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CONTENTS

PREFACE

The 10th Annual Conference of Knowledge Forum, hosted by National Institute of

Advance Studies (NIAS) Bangalore, was held during 27-28 November, 2015. The Co-

organiser of the event was Indian National Academy of Engineering (INAE). The

theme of the Conference was technological challenges for national growth. The

INAE is pleased to present this document. The document contains presentations by

eminent speakers on topics related to remote sensing in disaster management,

socio-economic impact of satellite based navigation systems, urban transportation

policies, impact of ship emission, sustainable supply chain, knowledge

management in agriculture, artistic creativity and technical innovations, and Indian

space programme. The INAE gratefully acknowledges the help and support of Dr V.

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Purnendu Ghosh
Chief Editor, INAE Publications

Challenges in using Remote Sensing Technology for Disaster Management

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Abstract : India experiences a large number of disasters every year and hence is one of the most vulnerable countries to be affected by various disasters. About 60% of the landmass is prone to earthquakes of various intensities; over 40 million hectares is prone to floods; about 8% of the total area is prone to cyclones; close to 5,700 km long coastline out of the 7,516 km, is prone to cyclones (National Flood Control Commission Report, 1980) and 68% of the area is susceptible to drought. Vulnerability of Indian sub-continent to variety of severe natural disasters is evident from the major disaster events experienced by the country in the past i.e. Jhelum floods and Cyclone Hudhud (2014), Uttarakhand flash floods and Cyclone Phailin (2013), J&K, Leh Flash floods (2010), Indian Tsunami (2004), Bhuj Earthquake (2001), Latur Earthquake (1993), Malpa Landslide (1994), Orissa Super Cyclone (1999) to name some. Hence, considering such a unique agro-climatic, agro-ecological and the re-occurrence of disasters from time to time, the Indian Space Research Organisation has setup a system with a combination of aerospace based observations, satellite communication network and GNSS to address quick response and mitigation of various disasters. Response to most of these disasters are done in the near realtime, including the provision to provide early warnings to help in coping up with disasters at local level. The current paper brings out the various details on the use of space technology, with specific illustrative examples, for disaster management support in the nation.

1.0 Introduction

India has a highly variable topographic, climatic and agro-ecological setup, which makes the country more vulnerable to a variety of disasters and also at times a complex ground situation in Himalayan terrain. The physiographic setup of the country is very unique in terms of the terrain it supports, viz., desertic terrain, thick forests, plain areas, oceanic setup, large coastal areas exposed to the vagaries of ocean dynamics, high altitude areas and mountainous terrain like Himalayas etc. The Indian Himalayan region being geologically unstable, tectonically and seismically active, geographically remote, economically undeveloped and ecologically most fragile (Sati, 2008) is prone to severe geological and extreme weather related disasters. The catastrophic hydro-meteorological disasters witnessed in the recent past i.e. Jhelum Floods (Jammu & Kashmir) during 2014 and Kedarnath flash floods (Uttarakhand) during 2013 best exemplify the vulnerability of the Indian Himalayan region which caused huge loss of life, livestock and infrastructure.

Monitoring and management of disasters in a country like India is a major challenge. As the natural disasters are of different kind, the responsibility of forewarning, observational networks, and other information are dealt by specific expert groups or departments in the country. For example, the meteorological department addresses weather and atmospheric parameters to track cyclones, geology department deal with earthquakes and landslides, Central Water Commission for flood, Geological Survey of India for landslides, Department of Agriculture & Cooperation for drought and Ministry of Environment and

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National Remote Sensing Centre (NRSC) Indian Space Research Organisation

Forests for Forest fires. Ministry of Home Affairs, Government of India is the nodal ministry in the country for management of all disasters, except agricultural drought - which is looked after by union Ministry of Agriculture. In 2005, India has brought out a Disaster Management Act; and set up the National Disaster Management Authority (NDMA). NDMA is bringing out detailed policy guidelines and mechanisms for management of all types of natural and man-made disasters in the country. Under the NDMA, the States and Districts are also setting up State and District Disaster Management Authorities (SDMAs and DDMAs), respectively. The National Institute of Disaster Management (NIDM) of the union Home Ministry is the apex institute for training and capacity building in disaster management in the country.

In last few decades, application of geospatial technologies for disaster management has gained momentum and space applications for disaster management has gone through different phases of experimental demonstration, semi-operational and operationalisation (Roy et al., 2008). The most important element in disaster management is the availability of timely information for taking decisions and actions by the authorities (Miranda et al., 1988, Okamoto et al., 1998). Space borne platforms have demonstrated their capability in quick disaster response during disaster and their support during post disaster recovery operations. Earth Observation satellites can provide uninterrupted and assured operational services required before, during and after the disaster because of the comprehensive, synoptic and multi temporal coverage of large, remote and inaccessible areas. While communication satellites help in disaster warning, relief mobilization and tele-medicinal support, earth observation satellites provide the basic support in pre-disaster preparedness programmes, in-disaster response and monitoring activities, and postdisaster reconstruction. The present paper discusses the application of geospatial technologies for disaster management.

2.0 Space based facilities / infrastructure for disaster management support

ISRO/ DOS has unique constellation of satellites in space to cater to the needs of the country in terms of Communication (SatCom), Satellite Navigation (SatNav), Meteorology (SatMet) and remote sensing (RS). The meteorological satellites, INSAT series and Kalpana, have capability to image on a continuous basis, which is essential for tracking the tropical cyclones and deriving wind vectors over large oceanic areas.

The constellation of IRS satellites provides vital information on disaster events, and help in risk management related activities. The aerial survey systems, such as the Aerial Laser Terrain Mapper (ALTM) and Synthetic Aperture Radar (SAR) help in filling the observational gaps under special requirements of accurate terrain height or observations through cloud-cover respectively. The INSAT Data Relay Transponder (DRT) has capability to collect data from platforms located in remote, inaccessible areas, and over the oceans.

The space enabled ground systems like Automated Weather Station (AWS), Cyclone Warning and Dissemination System (CWDS); and the Doppler Weather Radars (DWR) are further augmentations that provide important inputs in terms of weather observation networks. ISRO has set up the DMS Decision Support Centre (DSC) at National Remote Sensing Centre (NRSC), Hyderabad, as the single window service provider

3.0 Disaster Management Support (DMS) Programme

ISRO, with a dedicated communication, meteorological and remote sensing satellite series, provides the capability to help in disaster warning, relief mobilization, tele-medicinal support and quick disaster response. Indian Earth Observation (EO) capability has increased manifold since the launch of Bhaskara-I in 1979, improvements are made not only in spatial, spectral, temporal and radiometric resolutions but also in their coverage and value added products.

To strengthen the disaster management system, for integrating operationally the space technology inputs and services on a reliable and timely basis a Disaster Management Support (DMS) Programme was initiated by Department of Space (DOS), in the 10th Five Year Plan and a dedicated centre to support to provide operational services called Decision Support Centre (DSC) was established at National Remote Sensing Centre (NRSC), Hyderabad.

4.0 Decision Support Centre - Monitoring of Natural Disasters

Towards enabling the operational services, as cited above, DSC serves as a single window service provider, interfacing with the National/State disaster management agencies. DSC is an operational service provider for space-enabled inputs together with other important data layers for its use in disaster management by the Central and State Governments. A VSAT-based satellite communication network has been put in place for online transfer of space enabled inputs to the State and Central Government user departments. At present, DSC is addressing five natural disasters, viz. Flood, Cyclone, Agricultural Drought (transferred to Mahalanobis National Crop Forecast Centre, Delhi, Govt. of India), Forest fires, Earthquake and Landslides.
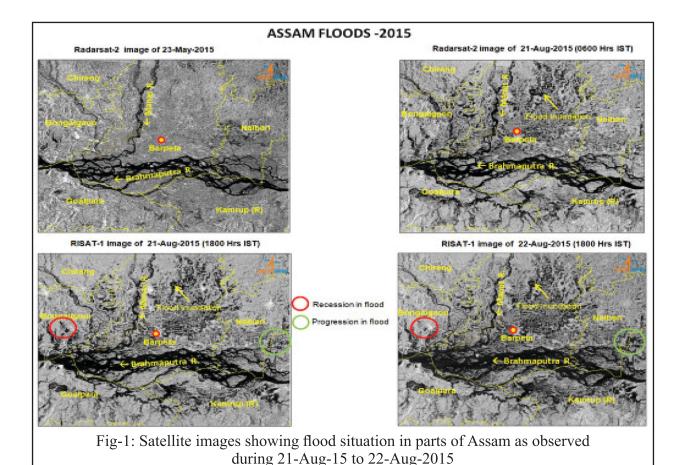
4.1 Activities related to flood disasters

Space technology has emerged as the most powerful tool for decision making in flood disaster management. Satellite images provide information required by the decision makers at different phases in flood disaster cycle i.e. pre flood (preparedness), during flood (relief and rescue operations) and post flood (mitigation measures). DSC provides support during floods, for early warning, flood mitigation, capacity building, support to states and international support.

a. Near Real time Flood Monitoring: DSC keeps a continuous watch on the flood situation in the country and all the major flood events in the country are regularly monitored. Satellite based inundation maps are prepared and disseminated in near real-time basis to Ministry of Home Affairs (MHA), National Disaster Management Authority (NDMA), Bhuvan Geoportal, National Database for Emergency Management (NDEM) (over Virtual Private Network or VPN) and Central Water Commission (CWC), besides concerned State agencies, especially the Relief Commissioners. Recent floods in Assam (2015) and floods in Jammu and Kashmir (2014) are discussed below wherein space technology data has been extensively used.

(i) Recent Assam Floods, August 2015
The second wave of floods was reported in Assam during the fourth week of August, 2015. All the major tributaries of River Brahmaputra were flowing above danger level due to heavy rains and River Beki at Beki Road Bridge was in spate. NRSC kept a close watch on flood situation and acquired and analyzed satellite datasets from IRS RISAT-1 and Radarsat-2 (Fig-1) to provide information on inundation situation to Govt. of Assam.

Fig-1: Satellite images showing flood situation in parts of Assam as observed during 21-Aug-15 to 22-Aug-2015

(ii) Floods in J&K, September 2014

Jammu & Kashmir experienced one of the worst floods in the past 60 years, during first week of September 2014, due to unprecedented and intense rains. The Jhelum River and its tributaries were in spate and caused extensive flooding in the region. Decision Support Centre (DSC) of NRSC immediately took necessary action on satellite data acquisition and processing and kept a close watch on the flood situation. All possible data from Indian Remote Sensing (IRS) satellites, as well as foreign satellites, covering Srinagar valley were obtained and analyzed. International Charter was also activated for additional foreign satellite datasets. Rapid flood mapping and monitoring was done on almost daily basis and the flood inundation information was disseminated in near real time to MHA, NDMA, Govt. of J&K, National Security Council Secretariat and Defence Services. A total of 50 flood inundation maps consisting of daily flood maps along with list of villages inundated, cumulative flood inundation maps and flood progression and recession maps (Fig-2) were disseminated. Flood inundation simulation study was done using CARTO-DEM for Jhelum River to identify the possible flood affected areas and the same was uploaded on Bhuvan portal as preparedness. Hydrological Modelling Study was done for approximate quantification of flood discharges in the Jhelum River. Satellite image maps were prepared using high resolution data and were provided to MHA, NDMA, Govt. of J&K to help in relief and rescue operations. The flood products and flood layers were continuously published on Bhuvan and NDEM web portals. Value added satellite images showing the status of the flood situation were published on NRSC website.
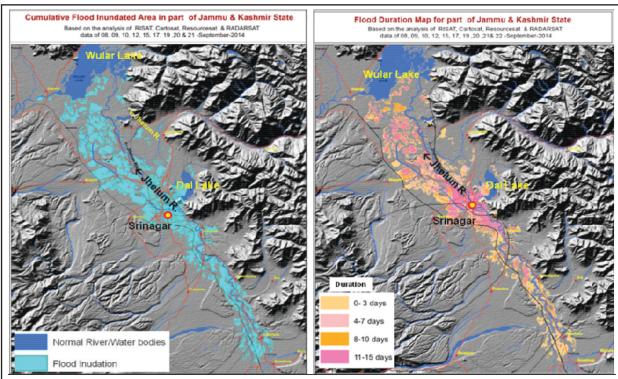
Fig-2: Cumulative inundated areas during 8-21 September, 2014 and flood duration map 8-22 September, 2014 for part of Jammu and Kashmir

b. Flood Early Warning: A pilot study on flood forecasting using satellite-based inputs was taken up for parts of Godavari basin jointly with CWC and the model was installed at CWC, Hyderabad. Similarly, Flood Early Warning System (FLEWS) has been taken up in Assam by North Eastern Space Applications Centre (NESAC) to help monitoring and management of floods in the region. This has yielded very good results over the past few years and given a lot of confidence to the local authorities to use these forewarnings to take safety measures and protect people and property from the floods. The FLEWS has become one of the popular projects in the region and this program is continued on a regular basis for Assam.

c. Flood Hazard Zone Mapping: Over a period of time, ISRO has created a repository of large data pertaining to the floods in different areas of the Country. These historical datasets, generated by ISRO, are useful for identification of the flood-prone areas and risk assessment. The information thus generated is very useful to the planners for devising area-specific mitigation measures. Under the Disaster Management Support Programme of NRSC/ISRO, for the first time in the country initiated Flood Hazard Zonation mapping using historical satellite data acquired during floods of different magnitudes. Flood Hazard Zonation Mapping and District-Wise Flood Hazard Atlases are prepared for Assam and Bihar (Fig-3); whereas for Odisha and Uttar Pradesh work is in progress and flood hazard zonation for West Bengal is initiated. The flood hazard maps have been classified into 5 categories, viz. very low (inundated once or twice), low (inundated 3-4 times), moderate (inundated 5-6 times), high (inundated 7-8 times) and very high (inundated 9-10 times).
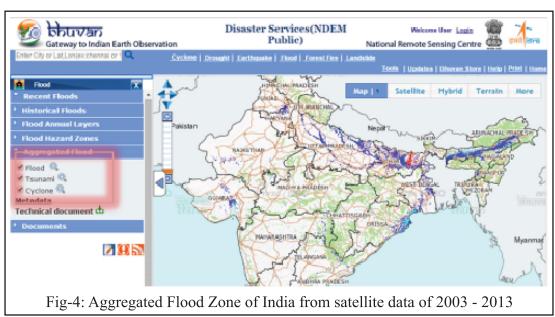
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Fig-3: Flood Hazard Zones in Bihar derived from satellite data of 1998- 2010

d. River Bank Erosion and changes in river course mapping: Frequent flooding in the North-North Eastern State has resulted in changes in river course and bank erosion due to heavy sediment loads and gentle river slopes. Using multi-year satellite data, the extent of bank erosion is carried out for Brahmaputra River and regularly is being updated also.

e. Aggregated Flood and Flood Prone Area Assessment

The flood prone area in India, generally referred official documents is based on the information aggregation of the information provided by State Governments. NRSC has initiated a study to scientifically assess the flood prone area. As a first step, available historical satellite datasets acquired during the flood season (more than 100 historical satellite datasets) from Indian Remote Sensing Satellites (IRS) and foreign satellites have been analyzed for generating the aggregated extent of flood inundated area (Fig-4). Only those datasets corresponding to either high flood situation or unprecedented floods were used in this study.

Fig-4: Aggregated Flood Zone of India from satellite data of 2003 - 2013

4.2 Activities related to Cyclone

Satellite communications provide an effective mechanism for real-time dissemination of information and early warning besides establishing communication link after cyclone hit. INSAT system provides half-hourly observation of cyclone movement and its associated parameters for warning and prediction of landfall. Using appropriate models and satellite data, ISRO is supporting the efforts of India Meteorological Department to predict the Tropical cyclone track, intensity and landfall. The INSAT system, particularly the INSAD 3D with its imager and sounder capabilities, has provided many additional parameters to the IMD to improve their forecasting skills. Also, the Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC) portal of SAC, ISRO provides number of weather and atmospheric parameters for the modelers and researchers to use the varieties of R&D activities and predictions. One of the unique features of MOSDAC is the online tracking of cyclones and providing visualization tools for the local Government to use for making preparations to face disasters. Not only the tracking of cyclone, the exact landfall site and time are being predicted accurately for the local administration to take specific measures of safety of the people at large.
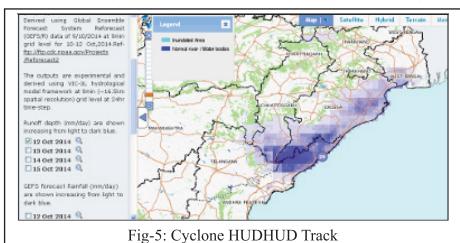
A close watch on the cyclone track and the potential areas to get inundated are closely monitored to program and acquire satellite datasets by NRSC. Bhuvan page on cyclone provides information on cyclone track, experimental surface runoff, inundation, ground information integrated through mobile apps (crowd sourcing), etc. Based on the landfall rapid damage assessment of the inundated areas is carried out and information is provided to the concerned state agencies. Odisha Super Cyclone of 1999 and the recent examples including cyclone PHAILIN (2013) and cyclone HUDHUD (2014) EO data has been used to provide information. During cyclone Hudhud Bhuvan has been extensively used to collect information on locations affected due to cyclone impact and information on about 25000 locations was collected using crowd sourcing.

