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A Methodological Approach for Cumulative Effects Assessment Assessing Road Transport Sector Sustainability

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ABSTRACT

The study focuses on a technique for sustainability assessment through cumulative effects assessment (CEA) of road transport sector, the performance of which relies on the performances of the factors (stressors) affecting the system. Planning for a system's sustainability thus depends on the interconnectedness of system stressors and their degree of connectivity. Therefore CEA can be a potential analytical approach for sustainability assessment because it provides an integrated framework with environmental, social or economic considerations drawn from multiple stressors' connectivity of any complex system. The study aims in conceptualizing the process to assess the degree of connectedness among the stressors affecting transport system through digraph and matrix analysis and conducting economic evaluation of the impacts on the system stakeholders. The innovative idea of the research is to account the synergistic effect of road transport sector (rather than accounting effects separately for different actions), which normally happens in a system when all the stressors prevail together. This approach can provide baseline scenarios to the motorized cities of developing countries (like Dhaka city of Bangladesh) through 'what-if' analysis, while opting for least cost (affect) generating system in conjunction with sustainability planning.
Keywords: Cumulative Effect Assessment; Sustainability; Transport Sector; Dhaka City.

I. INTRODUCTION

The road transport sector in the most developing countries (like Dhaka city of Bangladesh) is now challenged with huge population, rapid urbanization, unplanned land use, poor traffic management and massive pollution load. Sustainable transport may become a key tool for dealing with these problems and to provide better ways to cope with future demand in the transportation sector. A sustainable transportation system involves improvements in vehicles, fuels and infrastructure as well as reductions in environmental degradation and economic losses.

Cumulative Effects Assessment (CEA) is a systematic procedure for identifying and evaluating the significance of effects from multiple activities or actions or interventions [12, 19, 37]. Cumulative effect does not mean the simple summation of all the effects, the effects can be more or less than the summation based on the factors or stressors when associated together [12]. According to Frank et al., 2010 [18], cumulative effects are the successive, incremental and combined impacts of one or more activities on society, the economy and the environment. It results from the aggregation and interaction of impacts on a receptor to cause major changes in environmental, social and economic systems. Thus the cumulative effects of any system (or any plan or project) can be stated as the total effects on the resources, ecosystem, or human community due to the activities of that system; as was supported by Cooper, 2004 [12], Therivel and Ross, 2007 [41], Hegmann and Yarranton, 2011 [21]. Over the years, Cumulative Effects Assessment (CEA) has become an increasingly important component of environmental assessment (EA) for different systems and planning strategies (equally within Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) frameworks), which was highlighted in various studies; viz. Cavalcanti and Rovere, 2011 [11] for SEA of mining activities, Hegmann and Yarranton, 2011[21] for resource management, Beevers et al., 2012 [6] for road developments, Asha et al., 2012 [4] for hydroelectric projects on biodiversity, Weber et al., 2012 [45] for land use planning, and Caputo et al., 2015 [9] for seismic hazard assessment.

Thus CEA can play the role of an appropriate analytical approach for assessing the performances of any system. Road transport system of a city governs the quality of the city dwellers' life to a great extent and therefore the system's performances need to be assessed. In this study, a methodological approach was developed to assess the cumulative effects of the road transport system, which is an innovative approach within the scope of this research. CEA for the transport sector is not a new idea and it has been done to assess the impacts for specific strategies [6]; but the dissimilarity is encompassed in evaluating the transport system's performance considering it as a host of different interconnected factors and in analysing the connectedness of the factors, which is usually done for ecosystem's assessment. The study focuses on developing a methodology that can assess the state of a transport system, which consequently supports in analysing its sustainability.

