The Completeness and Vulnerability of Road Network in Bangladesh

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Abstract

Road transportation has emerged as the most popular mode of transportation in Bangladesh. Despite being the most popular mode, it suffers heavily from network failures due to natural as well as man-made disruptions. This paper presents the major findings of a study relating to the completeness of the road network with respect to the pattern of traffic flow and its vulnerability with reference to the disruptions caused by the flood of 1998. The study considered development of road network by regions on the basis of degree of network completeness by connectivity indices namely, γ and α indices that apply the Graph Theory to measure the geometric pattern of a network. The analysis revealed that the road network development in Bangladesh at the national and regional levels is still in its early stage. The existing network has a very few circuits for movement at all the levels and, therefore, susceptible to high risk of disruption. In terms of circuitry, the network has a bare marginal grid configuration at the divisional and national levels. The present overwhelming dependence on road transportation system will continue in the future. In this context, completeness of the whole road network should be considered in all future road planning exercises. Assessment of vulnerability of links around Dhaka deserves special consideration as any link failure of the national highways around Dhaka affects almost the whole system. To improve the reliability of the network, selected links of the existing feeder roads can be gradually upgraded to regional road standards so that alternative routes around the most critical links can be created. Additional alternative paths for the major movements should also be considered to improve network reliability and thereby upgrade the network to a modest grid.

INTRODUCTION AND BRIEF HISTORY OF ROAD TRANSPORT DEVELOPMENT

The history of modern road development in Bangladesh is not very old. During the British period, water transport and railways served as the two major modes. At that time, road development was considered as a subject of local interest and therefore, the responsibility was given to the provincial governments. They in turn transferred the responsibility to the local bodies - the District Boards (Khan, 1982). The colonial British Government prepared a master plan for road development in 1938 for India, which included the then Bengal. However, road development according to that plan did not advance much due to outbreak of the World War II in 1939. Consequently, at the end of the British Rule in 1947, there were only few kilometers of inter-urban paved roads in the parts of present Bangladesh.

Realizing the importance of road transportation, the Transport Advisory Council set up by the then Government of Pakistan recommended the preparation and implementation of a Six Year Plan. Implementation of this Plan also did not advance much due to non-availability of sufficient funds. After launching of the First Five Year Plan (FFYP) of Pakistan in 1955, the earlier road development plan had to be reviewed and revised. The FFYP was followed by two more successive Plans. Under these plans, about 2,500 miles (4,023 km) of mostly single lane paved roads and another 1,500 miles (2,414 km) of roads under various stages of construction were built by 1971 (Khan, 1982).

Road building received a new impetus after the emergence of Bangladesh in 1971. Very soon road transportation became the most popular mode of transportation. Its shares of both passenger and freight traffic became higher than combined shares of rail and water transport. The system is, however, still being developed and there are various issues that deserve attention for its effective functioning. The system suffers heavily from network failures due to frequent natural as well as man-made disruptions. This is especially prevalent during annual floods and other local disorders. In view of these network failures, it is critical that the vulnerability of the present network should be examined with respect to the present pattern of traffic flow. The road network development is not still complete. As such, the element of reliability of the existing network can be considered in future road planning so that in the event of any link disruption, major or strategic traffic flows can be re-routed to keep the system effectively functioning.

SCOPE OF THE STUDY

Examining the completeness and reliability of the road network system of Bangladesh was the major concern of this study. Vulnerability of the network was examined with special reference to the network disruptions during the flood of

1998. In addition, it considered the degree of completeness of the rail network as a supplementary mode of transportation. An attempt was also made to relate road network development to the overall transport demand and its spatial distribution in the country as revealed by the Bangladesh Transport Sector Study (BTSS) of 1993 and Bangladesh Integrated Transport System Study (BITSS) of 1998.

OBJECTIVES OF THE STUDY AND OUTCOME

The primary objectives of the study were to identify the nature of road network deficiencies at the national and regional levels and to assess network completeness in the event of emergency situations that may cause disruptions to the normal traffic flow pattern. The specific objectives of the study were: (1) Identification of disrupted road links during the flood of 1998; (2) Assessment of the degree of completeness of road network at national and regional levels; (3) Relating road network development to the major traffic flows at the strategic level and (4) Suggesting recommendations for network improvement.

The nature of the major deficiencies of the road network was identified. The degree of completeness and circuitry of the network were measured and suggestions have been made to make the road transportation system more reliable.

METHODOLOGY

Tools of Analysis and Their Theoretical Considerations

The study considered network development by regions on the basis of degree of network completeness, circuitry and other characteristics by *connectivity indices* namely, γ and α indices that apply the Graph Theory to measure the geometrical pattern of a network (Black, 1981; Taaffe and Gauthier, 1973). A brief discussion on these indices is presented next.

Structural configuration and complexity of a road network can be analysed by measurements that describe the degree of its network connectivity. Graph theory provides a number of such discriminating measures. Two of the most commonly employed measures of connectivity are the gamma and alpha indices. These are explained hereafter.