(a) Cyclone HUDHUD, October 2014
Cyclonic Storm 'HUDHUD' made landfall at Andhra Pradesh coast on 12th October 2014 causing heavy damage to Vishakhapatnam city, including the airport, a number of buildings, electrical and telecommunication supplies and roads.

Experimental surface run-off estimation was attempted using Global Ensemble Forecast System Reforecast (GEFS/R) data of 9/10/2014 at 9min grid level for 10-12 Oct, 2014. (Ref-ftp://ftp.cdc.noaa.gov /Projects/Reforecast2). The outputs are experimental and derived using Variable Infiltration Capacity (VIC-3L) hydrological model framework at 9min (~16.5km spatial resolution) grid level at 24hr time-step. Runoff depth (mm/day) are shown increasing from light to dark blue (Fig-5).

Fig-5: Cyclone HUDHUD Track

Further hydrological simulations are also carried out for typical rivers in order to estimate the discharge.

Decision Support Centre (DSC) of NRSC continuously monitored the cyclone track and planned all possible both Indian Remote Sensing (IRS) and foreign satellite data acquisitions over Andhra Pradesh in particular over Vishakhapatnam. Aerial flying was carried out over part of Vishakhapatnam and rapid damage assessment was carried out. International Charter was also activated for additional foreign satellite datasets. Rapid cyclone inundation mapping and monitoring was carried out on almost daily basis and the inundation information was disseminated in near real time to MHA, NDMA, and Govt. of AP to help in relief and rescue operations. A total of 21 inundation maps were sent consisting of daily inundation maps, cumulative maps, progression and recession maps, district inundation maps and detailed maps. List of inundated villages in AP were also provided. The inundation products and layers were continuously published on Bhuvan and NDEM web portals. Value added satellite images showing the status of the flood situation were also published on NRSC website. An Android based mobile application was uploaded on the Bhuvan portal for free download to facilitate crow sourcing. Information on about 25,665 locations covering damages to cell tower location, affected towers, total electrical sub-stations and affected sub-stations, damaged roads, crops, house etc were published in Bhuvan portal (Fig-6a&b) to help the Government of AP in providing relief. Appraisals were made to the Chief Executives of the Government of AP on a regular basis on the status of cyclone HUDHUD.

Fig-6a: Crop Damage data in Cyclone HUDHUD
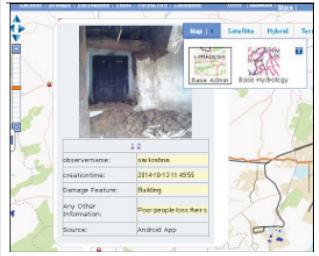
Fig-6b: Damage to buildings due to Cyclone HUDHUD.

4.3 Activities related to Agricultural Drought Assessment

Under the National Agricultural Drought Assessment and Monitoring System (NADAMS)regular information on prevalence, severity level and persistence of agricultural drought at state/ district/ sub district levels during Kharif season (June to November) is being carried out for 13 states which are prone to drought. The assessment reports are generated every fortnight and disseminated to Ministry of agriculture, Dept. of Agriculture and Co-operation, Relief/ Revenue Commissioners of different states, etc. Considering the success achieved in this mechanism, the entire drought mechanism has been transferred to Ministry of Agriculture as an operational activity. The newly established "Mahalanobis National Crop Forecast Centre (MNCFC)" of Ministry of Agriculture,

Government of India, at New Delhi, is effectively carrying out all necessary activities of NADAMS from Kharif 2012 onwards.

4.4 Activities related to Landslide

Proactive support for landslide disaster includes preparation of maps concerning to landslide activities, landslide hazard zonation maps, landslide inventory maps, comprehensive quantification of the magnitude and extent of the damage. As a part of the DSC activity all the major Landslides are being monitored for damage estimation. Experimental landslide prediction

works are also taken up by NRSC for important pilgrim routes of Uttarakhand based on the rainfall data and these are geospatially provided on Bhuvan portal for use by common man.

a. Landslide hazard zonation: Towards the identification of areas that are vulnerable for occurrence of future landslides, landslide hazard/susceptibility maps (Fig-7) have been prepared by integrating geological and topographic factors such as lithology, structure, landform, slope etc. These maps indicate unstable and stable areas.
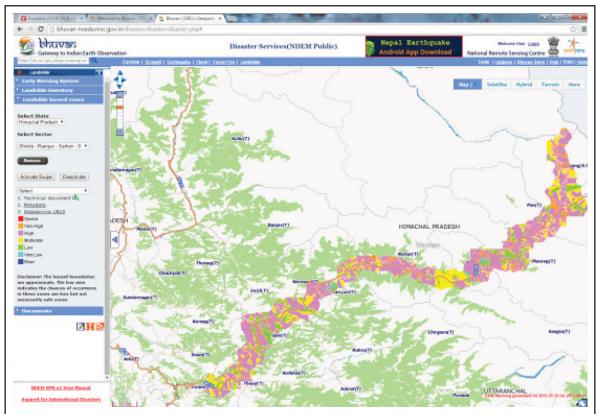
Fig-7: Landslide hazard zonation maps of Shimla to Manali route in Himachal Pradesh

Landslide hazard zonation maps for following routes in the states of Uttarakhand and Himachal Pradesh are available in Bhuvan.

i.   Rishikesh-Uttarkashi-Gangotri-Gaumukh
ii. Rudraprayag-Okhimath-Kedarnath
iii. Rishikesh-Rudraprayag-Chamili-Badrinath
iv. Pithoragarh-Khela-Malpa
v.   Chamoli-Usara-Okhimath
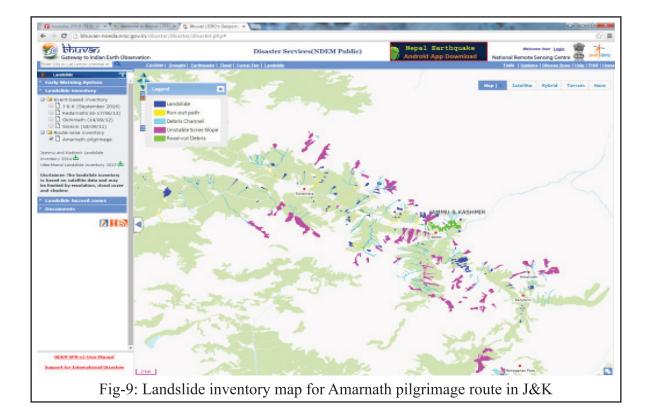
vi.   Dalhousie-Chamba-Brahmaur
vii. Shimla-Rampur-Sarhan-Sumdo
viii. Shimla-Bilaspur-Kulu-Manali

b.   Landslide damage assessment : Post-disaster support for landslide includes preparation of damage assessment maps and landslide inventory maps within 24 hours of the receipt of the cloud free optical satellite data. Landslide

inventory maps prepared for major disasters such as Uttarakhand 2013 (6585 landslides) (Fig-8), Okhimath 2012 (451 landslides), J&K 2014 (1071 landslides) (Fig-9) gives a comprehensive quantification of the magnitude and extent of the damage.

Fig-8: Landslide inventory after 2013 Uttarakhand disaster (light brown colour indicates landslides)

Fig-9: Landslide inventory map for Amarnath pilgrimage route in J&K

c. Reconstruction and Rehabilitation: Landslide susceptibility/hazard zonation maps will help to identify safe place for construction of settlements and roads. The new landslide inventory maps will also help to identify areas that can be avoided in the aftermath of landslide event.

d. Early warning for rainfall-induced landslides: Early warning for rainfall-induced landslides has been launched in Bhuvan as proactive support towards disaster mitigation. During monsoon, 72-Hour forecast is generated daily for road corridors leading to Gangotri, Badrinath, Kedarnath and along the Pithoragarh-Malpa route in Uttarakhand. Fig-10 shows Early Warning map for rainfall induced landslides for Rishikesh-Badrinath- Rudraprayag-Kedarnath-Chamoli-Okimath area.
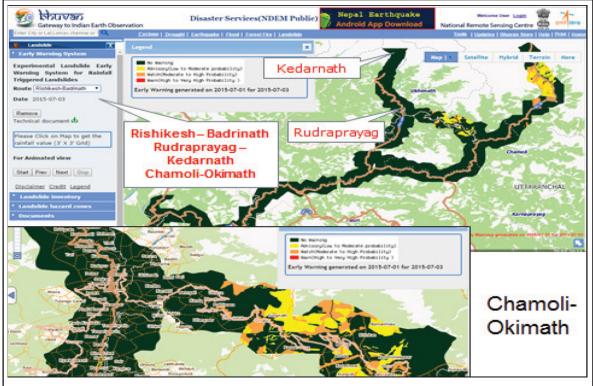
Fig-10: Early Warning for Rishikesh-Badrinath-Rudraprayag-Kedarnath-Chamoli-Okimath area.

Advisory: Moderate Landslide Susceptibility and Moderate to High (>0.75) Trigger Probability (Low to Moderate probability of landslides)

Watch: Very High Landslide Susceptibility and Moderate (0.75 - 0.85) Trigger Probability OR High Landslide Susceptibility and Moderate to High (> 0.75) Trigger Probability (Moderate to High probability of landslides)

Warn: Very High Landslide Susceptibility and High (>0.85) Trigger Probability OR Severe Landslide Susceptibility (High to Very High probability of landslides)
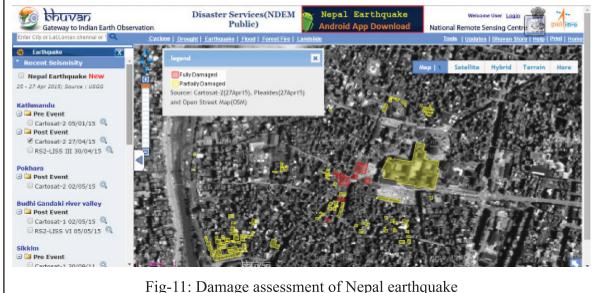
4.5 Activities related to Earthquake

Satellite Remote Sensing has a limited role in the prediction of earthquake but it plays a major role in earthquake damage assessment. Damage assessment, both at regional level and at detailed scales, is being carried out for any such events that occur in India. Recent event of Nepal was one of the major events that caused significant damages to the country. IRS satellite images were extensively used in this event as a support to Nepal in dealing with the situation.

Nepal Earthquake

A devastating earthquake of magnitude of about 7.8Mw occurred on 25 April, 2015, with an epicenter in Lamjung district. It was one of the worst natural disasters to strike Nepal– India (Bihar) boarder.

NRSC responded quickly and used all available IRS satellites. In addition, International Charter was activated for more number of high resolution observations. Damages to infrastructure were carried out in a rapid mode, using satellite images. Government of Nepal along with several agencies, worldwide used this information. Fig-11 shows the damages due to earthquake based on high resolution Cartosat-2 satellite data.

Fig-11: Damage assessment of Nepal earthquake

Due to the unpredictability of seismicity in time and space, the role of space support is realised in post-earthquake scenario. High spatial resolution satellite data along with geological and tectonic details of the areas around epicenter and other affected regions help to quickly evaluate damage in terms of amount of damage to buildings, transportation networks and other infrastructure and property. These data acquired preand post event are immediately made available on Bhuvan with value additions on damage and tectonic/geological information. Bhuvan also serves as the platform for dissemination of inventory of landslides occurred during the earthquake. It has facility for crowd-sourcing for public to report the damage.

4.6 Activities related to Forest Fire

Satellite data-based temperature anomalies are used for the detection of active fire locations. Daily forest fire alert (day and night time) is automatically generated and the information is sent through an automated chain of data processing to the Forest Survey of India (FSI) and also to the State Government as SMS alerts. This information is also posted on Bhuvan platform of ISRO for public use. Using high-resolution remote sensing data, burnt area assessment is also done based on the specific request by the local Government.

Out of 67.5 million hectares of Indian forests, about 55% of the forest cover is vulnerable to fires and may cause an economic loss of over Rs 440 crore every year apart from other ecological effects. The major causes of forest fires in India are anthropogenic, which include shifting cultivation practices, controlled burning, fire wood burning and others.

Forest fire monitoring has been taken up as part of

the Disaster Management Support Programme /Decision Support center (DMSP/DSC) activities. Under DSC activities of NRSC, a comprehensive system, "Indian Forest Fire Response and Assessment System (INFFRAS)", was established during 2006 to facilitate fire related operational and R&D activities. INFFRAS helps in generating daily near-real-time day-night forest fire alerts generation using MODIS data and dissemination of the alerts. It also involves fire burnt area assessment (includes both rapid and annual burnt area assessment) using Indian Remote Sensing Satellite (IRS) data sets. With live integration of INFFRAS with Bhuvan, dissemination mechanism for the forest fire alerts has been established.

a. Near Real Time Active Fire Monitoring

The activity is carried out jointly with the Forest Survey of India. Near real time alerts are produced using TERRA- and AQUA- MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data received and processed at NRSC Earth Station, Shadnagar. Typically two MODIS passes are required to cover the Indian area. Two daytime and two night-time alerts are produced. Alerts are sent in a pass-wise manner. Alerts are sent to the user agency (FSI, Dehra Dun) by email and value added products are simultaneously published on the ISRO geo visualization portal, Bhuvan.
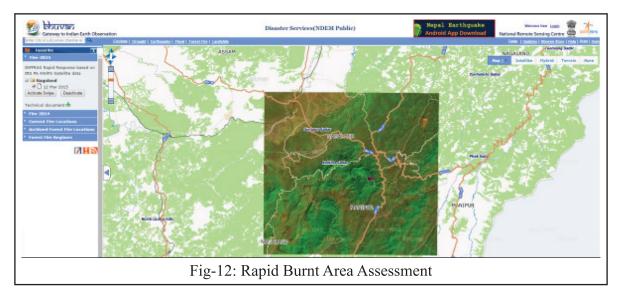
Active fires are detected using the MOD1KM and MOD03 products. A contextual detection algorithm that uses absolute thermal thresholds as well as background characterization and contextual tests is used to identify fire pixel (thermal anomaly). The output is the Level 1b MOD14 product. Processing routines for are obtained from the NASA DRL repository.

A true color image (daytime) and a thermal image (nighttime) are produced to show the coverage and cloud cover for a pass. The MOD14 product is converted to vector format (shape file) and attributes (satellite, date of pass and time) added to the shape file. Additionally a text file with fire locations is also produced. Products viz. shape file, text file and the image products are sent by email to the Forest Survey of India (FSI), Dehradun for value addition and dissemination to state forest department users.

Alerts are sent by SMS service to several forest departments. The service is provided on a no-cost basis and uses forest administration/ management layers linked with relevant mobile numbers provided by the respective state forest department. SMS alerts are sent through a gateway service provided by the state forest department. A user module for maintaining the mobile number database is used to ensure a current database.

b. Rapid Burnt Area Reporting

Rapid burnt area reporting is carried out on event basis for significant fires based on user request. Burnt area assessment is carried out using IRS LISS-III and AWiFS satellite data received and processed at NRSC Earth Station, Shadnagar. IRS AWiFS has a revisit capability of five days, however because of overlap between successive days and coverage with two satellites i.e., ResourceSat 1 and 2, in practice coverage of the fire area is obtained within the revisit period as well. In exceptional events satellite data from international satellites is also used by raising a data request under the international charter. Burnt area assessment is sent within a few hours of completion of overpass to the state forest department and made available as a report on Bhuvan (Fig-12).

Fig-12: Rapid Burnt Area Assessment

5.0 Creation of Digital Database

Digital databases for disaster prone districts of the country have been created and positioned at DMS-Decision Support Centre (DSC) at National remote Sensing Centre (NRSC). These databases are effectively being used for monitoring and damage assessment. Today DSC supports all major disasters in a near real-time manner by providing interpreted maps and data through Bhuvan and NRSC websites. These data sets are disseminated to MHA, NDMA and the respective State Governments to enable effective handling of such disasters. Each disaster is carefully mapped and monitored continuously in a sustained manner, while the data/ maps also get disseminated as a support to the disaster managers.

National Database for Emergency Management (NDEM) was conceived as a GIS based repository to support disaster/ emergency management in the country. NDEM is operational and provides direct support to the respective State through Virtual Private Network (VPN) and hence assures fail-safe disaster management capability. The repository contains datasets at different scales/ details: (i) National level core geo-spatial data at 1:50,000 scale; (ii) Hazard specific data for multi-hazard prone districts at 1:50,000 scale; (iii) Data for multi-hazard prone cities/ towns at 1:10,000 scale; and (iv) Data for major cities at 1:4,000 scale. All the satellite data and maps are made available to the disaster managers through NDEM Private (through VPN) and Public (Through Bhuvan) on a regular basis for the entire country.

6.0 Acquisition of close contour information

Using Airborne Laser Terrain Mapper (ALTM) and Large Format Digital Camera (LFDC) high resolution maps of 1: 5000 scale and close contour information of 0.5 meter interval are being prepared. This information is used in flood inundation model generation. Thousands of square kilometers of aerial flying is being done to create a permanent repository of very high resolution data for emergency management.