In this study, Dhaka city of Bangladesh was chosen as a representative of many cities of developing countries in order to highlight the factors that regulate the transport sector's performances and addressing of which (the factors) through management strategies can lead to a least cost inducing transport system. Dhaka's transport characteristics are discussed as a reference to the responsible set of factors, which might be different for different city's transport systems. Dhaka's transport environment is characterized by diverse vehicles using the same road space, traffic congestion, indiscipline and mismanagement, lack in law enforcement, and increasing environmental problems. Huge volume of vehicles, lack of parking facilities, occupancy of footpaths by several vendors, frequent u-turns/intersections and traffic management failures are some of the factors that exaggerate the congestion and pollution (Field Survey 2013; [31, 40]). The road traffic contributes a huge amount of air pollutants to the environment. To a large extent, the main cause of traffic pollution in the city is the number of vehicles on road and their running behaviour. Human exposure is the major apprehension of these pollutants, which initiates hidden costs to society with regard to its effects on human health. Exposure of this pollution to the population is an important sector to deal with and requires an efficient management strategy to ensure the quality of the transportation service while minimizing environmental, health and economic impacts.

The paper tends to focus on developing a methodological approach that is capable of assessing the impacts of the road transport sectors; not developing a strategy to attain total sustainability of this sector, but identifying the major responsible set of factors (stressors) and their degree of relationships. The study aims to provide an approach to scrutinize the stressors or the set of stressors that have synergistic impacts. Thus this paper can facilitate the development of sustainable road transport management strategy for mega cities like the Dhaka city by providing a pathway to attain the least effect incurring solution of the system, with the low cost, higher social acceptability and minimized pollution load from the transport sector.

II. HOW DOES CEA INCORPORATE WITHIN SUSTAINABILITY ASSESSMENT?

The concept "Cumulative Effects" works by the addition or accumulation of effects from different activities. It may result from the accumulation of similar effects or the synergistic interaction of different effects [16]. The magnitude of the combined effects along a pathway can be equal to the sum of the individual effects (additive effect) or can be an increased effect (synergistic effect) [12, 41].

The CEA analysis involves identification of impact sources, affected resources, using a set of key indicators to examine cumulative effects arising from the aggregate of these effects [2]. Since stressors may interact with each other and have combined effects on the system, it is essential to assess the kind of interactions among stressors.

Sustainability is a condition in which economic, social and environmental factors are optimized, taking into account indirect and long-term impacts [43]. The term 'sustainability' does not denote threat analysis; sustainability is about systems analysis. Sustainability is a concept that promises economic development, enhances social equity and protects the natural environment as the economic development strategy can be viable in the long run when social demand and environmental concerns are considered [23, 29, 44].

CEA can be a potential analytical approach for the sustainability assessment since it provides an integrated framework with environmental, social or economic considerations drawn from multiple stressors of any multi-faceted, interconnected, and complex system. CEQ, 1997[13] affirmed that without incorporating cumulative effects into environmental planning and management, it would be impossible to move towards sustainable development. To a large extent, the goal of cumulative effects assessment is to bring in environmental considerations into the planning process at an early stage for determining efficient decisions. Counsell and Hougton, 2001 [14] also explained that the potential direct, indirect and cumulative impacts need to be evaluated in order to integrate sustainable development objectives in the formulation of policies and planning strategies. As like Environmental Impact Assessment (EIA), CEA does not neglect additive and synergistic effects, besides CEA tends to integrate socio-economic, cultural, and environmental factors in decision-making that allows cumulative effect assessment to be an adequate tool to pursue sustainability assessment [36, 38]. CEA, if done well, predicts and approximates stressors that the system will actually be exposed to, which is equivalent to a sustainability appraisal for that system [33]. As revealed from the literature survey, several studies acknowledged CEA as an important tool for environmental sustainability assessment, and hence in this study, a methodology was developed for conducting CEA with the aim to assess the performance of the transport sector.

III. ROAD TRANSPORTATION SYSTEM IN DHAKA CITY, BANGLADESH

Dhaka city is discussed here as a case study to provide a reference of what the transport systems stressors could be. The stressors were identified for Dhaka city through a detailed field survey conducted in 2013. Being the administrative, commercial and cultural capital of Bangladesh, Dhaka city plays a major role in the socioeconomic development of the country. But the existing transportation system is a major obstruction for the development of the city. Unplanned urbanization, especially poor transportation planning and lower land utilization efficiency has turned the city into a dangerous urban jungle [26, 31].

