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# A Methodology to Design a Composite Accident Index and Assess The Links in a Network Carrying Hazardous Waste: A Case Study of Kolkata Metropolitan Area

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## Abstract

Hazardous waste management (HWM) involves transportation, storage, handling, treatment and disposal of these wastes. Transportation of the wastes is the only practice in HWM which is carried out in an unregulated offsite domain. These wastes are transported from their generating units (i.e. factories) and transferred to treatment, storage and disposal facilities (TSDF) for treatment and disposal so as to cause minimum damage to the environment. The transportation activity of hazardous waste imposes huge risk on the network it uses for routing of such wastes. The risk of accident involved during routing activity of hazardous wastes occurs in a totally uncontrolled domain making it ominous. Such accidents can result in explosions, fires, toxic fumes or spills contaminating the air, water or the earth. The adjoining population exposed to such catastrophes is unaware of the procedures to handle such waste and possible consequences they pose on human health due to exposure. Thus routing operations of these wastes have created concerns among researchers across the globe regarding the possible repercussions it may have on the human life, property and the environment at large. The possibility of accidents is on the rise due to expanding urban areas and increasing population density. However, the magnitude of the outcomes is increased manifolds due to involvement of hazardous waste. Risk assessments of networks through which such hazardous wastes are transported have been carried out in the past. The traditional definition of risk, which defines risk as a product of probability of occurrence of an event and the impact of a given event on the vulnerable population has been conventionally used by researchers across the world for quantitative risk assessment. However, this method requires database regarding the probability of occurrence of an event. Lack of such a database can jeopardize the above mentioned risk assessment methodology.

The present research aims at designing a methodology for assessing the accident index (AI) of links in a network based on its physical, traffic and landuse characteristics. These characteristics would incorporate attributes like carriageway width, surface

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condition of the links, congestion, night time visibility, pedestrians and non-motorized traffic on the link, type of adjoining landuse, etc. This index is designed based on the principles of aggregation used for designing environmental indices. AI act as a complementary tool in the assessment of risk in a network. Thus, unavailability of accident database would not deter researchers or industrial practitioners from assessing the risk posed due to hazardous waste transportation through a network. This can also be used to identify causal relationship between the attributes of AI and probability of occurrence of an event where such datasets are available. A regional network can be further analyzed based on the AI values of its constituent links and vulnerable links with high propensity of an accident can be identified. The proposed methodology has been demonstrated using the case study of the road network of Kolkata Metropolitan Area (KMA). Spatial analyses of the distribution of AI values over the network revealed concentration of AI values in few links of the network. The analyses of the network of KMA revealed that 4% links had AI values 3.5 to 5 times the mean AI value of the network. This analysis can be used for designing appropriate policy interventions for specific links of a network to reduce accident propensity of in a regional network.

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*Keywords:*Hazardous waste; Risk assessment; Routing; Aggregation; Composite Index

## 1. Introduction

Urbanization and the urban way of living has made human race captive to many manufactured products and this trend has had caught up with the rural areas as well. The dependence of modern lifestyle on manufactured products be it packaged food, detergents, electronic goods, building materials, modern textiles, etc has triggered the proliferation of the manufacturing sector. However, with every unit of manufactured product there involves an environmental cost which involves environmental pollution, depletion of natural resources and finally generation of unwanted waste (GEO-2000). These wastes have the potency to degrade environmental standards beyond repair and can pose serious threats to human health (Horton, Berkowitz, Haugh, Orr and Kaye, 2003).The disposal of such waste generated by different manufacturing sectors has become a burning issue for policy makers, environmentalists and manufacturers as well (Kumar, Mukherjee, Chakrabarti and Devotta, 2008).

Hazardous wastes thus generated are being disposed off in specialized disposal facilities to contain their negative impacts. This involves transportation of such wastes from their respective generating units to the centralized disposal facilities. Such transportation of hazardous wastes from the industrial units to these centralized Treatment, Storage and Disposal Facilities (TSDFs) receive hazardous waste from a number of generating units located in a region and usually have a catchment radius of 200 km (Chakrabarti, Patil and Devotta, 2003). Transportation of hazardous waste, though carried out by specialized vehicles can encounter an accident which may result in a devastating outcome, e.g. explosion fireballs, emission of toxic fumes, contamination of soil and surface water, etc (Rice et al., 2008). Thus an element of risk is involved during transportation of such hazardous waste. The route through which they are transported expose the entire population living adjoining these links of the road network to fatal risks. Moreover, the physical properties along these links are also exposed to risk of complete demolition (Alonso et al., 2008).