The Gamma Index

The gamma index is the ratio of the number of edges in a network to the maximum number possible in that network:

$$\gamma = \text{actual edges} / \text{maximum edges} = e / e_{max}$$

The actual edges (e) or linkages can be readily ascertained by counting. For a planar graph, the maximum number of edges (e_{max}) may be computed from the expression 3(v-2) as explained by Taaffe and Gauthier (1973). In this expression v represents the number of vertices in the network. Thus Eq. 1 can be rewritten as:

$$\gamma = e / e_{max} = e / (3(v-2))$$

Network connectivity as measured by gamma index can involve a set of nodes having no interconnections (i.e., an unconnected graph) at one extreme; the other extreme being a set of nodes in which every node has an edge connecting to it to every other node in the graph (i.e., a maximum connected one). The connectivity of a network is evaluated in terms of the degree to which the network deviates from an unconnected graph and approximates a maximum connected one. The numerical range for the gamma index is thus between 0 and 1.

The Alpha Index

In a minimal configuration of a network, only a single and a unique path can be identified between all pairs of nodes. Additional edges between nodes create circuitry. A circuit is defined as a finite closed path in which the initial node of a linkage sequence coincides with the terminal node. In practical terms, the existence of circuitry implies availability of alternative paths between nodes in the network.

The alpha index is a ratio measure of the number of actual circuits to the maximum number possible. The actual and maximum number of independent circuits in a network are functions of the number of nodes in the network and the number of linkages necessary for minimal connection between nodes. Taaffe and Gauthier (1973) explained that the actual and maximum number of circuits in a given network can be found from the following two expressions:

Actual circuits = e - v + 1
Maximum circuits = 2v - 5

where, e and v have the same meaning as before.

Thus alpha index can be expressed as:

$$\alpha = (e - v + 1) / (2v - 5)$$

Data Collection and Analysis

The analyses were primarily based on network and other information available from secondary sources. Data collected from the RHD and LGED sources and findings of the Bangladesh Transport Sector Study of 1993 and Bangladesh Integrated Transport System Study of 1998 were used in this study. However, collection of additional data from primary sources and newspaper clippings was also necessary to supplement the collected data from secondary sources.

In this study road network comprising only the national and regional roads under the RHD was considered. No feeder or other local roads were considered. This was done for the fact that feeder and other local roads are of much lower standards than the national and regional roads. As such, these roads are not capable of carrying heavy flows of national and regional traffic. Consequently, most of these roads do not supplement the national and regional roads. Furthermore, reliable information on their actual condition, length, alignment, etc. was also not available. A GIS-based analysis of the road network using PC ARC/INFO and other computing resources was carried out to accomplish the objectives of the study.

LIMITATIONS OF THE STUDY

Information on link failures only during the flood of 1998 was available from the RHD headquarters. Information on past failures was not readily available and so it could not be ascertained which link failures were more frequent. Feeder or local roads had to be excluded at all the stages of network analysis as reliable information regarding their alignment and condition was not available. In the absence of these information the present study was not able to make any specific recommendation for upgrading of existing selected feeder roads around a vulnerable link of the national network to improve the reliability of road transportation. Reliable data on water transport links around the broken road sections were also not available from secondary sources. Consequently, it was also not possible to ascertain if water transport can effectively play a supplementary role to road transportation at these locations.

ROAD NETWORK OF BANGLADESH

Roads in the rural areas of Bangladesh can be classified into four major categories such as national, regional, feeder, and other unclassified local roads. The Roads and Highways Department (RHD) maintains the national (category N), regional (category R), and feeder roads of type A (category F). The Local Government Engineering Department (LGED) has the responsibility for the type B of F category feeder roads and some of the other local roads. The rest of the local roads belong to local government agencies. Although both RHD and LGED have adopted standards for the various categories of roads under their jurisdictions, at present not all roads meet these specified standards according to their designated categories. However, it is expected that roads that do not meet the specified standards will gradually be upgraded to their specified standards.