Dhaka is one of the most crowded and congested cities in the world. Traffic congestion, the major concern of road transportation in this city not only causes increased costs, loss of time and psychological strain, but also creates serious threats to the socioeconomic environment [31]. Alam and Habib, 2003 [3] predicted that by 2020, about 60% of the major roads in Dhaka city would become highly congested with an average speed of less than 5 km/hr during peak hours. According to STP, 2004 [39], a major portion (43%) of all motorized vehicles within this city are car or light vehicles, but in the case of passengers' services their contribution is relatively very low (only 9.6%). Not only traffic congestion, but inadequate parking facilities, lack of mass transit facilities, poor traffic management, vehicular pollution all tend to worsen Dhaka's road transport with each day (Field survey 2013; [39]). According to a field survey undertaken during 2013, which was supported by ADB, 2011[1], the main problems of traffic system in Dhaka city include a lack of clear traffic regulations and their poor enforcement and air-noise pollution from old and ill-maintained motorized vehicles.

The major stressors that were identified by assessing the transport system characteristics of Dhaka city (among the 19 identified stressors) include high traffic volume, dominance of private vehicles in the vehicle composition, poor public transport system, traffic congestion, indiscipline driving, traffic mismanagement, lack of law enforcing, pedestrian jay walking, occupied footpaths and road sides, illegal on road car parking and illegal bus stopping on road, air and noise pollution, and so on. These identified stressors act as the input parameters of digraph and matrix analysis for the Cumulative Effects Assessment (CEA) of the transport system; the methodological approach to quantify the cumulative effects is discussed in the following section. The stressor might vary for different urban transport system of different cities, which need to be identified accordingly (like this paper identified for Dhaka city) prior to adopt the approach of CEA discussed in this research.

IV. CUMULATIVE EFFECTS ASSESSMENT: QUANTIFYING EFFECTS FROM ROAD TRANSPORT SECTOR

The purpose of this paper is to conceptualize and illustrate a CEA methodology of road transport sector as an analytical tool for sustainability analysis; where CEA is conducted based on analysing the structure of interactions among the road transport sector stressors and economic evaluation of effects or losses from these stressors. The series of conceptualized methodological steps are discussed briefly in the following sub sections. This study provides an innovative methodological framework of conducting CEA for transport systems, not the results of that CEA, and the framework is conceptualized after testing on Dhaka city's transport system.

The approach of conducting CEA involves 3 steps, (i) analysing multiple interrelationships among the stressors, (ii) the economic evaluation of the effects and the degree of connectedness among the stressors, and (iii) assessing the cumulative effects. This paper discusses how the steps can be followed to assess the cumulative effects of a road transport sector, and does not provide a result obtained by following the steps. The multiple interrelationships among the stressors are analysed (step 1) to identify the most interconnected stressors that affect the performance of the system simultaneously, and performance of one stressor regulates the performance of its correlated stressors. Therefore, it's important to identify the interconnected stressors in the first instance. The 'Digraph theory' and 'matrix analysis' are the approaches, which are usually used for identifying the interactions and interconnectedness among the stressors of a system respectively, especially for the ecosystems [7, 8, 24, 28, 32, 42, 46, 47, 48]; but haven't been used for CEA of an urban system. Thus, conducting CEA for a road transport system by using both digraph theory and matrix analysis (as one of the core steps) makes it an innovative approach.