A lot of research activity has been carried out in past in this regard. The focus of these researches has been on impact of hazardous wastes on human health and environment at large (Kales, Polyhronopolous, Castro, Goldman, Christiani, 1997. Misra and Pandey, 2004), improvement of collection efficiency and disposal techniques of hazardous wastes (Yang, 1996), risk assessment during transportation of hazardous waste (Das, Gupta, Mazumder, 2012a), routing methodology to transport such wastes (Das, Gupta, Mazumder, 2012b), exercises to optimize routing and siting of TSDF (Alumur and Kara, 2007), etc. It is evident from the list that for carrying out most of these studies database of accidents during transportation of hazardous waste would be needed. The lack of a proper database can completely jeopardize the entire methodology of most of such studies. This is a bottleneck in most of the developing economies where such specialized database does not exist or is not updated regularly. Many a time accidents go unreported and hence make the database unreliable. This study intends to look into this problem and attempts at finding an alternative methodology to predict accident propensity in a road network using network specific physical and traffic characteristics.

### *1.1 Need for the study*

As discussed in the previous section, transportation of hazardous waste can be precarious and poses huge risk to community living adjoining the network through which it is transported. Hazardous waste management in a region incorporates risk assessment due to generation, transportation and disposal of hazardous waste. This risk posed on human health or the environment has been calculated in the past by researchers using Quantitative Risk Assessment method or the traditional method of risk assessment (Caramia and Dell'Olmo, 2008). It can be represented as the product of impact due to possible event(s) during transportation of hazardous waste and the probability of occurrence of an event. The probable events that can be expected when a hazardous waste carrier encounters an accident can be represented using an event tree (Das, Gupta, Mazumder, 2012a) and the joint probabilities of occurrence of an accident and a probable event can be computed.

The propensity of occurrence of an event due to accident of a hazardous waste carrier is calculated based on historical records of such events. This record is obtained from a specialized database containing details of the type of waste involved, impact of the event, cause of accident etc. However, the problem arises in situations when no such database is available. Lack of information on accidents makes the entire risk assessment framework futile.

Attempts have been made in the past to devise a framework which would be able to provide a quantitative support to researchers for carrying out the risk assessment exercise without reliable accident information. An Accident Index (AI) designed by Das, Gupta, and Mazumder (2012a) took into account five physical attributes and five traffic attributes for all links in a road network. The AI is a composite index designed using the principles of environmental indices. It follows the principle of Parsimony and is simple to compute. It is based on a dataset which is readily available for most urban centres of India. However, this study did not consider the conventions as per the Indian Road Congress specifications. Moreover, limited numbers of attributes (indicators) were taken for evaluation of AI and important attributes like adjoining landuse, level of encroachment, road alignment and hierarchy of the network were overlooked.

This study carries forward the same framework, albeit more comprehensively, and demonstrates its utility in analyzing accident propensity in a regional road network due to freight transportation of hazardous waste.

### *1.2 Methodology*

The methodology for computing AI has been adopted from the work carried out by Das, Gupta and Mazumder (2012c). The AI is designed based on the principles of composite environmental indices proposed by Ott (1979). It involves three basic steps and is with the graphic (Fig. 1) below

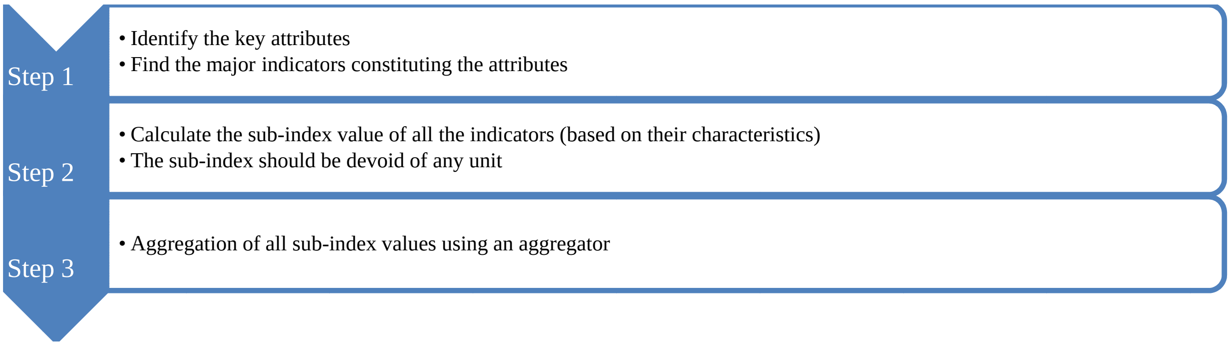

Fig. 1: Methodology for designing a composite index

After aggregation the composite indices are to be tested for two basic problems of aggregation namely, ambiguity (over estimation) and eclipsing (under estimation).

