incidence and extent of known environmental problems arising from transportation for natural resource development in developing countries; (b) research into the unidentified areas of environmental implications of transport for resources purposes; and (c) research into the technologies and techniques for control of the environmental effects of transport for resource development.

•THIS paper attempts to review existing knowledge in the area of study, to identify those issues requiring the attention of policy-makers, and to suggest some of the possible solutions that are available or will be in the future. It points out emerging environmental issues and provides a framework within which these problems can be appreciated and dealt with.

Four major sections set forth the subject. The first delineates major relationships between transport and natural resource development. It identifies the nature of environmental effects, both direct and indirect, that can result from the various transport requirements for resource development. It discusses the differential impact of these effects, from first-order consequences (e.g., erosion from road construction) to second- and third-order consequences involving changes in land use and settlement patterns and size.

The next section details the effects on the environment of transport infrastructure and operations. Transport modes considered include roads and highways, railways, pipelines, conveyors, overhead cable systems, waterways, and airways.

The third section is devoted to the economic development and equity issues arising from a high degree of concern with the environment. Costs, and their distribution, are considered, as are the problems of dealing with existing environmental violations and taking preventive action.

The final section highlights some of the major policy issues and future directions of effort. Alternate transport technologies to reduce environmental damage are also reviewed, and several priority areas for future research are suggested.

In this paper the analysis is focused on those environmental aspects of transport for natural resource development that are of particular interest to developing countries. It is worth noting, however, that the environmental concerns of developing and developed countries are different. The former are primarily concerned with resources in the sense of whether there are sufficient supplies of food, energy, materials, and so forth to meet their needs; the latter are increasingly concerned about the ability of air, land, and water to absorb all the wastes they generate.

RELATIONSHIPS BETWEEN TRANSPORT AND NATURAL RESOURCE DEVELOPMENT

The Environmental Effects: Direct and Indirect

The environmental effects that result from transport for natural resource development can be distinguished as to whether they are direct or indirect. As used in this paper direct effects are defined as those that take place in the immediate area of resource exploitation or in the transport way that provides access to it. (Although direct effects cover the full range of social, economic, and environmental impacts, in this paper we are primarily concerned with the environmental impacts.) For example, as a consequence of roads constructed to provide access to mineral deposits, thousands of acres of previously undeveloped land may fall prey to poor limbering practices, squatter settlements, strip burning, and so forth. Such direct effects are the primary concern of this paper. Before dealing with these, however, a brief digression on indirect effects is required.

The indirect effects of transport for natural resource development are those that occur in other areas of the country (or in the world) because of a change in access to a specific location. To continue the examples cited, uncontrolled timber cutting can reduce the economic viability of controlled timber cutting elsewhere; likewise, new cultivation of "free land" can compete destructively in some markets with existing cultivations in other locations. In arid countries where water is scarce, a new transport access may enable entrepreneurs to capture a new water resource with canals or pipes. The indirect effects can include drastic downstream consequences (e.g., seasonal water shortages) or long-term disadvantage (e.g., the dropping of stream standards below desirable water-quality levels).

Many indirect effects are subtle changes that are seldom of early and direct concern to the private entrepreneurs and public officials who are immediately involved in resource development. Nevertheless, indirect effects are noted here as being of potential concern to regional, national, or multinational planners. At the present time, most indirect effects are imperfectly understood or anticipated. Where they are identified, action can only be taken on a case-by-case basis. As more is learned about the indirect impacts—social, economic, and environmental—of seemingly separate problems, it may prove possible to identify in advance a broad range of indirect effects and to devise a long-range strategy for action. However, for the remainder of this paper the primary concern is with the direct environmental effects, i.e., those in the immediate area of resource development or in the transport way that provides access to it.

In discussing environmental effects, it is necessary to recognize the time frame within which the impacts occur. Direct effects may have an impact on the immediate environment almost at once or only after varying periods of time. Environmental effects that might have an immediate impact include those arising from transport into an area for access to and extraction of a primary material. Over longer periods of time, changes in land use or settlement patterns may result. And eventually an area's ecology can be altered basically. In these latter cases the processes of environmental change can be ones where the lead times are long but the momentum is strong and the process irreversible. It is extremely difficult for existing planning processes to deal with such long-range situations.

Transport Requirements for Resource Development

Direct effects on the environment will depend on the nature of transport requirements for resource development: the time frame during which transport demands arise; the direction of movement; the volume, type, and weight of materials that must be transported; and the settlement patterns that arise as a result of resource development. The diversity of these requirements in the real world, of course, is enormous; here it is possible only to distinguish the major possibilities and identify the various kinds of environmental effects that can be expected to result from each.

Time Frame for Development—Most resource development takes place in either of two quite different time frames. For such activities as the exploration for oil or the construction of dams, there is a temporary need to transport into a site a large volume of equipment and material. For resource development per se, the transport requirements in such cases rarely last more than 5 years. Following completion of the activity, the traffic to and from the site usually drops to a small fraction of its temporary total. For such activities as mineral extraction or lumbering, on the other hand, the need for heavy and sustained transport can extend over a period of 5 to 20 years or more.

The environmental implications of these two basically different time frames for resource development are important. Temporary transport needs are likely to be met with "least-cost" roads characterized by poor engineering, cheap construction practices, and little or no environmental planning. Such transport ways may not even provide a viable access for more than a few years after the close of the initial resource development activity. In contrast, long-term transport needs usually dictate better designed, more costly roads. Such roads are usually those with proper drainage and a good fit to contours of the land. In and of themselves they cause far less damage to the environment than does the other class of roads. Properly designed roads, however, are also available for access over long periods of time and are thus more likely to bring about long-term changes in land use and settlement patterns in the immediate area.