7.0 Development of Airborne Synthetic Aperture Radar

The aircraft version of Disaster Management Synthetic Aperture Radar - the 'DM-SAR' has also been developed at Space Application Centre (SAC) of ISRO. The development model of C-Band DM-SAR has been flown in many areas of the country, as an important support for disaster management considering the heavy manifestation of clouds under such conditions. This mode of imaging provides clear data/ information of the inundation in spite of cloud cover and hence found to be very useful for flood monitoring. The flight model along with associated near real/ real-time data processing sub-system is another important feature of that of interest for disaster management.

8.0 Development of Emergency Communication Equipment

INSAT based MSS Type D system (Portable satellite phones) supports voice communication through portable suitcase-type satellite terminal. The systems are being used at disaster sites as well as for emergency operations.

Distress Alert Terminal (DAT) for fishermen is a device which could be fitted into the fishing boats for activation during emergencies. The DAT could be activated manually or automatically while sinking of boats or in case of fire. The DATs are floatable that send distress signals for 24 hrs for the search and rescue operations. Around 1800 DATS are deployed in coastal areas through Indian Coast Guard.

In association with Indian Meteorological Department, around 350 **Cyclone warning Dissemination Systems** are installed in the coastal areas. The DTH based Disaster Warning Dissemination System (DWDS) of ISRO is a useful gadget that provides warning, particularly duing cyclones, to take safety measures. Disaster warnings could be sent through customised settop- boxes to the TV sets in the disaster affected areas. In association with Doordarshan and IMD, around 500 DWDS are being installed at coastal areas affected by cyclone.

9.0 Satellite based Communication network

ISRO has established the satellite/ VSAT-based satellite communication network, by interconnecting the National Emergency Operations Centre (NEOC) at MHA, the PMO, and the State Emergency Operations Centres (SEOCs). This also serves as a VPN for providing critical information on disasters to the managers in the affected area. More than 40 nodes, connecting important parts of the country, are operationally providing the support. More such devices are planned in the future, as this is the best means of establishing connectivity with affected even under distress conditions.
The network established, includes –
  • A hub in New Delhi

  • 10 primary nodes (National Remote sensing Centre, Hyderabad; National Remote sensing centre, Shadnagar; India Meteorological Department; Central Water Commission; Indian National Centre for Ocean Information Services; Geological Survey of India, New Delhi; Space Application Centre, Ahmedabad; Master Control Facility, Hassan, NESAC (North Eastern Space Applications Centre) Shillong, and National Institute of Disaster Management, Delhi),
  • 5 observation nodes (Prime Minister Office; Prime Minister residence; National Disaster Management Authority, Delhi; Cabinet Secretariat, Delhi; and Control Room North Block)
  • 20+ State Emergency Operation Centres (Andhra Pradesh; Andaman & Nicobar Islands; Arunachal Pradesh; Assam; Bihar; Delhi; Gujarat; Himachal Pradesh; Kerala; Maharashtra; Manipur; Meghalaya; Mizoram; Nagaland; Odisha; Sikkim; Tamil Nadu; Tripura; Uttarakhand and West Bengal).

10.0 International Initiatives

  • The International Charter on Space and Major Disasters aims at providing a unified system of Space Data Acquisition and delivery to those affected by natural or manmade disasters anywhere in the globe, through authorised users. ISRO joined the Charter in 2002 as a member and plays an important role in providing remote sensing imageries to the global community, for the major disasters, using IRS system.

  • ISRO has joined Sentinel Asia Project initiated by JAXA in 2007. Sentinel Asia (SA) is a "voluntary and best-efforts-basis initiative" led by the APRSAF (Asia-Pacific Regional Space Agency Forum) to share disaster information in the Asia-Pacific region on the Digital Asia (Web-GIS) platform and to make the best use of earth observation satellites data for disaster management in the Asia-Pacific region.

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11.0 Conclusions

All components of Space borne platforms, viz. remote sensing, satellite meteorology, satellite communication and global navigation systems, have successfully demonstrated their capability in efficient disaster management. While communication satellites help in connectivity, relief mobilisation and tele-medicinal support, the earth observation satellites provide the basic support in pre-disaster preparedness phase, disaster response and monitoring activities, including the post-disaster phase. Meteorological satellites with VHRR help in continuous monitoring of genesis, growth and movement of cyclonic systems and help in advance prediction of the landfall location, thus helping in reducing the human causalities. An excellent example of the role of satellite technology for early warning was well demonstrated during Phailin cyclone in Odisha during 2013 and Hudhud in Andhra Pradesh in 2014. Though providing right information for all disasters to the concerned is a challenging task, space technology helps in reducing the gap and help in reaching the concerned in right time in a cost effective manner and has proved to be effective time and again..

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13.0 Acknowledgements

Socio Economic Impacts of Satellite Based Navigation System

A.S. Ganeshan[1]

1. Introduction

Satellite-based navigation has become an integral part of human life in 21st century with pocket size GPS (Global Positioning System) receivers used in vehicles, GNSS (Global Navigation Satellite System) enabled smart phones etc. Today, the GNSS has entered the society with its multi-facet applications that ranges much farther that traversing from point A to point B. It has made its remarkable presence in location based services, survey, GIS (Geographic Information System), agriculture, industry and service sectors, the core contributors towards any country's economy. The Socio-economic impact is a major predictor of success of a large scale technological venture in any country. In a nutshell, any new technological development and its value added services will have considerable social and economical impact on the livelihood of common man and the associated society, in addition to the industrial impacts. Satellite based navigation system is one such newly advancing technology which is offering modern navigation services to the users in terms of highly accurate position, velocity and timing solution economically all around the world on a 24x7 basis.

2. Navigation

Navigation is the art of getting from one place to another, safely and efficiently. In ancient times, mariners navigated by the guidance of the sun and stars and landmarks along the coast. They navigated from island to island across the open ocean using observations of guide stars and the moon, the winds and currents, and birds, knowledge of which was passed from generation to generation.
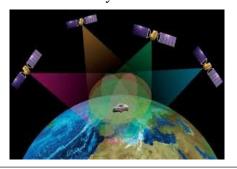
2.1. Early Navigational Instruments

In the earlier days the elements of nature, the celestial bodies, the geographical landmarks etc guided man along his journeys. As the humans evolved, new guidance mechanisms evolved with him. Compass, cross-staff, sextants, light houses etc. were invented. Later began the times of radio navigation with systems like LORAN (Long Range Navigation) which paved way for the next generation of navigation systems the Satellite-based Navigation.

2.2. Satellite Based Navigation

The era of Satellite Based Navigation began with the Timation and Transit systems. This was followed by the more advanced and currently operational GPS by USA and GLONASS by Russia. The Chinese and Europeans are entering the arena with COMPASS and GALILEO constellations respectively.

The Global Positioning System, better known simply as GPS, sends several signals that are used to decode the position and distance of the satellite. One signal encodes the satellite's "ephemeris" data, which is used to accurately calculate the satellite's location at any time.

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Accuracy offered by GPS is better than any other available land based system at almost all locations on the Earth, with few cents of modern electronics and few dozen satellites to provide worldwide coverage. As a result of these advantages, GPS has led to almost all previous systems falling from use. LORAN, Omega, Decca, Consol and many other systems disappeared during the 1990s and 2000s. The only other systems still in use are aviation aids, which are also being turned off for long range navigation while new differential GPS systems are being deployed to provide the local accuracy needed for blind landings.

In addition to GPS, GLONASS (Global Navigation Satellite System) developed by Russia is also operational. Galileo by European Union, Beidou/Compass by China are also under development. India is developing IRNSS as regional navigation satellite system. To further enhance the accuracy, availability and integrity of the navigation services to support Safety of Life operations, the augmented systems like EGNOS, WAAS and GAGAN have been developed.
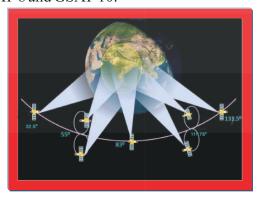
3. GAGAN

Considering the growing technological development in the field of satellite based navigation and its potential benefits to various application segments, India took early initiative in implementing satellite based navigation systems in the country. ISRO and AAI jointly developed GAGAN (GEO Augmented GPS Aided Navigation) System to provide Safety of Life navigation services over Indian airspace for different phases of flight. Also bounty of non-

aviation applications in Railways, Harbors, Road transportation, Surveying, Location based services etc., can exploit highly precise GAGAN solutions to their benefit.

Director General of Civil Aviation certified GAGAN system to provide Precision Approach services over Indian land mass and Non-Precision Approach/En-route services over Indian airspace through signal broadcast via GEO satellites GSAT-8 and GSAT-10.

4. IRNSS

IRNSS, the Indian Regional Navigation Satellite System, is an ISRO initiative to design an develop an independent satellite-based navigation system to provide positioning navigation and timing services for users over Indian region. The system is designed with a constellation of 7 spacecrafts and a vast network of ground systems operating in sync to ensure uninterrupted navigation service to the users. Four satellites (IRNSS-1A, 1B, 1C & 1D) are in their designated orbits broadcasting the IRNSS signal-in-space. With the addition of fourth spacecraft the minimum satellite requirement is met and independent position solution is being provided to its users for the first time using an Indian satellite-based navigation system. The initial performance results of IRNSS are in line with the expected design objectives using four satellites.

5. GNSS Applications

GNSS applications use GNSS Receivers to collect position, velocity and time information for their functionality. The GNSS-based

applications introduced great benefits in surveying, timing, aviation, maritime, agriculture, mining and logistic market industry, as well as other fields such as construction or oil offshore platforms. The GNSS-based applications for fleet management market are also expanding due to decreasing device prices and increasing accuracy of systems at a very low cost.

The GNSS Applications range from non-critical to highly critical applications. The different criticality of GNSS applications leads to different performance requirements from the GNSS systems. GNSS applications are categorized into :
- Civil Applications
- Surveying, Mapping and GIS
- GNSS-based Products
- Space Applications
- Scientific Applications
- Military Applications
- Autonomous Applications and Other applications

5.1. Civil Applications

Even though the GNSS systems (GPS and GLONASS) were developed for military purposes, later on they were made freely available for civilian users.

Different types of civil applications which use GNSS are :

- Personal navigation for travelers
- Railways
- Maritime Applications
- Vehicle navigation
- Aviation Applications
- Automated vehicle navigation in industries
- Search & Rescue operations etc

Given the easy availability of GNSS positioning in consumer products the use of GNSS positioning for personal applications has become customary and new uses such as pedestrian navigation, outdoor navigation for hiking, social networking, photography geo-coding etc., keep emerging.

In many places, Rail systems are beginning to use GNSS to track the movement of locomotives, rail coaches, maintenance vehicles, and wayside equipment in real time. The technology helps reduce accidents, delays and operating costs while increasing track capacity, customer satisfaction and cost effectiveness. The railway domain could considerably profit from the implementation of autonomous on-board positioning systems.

GNSS technology brought innovation and progress in navigation and many other marine activities such as fishing, oceanography and oil and gas exploitation. Satellite navigation benefits all maritime applications, including leisure boats, commercial vessels, and unregulated and Safety of Life at Sea (SOLAS) regulated ships. Each application will take advantage of the new characteristics offered by GNSS augmentation: increased accuracy and integrity, certified services and high availability and GNSS is being used in every phase of marine navigation: ocean, coastal, port approach and port maneuvers, under all weather conditions.

The road sector is a major potential market for GNSS applications. Satellite navigation receivers are now commonly installed in new cars as a key tool for providing new services to people on the move: electronic charging, real-time traffic information, emergency calls, route guidance, fleet management and Advanced Driving Assistance Systems. Satellite navigation will help regulate road use and minimize traffic jams and It could be used to charge motorists for using a stretch of road, to restrict access to congested roads, or to inform drivers of congestion and suggest alternative, quieter routes etc.,

The development of GNSS has provided a supplementary positioning service for many flight phases, in leisure flying as well as commercial air transport. Refining and improving satellite navigation through augmentation systems will assist pilots in all flight phases, from taxiing, to take-off, en-route flying, and landing in all weather conditions, reaching the level of safety that will be required to cope with the continuous increase in the number of flights.

Industry uses heavy machinery for many purposes. Satellite navigation and GNSS augmentation techniques can guide these machines precisely to perform their work. The same technique can be used for automated guidance of machines working in dangerous areas or simply to save manpower in repetitive work. The computer compares the GNSS position with the desired work profile and provides visual guidance to the operator for maneuvering the vehicles. The use of satellite-based machine guidance systems in surface mines is becoming common with very positive results in productivity and costs.

5.2. Surveying, Mapping and GIS

One of the most evident uses for GNSS is the realization of surveys and production of maps. Although a simple standalone GNSS Receiver might not have the required precision for some survey requirements, most of these requirements can be fulfilled using high-end dual frequency multi-constellation receivers built specifically for surveying and by using GNSS Augmentation techniques. The use of GNSS techniques in geodesy have revolutionized the way geodetic measurements are made. An increasing number of national governments and regional organizations are using GNSS measurements as the basis for their geodetic networks.

5.3. Space Applications

Even though the GNSS systems were originally designed for earth-based positioning and navigation, real-time spacecraft navigation based on space borne GNSS receivers is becoming a common technique for low-Earth orbits and geostationary orbits, allowing satellites to self-determine their position using GNSS, reducing dependence on ground-based stations. The different launch vehicles also use GNSS-based ranging systems for the launch and initial orbit phase.

5.4. Scientific Applications

GNSS systems offer important contributions to variety of scientific research work. New and improved data analysis techniques, jointly with a growing variety of available measurements encouraged development of more and more scientific applications in various fields. It is expected that evolving new systems such as Galileo and BeiDou, will contribute to further improvements in the current available applications as well to promote new applications in the areas of earth sciences and space science meteorology etc.,

5.5. Military Applications

Since the first GNSS systems (GPS and GLONASS) were primarily developed for military purposes, the military applications are one of the drivers for these systems. For instance GPS offers encrypted Precise Positioning Service which is available only to the US military and its allies. GNSS is used for different types of Military Applications such as Military Navigation and Target Acquisition.

5.6. Autonomous Applications

Autonomous vehicles technology is a multidisciplinary technology where different engineering areas, such as Navigation, are required. GNSS plays the pivotal role in the development of driverless car technology. GNSS systems where revolutionary in the area of Navigation by providing positioning and navigation capabilities to the autonomous vehicles. With precise positioning, GNSS can be used for lane or track determination (for road and rail vehicles) and attitude determination by using multiple antennas.

Autonomous vehicle technology is still at its infancy but currently the first laboratory prototypes are being tested and demonstrated. GNSS has been one of the key drivers for the recent developments in the area of Autonomous Driving and Autonomous Flying.

5.7. Location Based Services

Location Based Services (LBS) include applications that depend on the user location to provide a service/information that is relevant to the user at that location. LBS normally use mobile devices with positioning ability to provide the service or information to the user.

LBS can be used for personal or professional purposes such as:
- Location based Information Streams
- Tourist Information, Games
- Carpooling and Transport on Demand etc.

5.8. Other Applications

The main objective of GNSS systems is to provide positioning but by design other information is available from the measurements gathered by GNSS receivers. This led to less conventional uses of the technology in application areas that were not initially envisioned. By design GNSS systems deliver precise time along with the position and velocity of the user. This capability has been used to provide a precise time reference in different areas such as financial transactions and stock markets.

One other example of a less conventional use of GNSS technology is the use of the measured interference of the atmosphere on the GNSS signals to do atmospheric sensing.

5.9. Safety-of-Life (SOL) Services

In addition to the above regular applications, GNSS also provide safety-of-life services. To provide SOL services such as aviation, maritime etc., navigation systems must satisfy several stringent performance requirements such as

- Accuracy – The information that they give must be close to the actual value.
- Integrity – If the system cannot give sufficiently accurate information, it must notify the user of this in time.
- Availability – It may not occur that the system is unexpectedly unavailable.
- Continuity of service – If the system stops working after, for example, 2 years, it's not really useful.

A GNSS system, on its own does not possess these features. The GNSS system is then augmented using a ground-based (GBAS) or space-based (SBAS) system in order to meet the safety of life performance requirements. The various SBAS systems in place are: WAAS in USA, EGNOS in Europe, GAGAN in India and QZSS by Japan.

6. Socio Economic Impact of GNSS

In the recent past, GNSS technology has transformed business and lifestyles with innovative products and services across industries Ref (1). GNSS applications have improved business operations and practices in a range of industries like surveying, precision farming, maritime, construction, intelligent transportation, location based services and applications, aerospace etc,. In addition to increasing efficiency and reducing operating costs, the adoption of GNSS technology has improved safety, environmental quality, and many other less-readily quantifiable benefits.

GPS Vehicle Tracking System

Technological advancement is considered as an important determinant of economic environment. It includes:
(a) Use of technological progress for economic gains,
(b) Application of applied sciences resulting in innovations and inventions and
(c) Utilization of innovations on a large scale.

With the advancement of technology, capital goods become more productive. It has been rightly stated that "A high invention nation normally attain growth at a quicker pace than a high investment nation".

For example, all transport activities depend on GNSS positioning information, and this information has even become a critical component for the logistics chain that distributes

and supplies goods to consumers. Air and maritime transport show today an increasing dependence on satellite based navigation. Although terrestrial infrastructure continues to provide solid navigation systems, the trend towards increasing the density of air traffic relies essentially on the performance of GNSS, making these sectors increasingly dependent on GNSS.