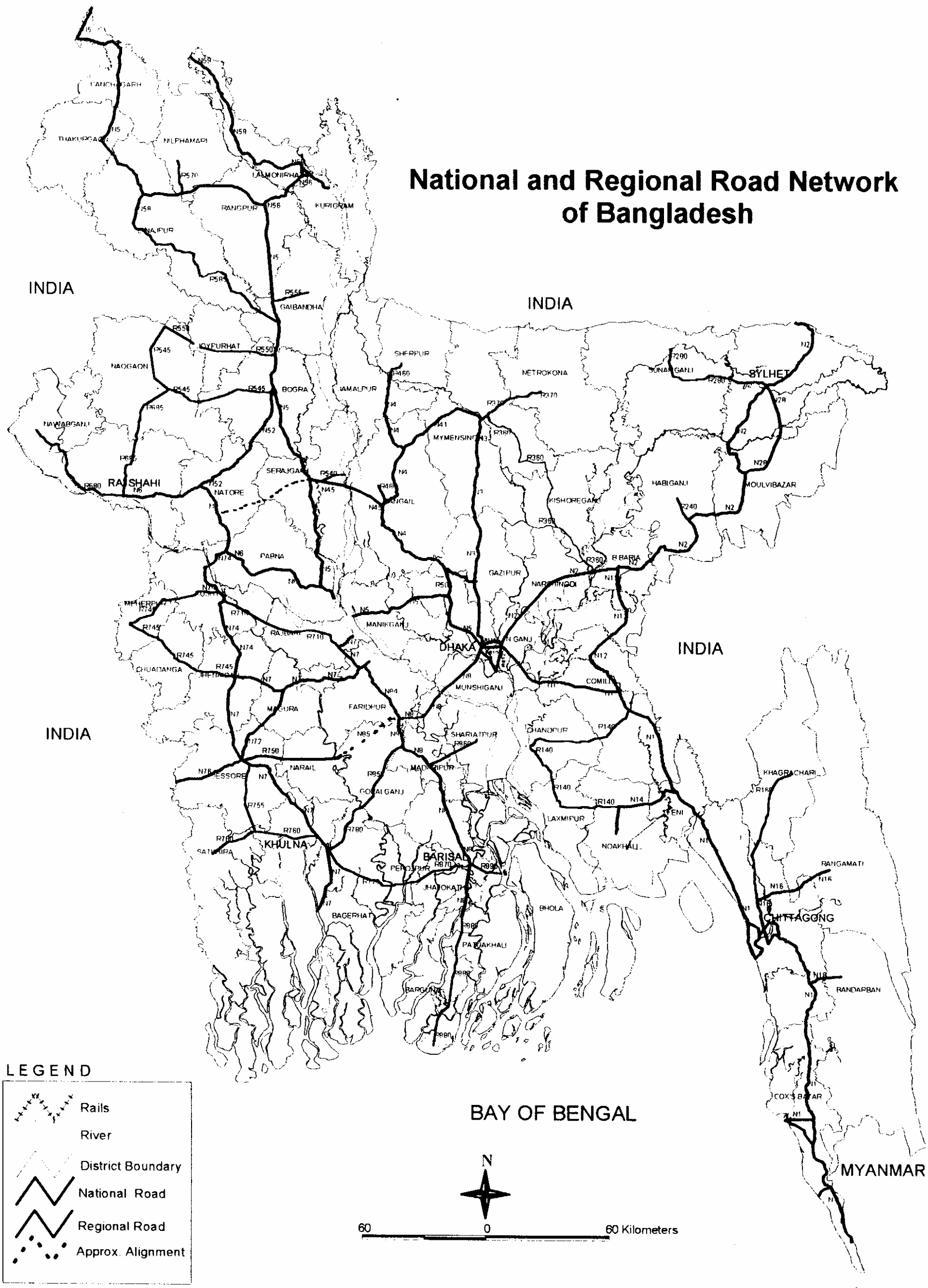

Figure 1: National and regional road network of Bangladesh

Density of national and regional highways (categories N and R) in Bangladesh and their lengths in seven RHD zones is presented in Table 1. The total lengths of national and regional highways in the country are 2,996 km and 1,710 km, respectively. The combined network of these two categories of roads is provided by Fig. 1. It may be mentioned here that RHD has adopted a numbering system for the roads under their jurisdiction. However, they have not yet finalised numbering of all the roads. It is also understood that some current road identification numbers may get changed in future.

As shown in Table 1, there is some degree of variation in road network density by zones. Rangpur Zone has the highest density with 3.95 km of road per 100 sq. km of area, closely followed by Rajshahi Zone with 3.80 km per 100 sq. km of area. Chittagong Zone has the lowest density with 2.33 km per 100 sq. km. The coefficient of variation (COV) is 17.9%, which indicates a moderate variation of road density by zone.

Table 1: National and Regional Road Network Density in Bangladesh by RHD Zones

RHD Zone	Road Length (km.)			Total Area (sq.km.)	Network Density per 100 sq.km.
	National Highway	Regional Highway	Total Length		
	(N)	(R)	(T = N+R)	(A)	(T / A)
Dhaka	562	263	825	24111	3.42
Comilla	558	229	787	25297	3.11
Chittagong	387	104	491	21070	2.33
Rangpur	556	243	799	20203	3.95
Rajshahi	336	208	544	14310	3.80
Khulna	338	376	714	22274	3.21
Barisal	259	287	546	20305	2.69
Total (km)	2996	1710	4706	147570	-
Mean	-	-	-	-	3.22
Standard Deviation		-	-	-	0.58
Coefficient of variation		-	-	-	17.9%

Source: Based on data obtained from RHD, Dec 1998

SIGNIFICANCE OF ROAD TRANSPORTATION IN BANGLADESH

As already discussed, road transportation has become the most popular mode of transport in the country. During the last twenty years the share of road transportation for the whole country has increased from about 40% for goods and 50% for passenger traffic to about 75% for both the sectors. However, when movement along the five major corridors (as identified by the BTSS of 1993) are only considered, share of road transportation is somewhat lower. Tables 2 and 3 provide movement of freight and passenger traffic by the three main modes along the five major corridors. Figures 2 and 3 portray these five major corridors, separately for passenger and freight movements. Relative significance in terms of volume of traffic of the three modes namely, road, rail and water transportation is also shown in these figures.