Direction of Movement and Volume, Type, and Weight of Materials To Be Moved—A second determinant of environmental effects is the direction of movement required by resource development and the volume, type, and weight of materials that must be transported. Taken together, these factors combine to determine the choice of transport way; for purposes here, however, it is useful to separate these factors for analysis.

The major consideration for direction of movement is in relation to the ruling grades, a particularly important factor in countries with hilly and mountainous terrain. If heavy weights are required to go downhill, overall road length can be shorter, with a somewhat closer fit to contours of the terrain. If heavy weights must go uphill, a longer road with larger cuts and fills is required. The latter, of course, carries with it a much more extensive environmental effect in terms of potential erosion, natural drainage, and so forth.

The volume of materials that must be moved determines in large measure the capacity requirements of transport ways and thus the potential environmental effect. To continue the example, if very large trucks must be able to pass each other easily in opposite directions at all points, the access road must be wider than otherwise would be the case. If volumes are sufficiently high, railway transport may be employed. However, because of the curve and grade restrictions on railways, the total length of the transport way will be longer than for roads, the cuts and fills larger, and the direct environmental effects more extensive.

The type and weight of materials to be moved can also have differing environmental effects by dictating the mode of transport that must be used. If, for instance, distances are more than a mile, timber must be hauled by truck. (Aerial cableways can be used for short distances, and recently there has been some experimentation with cable-guided balloons, but neither are cost-effective for distances of any consequence.) Large building stones are another example of a resource usually requiring truck transport, even for very short movements, as are most granulated or crushable materials. The latter two may be moved by conveyor systems or pipelines if the volumes to be moved are sufficiently high. Both of these modes disturb the immediate environment less than roads or railways. But any means of continously flowing transport must have high volumes of materials to be moved if it is to be justified economically for distances of more than a few thousand meters.

Settlement Size and Patterns—A third determinant of environmental effect concerns the settlement size and pattern that may be required to carry out resource development. Any organized activity must draw direct labor and supporting services from somewhere. If the distances involved in resource development are small and a local labor supply is available, people may be moved by vehicles from existing communities to the site of activity and no new settlements will be directly required. Much resource development, however, requires additional manpower and supporting services to be brought into the area, in which case a new settlement must be established. For some forms of resource development (e.g., dam building) such settlements are temporary. In other cases significant settlements may be permanently established despite their lack of amenity and place in a plan (e.g., Brasilia).

Large settlements of 2,000 persons or more generally tend to have a significant and long-term effect on the immediate environment, especially in motorized countries. (Some small settlements may also have important impacts in certain cases—for example, by drawing upon limited water supply in arid areas.) Eventually, settlements may bring more access roads, air pollution from vehicles, and sewage and solid-waste disposal problems. Construction of cities requires that large land areas be cleared and leveled. In some countries this may mean draining wetlands and other natural habitat areas to remove birds, small mammals, and other wildlife. And ultimately as settlements grow, residential, commercial, and industrial activity will come, thus increasing the potential environmental effects manyfold.

Particularly in developing countries characterized by great urban population growth, it is difficult to overemphasize the importance of planning settlement patterns. Clearly, planning is critical for settlements that are intended to be permanent. Less obvious is the need to take into account the population potential of even temporary settlements. If new access for one resource (e.g., minerals) opens up other easily exploited resources (e.g., timber, arable land), a temporary settlement may grow much faster and become much larger (and hence more permanent) than originally intended; as a result, of course, the environmental effects are multiplied. Furthermore, these effects may be magnified by other factors. In many nations, large segments of the population are chronically in search of jobs, particularly employment in the monetary sector of the economy. The possibility of a job and the attractions of city life can cause large-scale rural migration to settled areas. The result takes the form of squatter settlements at the periphery of a population center—all too often on submarginal land without basic services. Since to provide services to these areas becomes more difficult and expensive once squatter settlements have been built, it is usually desirable to discourage settlement in submarginal areas or at least to channel squatters to more suitable sites. In such cases the eventual savings in providing public services may justify additional transport costs to secure a better long-term location for the settlement.

ENVIRONMENTAL EFFECTS OF TRANSPORT INFRASTRUCTURE AND OPERATION

Environmental Effects of Transport Infrastructure

Roads and Highways—In most countries, both developed and developing, the major form of transport for resource development is by road or highway. Probably the major immediate effect of these transport ways on the environment is erosion. Erosion is an obvious problem with cheaply built, low-capacity roads, typically used for first access to a resource development area. Such roads are often crudely cut with bulldozers and are not well graded and drained. Even where roads are paved, erosion is a major effect because of the destruction of ground cover and the opening of new drainage channels. Natural drainage may also be changed in minor ways, affecting areas immediately adjacent to the road. However, the limited construction involved in low-capacity roads usually precludes more extensive drainage effects, and in some cases natural drainage may even wash out a cheaply constructed road.

Erosion is a major environmental effect of many transport ways, and it merits a brief digression here. Many factors determine the extent of erosion from transport ways, including the kind of soil, the slope of the terrain, the intensity of rainfall, and the construction methods used. Much erosion occurs during the construction period (and depends on the type of way constructed, as discussed later).

Erosion can also occur after the construction period. For example, areas below a completed construction site may still erode because of runoff from impervious pavement, service areas, or compacted soil.

As this example suggests, erosion affects both the immediate construction site and beyond. Erosion damage to the construction site (what are here called direct environmental effects) can include gullied slopes and channels, washed-out work roads, undercut pavements and pipelines, and debris-laden work areas. This kind of damage can be repaired but always at considerable additional cost and with delays in work schedules. In addition, the indirect environmental effects of erosion can extend far beyond the immediate construction area affected.