The commonly known aggregator functions are un-weighted and weighted additive and multiplicative operators, root square power additive, root mean square additive, max operator, etc.

The aggregator function used in this study has been proposed by Das, Gupta and Mazumder (2012a, 2012c) and is represented using eq. (1)

$$AI = \left( \sum_i \frac{x_i^n}{n} \right)^{\frac{1}{n}} \tag{1}$$

where, AI = Accident Index
$x_i$= Sub-index value of attribute ‘i’
n = Number of attributes

The same aggregator function was used by Das, Gupta and Mazumder (2012c) to calculate the value of Hazardous Waste Index (HWI) based on four parameters. The proposed aggregator function was compared to ten other prevalently used aggregator functions using sensitivity analyses and was found to be more consistent and devoid of any aggregation problems. The same operator has been used for computing AI (Das, Gupta and Mazumder, 2012a) and was pitted against other aggregator functions to evolve as the most consistent operator. The same aggregator function has been retained for this study too due to its consistency and robustness. However, sensitivity analyses in this study have been deliberately left out for brevity.

The attributes identified in this study have been characterized into two parts, namely traffic characteristics and network characteristics. The guidelines for attribute selection and scaling have been adopted from the IRC Road Accidents Forms A-1 and 2 (IRC: 53-1982). These forms provide a detailed questionnaire for collecting data after any accident. However, as this is a mere guideline, data collection in India still does not incorporate most of these items. Many details like classification of accident, nature of accident, driver characteristics, vehicle characteristics, etc mentioned in the same forms could not be incorporated in this study due to paucity of data. The data source for this study has been the Mobility Improvement Plan of Kolkata Metropolitan Area (KMA) and reconnaissance surveys carried out by the authors during the study.

The next section would elaborately discuss the attributes selected for calculation of AI and the scaling mechanism adopted for the same.

### 1.3 *Calculation of Accident Index (AI)*

The attributes identified for calculation of AI have been arranged under two major heads – network characteristics and traffic characteristics. The attributes identified under network characteristics are width of carriageway, hierarchy of network, street lighting provisions, road condition (horizontal alignment), encroachment or physical obstruction within right of way (ROW), landuse adjacent to the links, and surface condition. The data for each of these attributes have been collated based on a scaling system devised as per the guidelines mentioned in IRC Road Accidents Forms A-1 and 2 (IRC: 53-1982). The description of all these attributes and their scaling system are shown in Table 1.

Table 1: Attributes identified for computing AI

| Name of attribute | Description of indicators | Scaling system adopted |
|---|---|---|
| Network characteristics | | |
| Hierarchy of road | Major Arterial Road | 1 |
| | State Highway | 2 |
| | National Highway | 3 |
| Divided Carriageway | Divided carriageway | 1 |
| | Un-divided carriageway | 2 |
| Street Lighting | Good light | 1 |
| | Poor light | 2 |
| | No light | 3 |
| Road condition (Horizontal) | Straight | 1 |
| | Slight curve | 2 |
| | Sharp curve | 3 |
| Encroachment of ROW | Less than 10% | 1 |
| | 10-20% | 2 |
| | 20-30% | 3 |
| | 30-40% | 4 |

| | | |
|---|---|---|
| | 40-50% | 5 |
| | More than 50% | 6 |
| Adjoining Landuse (Adj. land) | Open space | 0 |
| | Residential (low density);<br>Commercial (small); Institutional | 1 |
| | Residential (medium density) | 2 |
| | Residential (high density);<br>Commercial (medium); CBD | 3 |
| | Commercial (large) | 4 |
| | Industrial | 5 |
| Surface Condition | Good surface | 1 |
| | Loose surface | 2 |
| | Wavy road | 3 |
| | Potholed | 4 |
| Traffic characteristics | | |
| Share of slow moving vehicles (%) | Percentage value | NA |
| Share of heavy vehicles (%) | Percentage value | NA |
| Congestion in a link (V/C) | Ratio of peak volume to the capacity of a link | NA |
| Average speed along a link (km/hr) | Average value of peak and off-peak hour traffic speed | NA |
| On-street parking | No on-street parking | 1 |
| | On-street parking partially occupying shoulder/footpath | 2 |
| | On-street parking fully occupying shoulder/footpath | 3 |
| | On-street parking fully occupying shoulder/footpath and partially occupying carriageway | 4 |