The BTSS forecasts showed that the share of road transportation for freight traffic would increase from 60.5% in 1993 to 75.5% in 2000. During the same period the share of passenger traffic is expected to increase from 41% to about 49%. It is important to mention here that during this period volume of freight and passenger movements were forecasted to increase by 84% and 80%, respectively from their levels in 1993. These findings clearly show that the strategic transportation system of the country will continue to remain very heavily dependent on road transportation in future. Similar conclusions were also reached by an earlier study concerning overall demand of road transportation (PCI et al., 1985).

Table 2: Freight Movement Along Major Transport Corridors of Bangladesh

Corridors	1993				2000			
	Road	**Rail**	**Water**	**All**	**Road**	**Rail**	**Water**	**All**
	(Million tons p.a.)				**(Million tons p.a.)**			
Dhaka-Chittagong	6.5	1.2	2.8	10.5	13.2	1.7	3.5	18.4
Dhaka-Northwest	3.8	0.7	2.6	7.1	15.3	0.6	2.2	18.1
Dhaka-Khulna	3.8	-	2.5	6.3	0.4	-	2.4	2.8
Dhaka-Sylhet	2.6	0.3	1.9	4.8	4.4	0.5	2.5	7.4
Khulna-Northwest	2.1	0.3	-	2.4	8.9	0.3	-	9.2
Total	18.8	2.5	9.8	31.1	42.2	3.1	10.6	55.9
(%)	60.5	8.0	31.5	100	75.5	5.5	19.0	100

Source: Calculated from the BTSS figures, (BTSS, 1994)