Beyond the immediate environmental effects of roads on erosion and drainage, the most important impact of roads is on land use. As a consequence of roads, thousands of acres of previously undeveloped land may be opened for easy exploitation. Uncontrolled timber cutting is a frequent result. In addition to being an eyesore, uncontrolled timber cutting can also damage forests and their habitats, which support varied species of wildlife. The tendency to raise only one crop (monoculture) for the benefit of lumber and pulp can have environmentally significant effects, not the least of which is the loss of many native species. This in turn allows insects to flourish, insects that can devastate large forests of single species. Widespread application of insecticides is often necessary in the aftermath.

Transport access can also open up land for other abusive monocultures, often accompanied by strip settlements, razing of forests, and removal to new sites every 2 to 4 years. This in turn serves to destroy natural cover and accelerate erosion and the destruction of watersheds. In less forested areas, overgrazing can have dramatic environmental effects of a similar nature. Overgrazing occurs where cattle, sheep, and other livestock are overstocked on already depleted ranges. As a result the range's exposed soil is eroded away as wind, rain, and drought sweep over it. Particularly in arid and semiarid countries, the climate can add to the destruction.

As a result of new transport access, significant new settlements may arise, either because of population pressures pushing migrants to look for alternative settlement sites or because of resource development activity that encourages settling. In the long run, such land use changes and population concentrations are often the most significant environmental effect of new access roads.

Modern highways of a relatively high standard occasion some of the same environmental problems as cheaply built low-capacity roads but in different ways. The widths and gradient control of most well-designed, high-capacity highways require that large amounts of earth be moved in areas of rolling or mountainous terrain. This means that highway construction tends to create a greater erosion problem at the time of construction than do most cheaply constructed low-capacity roads. Such highway construction can increase the rate of land erosion a hundredfold (1, pp. 37-38). Once built, however, higher quality construction usually reduces erosion directly around the highway itself, although the major changes in runoff can create erosion in adjacent areas.

The impact of highways on natural drainage may be considerable, particularly where highways must be planned in the absence of adequate data. Unfortunately, good hydrographic studies are extremely expensive. This problem is pervasive and deserves some discussion because it affects not just road and highway construction but most major construction projects for transport ways.

In most developing countries, and particularly outside of major river basins, hydrographic data (e.g., on local rainfall, waterflow, drainage) simply do not exist. Moreover, such data are usually very expensive to accumulate. A preliminary study and description of drainage, for example, typically requires the presence of professional hydrographers over at least a 1-year period, along with extensive complex measurements and observations. An additional difficulty is that such preliminary studies still cannot provide the historical measurements (e.g., the 10-year maximum 24-hour rainfall) that may be the most important information to take into account. It is well known, for instance, that major construction fills often create "dam" effects that have unforeseen consequences. A typical effect is that construction projects create dams across wet-season runoffs, which in turn can cause changes in water distribution and eventually major flooding. In areas where historical data on local hydrography are available, highway or railway engineers can plan on the basis of such information. More typically, however, data are nonexistent, with the result that estimating stream flows and rainfall fluctuations is purely guesswork. Consequently, the environmental effects from such construction projects can turn out to be very harmful.

Another environmental effect of highways is that a high-standard road will usually bring with it a large volume of traffic, particularly if vehicles are available and a large urban area is near. Traffic resulting from tourism and recreation is but one case of additional land use that can have significant environmental effects if uncontrolled. Unlimited access to wilderness areas, for example, may transform such areas into simply another extension of civilization. Land-clearing and the destruction of flora and fauna on a fairly large scale typically accompany such traffic where there are no controls. For the long run, the tremendous boom in tourism in some countries (e.g., Mexico), teamed with rapid and cheap transport access to new areas, can threaten the very values on which tourist attraction is based.

Finally, it should be stressed that, as a general rule, the more money that is invested in the design and construction of a road, the less its immediate impact on the environment. Nevertheless, the pressure is almost always to build the greatest length of road or highway with any amount of money that is available. Problems of cost, therefore, are probably paramount in attempting to alleviate the environmental effects of highways and roads.

Railways—Generally speaking, the very high geometric standard to which railways are built and the requirement for easy curves and grades tend to cause much greater environmental effects as a result of construction than in the case of highways and roads. Railways also result in an even greater dislocation of natural drainage, due to the very large cuts and fills that open up relatively greater topsoil areas. On the other hand, railways are generally accompanied with less change in land use and settlement along the areas adjacent to the right-of-way than are highways and roads; the latter are easily accessible to people of little or no means but with substantial household effects to carry. Railroads are much less so.

With regard to the area of resource development activity, however, the very large transport capacity and relatively low cost of railroads may bring pressure for timber cutting or sand and gravel removal on a larger scale than would be the case for highways and roads. These are perfectly acceptable activities, of course, when carried out in the context of effective public controls to prevent poor practices. However, such supervision does not exist in many countries, regardless of their state of development.

Inland Waterways—Typically, the development of river basins for resource exploitation requires reliance as well on a number of supplementary transport ways. Because only a minority of river basins are navigable, most require access by road or rail of some kind. What is more, if waterways are expensive to bridge, transport is usually required on both sides of the basin, with feeder networks extending into the hinterland. For such supplementary transport ways the same environmental effects discussed earlier would apply.

Aside from these effects of supplementary transport systems, the use of inland waterways themselves for resource development can have important environmental implications. Particularly in countries with long coastlines and extensive river systems, inland waterways may afford the easiest transport between widely dispersed inland areas. Inland waterways have long been the most important means of shipping agricultural products in some areas, and water transport can also maintain a position of some importance in mineral extraction (e.g., the large-scale iron-ore traffic on the Orinoco River system of Venezuela). Efforts aimed at improving inland waterways may range from the construction of canals to the dredging of deepwater channels in delta areas and along rivers themselves to permit direct access by oceangoing carriers. Full discussion of the environmental effects of river basin development is beyond the scope of this paper. It should be stressed in passing, however, that dramatic changes can result when attempts are made to alter the course of nature by tampering with river ecosystems.