A. Analysing Multiple Interrelationships among the Stressors

In order to analyse the multiple interrelationships among stressors, a series of actions are required to undertake-

a) Identification of the list of stressors (S_i) those have impacts on the road transport sector; Where, S = Stressors of concern and i = Number of Stressors (i =1, 2, 3,…., n).

b) Construction of a digraph [32] in order to use as the basis for analysing the multiple interrelationships among the stressors in S_i. Formally, a digraph is simply a collection of vertices or nodes with directed arcs joining certain pairs of vertices. Digraph of transport sector stressors is to be formed by treating each stressor as a vertex and linking stressors with directed arcs. By constructing a digraph, interactive loops among the stressors are created. An example of constructing a hypothetical digraph is provided in Figure 1. In order to analyse the structure of road transport sector stressors, the digraph is to be created not only based on the direct impacts of one stressor upon another but also based on indirect impacts resulting from a sequence of interactions. The diagraph construction was tested for a transport system (to conceptualize the interactions between stressors) by analysing the field survey data, which was conducted in 2013 to identify the stressors of Dhaka city transportation.

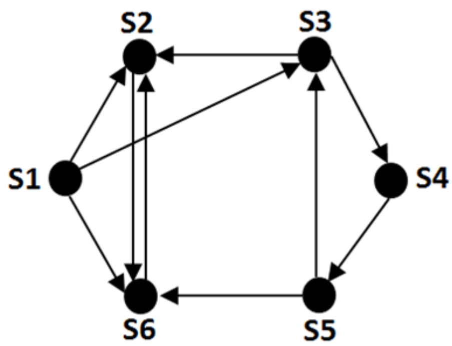

Figure 1: A hypothetical digraph of stressors S1, S2, S3, S4, S5 and S6

As an example , Figure 1 denotes that, S3 has direct impacts on S2, and S4; S3 does not directly effect on S5 and S6 but it does so indirectly through a pair of interactions represented by two directed arcs, the first joining S2 to S6 and the second joining S4 to S6.

c) Matrix analysis is to be done based on the constructed digraph of transport system stressors, in order to find the interconnected stressors of the system. The series of steps for matrix analysis, which was provided by Wenger et al., 1999 [46], would lead to identification of the interconnected stressors. The matrix analysis for the constructed hypothetical diagraph with 6 stressors (showed in Figure 1) is provided below.

i. An adjacency matrix (A= a_{ij}) (Figure 2) is developed for the stressors as, a_{ij}= 1, if S_i has an impact on S_j ; and a_{ij}= 0, if S_i does not have an impact on S_j.

A =

	S1	S2	S3	S4	S5	S6
S1	0	1	1	0	0	1
S2	0	0	0	0	0	1
S3	0	1	0	1	0	0
S4	0	0	0	0	1	0
S5	0	0	1	0	0	1
S6	0	1	0	0	0	0

Figure 2: Example of adjacency matrix (A) of stressors S1, S2, S3, S4, S5 and S6

ii. The reachability matrix, R (Figure 3) is computed directly from the adjacency matrix (A), as R = B $[(I+A)^{n-1}]$; where, I = Identity matrix, B = Boolean function, n = Number of vertices.

R =

	S1	S2	S3	S4	S5	S6
S1	1	1	1	1	1	1
S2	0	1	0	0	0	1
S3	0	1	1	1	1	1
S4	0	1	1	1	1	1
S5	0	1	1	1	1	1
S6	0	1	0	0	0	1

Figure 3: Example of reachability matrix (R) of stressors S1, S2, S3, S4, S5 and S6

iii. Then transpose matrix (R′) of reachability matrix (R) is determined (Figure 4).

R′

	S1	S2	S3	S4	S5	S6
S1	1	0	0	0	0	0
S2	1	1	1	1	1	1
S3	1	0	1	1	1	0
S4	1	0	1	1	1	0
S5	1	0	1	1	1	0
S6	1	1	1	1	1	1

Figure 4: Example of transpose matrix (R′) of stressors S1, S2, S3, S4, S5 and S6

iv. A matrix of RxR′ is then developed from the transpose and reachability matrix.

v. The products of RxR′ matrix portray the different clusters of closely related stressors. These clusters of closely related stressors provide with the interconnected stressors of the system (as shown in Figure 5).