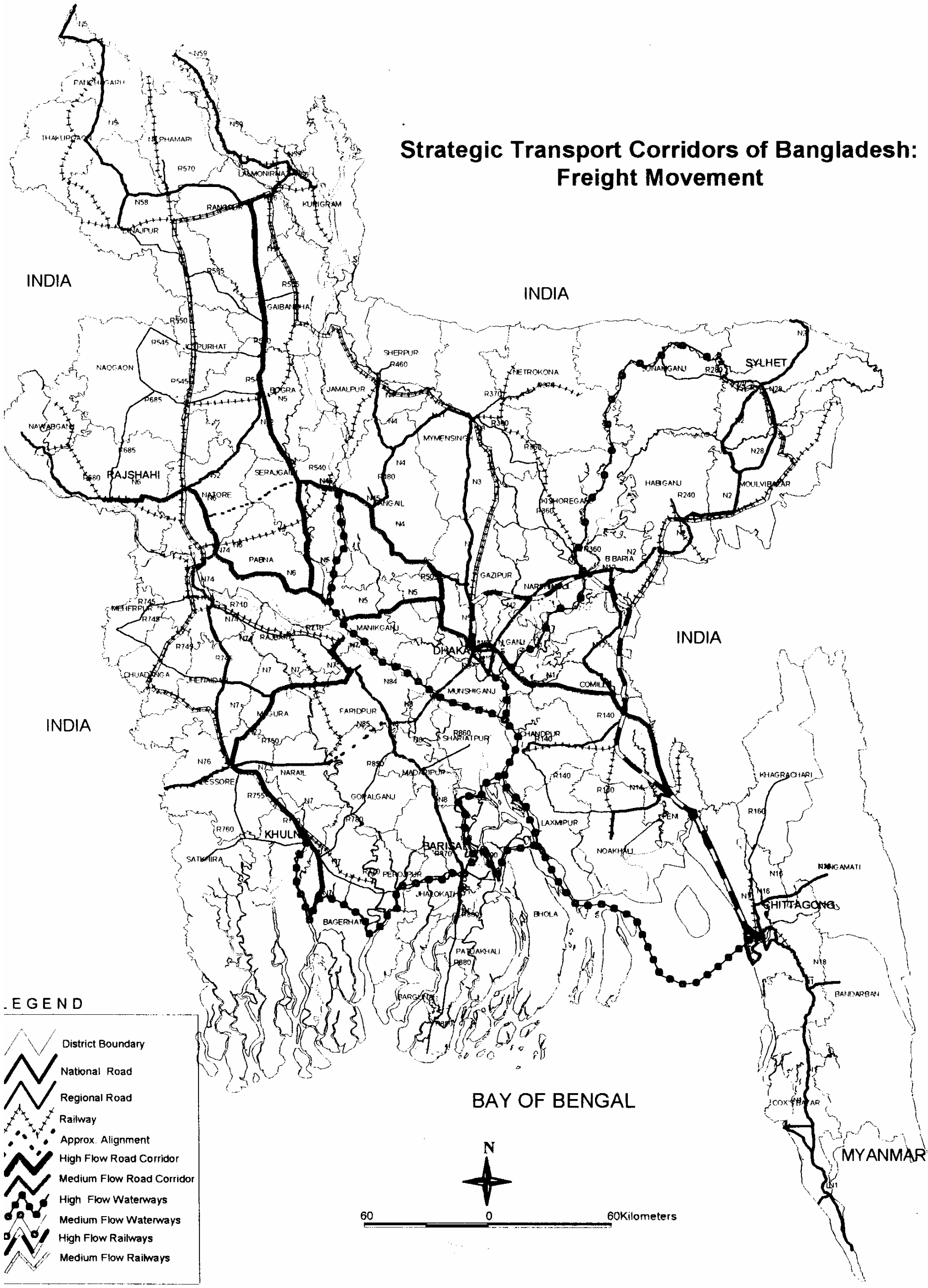

Figure 2: Strategic transport corridors of Bangladesh: Freight movement

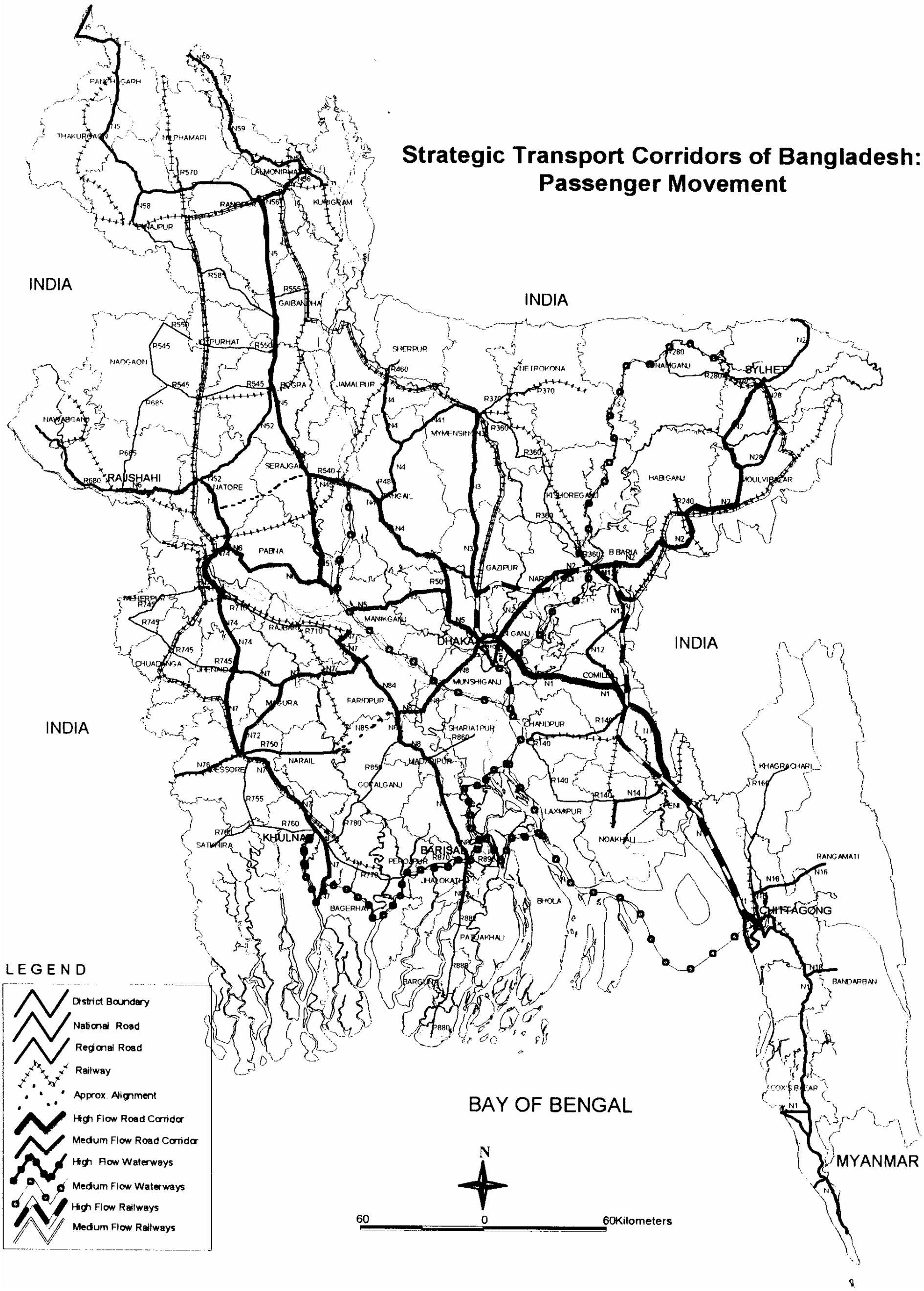

Figure 3: Strategic transport corridors of Bangladesh: Passenger movement

Table 3: Passenger Movement Along Major Transport Corridors of Bangladesh

Corridors	1993				2000			
	Road	Rail	Water	All	Road	Rail	Water	All
	(Million p.a.)				(Million p.a.)			
Dhaka-Chittagong	7.2	12.8	3.2	23.2	30.7	25.1	10.0	65.8
Dhaka-Northwest	4.6	4.5	1.6	10.7	16.0	7.2	2.9	26.1
Dhaka-Khulna	11.9	-	10.7	22.6	10.5	-	9.9	20.4
Dhaka-Sylhet	4.3	4.6	3.4	12.3	5.7	6.1	3.5	15.3
Khulna-Northwest	3.6	4.7	-	8.3	6.6	7.9	-	14.5
Total	31.6	26.6	18.9	77.1	69.5	46.3	26.3	142.1
(%)	41.0	34.5	24.5	100	48.9	32.6	18.5	100

Source: Calculated from the BTSS figures, (BTSS, 1994)

FINDINGS OF NETWORK ANALYSIS

The structural configuration of the road network (comprising national and regional roads) was analysed at three spatial levels to evaluate its degree of completeness and availability of alternative paths for traffic flow. The three levels were: the former district level, the divisional level and the national level (to capture the five major BTSS corridors of traffic flow). However, some adjustments were necessary to represent the actual spatial nature of traffic movement at these levels. The values for the two indices namely, gamma and alpha were calculated for the road network at these three spatial levels and are presented in Table 4.

The gamma index measures the connectivity or degree of completeness of a network. For an unconnected graph its value is 0 and for a maximum connected graph the value is 1. This index can also be used to compare relative network connectivity by regions. There are three basic network configurations: spinal, grid and delta. The spinal pattern or the tree structure is the characteristic of a minimally connected network whereas the delta represents a maximally connected one. The grid configuration is a transition between the spinal and delta types.

Boundary values for the gamma index can be logically established by considering the characteristics of these three types of network are as follows (Taaffe and Gauthier, 1973):

Spinal: $1/3 \leq \gamma \leq 1/2$ where, $v \geq 4$