The St. Lawrence Seaway has contributed significantly to the economic growth of the Great Lakes Region in the United States and Canada by permitting inland access for oceangoing vessels. Nevertheless, it has done so at a high and largely unforeseen cost to the environment:

> The completion of the Welland Canal let the predatory sea lamprey into the Great Lakes. Trout, which had been the backbone of the Lakes' fishing industry, suffered greatly from the lamprey invasion. By the mid-1950's the trout and some other large, commercial predatory fish were nearly extinct. And with their near extinction, smaller fish, especially the alewife, normally kept under control by these predators, proliferated. The agressive alewife dominated the food supply and greatly reduced the numbers of small remaining native fish, such as the lake herring. The alewife became so numerous, in fact, that on occasion great numbers died and the dead fish along the shore caused a major public nuisance.
>
> Man attempted to restore the ecological balance by instituting sea lamprey control in the 1950's and 1960's and by stocking the lakes with coho salmon beginning in 1965—to replace the lost native predatory fish. Feeding on the abundant alewife, the salmon multiplied rapidly and by 1969 had become important both as a commercial and sport resource. Some of the salmon, however, were contaminated by excessive concentrations of DDT and were taken off the commercial market (1, p. 7).

The lesson from such examples, of course, is not that large-scale attempts to develop river basins should be abandoned but that the consequences of developing major river basin projects should be carefully studied from an environmental point of view in advance of undertaking the project.

Pipelines—The major environmental effect of most pipelines is in their construction, which usually cuts a swath through ground cover. In arid or semiarid areas with a flat terrain and relatively little natural growth, the construction of a pipeline usually carries with it little effect on the environment. Likewise, pipelines normally do not cause uncontrolled exploitation of resources in adjacent areas, because there is no paving or metalling over the right-of-way.

Perhaps the most publicized environmental effect of pipelines is when, depending on the commodity and location involved, pipelines must carry heated materials. Even though pipelines are insulated, there will be some effect on the surroundings. The seriousness of such environmental effects depends on the diversity (and hence the stability) of the particular ecosystem affected. A complex tropical forest, for example, provides more ecological stability than the limited plant and animal life found on the Arctic tundra. In the latter case the introduction of instability—conceivably by a heated pipeline—could trigger frequent violent fluctuations in some animal populations such as caribou, lemmings, and foxes.

Generally speaking (and aside from the problem of oil pollution discussed later), one can conclude that, from the standpoint of their environmental effects, pipelines can be preferred to most other forms of transport ways. Concern for the environment would suggest, therefore, that more emphasis be placed on the development of slurry transmission at lower daily tonnages as a possible substitute for road or rail transport of excavated materials.

Conveyors—Of all the high-volume material movement systems, conveyors probably disturb the environment least. Conveyor systems are usually built on a series of concrete or masonry piers and hence cause less damage to the immediate environment than pipeline construction. The range of possible applications for conveyor systems is limited, however, because, if costs are to be competitive, large volumes of materials must be moved.

Overhead Cable Systems—Of all movement systems, overhead cables usually have the least environmental impact. Unlike conveyor systems, cableways usually have long spans between piers and thus do not require the construction of heavy components at relatively short intervals. The cost of movement for overhead cable systems, however, is relatively high, for both construction and operation. Moreover, capacities are limited compared to conveyors or pipelines. At the present time, therefore, overhead cable systems are used only for relatively short distances (usually under 2,000 meters) in conditions of sharp slopes and severe terrain.

Air Transport—The environmental effects of air transport facilities will depend in large measure on anticipated and actual volumes of traffic. For most resource development transport (as distinguished from passenger and cargo services), the traffic generated will be limited due to the restricted carrying capabilities and relatively high costs. In some areas, however, air transport may develop and hold a considerable advantage. One example is that of meat shipment in countries such as Venezuela that are heavily dependent on this product. In Venezuela, several companies specialize in airlifting freshly killed steer carcasses to urban markets from points in the llanos not served by roads. Large-scale ranchers selling in Caracas and Maracaibo find the relatively high freight charges well compensated for by avoiding losses that would have been incurred by driving their animals on the hoof.

Where the volume of anticipated traffic requires air transport facilities to handle airplanes substantially larger than DC-3's, this usually implies a major construction project. Typically, a bulldozed road must be cut to the construction site in order to move equipment in and out. (One can build a 3,000-ft strip for airplanes under 30,000-lb gross weight by flying in equipment by air; beyond this, however, such a process becomes extremely expensive.) Thus, for building airports of any significant size, a major construction project is involved, much in the manner of the mining or dam-building projects discussed earlier. The environmental effects of these efforts would also apply with regard to providing access for the construction of air transport facilities.

Environmental Effects of Transport Operations

Exhaust Emissions—Obviously, the operation of machines on highways and roads—particularly trucks and automobiles—creates some air pollution. Air pollution adversely affects man and his environment in many ways with regard to human health, to vegetation and materials, to visibility, and to climate. However, the environmental effects of exhaust emissions are probably not significant in most transport operations for resource development, since these do not normally involve high traffic volumes and air pollution of objectionable intensity. Therefore, transport operations for resource development generally do not cause significant air pollution, except insofar as settlements are encouraged and large cities eventually grow up. Exhaust emission concentrations are, however, extremely objectionable and costly in city street networks.

Noise and Vibration—Transport operations for resource development can also generate noise and vibration. Aside from the normal noise and vibration for air and surface transport, the major problems are likely to arise in the exploitation processes themselves, especially in mining and crushing. In areas subject to landslides or snow avalanches, however, even normal noise levels caused by heavy vehicles of any kind (including trains) are hazardous. Preventive action to alleviate this problem would thus entail a necessary additional cost.