There is a growing tendency in the transportation sector to incorporate GPS data into traffic information and management functions by providing vehicle-to-vehicle and infrastructure-to- vehicle communication, giving rise to so called Intelligent Transportation Systems (ITS). The timing information of GNSS is used to synchronize telecommunications networks and power management systems, especially in the framework of the development of smart grids; the banking system uses to a large extent the GPS time to stamp and certify financial transactions.
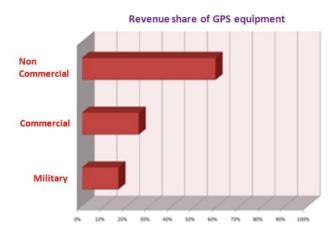
The size of economic activities that rely on GNSS is conservatively estimated as 6-7% of the whole GDP of the European Union, indicating that a disruption of the GPS signal would have a major impact on the European society.

6.1. GLOBAL INDUSTRY OVERVIEW

The applications of Global Navigation Satellite System (GNSS) are rapidly increasing across sectors. As an innovative industry, the GNSS industry directly affects economic activities and economic growth worldwide. During the past several decades, GNSS technology has transformed businesses and lifestyles with innovative products and services across industries. Furthermore, GNSS applications have entered into our daily life in many ways that we might not think about and the values of those services are beyond monetary values. Yet, the future potential is still far reaching (Ref.1).
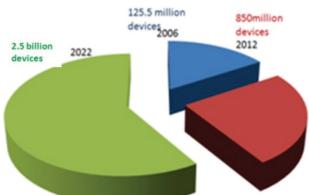
6.1.1. Market segments

The existing GPS market can be divided into three broad categories: commercial, noncommercial (consumer), and military. During the period 2005-

Revenue share of GPS equipment

2010, commercial equipment sales accounted for 25 percent of the total, while noncommercial and military equipment accounted for 59 percent and 16 percent, respectively, in the United States(Ref.2).

The applications of GNSS technology are rapidly developing into commercial and noncommercial industries. Global shipments of GNSS devices grew from 125.5 million units in 2006 to more than 850.7 million units in 2012.
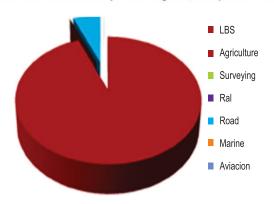
Annual Shipment of GNSS devices

The European GNSS Agency projects nearly 2.5 billion units of GNSS devices will be sold in 2022. The Agency estimates the number of installed base units of GNSS devices will increase almost four-fold from less than 2 billion units in 2012 to nearly 7 billion units by 2022, almost one GNSS receiver for every person on the planet.

The market segment of location-based services (LBS) that covers smart phones, tablets, digital cameras, laptops, fitness and people tracking

devices, and mobile data revenues has been growing exponentially and dominates the GNSS markets. Indeed, the global market of GNSS-enabled location-based services (LBS) devices alone increased more than eight-fold from 100 million devices sold in 2006 to 800 million devices sold in 2012. The European GNSS Agency expects annual sales of LBS devices will increase three-fold to more than 2.3 billion units in 2022. In terms of units, GNSS-enabled devices sold in LBS market account for more than 94% of total GNSS devices sold annually.

Annual Shipments of GNSS Devices by Market Segment, 2012(million of units)

- LBS
- Agriculture
- Surveying
- Ral
- Road
- Marine
- Aviacion

Cumulative Global GNSS Core Revenue, 2012-2022

Precision Agriculture 1.4%
Surveying/Mapping 4.2%
Location Based Services 47.0%
Road/Rail 46.2%
Aviation/Maritime 1.2%

It is estimated that global revenues of the GNSS enabled market will grow from approximately $204 billion in 2012 to approximately $340 billion in 2022. During the same period, global revenues of the GNSS core market that include only the part of the retail value attributable to GNSS (e.g., chipsets) is expected to double from approximately $68 billion to $136 billion. According to the report (Ref.3), the average cumulative revenues of LBS are expected to account for nearly half of total GNSS revenues in the next two decades.

6.2. Economic impacts on commercial & non-commercial users

Technological advancement has led to revolutionary progress in industrial development. The technology has improved the quality of manufactured goods, increased the efficiency of industrial production and tremendously diversified and multiplied technological advancement has enhanced the quality of life and the standard of living of people. The radical developments in communication, transportation, entertainment and domestic conveniences have made human living quite smooth and comfortable.
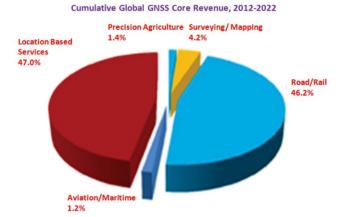
The economic benefits of GNSS to society are substantial. Like other innovative products, the economic benefits of the GNSS technology on the economy and society are generated from the GNSS manufacturers and the benefits of the GNSS technology to consumers. GNSS manufacturers create employment, provide earnings, and generate tax revenues for governments. Far more important, GNSS technology produces cost-savings for end-users, improves productivity, and in addition provides nonmonetary values for users. Furthermore, the spillover effects from the GNSS technology to other sectors otherwise unavailable.

6.3. Impacts on GNSS Manufacturers

The Europe GNSS Agency estimates there are 1.8 billion GNSS devices currently installed globally and are expecting the number of installed units to grow by nearly four-fold to reach nearly 7 billion units by 2022. The number of GNSS devices sold in 2012 was over 850,000 units and is estimated to be nearly 2.5 million units by 2022. Total revenues of GNSS devices sold in 2012 were nearly $60 billion and are estimated to be nearly $144 billion by 2022. The estimated revenues include only the value of GNSS functionality and service revenues directly attributed to GNSS functionality. For example, only the value of

GNSS chipsets in smart phones is counted and only the value of the GNSS receiver inside the Flight Management System is included (Table 1).

Location-based services (LBS), accounted for nearly 90% of number of GNSS installed-base devices. Since the price per unit is relatively inexpensive (approximately $20 per unit in 2012), revenues of LBS accounted for less than 30% of total revenues in 2012. However, revenues of LBS are expected to rise up to nearly two-thirds of total revenues by 2022 (Table 1)

Table.1 Global GNSS Market 2012-2022

Market Segment	Installed Base Units-million		Shipments Units-million		Revenue $-billion	
	2012	2022	2012	2022	2012	2022
LBS	1600	6300	800	2350	16.3	93.8
Survey	0.3	1.3	0.1	0.3	2.9	5
Agriculture	0.5	3.6	0.2	0.8	0.8	2.4
Aviation	0.8	1.5	0.3	0.4	1.1	1.2
Rail	0.1	0.4	0.1	0.1	0.1	0.1
Road	200	500	50	120	38	41
Marine	0.5	1.0	0.1	0.2	0.2	0.4
Total	1802.2	6870.8	850.8	2471.8	59.4	143.9

GNSS manufacturers are spreading in several industries including radio, TV broadcasting, wireless communications equipment, search, detection, navigation, guidance, aeronautical and nautical systems, instrument manufacturing, and other measuring and controlling device manufacturing. According to the U.S. Census data, there are 2,206 establishments in these three industries. These establishments employed 241,964 workers in 2011 and paid nearly $20.4 billion in wages. Value of shipments and value added in 2011 were approximately $91.9 billion and $54.3 billion, respectively. Annual payroll per employee averaged $81,969. Value of shipments and value added per employee in 2011 averaged $379,809 and $216,202, respectively (Ref.4). The same trend is expected worldwide in the days to come.

GNSS revenues in 2012 (estimated by the European GNSS Agency) and the manufacturing industry averages (estimated by the U.S. Census) are used to estimate the economic impacts of GNSS manufacturing companies on the U.S. economy. The European GNSS Agency estimated GNSS revenues in 2012 were approximately $16 billion in North America, which are mostly in the United States. Using averages of three GNSS-related manufacturing industries, it is estimated that GNSS manufacturers employed 42,126 workers in 2012, paid nearly $3.5 billion in wages, and contributed over $9.1 billion to the U.S. GDP (Table 2).

Table.2 Economic Contributions of GNSS Manufacturing Companies

Economic Benefits	Total
Direct Economic Impacts	
Total Revenues	$ 16.000 billion
Total Value Added	S 9.107 billion
Total Payrolls	$3.453 billion
Number of Employees	42,126
Payroll per Employee	$ 81,969
Direct and Indirect Economic Impacts	
Output	$32.0 billion
Earnings	$6.8 billion
Employment	105,315

The Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce produces job, wage, value-added, and output multipliers to estimate the indirect and induced effects of U.S. industries. The BEA estimates the job multiplier of the related-GNSS manufacturing industries ranges between 2.3 and 3.1 and the wage and output multipliers range between $1.8 and $2.2(Ref.5). Direct effects are the dollar amount of inputs required by an industry to produce a dollar of the industry's output, while indirect effects are the dollar amount of inputs required by all other industries in the supply chain to meet the industry's initial demand for the dollar of its output. The direct effects are the input production requirements such as the paint, steel, and plastic for the motor vehicles industry to provide additional motor vehicle outputs. The indirect effects are those "trickle down" production requirements for all other industries necessary in the supply chain to support the additional demand for intermediate inputs from the motor vehicles industry, such as the additional requirement for tire cord and synthetic rubber by the plastics and rubber industry to provide the additional tires required by the motor vehicles industry. The induced effects are the impacts of household expenditures on goods and services from the income earned by all direct and indirect employees. It is estimated that the GNSS manufacturing companies supported 105,315 workers (including direct jobs) with $6.8 billion in earnings and $32 billion in outputs.

Like all other manufacturers, GNSS manufacturers create additional economic activities for upstream and downstream business entities. While GNSS manufactures purchase intermediate goods and services from upstream vendors to produce chipsets, the GNSS technology creates additional economic activities for downstream companies who rely on the technology to create other products and services. The downstream business entities include GNSS device vendors, service and content providers, original equipment manufacturers, application developers, and retailers.

Oxera Consulting Group estimates that the direct economic effects of the downstream location-

based service companies (Geo services) to be around $150-$270 billion in revenues per yearglobally. These companies contribute around $113 billion value added to GDP per year,accounting for 0.2% of global GDP.16 The Boston Consulting Group (BCG) estimates thegeospatial services industry employs the GPS technology to generate about $75 billion revenues and provides more than 500,000 workers in the U.S. to support consumers, businesses, and government agencies. The downstream effects are expected to continue growing to reach $100 billion in annual revenues between 2012 and 2017 in the United States.

Another major commercial market of GNSS applications is ground transportation that applies intelligent transportation system (ITS) technology. According to an IBM report, the ITS industry markets in North America were $52 billion in 2009 and is expected to grow to $73 billion by 2015. The industry employed over 513,000 workers and is expected to expand to 564,000 employees by 2015.

Clearly, the impacts of GNSS technology on economies and societies are large. However, there are at least three technical challenges to quantify the exact direct economic activities of GNSS manufacturers and their upstream and downstream vendors. The first challenge is related to the industry classification system. As shown earlier, GNSS manufacturers are among 2,206 establishments in three industries. However, not all of these companies produce GNSS-related products and government statistics do not have exclusive data for GNSS companies.

The second technical challenge is to estimate the portion of GNSS-related activities in each company. For example, key chipset manufacturers like Broadcom, Intel, Qualcomm, and Texas Instruments produce many other products. Similarly, device vendors and application developers and stores have other products and services as well. The third technical challenge is the rapid development of the GNSS applications that affect downstream vendors. As shown in the 2013 European GNSS Market Report, the location-based services market alone increased by eight- fold in the past seven years. The number of mobile applications increased more than ten-fold within one year. As results, data becomes outdated quickly.

6.4. Impacts on Major Markets
Commercial users apply GNSS technology to increase productivity which in turn has positive impacts on cost-savings. Direct economic impacts include savings on inputs of labor, capital, and time. Noncommercial users enjoy GNSS technology for their daily life activities. In additionto monetary measures, GNSS technology creates nonmonetary benefits for noncommercialusers. Altogether, GNSS technology creates values for personal and business consumers.

6.4.1. Location-based Service (LBS) Market
LBS is increasingly integrated into our day to day life. The LBS applications include personal

Global personal location data
- $100 billion+ revenue for service providers
- Up to $700 billion value to end users

navigation, point of interest search, LBS advertising, person and objects tracking, emergencycaller location, location based gaming, sport and entertainment, weather information, and social networking. The number of applications is estimated to be around 775,000 in Apple App Store in 2013 and the number of Android Apps increased from 88,000 in 2011 to 700,000 in 2013. Various into one device such as cameras, watches, and binoculars. Location information is sent from devices to application layers to enable sharing and tracking functionalities.

The economic benefits of location-based services span across personal and business consumers as well as governments. The GNSS applications enable law enforcement to improve the efficiency of disaster response, people tracking, and community safety, in addition to national security and defense services. Geospatial services become an essential element in our daily life to accessinformation on computers, mobile phones, tablets, and GPS devices. On the commercial front, geospatial services are integrated into their core business operations, sales, and marketing by the companies. In its 2012 report, the Boston Consulting Group estimates that the multiple effects of the $75 billion geospatial services industry range between 15 and 20 times (Ref.6). The report estimates that the overall impacts of geospatial services in the U.S. economy are 1.6 trillion in economic activities and an additional $1.4 trillion in cost savings a year. The report also projects the overall impacts to reach $2.6 trillion per year by 2017.23

Studies have shown geospatial services create benefits via many channels including time savings, fuel savings, emergency response, and education. The GNSS applications help drivers to get to their destinations faster and in shorter routes which in turn save fuel consumption. In addition to personal trips, time savings add the substantial benefits for emergency services to locate and reach the scene quickly. The GNSS applications provide educational tools for students to gain information and knowledge and to sharpen their skills to enter the workforce.

For example, Oxera Consulting estimates the consumer benefits from geospatial services are nearly $50 billion per year globally ($22 billion in journey time and fuel savings, $12 billion in educational benefits, and up to $13 billion in emergency responses)(Ref.7).

6.4.2. Civil Aviation Markets

The GNSS applications cover all commercial and noncommercial aviation to provide theaccuracy and integrity of the position of aircrafts. Application of GNSS in aviation sector helps comprise various socio-economic benefits and helps to increase safety, reduce congestion, save fuel, protect the environment, reduce infrastructure operating costs, and maintain reliable all weather operations, even at the most challenging airports.

Indeed, the Federal Aviation Administration (FAA) projects daily flights in the U.S. will increase by 40% from 43,000 in 2010 to 60,000 in 2030. The number of passengers will increase by more than 68% from 712 million in 2010 to 1.2 billion in 2030. Thus, operational efficiency and passenger safety are essential for the future of the aviation industry.

The economic impacts of the GNSS application on the aviation industry are significant. The FAA's initiative of Next Gen is to create satellite-based procedures to transform the national airspace system to remove bottlenecks and improve safety and efficiency to deliver more on-time and fuel-efficient flights. The FAA estimates the benefits of Next Gen to reach $123 billion through 2030. Consumers will benefit from better travel experiences through the reduction in delays resulting from on-time performance by controllers and operators. The FAA expects that Next Gen improvements will reduce overall flight delays in the U.S. by 41% between 2013 and 2020. The application of Next Gen in aviation industry also helps consumers to indirectly benefit from a reduced adverse impact on the environment through the reduction of carbon dioxide emissions.

6.4.3. Ground Transportation Markets

The role of transport is crucial in creating jobs and sustaining economic growth in growing urban/rural areas. The ground transportation systems of cars, buses, metros, and rails are required to be efficient and safe to move workers and goods around the city smoothly. Therefore, it is more important for cities and communities to ensure to implement and maintain suitable transportation systems to support the increasing demand.

The development of the intelligent technology systems (ITS) provides cities with cost-effective solutions to maximize the economic returns of the city infrastructure to build safe, smart, and efficient transportation systems. The benefits of ITS application in the transportation segment are tremendous, by reducing congestion while enhancing mobility. The study conducted by U.S. Government Accountability Office (GAO) reports (Ref.8) that the benefits are greater than the costs of the real-time information systems. The report emphasizes an important finding from the Department of Transportation (DOT) that the benefit-to-cost ratio of real-time information systems is over 25, compared to the ratio of 2.7 for conventional highway projects. The DOT study found that the present value of total cost savings are about $30.2 billion (generating from the benefits to mobility, the environment, and safety) compared to the present value of the costs of $1.2 billion of the program.

6.4.4. Other Markets

The GNSS technology is also popular in agriculture and engineering construction industries. The GNSS technology helps farmers to match production techniques including farm planning, field mapping, soil sampling, tractor guidance, and crop scouting. In addition, the technology enables more precise application of pesticides, fertilizers, and better control of the dispersion of those chemicals. Thus, farmers are able to reduce input costs and to increase yields. It is estimated that the economic benefits of GPS on agriculture are between $19.9 billion to $33.2 billion per year based on 10% yield gain and savings of 10% in labor wages, 15% in capital, and 15% in inputs.