Grid: $1/2 \leq \gamma \leq 2/3$ $v \geq 4$

Delta $2/3 \leq \gamma \leq 1.0$ $v \geq 3$

Table 4: Degree of Completeness of Road and Rail Network at Different Levels

Level	Name	Road network		Rail network	
		Gamma Index	Alpha Index	Gamma Index	Alpha Index
Old District	Sylhet	0.42	0.07		
	Mymensingh	0.37	0.00		
	Jamalpur	0.44	0.00		
	Dhaka	0.39	0.06		
	Chittagong	0.37	0.00		
	Tangail	0.39	0.00		
	Comilla	0.36	0.00		
	Noakhali	0.40	0.00		
	Rangpur	0.36	0.00		
	Dinajpur	0.39	0.00		
	Bogra	0.39	0.00		
	Rajshahi	0.36	0.00		
	Pabna	0.37	0.00		
	Kushtia	0.38	0.00		
	Jessore	0.40	0.05		
	Khulna	0.36	0.00		
	Faridpur	0.35	0.00		
	Barisal	0.38	0.00		
	Patuakhali	0.38	0.00		
Division	Sylhet	0.42	0.07		
	Dhaka	0.38	0.06		
	Rajshahi	0.39	0.07		
	Chittagong	0.36	0.02		
	Khulna	0.38	0.05		
	Barisal*	0.34	0.00		
National	All Districts	0.38	0.06	0.35	0.01

(*) Faridpur region included

Findings of the analyses as presented in Table 4 show that at all the three spatial levels the values of gamma index varies between 0.34 and 0.44. This is a characteristic of a spinal type of network - that is the network is connected only to a minimal degree. The variations of the index values either at the old district or divisional levels are not statistically significant. The index values indicate that the network can still be considered at its early stage of development. There are very few alternative links for movement from one node to another node. Consequently, the majority of the paths of traffic flow are unique.

The alpha index indicates availability of alternative paths or circuitry between nodes in a network. Thus it can give a measure of network reliability. The values of this index are also provided in Table 4. At the old district level of movement, only two districts have a single circuit or alternative path of movement. At the divisional level, except Barisal, the situation is marginally better. However, the values of the index are still lower than 0.1. It shows clearly, that the existing network has a very few circuits and therefore, susceptible to high risk of traffic flow interruptions. The situation is not different at the national level also where very few alternative paths are available for movements.