Temperature Changes—Changes in temperatures would seem significant only with regard to pipelines, as previously mentioned, and then only in relatively few cases. As indicated, heated pipelines would be objectionable in Arctic regions because of the effect on local ecology. In tropical countries, however, there would not appear to be any marked effect, as witness the movement of palm oil by pipeline in Malaysia. Neither would a properly insulated refrigerated line, which in most cases would be short in length anyway.

Oil Pollution—Oil pollution can result from the operations of various transport modes, many of which are not peculiar to resource development. Certainly the most dramatic of examples are the large oil spills (those exceeding 100 barrels), most of which come from oceangoing carriers operating outside of inland waterways. Nevertheless, a particularly significant source of pollution in some harbors and river basins occurs when ships discharge bilge and ballast water heavy with oils and other substances.

Oil pollution can also spring from sources on land. The disposal of millions of gallons per year of used motor-vehicle (crankcase) and industrial lubricating oils can pose a severe pollution problem. Principal disposal methods are dumping in sewers and rivers, dumping on land, use as road oil or for agricultural purposes, incineration, and reprocessing to fuel or lubricating soils.

In addition, oil (and other) pollution can result from hundreds of thousands of miles of pipelines, with daily capacities in the millions of barrels, that cross land, waterways, and reservoirs. Such pollution (in addition to the effects of pipelines on local ecosystems, as discussed earlier) can come both along the line and at terminus points. Construction and operation of such pipelines may create oil pollution along the line, either through chronic low-level leakage or through major breaks. Contamination of the water supply can be among the most damaging environmental effects. For example, if pipelines are laid in areas with extensive underground aquifers used as sources of drinking water or as catchments, there is a potential danger of serious water pollution. Because pipelines are often laid in trenches, it is frequently difficult to detect the point of leakage, and pollution may become apparent only miles away from its source. Where pipelines are above the ground, leaks and breakage can occur from faulty construction of foundations.

For most pipeline systems, the primary potential for oil pollution occurs at pipeline terminal points, where oil spills can be associated with the terminus itself or with storage loadings, de-ballasting, and shipping disasters. Oil spills can have damaging effects on marine life at the terminus (and consequently on the livelihood of local fishermen) as well as affecting water quality, as indicated above.

Prevention of oil pollution calls for careful planning of pipeline location, sound construction practices, and regular inspections of pipeline systems, particularly at terminus points. Contingency plans should be developed for cleaning up any oil spills, and tanker traffic should be controlled with the assistance of the latest navigational and communication systems. The dumping of oily ballast water in port areas should also be prohibited.

<u>Waste Disposal</u>—Waste disposal as a result of transport for resource development would appear to be a problem only in the case of slurry pipelines where water used to prepare the slurry may be wholly or partly drained off. Conceivably, the local pollution problem created could become serious if this water were dumped directly into a stream. On the other hand, if the water were put through settling ponds, the accumulation of residue over the years might be considerable. This suggests that interface terminals for the removal of water from slurry pipelines be placed away from peopled settlements. (In some applications, such as coal movement, this may not be necessary because the water is not removed.)

<u>Routings</u>—As transport networks grow, there may be cases where alternate routings for heavy motor vehicles from mineral- or timber-producing areas would enable these vehicles to be detoured away from areas of recreational appeal. The desirability of alternative routings would arise both to enhance the enjoyment of tourists and to preserve wilderness areas from ecological damage.

<u>Settlement Implications</u>—Another aspect of routing that merits separate attention concerns settlement implications. As indicated, the mere existence of regular transport of any kind has the tendency to encourage settlements unless local conditions are very forbidding. If settlements are undesirable in areas adjacent to access ways, controls of some sort will be necessary. Concern with settlement implications also suggests that resource access roads avoid routings too close to existing settlements. If it becomes necessary in exploiting a resource to recruit local labor, a connecting road for buses may be built. But construction and heavy hauling traffic should be kept away from settlements.

<u>Processing Plant Locations</u>—A great many materials—most notably mineral ores of any kind—place a premium on processing near the point of extraction in order to reduce the amount of unusable material that must be transported long distances. Processing plants require transport on their own account, and they produce waste (sometimes in very large volumes) that can have considerable effects on environment. In some cases the location of a processing plant so as to minimize transport costs could have drastic

effects on the environment. This would be particularly true where plant locations are close to population concentrations. Concern with the environment would suggest that the consequences of processing plant location be studied carefully from an environmental point of view in advance of undertaking the project. In some cases higher costs may have to be accepted if the potential environmental effects appear particularly damaging.

ECONOMIC DEVELOPMENT AND EQUITY ISSUES ARISING FROM A HIGH DEGREE OF CONCERN FOR THE ENVIRONMENT

Increased Transport Costs

The Effects of Increased Costs—Any improvements over existing transport practices for resource development will require additional costs. Transport costs are essentially of two kinds: one-time outlays (for providing transport infrastructure) and continuous outlays (for providing transport operation over time). The environmental effects of transport infrastructure and operation, as well as the kinds of improvements that could be made, have been discussed in the foregoing. In this section the concern is with the economic development and equity issues that arise as a result of increased transport costs.

The effects of increased transport costs on resource development enterprises will be determined generally by the principle of marginal costs. Simply stated, each increment in costs (over and above "existing" conditions, either actual or estimated) in the delivered price of a primary resource (or products produced therefrom) will make the resource more expensive relative to similar resources from other locations. (The quantity of the product that can be sold at the new price, of course, will depend on the elasticity of demand, discussed later.) To illustrate this principle in practice, two examples may be distinguished: that of the monopoly supplier and that of the multiple supplier.