Another market that receives significant contribution of GNSS application is engineering construction. The GNSS equipment increases productivity in the construction industries by providing accurate machine guidance and measurement technology. The technology improves accuracy and increases efficiency in many related functions such as surveying, excavating, grading, sub-grading, transportation management, facility delivery, urban planning, and jobsite safety monitoring. The benefits of GPS to the industry can be measured in terms of savings of labor, capital, and materials. In our previous report, we estimate the economic benefits of GPS technology on the industry are between $9.2 billion and $23 billion per year. Table 3 summarizes economic benefits of GNSS applications on selected industries in the United States.

Table.3 Economic Benefits of Major Market Segments in United States

Markets	Economic Benefits
Location Based Services	$1.6 trillion in economic activities $1.4 trillion in cost savings
Civil Aviation – NextGen	$123 billion cumulative money saved through 2030
Ground Transportation -ITS	$30.2 billion cumulative money saved through 2018
Precision Agriculture	$19.9 ~ $33.2 billion per year
Engineering Construction/ Survey	$9.2 ~ $23 billion per year

7. CONCLUSION

The application of GNSS technology in a number of market segments has delivered enormous benefits to global economy. The GNSS-enabled products and services create values for commercial and noncommercial users. For commercial users, the GNSS technology has made the production processes and operations to be easier, safer, and cost-effective. For noncommercial users, the GNSS technology creates monetary values of time and cost savings as well as nonmonetary values of safety and lifestyles. Like other innovative products and services,the GNSS industry directly creates jobs and economic activities to support the economic growth.

The economic benefits of GNSS to society are substantial. Like other innovative products, the benefits of GNSS technology on the economy and society are generated by GNSS manufacturers and the advantages the technology provides to the customers. The GNSS industry directly creates jobs and economic activities to support the economic growth. GNSS manufacturers create employment, provide earnings, and generate tax revenues for governments. Far more importantly, GNSS technology imparts cost-savings and improves productivity in agriculture, industry and service sectors, which further contributes the major share of the country's GDP.

Like any other manufacturers, GNSS manufacturers also create additional economic activities for upstream and downstream business entities. GNSS manufactures purchase intermediate goods and services from upstream vendors to produce hardware, chipsets, etc. For downstream companies who rely on the technology the GNSS generates additional economic activities in the form of applications and services. The downstream business entities include GNSS device vendors, service and content providers, original equipment manufacturers, application developers and retailers. Commercial users utilize GNSS technology to increase productivity which in turn has positive impacts on cost-savings, that include savings on labor, capital, and time. Noncommercial users enjoy Satellite Based Navigation technology for their daily life activities, like visual navigation for drivers for an instance. Altogether, GNSS technology imparts value for personal and business consumers.

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Quantifying Sustainability to Assess Urban Transportation Policies and Projects - Case Studies from Bangalore

Ashish Verma[1]

Abstract: This work presents a new methodological framework for testing urban transportation policies and projects on the dimension of sustainability through development and use of sustainable transport model. This model is conceptualized to encompass economic, environmental and social indicators and is represented in terms of Composite Sustainability Index (CSI). The key effect of any transport policy measure, like parking charges, congestion charging, fare revisions, pedestrianization etc., is the change in travel behaviour, particularly the mode choice behaviour. To assess any such policy for sustainability, this change in choice behaviour is captured by a discrete mode choice model and the output of same is used to assess the change in CSI from base scenario to policy scenario. Case studies of congestion charging, Non-Motorized Transport (NMT) infrastructure in Bangalore are also presented. The next part of the research work focuses on developing methodology to test any transportation project against sustainability. To develop and demonstrate this, a bi-level optimization model is proposed for generating Feeder Bus Route Network and service frequencies for stations of Bangalore metro rail system. The proposed framework could be potentially useful in assessing various policies and projects on the key criteria of sustainability, and to also carry out scenario analysis.

Keywords :
Sustainable transport; urban transport policy; urban transport projects, Feeder Bus, Bangalore, India.

1. Introduction

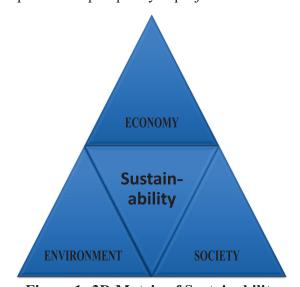Urban form and transport system have an enormous impact on the way people travel. With rapid growing economies and population typically seen in developing countries, there is an increasing trend of expansion of urban sprawl and auto-based mobilization. This has a direct effect on the level and form of transport demand and pattern. In the absence of the implementation of proper policy measures like, parking charges, congestion charging, fare revisions, pedestrianization etc., it also leads to an increased additional cost for transportation infrastructure and its operation, while at the same time, creating many environmental, economic and social problems. The world is now facing the problem of depleting fossil fuel and increasing levels of green house gases resulting in excessive emissions which are responsible for global warming and climate change.

Also the factors like safety, commuting time, accessibility to public transport system etc. need to be quantified in highly socio-economic disaggregated Indian cities.

Sustainable transport systems are those which aim to reduce emissions, fossil fuel consumption, and the consumption of natural land, while providing easy access to people. Mo e fundamentally, more emphasis should be on reducing the role of the private automobile as the prime mode of transportation and shifting travel toward other sustainable modes such as public transit, cycling and walking. Today, public transport systems are increasingly utilized by cities looking for cost effective and sustainable mobility solutions. However, even while planning their infrastructuraland scheduling improvements to provide high level of service, they need to be assessed forsustainability over a certain period of

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time. Thus an easy, yet predictable model, is needed to test the same.

The notion of sustainability covers a wide range of issues from economical to societal. Sustainability of any service can be evaluated in terms of society, economy and environment represented in a 3D matrix as depicted in **Figure.1**. Each of these three pillars can be expressed in terms of various qualitative and quantitative indicators that help in measuring sustainability for a given state of transportation system. In this paper, the attempt is to choose quantitative indicators that are sensitive to change in traffic flows on the transport network, which enables measuring the impact of a proposed transport policy or project.

Figure.1: 3D Matrix of Sustainability

However the distribution of the three elements of

the 3D matrix can vary from high-income to low-income economies. Essentially sustainability of urban transportation system can be judged on the basis of how well it serves and improves the quality of life of a system that refers to cities, regions and countries in this context of study. Approach to sustainable transport can be addressed through strong sustainability and weak sustainability. Strong sustainability refers to any kind of sustainable development without considering the cost involved in attaining the same. On the contrary weak sustainability refers to attainment of sustainability maintaining tradeoff between environmental, social issues and benefits involved in the process using Cost-Benefit-Analysis, which could be adhered to by developing countries, like India.

For comprehensive sustainable development it is essential to monitor the three pillars of sustainability with potential indicators that are reflective of changes in travel behavior of commuters. There are a number of practical ways of addressing social and economic concerns and simultaneously reducing environmental effects. For instance allowing mixed land use in urban areas moves residents closer to their places of business, reducing commute distance and footprint, providing incentives for public transport use, encouraging non-motorized transport through improved and effectively proven policy measures. **Table-1** summarizes the past studies done in related areas.

Table-1: Summary of Past Studies

Quantifying Sustainability	Testing Policies	Testing Projects
Strategic Environmental assessment for sustainable urban development (Shepherd, and Ortolano, 1996)	Utilization of Sustainability Indicators and impact through policy learning in the Malaysian policy process (Hezri, 2004)	Multi-objective Decision model with System Optimum conditions considering environmental parameters. (Teng & Tzeng, 1996)
An Indicator based approach to measuring sustainable urban regeneration performance (Hemphill et. al., 2004)	Incorporating sustainability into transportation planning and decision making: Definitions, Performance Measures and Evaluation (Jeon & Amekudzi, 2005)	Multicriteria traffic network model with emissions as objective function (Nagurney, 2000)
A tool for evaluating urban sustainability via integrated transportation and land use simulated models.(Maoh and Kanaroglou, 2009)	Impact of Modal Shift on Transport Ecological Footprint: A case study of proposed BRTS in Ahmadabad, India (Brajacharya, 2008)	Multiobjective network design for emission and travel time trade-off for sustainable urban transportation network (Sharma & Mathew, 2007)
Developing a Sustainability Assessment Model: The Sustainable Infrastructure, Land- Use, Environment and Transport Model (Yigitcanlar and Dur, 2010)		Environmental Impact Assessment for Transportation Projects: Case Study Using Remote-Sensing Technology Geographic Information Systems, and Spatial Modeling. (El-Gafy et.al., 2011)

Most of the studies in past have emphasized more on environmental parameters and social and economic factors have not been addressed well. While studies in past have devised various indicators, they have not attempted to build the sustainability model out of them and demonstrate its use to assess transport policies and projects. This study is an attempt to address this limitation of the past work.

2. Research Problem and Objective:

In Indian cities like Bangalore, there has been a steady increase in the public transport infrastructure including bus services, over the past few years. However use of private vehicles has not shown much decline owing to absence of proper complimentary transport policy measures that inhibits auto-mobilization and gauges for effective and sustainable public transport. The car, two-wheelers and auto-rickshaw are contributing most to the share of motorized modes of transport and the share of public transport is comparatively less. As a result, the cities are facing problems of inefficient mobility and decreased levels of performance in the urban transport sector. Thus it is necessary to put a model in place that captures the indicators of the three pillars of sustainability in a quick and comprehensible manner and that can be used to assess various transport policies and projects. Considering this aim, the following are the objectives of the study:-

❏ To define a sustainable transport model in terms of:
- *Environmental Indicators*
- *Economic Indicators and*
- *Social Indicators that are relevant*

for Indian cities

❏ To develop a model to test transportation policies against sustainability

❏ To develop a model to test transportation infrastructure projects against sustainability.

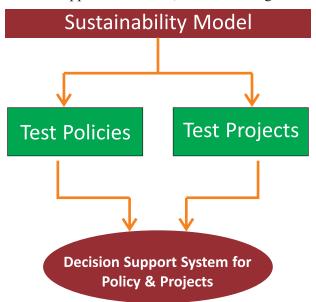Based on above the work attempts to create a decision support framework, as shown in Figure-2.

Figure-2: Decision Support Framework

The main contribution of this study is to develop a framework for incorporating sustainability considerations in transportation planning and decision making. Such decision support tools can be particularly versatile in capturing uncertainties commonly inherent in the decision making process by reflecting changing regional priorities and subjective preferences over time and space. Integrating sustainability considerations into the planning process will force decision makers to view different transportation plans in a much broader context, particularly with respect to evaluating the tradeoffs associated with implementing alternative transportation plans and possibly land use scenarios. It will also encourage decision makers to consider the idea of sustainable development priorities, recognizing that as transportation needs, land development patterns, and the quality of the environment and economy evolve, different sustainability

dimensions may emerge as the transportation development priorities for a region. The subsequent sections describe the methodological framework in detail.

3. Development of Sustainable Transport Model

There has been a growing body of literature advocating the development of sustainable indicators to support urban planning process (Litman, 2007: Joen 2005). Indicators in this context are standardized measures suitable for analyzing and evaluating the importance of targeted outcomes. For example, a measure such as vehicle kilometers travelled (VKT) per capita can be used as an indicator to evaluate the level of mobility in the part of city where the policy is to be brought in. Various methods have been proposed in the past to devise sustainable indicators that could be used to gauge progress towards sustainability. The general consensus is that urban sustainability can only be achieved by addressing various aspects that are related to the pillars of sustainability: (1) Environment, (2) Society, and (3) Economy. The existing body of literature suggests that the sustainability of alternative future policies can be evaluated bycalculating several indicators (i.e quantifiable measures of particular outcomes) pertaining to a list of pre-defined themes that correspond to the three pillars of sustainability. The objective is then to combine those indicators to identify which of the alternative policies will result in minimizing negative environmental and social outcomes, while maximizing economic benefits. Kelly (1998) identified several criteria for evaluating sustainability indicators in the study of an urban system. The study notes that any devised indicator should be:

● Calculated by using already available or easily obtainable information

● Easily understandable without ambiguity and exceptional overlapping

● A measure of something important in its own right

● Comparable in terms of different geographical scales and the actors involved

Based on the study of past literature and the above criteria, a number of sustainable indicators are selected as shown in Table 2 to represent various aspects and domains of sustainability. The indicators are devised such that they are policy responsive.

Table 2: Sustainable Indicators for Evaluation

Pillar	Theme	Label	Indicator	Definition
Environment	Air pollution	AP1	Greenhouse gases	Level of CO[gm]/km of vehicle type
		AP2	Acidifying gases	Level of NOx[gm]/km of vehicle type
		AP3	Volatile organic compounds	Level of HC[gm]/km of
		AP4	Fine particles< 2.5 μm	Level of Particulate Matter (PM) 2.5[gm]/km of vehicle type
		AP5	Fine particles<10 μm	Level of PM 10[gm]/km of vehicle type
	Natural resources	NR1	Energy use from fossil fuel	Litres consumed per km
Society	Health	HL1	Exposure to NO_x from transport	Number of people exposed to harmful levels of NO_x
		HL2	Exposure to CO from transport	Number of people exposed to harmful levels of CO
		HL3	Traffic injuries and deaths	Number of traffic injuries and deaths per mode over a year
	Accessibility	AM1	Accessibility to services	Average potential accessibility to services
	Commute	AM2	Vehicle kilometers travelled	Total VKT per mode
		AM3	Vehicle minutes travelled	Total VMT per mode
	Mobility	AM4	Congestion Index	Average level of congestion in the area under study, based on ratio of actual to design speed or volume to capacity ratio.
Economy	Cost(rupees)	EC1	Transport investment cost	Total rupees spent on upgrading and maintenance of road infrastructure
		EC2	Transport commuting cost	Overall cost of commuting
		EC3	Transport external cost	Total rupees due to externalities associated with health

The above table gives the raw value of each indicator for a certain flow scenario. These values are in different units and hence cannot be compared. Certain Indicators are obtained as absolute values while others may not be in standard form. This prompts using normalization technique that can bring all indicators to same unit of comparison. For this, the method proposed is min- max method of normalization owing to its simplicity and easily obtainable values. Mathematically the normalized value is represented as :

$$\frac{100 \; (actual \; value \; - \; minimum \; value)}{(maximum \; value \; - \; minimum \; value)} \; \ldots\ldots..(1)$$

Here, the actual, minimum and maximum value of indicator corresponds to the different flow conditions respectively.

- ❏ Actual value : Normal flow condition
- ❏ Minimum and Maximum value: Free flow and Congested flow condition

The CSI is conceived as a maximizing function i.e. higher the value of CSI. better is the sustainability impact of any transportation policy or project that is being tested. In other words, in scenario analysis, the option with the highest CSI value will be best to adopt to achieve sustainability. To obtain CSI, firstly the sustainability indices are obtained for each of the three pillars of sustainability (SI$_p$), where P stands for social, environmental, and economic pillars.

$$SI_p = \sum_{i=1}^{n} \alpha_i . w_i . x_i \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

Where,
$x_1 \ldots x_j$ are normalized variables
n is the no. of indicators influencing SI
w_i is the weight attached to x_i, such that

$$\sum_{i=1}^{n} w_i = 1$$

The weight (wi) for each indicator can be determined using Analytical Hierarchy Process (AHP).

α is a binary variable with the following values

$$\alpha \; \begin{array}{l} = +1 \; \textit{if indicator has positive effect on csi} \\ - \; -1 \; \textit{if indicator has negative effect on csi} \end{array}$$

Hence Composite Sustainability Index (CSI) over a single link is calculated as the sum of the weighted sustainability indices for each pillar P, as given below:

$$CSI_{Link} = SI_{Environment} + SI_{Social} + SI_{Economic} \qquad \ldots..(4)$$

The Composite Sustainability Index (CSI) over the whole network can then be obtained as:

$$CSI_{Network} = \sum CSI_{Link} \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

As indicated earlier, higher value of CSI in equation (5) will imply better sustainability.

3.1 Mode choice analysis

Discrete choice modelling based framework is used to capture the change in mode share and hence sustainability due to the introduction of a policy like congestion pricing. The aim here is to determine the mode shift under a policy scenario and then using the mode shift to determine the sustainability indicator under the new scenario. Discrete choice models are typically based on the theory of utility maximisation. Utility is an indicator of the value an individual gives a mode. The mode choice mode gives the choice probabilities of each alternative as a function of the systematic portion of the utility of all the alternatives. The general expression for the probability of choosing an alternative 'i' (i = 1, 2,..., j) from a set of j alternatives is:

$$Pr(i) = \exp(V_{i)}/ \sum_{j=1}^{J} \exp(V_j) \; \ldots\ldots\ldots\ldots\ldots(6)$$

where
Pr(i) is the probability of the decision-maker choosing alternative i
V_j is the systematic component of the utility of alternative j

Utility is usually expressed as a linear function in parameters of variables like travel time, travel cost, household income etc. The model is estimated using maximum likelihood method.

The values of the parameters which maximise the likelihood function are obtained by finding the first derivative of the likelihood function and equating it to zero. The model parameters in our study are estimated using Biogeme [3] [4].