The boundary values of this index for the three types of network configuration - spinal, grid, and delta are also provided in Taaffe and Gauthier (1973). In a spinal type the value is 0. For a grid the value is greater than 0 but less than 0.5; and for a delta it is higher than 0.5. Accordingly, it shows that in terms of circuitry the network has a bare marginal grid configuration at the divisional (except for Barisal) and national levels. All the five major corridors of traffic movement are served by a very few alternative routes.

It can be seen from Table 4 that the network characteristics of the rail network are even worse. Furthermore, the present network was developed about a hundred years back to serve a different pattern of traffic movement. Unless the network is reoriented focussing the present movement pattern, it would be difficult to regain any part of rail's lost share of traffic. However, if network were improved to increase the accessibility of the major centres by railway at a level comparable to that by road transportation, it would make some difference only for the share of traffic at the strategic level.

FLOOD AFFECTED ROADS

The 1998 flood was the most severe in the last 100 years in terms of magnitude and duration, extent of damage to properties and physical infrastructure and human sufferings. It started in early July and did not recede until September. The flood affected about 75% of the whole country.

Many roads were under water for more than a month. Typical road damage was wearing of surface, shoulders and embankments due to heavy flow of water over the road surface. In the more severe cases, road embankments were breached and the backfills to bridges and culverts were washed away. However, the proportion of damage to feeder or F category roads was much higher than to national and regional (categories N and R) roads. According to the flood damage assessment report of RHD, 22 bridges on national highways were washed away and a total of another 1263 bridges were assessed as having suffered flood damage (RHD, 1998).