In the first situation, a resource is extracted by a single supplier, often for consumption in the originating country. In such cases there is the possibility of controlling exploitation of the resource or the prices charged. If there are no controls, the elasticity of the product's demand will determine its market following an increase in transport costs for protection of the environment. (If there are multiple suppliers under oligopolistic conditions, there will most likely be a differential increase in transport costs. If environmental protection is required in one producing area but not another, the higher cost area will be at a competitive disadvantage. This will at least restrict the marketing radius of the high-cost production area and may even render prohibitively expensive the continued exploitation of resources there.)

In the second situation, there are many suppliers, and presumably the resource is traded in world markets. The possibilities of price and marketing controls when goods are traded in highly competitive markets are considerably reduced. The increment in transport costs will tend to limit the radius of marketability and may dictate whether the resource material can be developed profitably at all.

The extent of increased transport costs (and thus the effects on resource development) will be closely related to the degree of environmental protection desired. In general, the stiffer the standards applied, the higher the additional transport costs are likely to be.

The Distribution of Increased Costs—The increased costs for transport that arise as a result of concern for the environment may be borne by producers, consumers, the general public, or some combination thereof. As a general matter it can be assumed that producers will attempt to pass on any increased costs to the consumer. If a product is locally consumed and the demand for it is inelastic, then the consumption of the product will be largely maintained, at least in the short run. In the more likely event that the demand for a product is elastic, then less of the product will be purchased at its higher price. Governments may be called on to relieve this situation through various subsidies, price controls, and other measures.

If a product is traded internationally, then the shifting of additional costs to the foreign consumer will depend on the strength of the product's market, its relative price sensitivity for a given production area, and possible changes in the costs (and prices) of other producers. International policies of environmental protection might come into play here, and variations as to local meteorology, terrain, and drainage would be among the determinants of relative market prices, as discussed later.

It should be pointed out that many products, especially those with high unit values and small volumes (e.g., tin and chrome concentrates) have a high profit margin. Consequently, suppliers of these products who are faced with additional costs as a result of environmental standards may still stay in the market but at a lower level of profit. At least in the private sector, the more marginal firms will always be the first to be closed in times of increased market slack. (Public sector enterprises are probably more likely to get government subsidies for environmental protection, particularly where the establishments provide significant employment and/or contribute importantly to foreign-exchange earnings.) For products with low profit margins, with many sources of supply, and with sales in large volumes (e.g., bauxite, wheat) the economic viability can be vitally affected by very small increases in costs.

The Possibility of Internationally Distributed Costs—The costs of applying environmental protection standards seem certain to vary considerably from country to country. As a result, if standards are applied uniformly, then the differential increases in cost would certainly change the market relationships of both existing and prospective producers. Therefore, some form of international equalization may be deemed desirable. One approach might be an international aggreement on environmental protection standards modeled after the General Agreement on Tariffs and Trade (GATT), which has set forth principles of fair trading practices and has also led to a reduction in tariffs and other trade barriers. As applied to environmental protection standards, this approach could be accomplished in a manner that would keep most of the higher cost producers in the market at the expense of part of the profits of the low-cost producers. To some extent this would be a form of cross-subsidy from consumers—i.e., paying higher than necessary prices in order to obtain the largest and most widespread array of producers and at the same time a greater degree of environmental protection. The economic effect, of course, would be to spread the high costs of the most serious environmental preservation cases over the whole of the world market. If such an arrangement were not possible, then the enforcement of environmental standards would have exactly the same effect as any other cost element in the delivered price. As a result of increased costs, some production would not be initiated, some marginal existing operations would be forced to close down, and the rest would become less profitable.

Dealing With Existing Violations—If environmental standards are applied to new facilities only—and not to existing operations—then their major effect would be to discourage the establishment of certain new economic activity. New resource exploitation would be undertaken at a slower rate. However, the retroactive application of standards—that is, to both new and existing operations—poses an additional dilemma, i.e., the problem of existing violations.

The application of standards may mean substantial investments in nonproductive equipment and operations, interruptions in production, reductions in labor force and share of the market, and, conceivably, relocation to another country or shutting down altogether. Noncompliance with standards, on the other hand, implies a continuation of damages to the environment as well as the possible risk of international retaliation (e.g., through trade restriction).

Where existing violations are from operations that provide significant employment or contribute substantially to foreign-exchange earnings, the dilemma is particularly difficult. The fact that private enterprise may bear part of the compliance costs does not basically alter this public-policy consideration. In countries attempting to achieve sustained economic growth, the use of resources from either the public or the private sector for environmental protection is probably unproductive in the short and medium term. This assumes, of course, that most benefits to be derived from environmental protection are long run in nature (i.e., 15 to 20 years) and are therefore difficult to justify on a discounted cash flow basis over shorter periods of time.

If standards are applied, it is difficult to avoid the conclusion that governments would eventually pay for at least part of the cost of compliance in a majority of cases. If large investments are involved, however, it seems unlikely that many governments, particularly those in developing countries, can be reasonably expected to act. Action is especially unlikely on the part of those governments that believe they are already in an unfavorable competitive position.

Measuring Relative Cost Burdens

If in the long run some international financial assistance is to be made available for hardship cases, or if enforcement variances are to be granted, some means of measuring the relative cost burdens between nations in each case will be required. Among the factors that would be considered are the following:

1. The relative costs of environmental protection;
2. The relative wealth of the country (per capita GDP or some similar index could be used);
3. The relative fiscal capability of the country and the way this capability is used;
4. The extent to which environmental protection costs can be covered by the private sector;
5. The extent to which costs are in foreign exchange (particularly significant where up-to-date capital equipment must be installed); and
6. Some type of "optimum opening year test" on major portions of the larger outlays.