	S1	S2	S3	S4	S5	S6
S1	1	0	0	0	0	0
S2	0	1	0	0	0	1
S3	0	0	1	1	1	0
S4	0	0	1	1	1	0
S5	0	0	1	1	1	0
S6	0	1	0	0	0	1

Cluster of closely related stressors of S3, S4 and S5

Figure 5: Example of a product of matrix (RxR′) of stressors S1, S2, S3, S4, S5 and S6

B. Economic Evaluation of the Effects and the Degree of Connectedness

After identifying the interconnected and individual (non-connected) stressors, the next step adopted for the CEA approach was economic evaluation of the effects. The cost associated with each stressor while accumulated would provide the total cost of the system, which is the cumulative cost (or effect) of the system. The economic evaluation of the effects of different stressors (like estimating monetary value of losses resulting from stressors) can be diverse, and the evaluation can be done as per the suitable methodological approach. The paper presents the concept of economic evaluation for conducting CEA and thus the details of the economic evaluation methodology are not provided (as economic evaluation of stressors is itself a big task to perform with sophisticated and varied methodological approaches and requires another dimension of research for that). Several studies have been conducted to economically evaluate the effects associated with transport sector, viz. direct estimation of damages associated with air emissions (Small 1977[45]; Krupnick and Portney 1991[22]; Hall et al. 1992[20]; Small and Kazimi 1995[34]; Maddison et al. 1996[25]), health cost related to air/noise pollution (Azad et al. 2003[5]; Caulfield and Mahony 2007[10]; Chowdhury and Imran 2010[15]; Michiels et al. 2012[27]), air pollution impacts on human health and ecosystem (Preiss and Klotz 2007[30]), external costs (congestion, accident and others) of transport sector (EC 2008[17]). These studies can guide to formulate a suitable methodological structure for economic evaluation of the effects of a transport system depending on the stressors of concern in that particular transport system.

Analysis of the degree of connectedness among the interrelated stressors, as the they create the synergistic effects, can be done by statistical analytical methods, based on the effects (costs) of the stressors or based on the characteristics of the stressors in the system. The resulting effects of the connected stressors would provide the synergistic effects (or synergistic costs when considered the monetary value) of the stressors.

C. Assessing Cumulative Effects (CE) of Road Transport System

After identifying the interconnected stressors, their degree of interconnectedness and the costs associated with the stressors, the Cumulative Effects (CE) of road transport system can be assessed by using following equation:

$$CE = CEc = \sum_{i=1}^{n} SEc + \sum_{i=1}^{n} IEc + \sum_{i-1}^{n} IEnm$$

Where,

CE = Cumulative Effects

CEc*= Cumulative costs (monetary value of cumulative effects)

SEc*= Synergistic Effects of mostly connected stressors (in term of monetary value)

IEc*= Individual Effects of non-connected stressors (in term of monetary value)

IEnm= Individual Effects of non-connected stressors (Non-monetary effects)

n= number of individual stressor

*c = Costs = Economic, social and environmental effects (including cost of pollution) that are convertible to monetary values in order to bring those effects on the same platform, which enables to account cumulative effects on the same criteria.

Depending on the identified degree of connectedness among the stressors and their positive or negative relationships, the synergistic effects (or costs) of the connected stressors (SEc) would be accounted. The individual effects (IEc and IEnm) would be obtained from the individual stressors. The summation of all the effects thus would provide the cumulative effects of the transport system.

V. CONCLUSION

The planning strategy for sustainable road transport system can be developed through analysing the total circumstances, which can be obtained by a CEA considering all the stressors prevailing in the system. The approach of assessing the stressors' connectedness developed in this study is an important phase of CEA framework. The obtained stressors relations can support developing different scenarios to illustrate 'what-if' relationships, which can act to formulate a generalized linear model for planning strategy of a given system. Developing such model can thus provide the cumulative effects of a given system and the parameters (or set of parameters) responsible for increasing total effects; which can facilitate to identify the focus point to address while planning for road transport sustainability.

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