The higher points in the scale signify that an indicator would contribute more to an accident. The hierarchy of road indicates the predominant order of the link, indicating whether it is a national highway, state highway or major arterial road. The concern that NH carries a lion's share of freight vehicles make them susceptible to severe accidents as against arterial roads (which are mostly operating beyond their prescribed capacities). Lighting conditions have been sub categorized into three parts – no provision of street lights, poor street lights and good street lights. These factors would define driving conditions in dark and can be responsible for an accident. Road condition (horizontal) specifies the horizontal alignment of the road and indicates that higher propensity of an accident is observed when a road has sharp curves. Encroachment of road/obstruction within ROW indicate towards the level of impediment that has been posed on a given link due to physical barriers like electrical posts, hawkers, illegal construction, etc.

The value for adjoining landuse has been calculated using the scaling system based on the traffic generating and attracting capability of a particular landuse. Industrial landuse being rated highest owing to its capability of attracting and generating heavy motorable vehicles. The residential landuse has been further sub-divide into low (where density is less than the average density of KMA i.e. 7480 person per square km as per Census of India, 2011), medium (where density is between 7480 and 15000 person per square km) and high (when population density exceeds 15000 per square km). Each link has been assigned a weighted value based on its share of different landuse. The score of a link has been calculated using eq. (2)

$$\text{Landuse Score}_{\text{i-j}} = \sum Adj.land_{i-j} \times w_{i-j} \tag{2}$$

where, Landuse $\text{Score}_{\text{i-j}}$= the score due to adjoining landuse along a link i-j

Adj. $\text{Land}_{\text{i-j}}$ = the percentage share of each category of landuse along the link i-j (within a band of 50m on each side of the link from its centre line has been assumed)

$w_{\text{i-j}}$ = scale value for corresponding landuse along the link i-j

The landuse scaling system has been designed in this study keeping in mind the vulnerability of adjoining population and/or physical property due to a probable accident involving hazardous waste. The type of landuse which is more susceptible to negative impact or can further aggravate the impact has been assigned the highest value whereas the type of landuse which can experience least impact due to a similar event has been assigned the least score.

For example a link with 60% open space, 20% low density residential space and 20% industrial space has been assigned a value of 1.2.

The surface condition for the road surface has four categories and has been scaled accordingly with highest score being labelled to potholed roads.

Traffic characteristics include five attributes namely, share of slow moving vehicles, share of heavy vehicles, congestion in the link, average speed (peak and off peak hours) and impediment due to on-street parking. Slow moving traffic increases propensity of accident particularly in high speed corridors like the NH or SH. Links where traffic constitutes of higher share of heavy vehicles (as heavy vehicles are difficult to manoeuvre) is also more prone to accidents. Links which have more congestion are also prone to more accidents where the risk of overturning might not be there but minor conflicts may lead to leakage of hazardous waste which can aggravate the outcomes of the event. Higher average speed (measured using the peak and off-peak hour speed along a link) in a link can lead to more accidents. Finally, on-street parking and the amount of carriageway (reducing its capacity and impeding thorough traffic due to vehicle movement from on-street parking zones) as well as footpath it occupies also determines the involvement of pedestrians in an accident.

The sub-index values of these attributes and their indicators after scaling and finalization were computed based on the eq. (3) as given below

$$S.I = \frac{(x_i - x_{\min})}{(x_{\max} - x_{\min})} \qquad (3)$$

where, S.I= Sub-index value
$x_i$ = Indicator value
$x_{min}$ = Minimum value of a given indicator
$x_{max}$ = Maximum value of a given indicator

The above mentioned equation, i.e. eq. (3) has been used by Neumayer (2001) during calculation of Human Development Index.

### 1.3.1 *Computing Accident Potential (AP) of a link*

The value of AI calculated for a link (using eq. 1) gives an aggregate value of the accident propensity of a link. However, the propensity of an accident would linearly vary with its length, with longer links being more susceptible to an accident than a shorter one (provided their AI values are same). Thus, the concept of Accident Potential (AP) has been devised to address this need; it can be expressed as shown in eq. (4).

$$AP_{i-j} = AI_{i-j} \times Length_{i-j} \qquad (4)$$

where, $AP_{i-j}$ = Accident potential along link i-j
AI= Accident index along link i-j

The AP values of the links thus calculated can be added for all the links of the network and the total accident potential of a regional network can be calculated. Thus, two regional networks can be broadly compared in terms of their propensity to experience an accident.