It may be desirable to include other factors, of course, and these are listed only to suggest some of the more important possibilities.

Distributing Relative Cost-Burden Assistance

If international assistance were available for hardship cases as a result of environmental protection controls, such assistance would clearly not cover all the control costs for all applicants. This raises the problem of how much assistance should be distributed. Among the factors that could be considered are the following:

1. The incremental costs of environmental protection compared with the incremental benefits that are expected to result from controls;
2. The overall project cost in relation to general measures of government activity (e.g., GDP, total government budget, capital budget, public works budget);
3. The relative foreign-exchange content and current foreign-exchance position of the country;
4. The public finance capability and relative "extent of effort"; and
5. The relationship of the case in question with regional, multinational, or international plans and problems.

Again, this list is illustrative, not necessarily complete.

MAJOR POLICY ISSUES AND FUTURE DIRECTIONS OF EFFORT

Identifying Problems, Priorities, and Objectives

The Appropriate Policy Context—Environmental problems are large and diffuse, and their true nature may be masked in many ways. As a result, policy-makers are not faced with a given problem (or even a set of problems) but a number of discrete environmental effects (e.g., erosion from road construction, abusive monoculture that arises as a result of new access ways). How these problems are dealt with will depend on how problems are defined. This, in turn, will be determined by the context in which policy-makers consider the environment. How a policy problem is perceived, how it is classified (either consciously or unconsciously) for purposes of analysis and action, and what group of policies it is related to are all part of the policy context.

Among the issues that might be considered in this connection are the following: Does it make sense to talk about the environment as a whole? Or must one deal with a series of specific problems? Should the focus be on the medium through which effects occur (e.g., air, water), on particular kinds of pollutants (e.g., oil, solid waste), or on the immediate location where effects are felt (e.g., land adjacent to transport ways)? Would a program of environmental protection be different from existing approaches (e.g., natural resource management), or is the environment simply a new way of looking at old things? The context in which environmental concerns are considered will determine (and be partially determined by) what standards are set, what enforcement policies are planned, and what levels of government and administrative agencies are assigned the tasks.

The Priorities—Perhaps the most important question facing policy-makers with respect to the environment concerns which problems to consider. The number of environmental problems is enormous; the time, money, and manpower available to deal with them are limited. Given the value differences and variations among areas, setting priorities is bound to be difficult. It is made even more so by the limited state of current knowledge. Nevertheless, an order of priorities has to be made, and an efficient program for solution of the problems has to be designed.

In light of this, what environmental problems resulting from transport for resource development are most pressing for an individual country? On what basis should priorities be set? The short-term benefits compared with the cost of taking action? The rate at which problems are increasing in intensity over the next few years? The irreversibility of long-term damage if immediate action is not taken?

The Objectives—Once problems are defined and priorities established, there are many specific environmental objectives that can be defined. One approach might begin with an objective stated in qualitative, nonnumerical terms (e.g., water suitable for swimming). This could then be translated into specific numerical quality levels to be applied to the environment (e.g., no more than X parts of suspended solids are to be allowed in river Y). Implicit in this approach is the notion that environmental protection is not an end in itself but a means to other societal values, such as health, recreation, aesthetics, and economic growth.

Thus, in this example, the objective of environmental protection is purely recreational. In this case investments in environmental protection should logically be compared with alternative investments for other kinds of recreational opportunities—e.g., the construction of swimming pools near centers of population. In the real world, of course, the objectives of environmental protection are likely to be much more complicated. But the important point is that policy-makers faced with decisions about the environment must weigh the costs and benefits of environmental protection against other societal goals—e.g., economic development. They must decide not just whether environmental protection is desirable, but how much should be spent to control what kinds of environmental effects, and where.

Standard Setting and Enforcement

The Standards—Assuming some agreement on the foregoing, policy-makers should be concerned with the two crucial steps in any program of environmental control: standard setting and enforcement. In the first, standards are set that prescribe what controls should be imposed or what action should be taken. In addition to stating the operational objectives of the program, such standards also provide a benchmark on the basis of which it is possible to measure progress.

Presumably, standards could be based on those environmental quality levels that are deemed desirable. To continue the previous example, a standard might state that no industrial plant could discharge effluent containing more than X parts of suspended solids into river Y. Such standards would represent the "teeth" of any control program.

Assuming that the desired environmental quality levels were not stipulated, another approach would be to tie standards not to some environmental objective but to prevailing "good practice"—e.g., installation of the best available control device or use of the best safeguard procedures possible. Particularly in developing countries dealing with the environmental effects discussed in this paper, the latter would probably be the only standard-setting procedure possible. Standards of this sort might stipulate that certain studies be made of the immediate environment prior to initiating major transport projects or that specified design characteristics be incorporated at the time of construction. This implies that there is some public body to determine what good prevailing practices are, to see that such practices are adhered to, and possibly to provide incentives to encourage improvements in existing practices.

Whatever approach is taken to standard setting, a number of questions must be resolved. Should standards take into account the differences in marginal costs and benefits of environmental protection among various areas? Or should they be stipulated "across the board" for everyone? What account, if any, should be taken of variations in meteorological and hydrographic conditions, topography and terrain, and local ecology? In the event that the least-cost (including cost to the environment) transport route would traverse two or more areas, what should be proposed? Should standards be set ex post facto or retroactively?

The Enforcement—As used here, enforcement is the process whereby damaging environmental effects are halted or reduced and/or potential environmental effects are prevented. Presumably, enforcement would proceed on the basis of the standards set. But the step from standards to enforcement is by no means automatic. Consequently, a number of issues similar to those involved in standard setting arise, if in slightly different form.