3.2 Analytical Hierarchy Process

The AHP used for determining the weights of sustainability indicators is a tool for multi-criteria evaluation. According to the definition of World Bank (2014) Multi Criteria Analysis is a technique to assess alternative options according to a variety of criteria that have different units (e.g. dollars, tonnes, and kilometres). AHP was developed by Saaty (1980) and quite often is referred to, as the Saaty method. It allows for a pair-wise comparison between the different indicators for single respondent to obtain the relative priorities of that respondent. In our study these relative priorities are obtained from 7 expert respondents from the transportation field, which is then averaged to form the local weight of that indicator. It is these local weights which are used in the determination of sustainability pillars in section 4.1. So these weights determined for an indicator give an indication of the average priority in the mind of respondents attached with that specific indicator.

The essence of AHP lies in constructing a matrix expressing the relative values of a set of indicators. It is done by assigning these relative values a number on a scale. A basic, but very reasonable, assumption is that if indicator A is absolutely more important than indicator B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9. In the present methodology the adopted rating is used to find out the local weight of indicators in each theme. This weight when multiplied with the weight of sustainability pillar, an assumed value of 0.33 for each, gave the global weight of each indicator. The global indicator values were determined for indicators based on the responses from 7 experts in the field of transportation including academicians as well as experts from the industry. The highest weight among the environmental indicators was given to the greenhouse gas emissions (AP1), and the highest weight among the social and economic indicators was given respectively to the accessibility and transportation investments.

3.3 Framework for Assessing Urban Transportation Projects

Apart from policies it is also important to analyze infrastructure projects with respect to sustainability. Thus the second part of the work focuses on developing methodology to test any transportation project against sustainability, which may assist any transport planner/engineer to take decisions on implementing the project. To develop and demonstrate this, a case problem of feeder transit network design for a metro rail station is considered. Usually objective of any transit system network design is to optimize user and operator cost, however they are seldom tested on sustainability criteria (environmental, social, and economic). In this study a bi-level optimization model is proposed for Feeder Route Network Generation and Schedule Coordination of feeder buses with metro trains, where besides optimizing the user and operator cost at first level, the solution is also optimized for sustainability using CSI at the second level, and the best solution obtained from this model is recommended.

3.4 Proposed Model for Feeder Route Generation and Schedule Co-ordination

In this model the aim is to develop the feeder street transit route network for the Metro rail as well as schedule coordination of bus and train. Choosing suitable feeder street transit routes and their schedules is a critical process in the design of a good integrated transit route network. The problem to be addressed can be defined in the following general terms: given the transit demand matrix for feeder area and a description of the network specifying for each node its neighbouring nodes and the distance of all connecting links, the aim is to determine set of feeder routes and their schedule that correspond to a tradeoff between user and operator costs.

Considering the above aim, the proposed combined model for feeder route generation

and schedule coordination is developed. In this model, the routes are generated in two levels, the first level generates the initial set of shortest paths based on the maximum and minimum route length criteria, and in the second level, search is made around these corridors by generating K shortest paths for each station-to-terminal node pair. Finally, using GA, one route combination out of all possible routing configurations is selected along with their corresponding optimal headway.

For developing the combined model, the following inputs are required:-

Network: Details for all the links, including the link travel time, travel distance etc, within the feeder area and the initial set of shortest paths generated earlier.

Demand: OD matrix of station to every node and vice versa within the feeder area.

K-Shortest Paths: K-shortest paths for each station to terminal node pair of the initial set identified in previous level. The program requires as an input the matrix specifying the distance between each of the connected nodes in the network.

Route-Node Structure: For a given station, data structure is created to be read by the program. Data structure includes the nodes for different K-shortest paths for each terminal node.
Other data required includes number of passengers boarding and alighting at each stop (along the feeder routes) within a fixed period, number of passengers transferring from the rail transit station to a feeder route and vice versa

within a fixed period, the ridership on each link of the feeder route, round trip time for each route, capacity value of different types of buses, value of travel time, waiting time, and transfer time cost of passengers and bus operating cost.

Decision Variables and Their Coding: In this problem, one feeder route (from K different routes for each station-terminal node pair) and the corresponding frequency of operation (out of a given range) have to be selected simultaneously so as to optimize the objective function. Therefore, decision variable will be the path number for each station to terminal node pair (route) and corresponding headway for each route.

Objective Function: With an attempt to overcome the drawbacks of the previous work [Verma and Dhingra (2005, 2006)], the present study carries out simultaneous optimization of feeder routes and co-ordinated schedules at upper level and assessing sustainability at lower level to get more effective results. The objective function of the upper level problem is defined to minimize the sum of operating cost of buses (operator cost), transfer time cost for passengers transferring from train to feeder buses, waiting time cost of passengers boarding along the feeder routes and in-vehicle time of the passengers travelling along the feeder routes (user costs) subject to load factor and transfer time constraint and the constraint for unsatisfied passenger demand. The lower level attempts to maximize CSI at each iteration for path configuration as obtained from upper level. The objective function can be mathematically represented as follows:

Upper level:-

Objective

Minimize :

$$\left[C_1 * t_{tt} * \sum_{j=1}^{n} d_{tt\,j}\right] + \left[C_2 * \sum_{i=1}^{(n+1)} \sum_{j=1}^{(n+1)} d_{ij}^{k_l} * t_{wt\,i}^{k_l h}\right] + \left[C_3 * f_{k_l}^{h} * T_{k_l}^{h} * 60\right] +$$
$$\left[C_4 * \sum_{i=1}^{(n+1)} \sum_{j=1}^{(n+1)} d_{ij}^{k_l} * \left\{t_{avg\,ij}^{k_l} + \sum_{r \epsilon IS} t_{dw\,r}^{k_l h}\right\}\right]$$

......(7)

Lower level:-

Maximise *CSI*= *(SI*Environmental *+ SI*Economic *+ SI*Social*)*   ....(8)

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Where,

$$SI_p = \sum_{i=1}^{n} \alpha_i . w_i . x_i$$

[p corresponding to environmental, economic and social indicator]

Subject to:

$$g_1 = \left[[q_{max}^k / CAP_b] \leq L_{max} \right]$$

$$g_2 = \left[[q_{min}^k / CAP_b] \geq L_{min} \right]$$

$$g_3 = \left[\left[t_{wt,ij}^k \leq t_{wt,max} \right] \right]$$

$$g_4 = \left[\left[t_{wt,ij}^k \geq t_{wt,min} \right] \right]$$

$$g_5 = Upd \leq x$$

$$d_{ij}^{k_l} = d_{ij} * \left[0.5 * \frac{f_{k_l}^h}{\sum_{r \in OR} f_{r_l}^h} + 0.5 * \frac{\exp(t_{k_l}^h)}{\sum_{r \in OR} \exp(t_{r_l}^h)} \right]$$

the above expression attempts to mimic the natural route choice behaviour where a person would attach equal importance to both frequency and travel time on alternate routes available between the same Origin-Destination (O-D) pair; OR = overlapping routes between nodes i and j; f_{kl}^h = frequency of feeder bus along the route k of lth terminal node; d_{ij} = total demand from node i to node j; t_{wti}^{kjh} = waiting time of passengers at node i waiting for the bus moving along the route k of lth terminal node, for the headway value $h_{kl} = \alpha h_{kl}$; α is a calibration parameter that depends on the distributions of transit headway and passenger arrival; T_{kl}^h = round trip time that bus running with headway 'h' takes on k^{th} route of the terminal node $l = T_{rtt}^{k_l} + T_{dwell}^{k_l h} + T_{layover}$; $T_{rtt}^{k_l}$ = running round trip time for any bus on the kth route to the terminal node l; $T_{dwell}^{k_l h}$ = sum of dwell time of all the stops lying on k^{th} route to the terminal node $l =$ $\sum_{(r \in All\ Stops\ along\ route\ k)} (t_{dw\ r}^{k_l h})$; $t_{dw\ r}^{k_l h}$ = dwell time at intermediate station r along the route k of lth terminal node $= \left[\frac{P_a t_a + P_b t_b}{n} \right]_r^{k_l h}$; P_a = number of persons alighting at the bus stops (depends on the headway of bus); P_b = number of persons

Where,
l is terminal node varying from 1 to m; m is the total number of terminal nodes selected based on maximum/minimum route length criteria; k is the potential route from the set of K-shortest paths generated between station and the terminal node l; h is the headway on k^{th} potential route for the terminal node l; C_1 = Transfer time cost in Indian Rupees (Rs.)/min; C_2 = Waiting time cost in Rs./min; C_3 = Vehicle operating cost in Rs./min;) C_4 = In-vehicle travel time cost in Rs/min; t_{tt} = transfer time from train to the bus stop; n = total number of nodes; d_{ttj} = number of persons moving to node j along the potential feeder routes, from the rail station; d_{ij}^{kl} = number of persons moving along route k (for l^{th} terminal node) from node i to node j and is assigned based on proportionate frequency and travel time criteria (logit function) as given below

boarding at the bus stops (depends on the headway of bus); t_a = time required to alight the bus; t_b = time required to board the bus; y = number of people who can board simultaneously in the bus; $T_{layover}$ = Layover time during one round trip; $t_{avg\ ij}^{k_l}$ = average travel time from node i to node j along the route k of lth terminal node; $t_{wt.max}$ = maximum allowable waiting time; $t_{wt.min}$ = minimum allowable waiting time; UPD = unsatisfied passenger demand; x = Maximum allowable unsatisfied passenger demand in percent.

In the following the meaning of each constraint is briefly described:
- Constraint g_1 states that the load factor on any feeder route k should be less than the maximum allowable load factor L_{max} for that route.
- Constraint g_2 assures that the load factor on any feeder route k should be more than the minimum allowable load factor L_{min} for that route.
- Constraint g_3 states that the waiting time $t_{wt,ij}^k$

incurred while traveling between node pair i,j along the path k should be less than the maximum allowable waiting time $t_{wt,max}$ between the modes.

- Constraint g_4 assures that the transfer time $t^k_{wt,ij}$ incurred while transferring from one transit mode to other between a node pair i,j along the path k should be more than the minimum possible transfer time $t_{wt,min}$ between the modes.
- Constraint g_5 assures that the unsatisfied passenger demand is less than a maximum value x.

The output of this bi-level optimization would be a set of feeder bus routes and their corresponding frequencies that maximizes sustainability as defined by CSI, while also optimizing the user and operator cost involved. Thus, this case problem demonstrates the use of CSI in arriving at configuration/alignment of any transportation infrastructure project that scores high on sustainability. Similarly, CSI can be used for cases like, optimum alignment of road/rail corridors, road expansion, or a comparison between them to arrive at best solutions.

4. Case Studies

This section presents various case studies in brief with respect to transport policies (congestion charging, non-motorised transport (NMT) provisions) and projects (metro feeder route generation).

4.1 Congestion Charging in Bangalore

A case study for the impact of congestion pricing in CBD (Central Business District) was done for the city of Bangalore. The impact was determined as the variation in the composite sustainability index before and after the introduction of congestion pricing. The value of congestion charge was found by dividing the total congestion cost imposed by each vehicle type in Bangalore by the total vehicle trips by that vehicle type. Accordingly, a value of 40 Rupees for car and 20 Rupees for two-wheeler is used. The CBD was determined along a radius of 2 Kilometer (Km) around the town hall. It included some of the highly congested areas in the cityincluding Shantinagar, Cubbon Park, and Chickpete. The

sustainability indicators and the composite sustainability index before introduction of congestion charging are obtained as follows.

$SI_{Environmentall} = (-)2.86$
$SI_{Social} = (-)1.43$
$SI_{Economics} = (-)2.22$

$$CSI_{before} = SI_{Environmental} + SI_{Social} + SI_{Economic}$$

Hence, $CSI_{before} = (-)6.51$

Following the same procedure sustainability corresponding to the changed modal share after introduction of congestion pricing is determined as below.

$SI_{Environmentall} = (-)2.81$
$SI_{Social} = (-)1.40$
$SI_{Economics} = (-)2.19$
$CSI_{after} = (-)6.40$

The CSI after the introduction of congestion charging is increased by 1.7%. It indicates an improvement in sustainability on introduction of congestion charging (Verma 2015).

4.2 NMT Provisions in Bangalore

In the present section, the methodological framework developed in the previous sections is used to evaluate the sustainability impacts on providing NMT infrastructures, for the year 2021, in the Central Business District (CBD) of the Bangalore city, as well as around the bus stops carrying trips to this CBD. The year 2021 is selected because of the availability of population and employment growth factors for that year. The CBD is determined at a radius of 2 kilometer around the Town hall in Bangalore.

In order to understand the sustainability impact of providing NMT infrastructures on NMT as a main mode as well as on NMT as an access mode to public transit, three separate case studies were done as given below.

1. In case study 1, only intra zonal trips inside the CBD were used in evaluating the sustainability impact. Because the two kilometer radius of the CBD was well within the limit of an acceptable trip distance of 2.1 kilometer (Rahul and Verma, 2014), found for cycling in the city of Bangalore, most of the trips inside the CBD were expected to have trip

distances conducive to promote NMT as the main mode, and this later was proved right on analyzing the trip data of CBD. Further, considering only intra-zonal trips confined the origins and destinations of the trips within the CBD, and this confinement ensured that these trips would have the benefits of NMT facilities for their entire trip length. So, this case study analyzed the impact of providing NMT infrastructures, along an acceptable distance found out when NMT is used as the main mode. Acceptable distance gave the maximum distance after which a person using NMT will shift to a faster mode of travel (Rahul and Verma, 2014). The difference in CSI between the scenarios before and after introduction of NMT facilities is as shown below.

$CSI_{difference}$ = -6.557 – (-6.555) = -0.002

2. In case study 2, only inter-zonal trips with their destination as the CBD were considered. Because these inter zonal trips can be expected to have trip distances conducive for promoting public transits as main modes, this case study was expected to give the impact of providing NMT infrastructures, along an acceptable distance found out when NMT is used as the access mode, around bus stops as proposed in Rahul and Verma (2014). These trips utilized NMT infrastructures inside the CBD as well as around the bus stops carrying public transit trips to the CBD. For this case study, NMT facilities were assumed to be provided along a distance of 750 meter around bus stops (Rahul and Verma, 2014). The difference in CSI between the scenarios before and after introduction of NMT facilities, for case study 2, is as shown below.

$CSI_{difference}$ = -20.560 – (-20.484) = -0.076

3. In case study 3, both the intra zonal trips inside CBD and the inter-zonal trips to the CBD were considered. The difference in CSI is calculated as given below.

$CSI_{difference}$ = -18.531 - (-18.431) = - 0.100

In all the three cases, the CSI after the construction of NMT facilities decreased on a negative scale, and this decrease in the negative scale revealed an improvement in the

sustainability inside the CBD. All these case studies were done at a strategic level (Saelensminde, 2004), and this meant that the studies did not consider any specific sections of the network along which NMT facilities are built. By NMT facilities, the authors intended continuous, un-encroached, well- maintained, and separate footpaths and cycle ways; proper crossing facilities for NMT; and parking facilities for cycles at public transit stops (Wardman et al., 2007; Rietveld, 2000; Ortuzar et al., 2000).

4.3 Bangalore Metro Feeder Route Generation
Namma Metro, also known as Bangalore Metro, is a metro rail system in the city of Bangalore, Karnataka, India. The agency responsible for its implementation and operation is the Bangalore Metro Rail Corporation Ltd (BMRCL), which is a joint venture of the Government of India and the Government of Karnataka. The existing operational purple line of Bangalore metro rail has six stations in Reach-1 from Byappanahalli to MG Road, out of which Indiranagar metro station is selected as the study area because of its land use pattern and better trip generation compared to other stations. Metro feeder routes were developed using the proposed methodology for this station. To analyze the sensitivity of results due to introduction of CSI, the feeder routes were developed for three different cases given below.

Case 1 - Optimal total cost and corresponding CSI value: In this case upper level objective function is optimized and corresponding solution CSI value is calculated.

Case 2 - Optimal CSI value and corresponding total cost: In this case lower level objective function is optimized and corresponding solution total cost is calculated.

Case 3 - Optimal total cost and CSI value: In this case total cost is optimized and corresponding solution CSI value is calculated. Then a check is carried out for both total cost and CSI values. If both the solutions are improved in the current generation compare to previous generation, then those solutions are stored. Thus the best solution so far is obtained at the end.

The comparison of total cost and CSI values obtained for Case1, Case2, is presented in **Table.3.** The result shows that the first case gives the best values of total cost and the number of buses required, but lower value of CSI. When only CSI value is considered second case gives the best result, but very high values for the total cost and the number of buses required. The results with Case3 which give a number of solutions to decision makers providing a balance between CSI and total cost are presently being generated.