The concepts of AI as laid out in this study have been substantiated in the next section with the help of a demonstration of the network of KMA.

## 1.4 *Case study of road network in Kolkata Metropolitan Area (KMA)*

Kolkata Metropolitan Area (KMA) is the third largest metropolis in India with the highest population density. It has a population of over 14 million and has an average population density of 7480 person per square kilometre. It comprises of 41 urban local bodies and 24 rural local bodies. A network of important national highways (NH-6, NH-117, NH-34) passes through this metropolis. The network taken up for this study comprises of the national highways, state highways and the major arterial roads of KMA only. The dataset pertaining to this study has been collected from the Mobility Improvement Plan prepared under the National Urban Transport Program (NUTP) of the Government of India and reconnaissance surveys conducted by the authors.

The entire network was subdivided into 68 nodes and 119 links (as shown in Fig.2) and the computation of AI and AP were carried out. The detailed worksheet of the same could not be furnished due to space constraints.

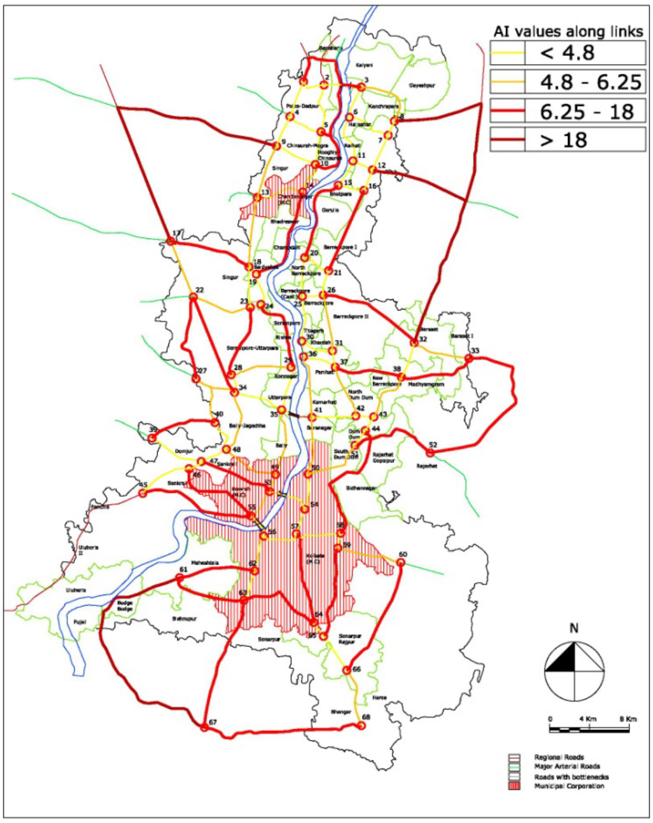

Fig.2: Road network showing AI values of the links in KMA

The AI values of all the links have been plotted using a scatter diagram and represented in Fig. 3.