An initial set of questions concerns how far enforcement should be extended. Should enforcement extend to all areas, or only those that can afford the burden of control costs (including reduced economic activity, if applicable)? To all areas affected by transport for resource development? Or only to those that appear to be experiencing significant environmental effects at this time? To all existing and future transport infrastructure and operation, or just to those in effect after enforcement begins?

A related set of questions concerns how swiftly enforcement should proceed. If ex post facto enforcement is required, should this be given first priority? Or should such improvements be implemented gradually over an extended period, as priority is accorded to the enforcement of standards for all new transport facilities? Should some areas—i.e., those with greater burdens—be given longer periods than others to reach full compliance?

A third set of questions concerns the economic development and equity issues discussed earlier. What variances, if any, should be granted to hardship cases? Should assistance of some sort be provided to help cover the costs of control? If so, who would pay for such assistance, and how would it be administered?

Areas for Enforcement—Environmental protection provides some excellent examples of problems that defy political boundaries. The appropriate area for dealing with water pollution, for example, is generally assumed to be the river basin. But most rivers cross jurisdictional boundaries of some sort, and many are in fact the dividing line between countries. This is perhaps less a problem with man-made transport facilities, largely due to the lack of cooperation among nations on regional airports, roads, and port facilities.

Nevertheless, a decision that must be faced in any environmental protection program concerns the logical geographic area for planning and implementing enforcement programs. Should it be the area(s) served by the transport way or the land immediately adjacent to it? Or should the area for enforcement be the region in which resource development occurs? Should the area of enforcement for the environmental effects discussed in this paper be one that coincides with the one for dealing with related environmental problems (e.g., water pollution)? In large measure, the appropriate area for enforcement may be determined by how the problem is defined (a transport problem, a water pollution problem, a resource management problem, etc.).

Another set of questions concerns the difficulty of striking a balance between the appropriate area for dealing with the problem (however defined) and the administrative agencies capable of dealing with it. Where the area of enforcement does not coincide with existing jurisdictions, what new kinds of legal authority and administrative machinery are needed? Where existing agencies are available, what are their capabilities?

Alternate Transport Technologies—Although alternate transport technologies probably offer little to relieve the existing environmental effects of transport infrastructure and operations, they may open up some medium- to long-term opportunities. The following are illustrative of these possibilities.

Where transport access is required only temporarily and where extreme weights are not involved, airlifts, particularly by helicopter, may be used to lessen environmental effects. Oil-drilling operations offer an excellent opportunity of such an application. The use of airlift could also be applied to the laying of pipelines and conveyor systems. This would eliminate much of the bulldozer damage to ground cover and resulting erosion that was discussed earlier in detail. It may also be possible to airlift some seasonal crops, especially high-value perishable commodities like meat and fruit.

Another possibility would be the use of all-terrain vehicles with large tires and very low unit ground pressures. In many cases their use would require only the removal of trees, with the result that the typical environmental effects of road-building (e.g., ground damage, erosion) would be reduced. Not the least of the problems that could be alleviated by the use of ATV's are the long-term changes in land use and settlement patterns that are often occasioned by the opening up of new access roads. Access by ATV's would provide not nearly so attractive a transport way for settlement migrations. At present, however, ATV's have higher purchase prices and unit operating costs than conventional road vehicles. Another drawback is that, although ATV's can be obtained with high load-carrying capacities, they are presently rather slow, and thus the distances over which they can be used are limited.

Areas for Future Research—Three major areas of research are suggested as a result of this review of existing knowledge in the area of study covered here. First, much more needs to be known about the extent and seriousness of the problems that have been identified. Poor limbering practices may be cited as an excellent example. The prevalence of this problem is not entirely known, although it is suspected to be very widespread. Furthermore, there are likely to be built more access roads with serious environmental effects for log and lumber production than for most other major tropical products. (Pineapples, cane sugar, palm oil, and rubber are examples of commodities that are presently produced for the most part in well-established areas to which access roads have already been constructed.) With total world demand for sawlogs and timber growing faster than total world population, poor lumbering practices are likely to be an increasingly serious problem. Already some islands in the South Pacific have been denuded of timber in the process. But the worldwide prevalence of this problem is not known. If this were seen as a priority area, presumably some sort of global survey would have to be initiated before an environmental program could be begun. Other equally relevant examples could also be cited.

The second major area of research is concerned with the nature and extent of environmental effects. Much environmental research has been done along these lines in recent years. Yet, as this paper points out, much more needs to be known if problems are to be defined and enforcement programs developed. At the present time, roads are constructed and dams built with exceedingly imperfect knowledge as to their environmental effects on water, soil, fish, and wildlife. Concern for the environment would suggest more attention at the design stage of major transport projects to the environmental implications of construction, as well as the possibility of incorporating environmental safeguards into the basic design of new projects. It also suggests that more basic research and monitoring of the environment are needed. For example, the lack of basic hydrographic data for many regions of the world has been discussed earlier as a major problem facing planners engaged in resource development projects. Until more is known about the environmental consequences of alternative actions, it will be extremely difficult to determine what controls or safeguards should be imposed and how stringent they should be. The problem is particularly difficult because some environmental changes have long lead times, and their consequences do not turn up until many years later. Without better basic knowledge and information (What are the significant trends and changes? What are the important interrelationships? What do these mean to man?) one can only react to environmental effects after they have become serious enough to see. And unless some changes can be anticipated in advance, their consequences can be extremely costly and difficult (indeed impossible) to correct.

The third area of environmental research is concerned with methods of controlling the effects discussed in this paper. More needs to be known about effective and economical control techniques (e.g., practical ways of preventing erosion from transport ways). More also needs to be known about alternate transport technologies that are (or could be made) available to reduce environmental effects. The desirability of doing something about the environment depends in part on what can be accomplished and at what cost. More research in this area would go far in assisting policy-makers to determine what should be done.

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