Table 3: Comparison of Case1 and Case2 for feeder route generation

	Total cost	Solution CSI	Fleet Size
Case1	4761	-0.51	80
Case2	25219	-0.46	251

5. Summary & Conclusions

This work presents a new methodological framework for testing urban transportation policies and projects on the dimension of sustainability through development and use of sustainable transport model. This model is conceptualized to encompass economic, environmental and social indicators and is represented in terms of Composite Sustainability Index (CSI). A discrete choice modelling based framework is presented to assess various urban transportation policies against sustainability such as, parking charges, congestion charging, fare revisions, pedestrianization etc.. To assess any such policy for sustainability, this change in choice behaviour is captured by a discrete mode choice model and the output of same is used to assess the change in CSI from base scenario to policy scenario. Similarly, a methodological framework is presented to demonstrate the use of CSI in testing urban transport projects and a case problem of Feeder Route Network Generation and Schedule Coordination of feeder buses with metro rail is taken for this purpose. The framework is presented as a bi-level optimization model. The proposed framework could be potentially useful in assessing various urban transportation policies and projects on the key

criteria of sustainability, and to also carry out scenario analysis. The following are the main conclusions from this work:-

- An increase of 1.7% in CSI after the introduction of congestion charging indicating an increased sustainability after the introduction of congestion charging. The increased sustainability was the result of a decreased pollution, natural resource depletion, congestion, and transport investment.
- There is an increase in the values of CSI for all the three case studies after the construction of NMT facilities. This increase in the CSI indicates an improvement in the sustainability.
- The case study on metro feeder route generation demonstrates the difference in result between using objective of total cost as compared to community objective (CSI).

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Impact of ship emission on the Bay of Bengal pollution and climate

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Abstract : Seagoing ships play an important role in the transport sector of economy. However, seagoing ships pollute the clean marine environment and contribute significantly to the total anthropogenic emissions from the transportation sector. Key compounds emitted from shipping are carbon dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds, sulphur dioxide and particulate matter such as sulphate, organic carbon, black carbon and ash into the atmosphere. Ship traffic is currently growing by about 3 percent globally which is leading to considerable increase of long-lived greenhouse gas concentrations in the atmosphere. In this study, we analysed the multi-year satellite data to derive a global distribution of ship emissions and their radiative forcing. We constrained the analysis to shipping corridor over Bay of Bengal by separating 'clean' from 'polluted' oceanic regions based on the location of shipping routes. The enhanced NO_2 emissions in the shipping lane are reducing the surface reaching solar radiation by ~1 W/m² during the solar noon hours and heating the lower troposphere by 0.05 K. As ship emissions are released in regions with frequent low marine clouds in an otherwise clean environment, the possible impact of ship emissions on Cloud Condensation Nuclei (CCN) are examined. CCN efficiency varied from 0.56 ± 0.06 over relatively pristine location to 0.17 ± 0.1 over polluted shipping corridor. The effects seen here may have significant implications for climate mitigation strategies.

1. Introduction

Over the last 30 years a sudden increase in the amount of freight transport by international shipping is observed (Eyring et al., 2009). Emissions from international shipping contribute significantly to the total budget of anthropogenic emissions from the transportation sector (Eyring et al., 2005). The total emissions of particles and their precursors are even higher than those from road-traffic because of the high sulphur content of the fuel burned in marine diesel engines today. The principal gaseous and particle emissions from ships include CO_2, H_2O, NO_X, SO_X, CO, unburned hydrocarbons, and particulate matter. While all these components do have an impact on the atmosphere and on climate (Capaldo et al., 1999), in this paper we concentrate on NO_2 since no significant measures of NO_X-reductions have been introduced.

The absorption of incoming solar and outgoing terrestrial radiation by trace gases is one of the key factors in the Earth's radiative budget and plays a leading role in climate change (Hansen et al., 2007). Carbon dioxide (CO_2) is the largest anthropogenic climate forcing gas, but other trace gases are also important including methane (CH_4), tropospheric ozone (O_3), nitrous oxide (N_2O), and halocarbons such as chlorofluorocarbons (CFCs) (*Forster et al., 2007*). Little attention has been paid to nitrogen dioxide (NO_2), because its effect on the global radiative budget, particularly the radiative forcing, is small. However, on a local scale, enhanced NO_2 in polluted areas can change the partitioning of absorbed solar radiation between the atmosphere and surface. *Lawrence and Crutzen, (1999)* reported that the plumes from fossil-fuel burning ship contribute to more than 10% of global NO_X production and in heavily traversed ocean regions ship emissions lead to

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more than 100-fold increase in surface NO_x concentrations. Being a greenhouse gas NO_2 contributes considerably to local radiative forcing (*Solomon et al.,* 1999). Moreover, NO_2 absorbs incoming solar radiation at ultraviolet and visible wavelengths (300–650 nm). Thus it produces atmospheric heating in the troposphere and contributes to dimming (reduction of solar radiation) at the surface.
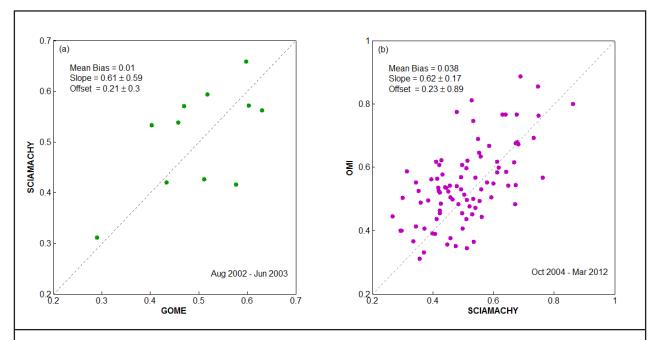
In addition, emissions of aerosols and their precursors by ships result in a high amount of additional cloud condensation nuclei and can possibly lead to a change of the optical and microphysical properties of clouds (*Durkee et al.,* 2000).The primary objective of this study is to analyse the trends in ship induced NO_x emission and their radiative forcing usingsatellite data. The shipping lane between Sri Lanka and Indonesia in the Bay of Bengal has been selected as a suitable region for study since it is a heavily traversed narrow track.

2. Data and Methodology

In this study, tropospheric NO_2 columns retrieved by GOME, SCIAMACHY and OMI sensors on board the satellites have been used to identify the ship tracks over Bay of Bengal. GOME (Global Ozone Monitoring Experiment) is a nadir-viewing spectrometer that measures earthshine radiance and solar irradiance in ultraviolet-visible range (240 – 790 nm) and was launched on-board the second European Remote Sensing Satellite (ERS-2) on April 21, 1995. It has a spatial resolution varying from 40 X 320 $km^2$to 80 X 960 km^2, spectral resolution of 0.2 - 0.4 nm and achieves global coverage in 3 days after 43 orbits (*Burrows et al., 1999; Boersma et al., 2004*). SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY) is a passive remote sensing spectrometer launched on-board ENVISAT which was operational from March, 2002 to April, 2012. It measures sunlight transmitted, reflected and scattered by the earth's atmosphere or surface in ultraviolet-visible and near-infrared region (240 – 2380 nm) with spectral resolution of 0.2 - 1.5 nm and horizontal resolution of 60 X 30 km^2 for nadir viewing pixels.

It can make both limb and nadir measurements and global coverage is achieved in 6 days at the equator and more frequently at higher altitudes (*Boersma et al., 2004; Bovensmann et al., 1999; Zyrichidou et al.,* 2009). The Dutch-Finnish OMI (Ozone Monitoring Instrument) on-board NASA's EOS Aura satellite was launched onto a Sun-synchronous polar orbit on July 15, 2004 with an equator crossing time of 13:30 local time. OMI is a nadir-viewing imaging spectrometer which measures direct and atmosphere-backscattered sunlight in the ultraviolet-visible range (270 - 500 nm) using two two-dimensional CCD detectors. With its swath width of 2600 km it can achieve daily global coverage with a spectral resolution of 0.5 nm and spatial resolution of 13 km along track and 24 km to 128 km in across track (*Boersma et al.,* 2007; *Levelt et al.,* 2006a).

The datasets used in this study are GOME (April 1996 - June 2003), SCIAMACHY (July 2003 – March 2012) and OMI (April 2012 – December 2014). The OMI satellite data sets have been rescaled to match the coarser resolution of GOME and SCIAMACHY data. Monthly means were calculated on a grid of 0.25^0 x 0.25^0. In order to understand the consistency among the measurements from the three sensors, the comparison of monthly mean tropospheric columnar NO_2 densities over Bay of Bengal region are shown in Figure 1. The tropospheric columnar NO_2 retrieved from GOME and SCIAMACHY agree within 0.01 x 10^{15} molecules/cm^2 (Fig 1a). The maximum difference of 0.038 x 10^{15} molecules/cm2 (Fig 1b) was seen between SCIMACHY and OMI. It is important to note that the OMI equator crossing time is 13:30 local time, as opposed to SCIAMACHY's equator crossing time of 10:00 local time. The relative offset noted between the three satellite's data values could be due to the different equator crossing time of each of the satellites and different temporal sampling rates of each sensor (*Zyrichidou et al.,* 2009). Taking into account of these reasons, we have examined the 19 year inventory of tropospheric NO_2 emissions combining the data from the three sensors. Linear regression has been used to study the trend in NO_2 values.

Figure 1: Scatter plot of the comparison of tropospheric columnar NO2 (x10^{15} molecules/cm^2) retrieved by (a) GOME and SCIAMACHY and (b) SCIAMACHY and OMI with all available common data. The dashed line corresponds to perfect agreement.

In order to understand the impact of NO2 on the radiation budget, the calculations are performed with the MODTRAN (short for MODerate resolution radiative TRANsfer program) code (*Berk et al.,* 1998). The clear-sky (i.e., cloud-free condition) calculations are performed with MODTRAN5 code, which is the latest version of the radiative transfer code. The code simulates fluxes at mid-ultraviolet to visible to far-infrared bands to cover the solarspectrum from 0.2 to 100.0 μm. Broadband integration in the shortwave region (0.2–4.0 μm) is used for estimation of fluxes at multiple altitudes (incoming and reflected), atmospheric solar absorption and heating rates. Correlated k-distributions are used to incorporate gaseous absorption by water vapour, ozone, oxygen, carbon dioxide etc. (see MODTRAN manual for more details, *Berk et al.,* 1998). The model accounts for all multiple scattering and absorption by individual aerosol species, cloud droplets, air molecules, and reflections from the surface. The underlying surface is considered to be oceanic surface. The oceanic surface albedos were calculated according to *Briegleb et al.* (1986) and were incorporated in the code. The diurnal time

averaging is performed by integration over the solar zenith angle. The model profile uses 33 atmospheric layers with a vertical resolution of 1 km from the surface to 25 km, 2 km from 25 to 30 km, 5 km from 30 to 40 km and 10km, 20km, 30km from 40 to 50 km, 50 to 70 km and 70 to 100 km respectively. The top of the atmosphere solar flux is from Kurucz et al (1992). Vertical profiles of meteorological parameters and gaseous concentrations were taken from the tropical standard atmosphere. Simulated fluxes were calculated by varying tropospheric columnar NO$_2$ amount using temporally relevant data. In this paper, we compute the net atmospheric heating due to tropospheric NO$_2$ with an emphasis on polluted shipping lane.
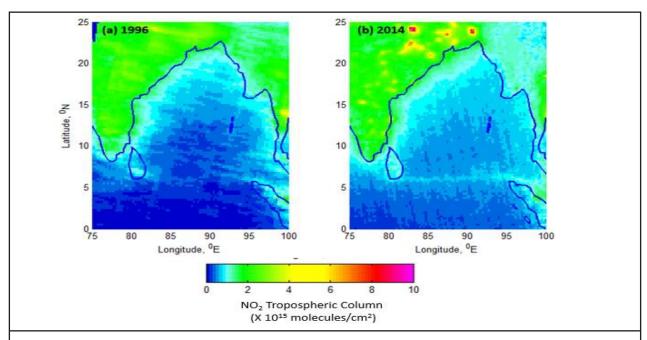
3. Results and Discussions

3.1 Enhancement of NO$_2$ in shipping corridor

Fig 2 shows the annual mean tropospheric columnar NO$_2$ amounts over Bay of Bengal in 1996 (from GOME measurements) and in 2014 (from OMI measurements). The large expanse of NO$_2$ values near the east coastline of India (and west of

China) is due to the continental outflow of pollution. For instance in the Chennai region, tropospheric NO2 increased by ~17% since 1996. Moreover, it can be clearly noted that in comparison to the 1996 image the shipping lane along ~5^0N has become more pro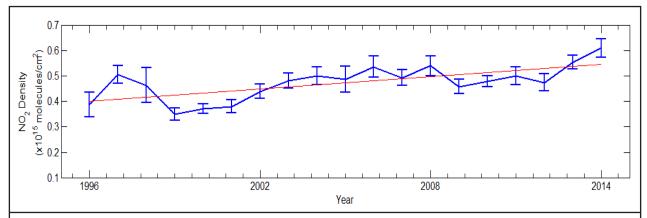minent and elevated in magnitude in the 2014 image. The shipping lane is identified by the region having NO_2 of about 1×10^{15} molecules/cm^2 in comparison to the surrounding region, where values of around 0.2×10^{15} molecules/cm$_2$ are found. This can be attributed to the increase in NO_2 due to ship emissions. The width of the shipping lane is approximately 10 in latitude (~110 km).

Figure 2: NO2 signature of shipping in the Bay of Bengal. Annual mean tropospheric NO_2 retrieved by (a) GOME for the year 1996 and (b) OMI for the year 2014. A discernible rise in NO_2 concentration levels can be observed in the shipping lane at~5^0N.

For the purpose of quantitative analysis, we have considered the region between 82^0E to 95^0E and 4.5^0N to 6.5^0N which contains the shipping track from Sri Lanka to Sumatra. Figure 3 shows the annual mean variation of tropospheric NO_2 over the above mentioned region. Linear regression over 8 years of GOME measurements in the shipping region yields a slope of $(0.06 \pm 0.2) \times 10^{14}$ molecules/cm^2/yr. For the 11 years of SCIAMACHY measurements the regression gives a slope of $(0.05 \pm 0.08) \times 10^{14}$ molecules/cm^2/yr. Whereas for the 2 years of OMI measurements the regression yields a slope of (0.3 $\pm$ 0.7) x 10^{14} molecules/cm^2/yr. The rise in NO_2 values over the time period covered by GOME measurements (1996-2002), SCIAMACHY observations (2002-2012) and OMI observations (2012-2014) is 13%, 26% and 27% respectively. When we carry out the linear regression for the entire data (i.e., 1996-2014), the polluted shipping lane show an increase of NO_2 concentrations with a slope of $(0.08 \pm 0.04) \times 10^{14}$ molecules/cm^2/year. Since there are no oceanic sources of NO_2 over this region, the observed increase in tropospheric NO_2 values due to commercial ships at 5^0N is significantly high.
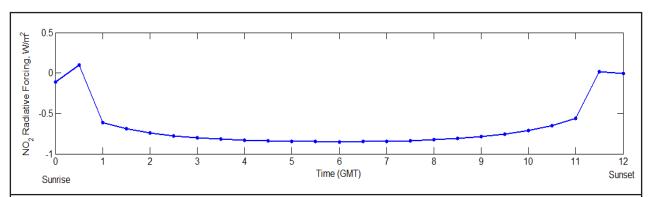
Figure 3 : Time series analysis NO2 concentrations for the shipping corridor over Bay of Bengal from the satellite observations of GOME, SCIMACHY and OMI.

3.2 Dimming due to NO$_2$

Dimming (i.e., a reduction in surface reaching solar radiation) has been reported over the last several decades primarily due to aerosol direct and indirect effects (e.g., *Stanhill and Cohen.*, 2001). Various estimates of dimming have been reported, and they vary with location (*Liepert et al.*, 2002). *Ramanathan and Ramana* (2005) estimated a reduction of surface reaching solar radiation due to aerosols from about 5% to 10% of Top of Atmosphere (TOA) insolation over the variety of polluted regions around the world.

NO$_2$ absorbs solar radiation at ultraviolet and visible wavelengths and Fig 2 shows clear enhancement of tropospheric NO$_2$ in the shipping lane. Using the MODTRAN radiative transfer code, the net surface reaching solar radiation with NO$_2$ and without NO$_2$ is estimated in the shipping lane (6^{0}N and 86^{0}E) over the Bay of Bengal. The NO$_2$ radiative forcing at the surface is the effect of NO$_2$ on the net short-wave radiative fluxes and is defined as the difference between the clear-sky net shortwave radiative flux with and without NO$_2$ atmosphere. In the radiative transfer model, NO$_2$ columnar amounts are fixed as per the OMI gridded monthly mean value (i.e., the value near 13:30 local time). The calculated diurnal variation of NO$_2$ radiative forcing at the surface is plotted in Fig.4. The reduction in the surface reaching irradiance by NO$_2$ is close to -0.8 ± 0.2 W/m^2 during the solar noon time in the shipping lane over the Bay of Bengal. Therefore, NO$_2$ is contributing to the observed global dimming and may be of importance locally in radiative forcing.


Figure 4 : Time series analysis NO2 concentrations for the shipping corridor over Bay of Bengal from the satellite observations of GOME, SCIMACHY and OMI.

3.3 Diurnal mean Atmospheric heating due to NO₂:

The 24-hour mean atmospheric heating in the shortwave region (0.2 – 4.0 μm) from surface to 16 km altitudes with NO_2 and without NO_2 atmosphere is calculated using the MODTRAN radiative transfer code. The increase in NO_2 concentrations during the 19 year period is almost 2×10^{14} molecules/cm^2. The vertical profiles of net atmospheric heating rates for the respective atmospheres are computed at different zenith angles and are converted into 24-hour mean (i.e., diurnal mean) values. The radiative transfer computations show that the diurnal mean atmospheric heating for the lower atmosphere in the shortwave region due to the increased tropospheric NO_2 concentration in the study area for the 19 year period (from 1996 to 2014) is close to 0.05 $\pm$ 0.02 K for clear sky conditions. Ship emitted NO_2 may reside in the atmospheric boundary layer (i.e., ~1 km above the ocean surface), which may heat the lower atmosphere further.