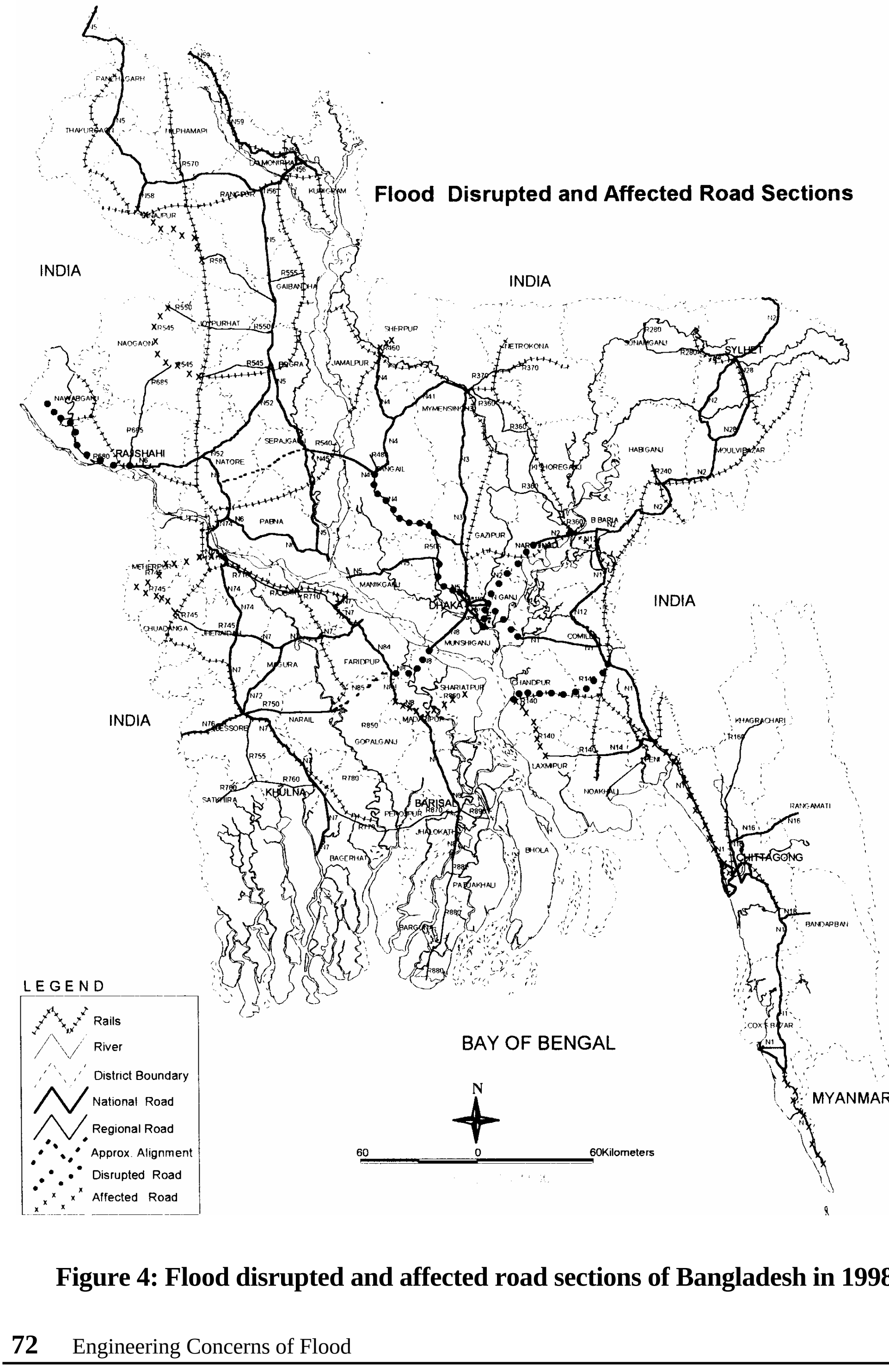

Figure 4: Flood disrupted and affected road sections of Bangladesh in 1998

The disrupted and affected road links are shown in Fig. 4. In Dhaka Zone four links of national highways (N1, N2, N4 and N5) were disrupted and traffic movement on one regional highway (R460) was affected. The Kanchpur to Daudkandi link of N1 was totally disrupted which obstructed the traffic movement along the Dhaka-Chittagong strategic corridor. The disruption of the Kanchpur-Narshingdi link on N2 affected another strategic corridor between Dhaka and Sylhet. The traffic movement along Dhaka-Northwest strategic corridor was also severely affected due to two link failures on N4 and N5. The Kaliakoir-Tangail link on N4 was totally disrupted due to a number of bridge failures. On N5, the Mirpur bridge to Nabinagar link was deeply flooded. This caused disruption of normal traffic along both the Dhaka-Khulna and Dhaka-Northwest corridors.

Two links of the national highway N1 were affected in Chittagong Zone. The Feni-Chittagong link affected movement along the strategic Dhaka-Chittagong corridor. It may be mentioned here that there is no alternative route to this affected link. The second affected link was between Cox's Bazar and Teknaf. In Comilla Zone, regional highway R140 was disrupted in one location between Lalmai to Chandpur and was affected at two other locations between Chandpur to Raipur and Raipur to Lakshmipur. These links play a significant role in movement within this region.

All the affected and disrupted road links in Rajshahi Zone were on regional highways. The Rajshahi to Nawabganj link of R680 was totally disrupted. Three links of another regional highway R545 were also affected. These were from Naogaon to Mohadevpur, Mohadevpur to Patnitola, and Patnitola to Dhamoirhat. Only one regional highway in Rangpur Zone was affected. The link between Dinajpur to Phulbari of the regional highway R585 was affected. Consequently, direct movement between Dinajpur and Gobindaganj was in despair and corridor movement to the North-West was also partially distressed.

In Barisal zone, the link between Mawa Ferry to Bhanga of national highway N8 was disrupted and the link between Tekerhat to Mostafapur was affected. Because of this, the movement along the Dhaka-Khulna strategic corridor suffered seriously. In this zone two other links between Mostafapur to Madaripur and Madaripur to Shariatpur of R860 were also affected. Only one regional highway R745 in Khulna Zone was affected on two different links between Trimohoni to Meherpur and Meherpur to Chuadanga.

From the discussion presented above, it is observed that although there were not many link-failures of the national and regional roads, movements along all the five strategic transport corridors were severely distressed. As there are very few alternative routes in the existing network, a single link failure can cause a total disruption along a strategic corridor. It is observed further that most of the link failures were around Dhaka. As Dhaka is the centre of the highway system, the effects of any link failure around Dhaka do not remain limited to a particular corridor but severely affects most of the other corridors and thus the whole road transportation system is distressed.

CONCLUSIONS

The transport system of Bangladesh has an overwhelming dependence on road transportation. As the spatial spread of the country is limited, road transportation has an inherent advantage over the two other major modes - rail and water. This has been further helped by the country's consistent public policy of investment for transport development favouring the road sector.

Due to limitations of rail and water transport, the present overwhelming dependence on the road transportation system will continue in the future. In this context, completeness of the whole road network should be considered in all future road planning exercises to make the system less vulnerable in the event of any link disruption. Assessment of vulnerability of links around Dhaka deserves special consideration as any link failure of the national highways around Dhaka affects almost the whole road transportation system. To improve the reliability of the network, selected links of the existing feeder roads can be gradually upgraded to regional road standards so that alternative routes around the most vulnerable links of the existing national and regional roads can be created

Reliable information on alignment and condition of the existing feeder roads was not available and as such this study did not make an attempt to identify any such link for upgrading. However, initial examination of the feeder road links around Dhaka City revealed that identification of such links is possible. For example, upgrading of Tongi-Ashulia link has greatly increased the reliability of Both N4 and N5. There are other similar links (between Tongi-Gazipur area and Bhairab-Narshigdi area) which can be considered to increase the reliability of N2 and N4.

The analysis presented in this paper revealed that the road network development in Bangladesh is still in its early stage. The existing network has a very few circuits for movement at all the levels and therefore, susceptible to high risk of interruption. In terms of circuitry, the network has a bare marginal grid configuration at the divisional and national levels. Additional alternative paths to cater to the major movements need to be considered to improve network reliability and thus upgrade the network at least to a modest grid.

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