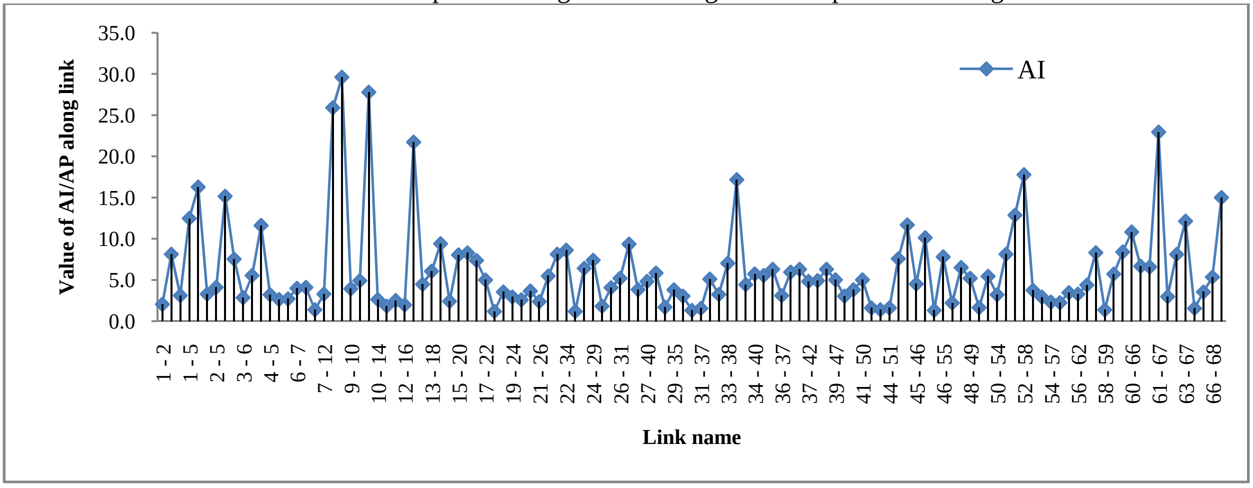

Fig.3: AI values along 119 links in KMA road network

The values show that the mean value of AI is 6.24, the median value is 4.8 implying that most links in the KMA road network have very low AI values (almost 66% links of the KMA network have AI values less than the mean value). However, it also indicates that a few links have large AI values which increase the mean AI value of the network (4% links have AI value ranging from 3.5 to 5 times the mean AI value of the network).

The AI values of all the links have been categorized into four categories. The first category belongs to the links whose AI values are below the median AI value of the links in the network. The second category is for the links whose AI value lies between median and the mean value. Apart from these, two more categories have been made and the links distributed in each category depending on their respective AI values. This has been shown in the Fig.2.

A wide disparity is observed in the network in terms of distribution of the AI values. The cumulative AI values (in percentage) and the cumulative link lengths (in percentage) had been plotted to obtain a Lorenz curve (shown in Fig.4). The profile of the curve depicts at disparity in distribution of the AI values along the network. The Gini coefficient for the network was also computed (0.36).

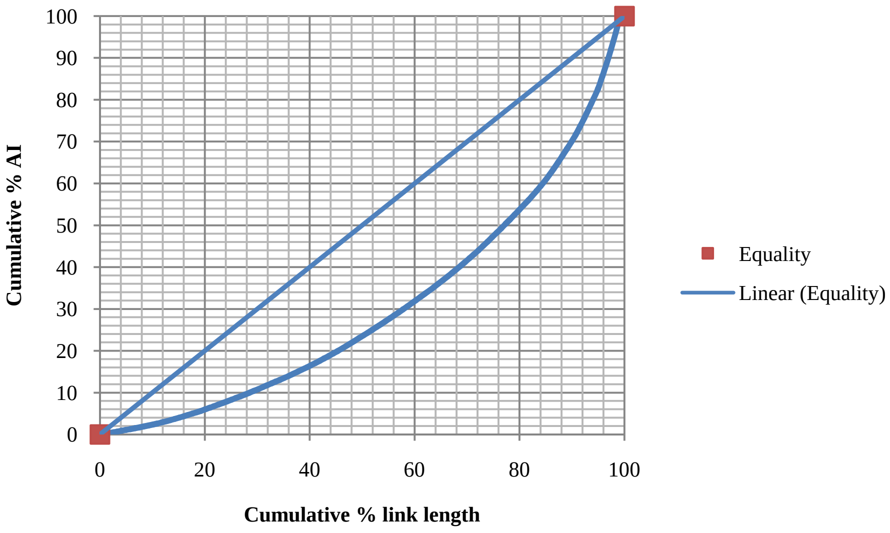

Fig.4: Lorenz curve showing distribution of AI values along the road links of KMA

This information can be utilized for planning in the short term as well as medium term for interventions required for reducing or restricting accident propensity in a regional road network. These interventions can be either traffic engineering and traffic management solutions.

### *1.5 Conclusion*

The present study proposes a methodology to compute AI based on traffic and network characteristics. This AI value can be easily computed based on the principles of aggregation. The AI can be used as a proxy for specific data pertaining to accident during transportation of hazardous waste. In case there is inadequate or lack of specialized historical accident datasets the proposed methodology in this study can be utilized for computing risks in a network. The AI can further be utilized for computing AP which can be used for comparing two networks for accident propensity or further can aid in policy decisions related to reducing and restricting accident propensity in a regional road network. It can also be used for planning new links in the regional road network (to reduce accident propensity), hazardous waste routing or locating new waste generating units. The proposed methodology was substantiated by a case study of the road network of KMA and analyses of its accident propensity.

However, few important parameters like vehicle specifications, pedestrian involvement, etc had to be omitted from this study due to paucity of dataset. Incorporation of these dataset would make this methodology more robust.

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