4. Conclusions

The distinct line of NO_2 in the ocean identified in the satellite image clearly coincides with the ship routes from Sri Lanka to Indonesia. In this study, ship emissions of NO_2 in the Bay of Bengal have been analysed with the help of measurements from GOME (April 1996 - June 2003), SCIAMACHY (July 2003 - March 2012) and OMI (April 2012 – December 2014). The shipping route from India to Indonesia can be detected in satellite data with an enhancement in tropospheric NO_2 of about 2×10^{14} molecules/cm2 (~50% increase). Linear regression has been used to study the trend in tropospheric NO2 within the measurementperiod from GOME, SCIAMACHY and OMI measurements. From the trend analysis statistically significant increase in NO_2 was identified.

The radiative impact of tropospheric columnar NO_2 is calculated using MODTRAN radiative transfer code. Our calculations of the surface irradiance reduction by NO_2 is ~1 W/m^2 during the solar noon hours during clear sky conditions.

Therefore, NO_2 is important locally in radiative forcing, but the trace gas may not be contributing significantly to the observed global dimming. The contribution to net atmospheric heating by the increased tropospheric NO_2 is 0.05 K. Although the MODTRAN calculated flux values have uncertainties (due to uncertainties in the NO_2 satellite observations and model calculations), the result highlights the contribution of ship emissions to the radiative forcing in marine boundary layer over the Bay of Bengal.

In addition, our group carried out direct measurements of cloud condensation nuclei (CCN) over Bay of Bengal region during summer 2012. CCN concentrations over polluted shipping regions are about one order of magnitude greater than over their remote counter parts. CCN efficiency varied from 0.56 $\pm$ 0.06 over relatively pristine location to 0.17 $\pm$ 0.1 over polluted shipping corridor. The seaborne trade in South Asia grew by an average of 5 - 6% per year in recent times [*Streets et al.*, 2000]. There are efforts to decrease sulphur emissions from ships [*Capaldo et al.*, 1999; *Streets et al.*, 2000], and the data presented in this study suggest that such reductions should be accompanied by reductions in NO_2 also. The complexity of myriad nonlinear effects resulting from anthropogenic emissions from commercial ships over southern Bay of Bengal is an area worthy of study.

Acknowledgments

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Urban Transport Policies in India in context to Climate Change: An International Perspective

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Abstract: Climate change, in the present day scenario, profoundly concerns all the world economies unequivocally, particularly the developing nations. It is certain that climate change impacts would be more pronounced in these nations than in the developed ones due to vulnerable infrastructure and population groups. Transportation sector emissions, one of the main drivers of climate change accounts for 22% of global CO_2 emissions. Transport Greenhouse Gas (GHG) emissions and energy demand will have far reaching implications in developing countries like India, where increasing personal motorization and growing urbanization are the main challenges faced by its metropolitan cities. This paper summarizes an overview of relevant policy instruments in the urban transport sector internationally that have been effective in tackling climate change mitigation & adaptation based on the review of existing literature. The different methodological approaches that have been adopted to develop mitigation and adaptation strategies in the urban transport sector are also discussed. The objective is to identify the scope and application of these methodological choices in Indian scenario. The paper further emphasizes on the case study of Bengaluru city examining the current state of urban transport and state/city level urban transport policies and assessments that have focused on climate change mitigation and adaptation. The review of literature suggests that urban transport and related policy assessments have not been central to the growing concerns of climate change. It is concluded that appropriate and time bound urban transport adaptation strategies must be put to place in order to reduce climate induced risks and deliver multiple social and economic benefits.

1. Introduction

Growing energy demand and its link to increasing GHG emissions remains a key global concern. As the world awaits a crucial climate change meeting in December 2015, it is most likely foreseen that developing countries, especially fast-growing regions such as those in the BRIC (Brazil, Russia, India and China), will have a major impact on future emission scenario and will play a considerable role in climate negotiations.Climate change is a global challenge and Transport sector is a significant source that contribute towards increasing GHG emissions. In 2011 the transport sector accounted for 19% of global energy use and contributed 22% to the total carbon dioxide (CO_2) emissions in the world (IEA 2014). This contribution is majorly driven by the road transport sector which increased by 64% since 1990 and accounted for about three quarters of transport emissions in 2012(IEA). Transport sector is also responsible for 20 per cent of global emissions of Black Carbon (BC), the second largest contributor to warming of the planet, next to CO_2 (TERI, 2014). Climate change is already happening and is manifesting itself globally in the form of extreme weather events,

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heat waves, and high temperatures. It is expected that these effects will be stronger in developing countries, whose geography and lack of resources make them more vulnerable (IPCC 2007). Also not only does transport sector contribute to climate change but climate change also impacts transportation infrastructure and mobility. A changing climate could have serious consequences on the resiliency and performance of surface transportation systems in response to environmental conditions (Schmidt, 2009).

Urbanization and increasing reliance on personal mode of transport remain a challenge for most of the developing cities particularly in Asia .Growing GDP per capita will continue to drive the demand for mobility and use of personal motorized vehicles. Though per capita urban transportation emissions in developing countries remain many folds lower than developed country cities, it is most certain that developing countries will contribute in increasing emissions proportion to global CO_2 emissions considering the urban growth and vehicular emissions as can be understood by figure 1. There is now a growing international consensus that future targets for CO_2 reductions in the post-2012 Climate Policy Framework will not be achieved unless CO_2 contribution from the transport sector in developing countries is appropriately addressed (ADB, 2009).

India emerging as a strong economy where higher urban densities are resulting in higher levels of private motorization. In light of such trends, rate of growth of GHG emissions would be significant and Holistic Policy framework that decouple economic growth from growth of personal motorization unlike the developed countries like USA are needed to put the country on a sustainable low carbon growth trajectory.

This paper attempts to review policy instruments that have been instrumental in putting urban transport on a low carbon pathway in cities that have set a benchmark in integrated land use transport planning. The initial sections of the paper describe the urban transport scenario in India and transport sector contribution to GHG emissions. The later sections delve into climate change and how it needs to be addressed from urban transport point of view. Examples of sustainable transport policies from various cities and how they have addressed to the different transport needs along with reducing emissions are discussed. In Indian context, policies that focus on climate change mitigation are listed and discussed. Finally the case study of Bangalore has been taken up, wherein various policy instruments in the urban transport sector that directly or indirectly address GHG mitigation and adaptation are discussed.
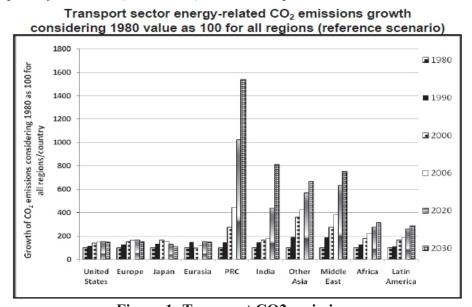

Figure 1: Transport CO2 emissions

Source: ADB 2009 (adopted from IEA 2008)

2. Urban Transport scenario In India

Burgeoning urban population and area in most of the cities in India is leading towards an increasing travel demand as can be noted in figure 2. Growing per capita income levels and inadequate public transport system have contributed to the increase in demand of personal vehicles. India's most acute Urban transport problems are not because of the number of vehicles but the high concentration of private vehicles in a few selected cities (NTDPC, 2010). About 32 percent of motor vehicles are in metropolitan cities alone, which constitute just around 11 percent of the total population (NTDPC, 2010). The total passenger kilometres are expected to increase from nearly 3,635 billion in 2005 to nearly 19,437 billion by 2030.
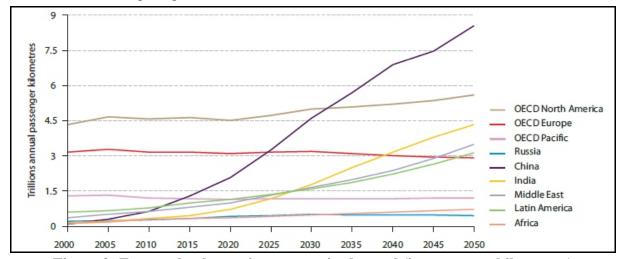
Figure 2: Expected urban private motorized travel (in passenger kilometers)

Source: IEA 2014

(92% on-road transport), resulting in a 5-fold increase in energy demand and carbon emissions in transport by 2020 relative to 2000 under the current trend (Singh, 2006).

2.1 Transport Sector in India – Contribution to GHG emissions

The transport sector, overall, is responsible for about 10% of the total final energy demand, especially dominating the growing demand for oil in India. IEA (2013) estimates that India's transportation energy use would grow at the fastest rate in the world, averaging 5.1% per year, compared with the world average of 1.1% per year. Although, currently, India is one of the lowest per capita emitters of CO_2, at 0.27 metric tons of carbon equivalent, energy sector's carbon intensity is high, and the country's total CO_2 emissions rank among the world's highest (Singh, 2006). The transport sector comprising of road transport, aviation, navigation and railways accounted for 142.04 million tons of CO_2 eq

emissions, i.e., 7.5% of the total GHG emissions in the country in the year 2007. Of this, road transport alone accounted for 87 percent of the GHG emissions (i.e., 123.57 million tons of CO_2 eq) (ICAMP, 2013) .It accounts for more than half of India's total petroleum consumption and more than 25 percent of the overall energy needs (second only to industry) (MoSPI, 2013). It is also a significant contributor to the emissions generated by the country, accounting for about 13 percent of the emissions from the energy sector.

The vehicle-wise share in overall energy consumption in 2010 in the road transport sector is shown in Figure 3. Under BAU scenario CO_2 emission from road transport in India will increase from 19.80 to 93.25 million metric tons of carbon equivalent in 202-2021(Singh 2006). In 2007, India consumed 595 Mt of energy, and energy-related CO_2 emissions reached 1324 Mt, ranking India the 5thmajor GHG emitter in the world (MOEF, 2010).

Figure 3: Vehicle-wise share in overall energy consumption in the road transport sector in India (2010)

Source: TERI ICAMP Report 2014

Transport sector as a source of GHG emissions not only drives climate change but also contributes to air pollution and related health impacts. As cities grow bigger, dependence on personalized transport, the en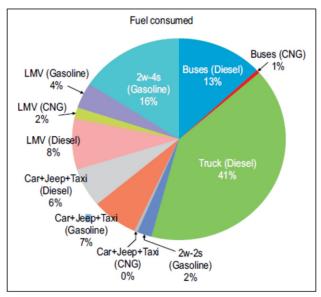ergy demand from transport sector and vehicular emissions are bound to increase predominantly. Apart from building climate proof urban systems, developments that increase the vulnerability of cities by ignoring climate change implications must be avoided (GTZ,)

3. Addressing Climate change- Measuring GHG emissions and Impacts

The transition to sustainable transport futures demands an integrated approach to transport policy development and implementation. This includes lowering carbon dioxide (CO_2) emissions in transport, and achieving progress against wider economic, social and local environmental policy objectives (Hickman, 2012). Responding to Climate change not only includes quantifying the transport sector emissions but also to ascertain the possible impacts of climate change on the transportation system. Changes in frequency and magnitude of climate variables are bound to increase the

pressing issues of infrastructure damage, floods, urban heat islands and air pollution amongst many other health and ecological impacts. Increased temperatures, rising sea levels and water shortages may lead to changes in behaviour and use of resources. (Walsh et al., 2011).

The foremost step in developing responses to climate change in a specific sector is quantifying the GHG emissions from that sector. In order to assess future impacts of climate change, the degree to which future GHG emissions will effect climate needs to be assessed. The estimation of GHG emissions from transportation sector forms the primary basis in evaluating the impact of motorized transport on climate. Analyzing the potential impact of GHG emissions consists of three key tasks (ADB, 2009):

i. Analyzing and monitoring present transport activity, pollutant emissions, fuel use, and CO_2 emissions.

ii. Projecting future transport activity as outcome of changes in the form of transport Costs, incomes, land uses and many other variables, and projecting resulting fuel use and CO_2 emissions levels.

iii. Evaluating the impact of policies aimed at both transport activities and CO2 emissions.

The expert group on low carbon suggests an in-depth study for quantification of energy consumption and GHG emissions from the transport sector in India would help examine the impacts that various policies might have on reducing the energy and emissions from the sector. Singh et al (2008) estimated the GHG emissions (CO_2, CH_4, NO_x) and trends in energy consumption road transport sector in India from 1980 to 2000.Ramachandra, Shwetmala (2009) developed a state wise inventory of GHG emissions from India's transport sector for the year 2003-2004. Singh (2006) estimated the level and growth of energy demand, CO_2 emissions from passenger transport in India upto the year 2020-2021.

Measuring and quantifying GHG emissions from the transport sector is a huge challenge in developing countries mostly due to the lack of data. Emissions (G) in the transport sector are dependent on the level of travel activity (A) in passenger km (or ton-km for freight),across all modes; the mode structure (S); the fuel intensity of each mode (I), in litres per passenger-km; and the carbon content of the fuel or emission factor (F), in grams of carbon or pollutant per litre of fuel consumed. This approach known as ASIF framework (Schipper, 2009) shows that actions on total activity (A) and mode share (S) can significantly reduce transportation energy consumption and emissions.

Estimates of vehicle activity data based on vehicle type, fuel intensity data is still in adequate in most of these countries and hampers the measurement of impact of urban transport policies that can limit the growth of CO_2 emissions. Measuring both fuel consumption and distance for each kind of vehicle-fuel combination is important for measuring policy outcomes and impacts (ADB, 2009).

3.1 Approaches

A wide variety of modeling approaches have been employed in the studies for climate change mitigation. There are many studies that use quantitative empirical data and derive conclusions about how climate change might be mitigated in the future from analysing those data using regression or econometric modelling and scenario analysis (Das, Parikh 2004). Most of the research works have estimated future emissions from past trends by developing scenarios about technology development, behavior change, and population growth. Back casting approach (Hickman et al., 2012) has also been used to assess longer-term desirable futures and the different pathways to achieve an emission reduction target from transport sector. Integrated modeling tools like TRANUS and LEAP (Bose 1996) have also been applied to assess the effects of policies on energy consumption and GHG emission from the transport sector.

Most of the studies on climate change mitigation and adaptation have been carried out with the purpose of reducing the Vehicle miles travelled (Schmidt, 2009). There have been limited studies on economic assessment of adaptation measures. Evaluating how well different practices and technologies will avoid adverse climate change impacts and how the social equity will be addressed needs to be ascertained. For assessing the impacts on urban transport systems, it is also important that a vulnerability assessment of the transportation assets is undertaken. There are quite less instances where susceptibility of the transportation assets to climate change effects is measured or quantified. An impact assessment that allows for an interactive temporal and spatial analysis of explicit climate change impacts for different combinations of scenarios can prove to be an effective tool for evaluation (Kit et al., Hyderabad, 2011).

3.2 Mitigation and Adaptation in Urban Transport - Policies for dealing with Climate change

Effective responses to climate change require policies that consider mitigation and adaptation central to the transportation planning and integrate climate change in the overall policy framework. Strategies/Policies are generally aimed at:

- Reduction in greenhouse gas emissions resulting from movement of goods, services, and people in cities (Mitigation).

- Minimizing the potential impacts on the transportation system from climatic changes such as rising average temperatures, increased intensity of storms, rising sea levels, and increases in overall climatic variability(Adaptation).

Whereas mitigation is a global mandate, adaptation is a local necessity. Mitigation strategies like the Kyoto Protocol have enabled global participation in mitigating climate change. Adapting the urban transport system at city/local level through effective strategies and their prospective evaluation is however the need of the hour.

The Avoid-shift-Improve approach (A-S-I) makes an important contribution towards climate change adaptation strategy. Urban transport mitigation and adaptation strategies and planning need to be broadly considered within the A-S-I framework. The ASIF framework (Schipper, 2009) shows that actions on total activity (A) and mode share (S) can significantly reduce transportation energy consumption and emissions.

The Avoid-Shift-Improve approach to Sustainable Transport Systems

Avoid	Shift	Improve
Smart Infrastructure planning reduces need to travel- improved overall system efficiency	Non Motorized transport and Public transport. Improves efficiency of the travel	Low sulphur fuels; engine design; particulate filters; Energy efficiency; Low-Carbon Fuel Standards
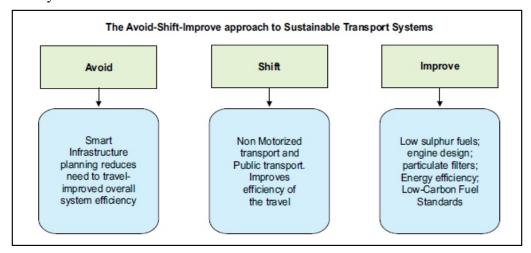
Figure 4: A-S-I framework

Source: ICAMP, TERI

Dhar et.al recommends demand and supply side interventions as described in Figure 5 for reducing transport emissions. The demand side interventions rely on reducing the trips, retaining modal shares of non-motorised transport, and shifting demand from private vehicles to public transport. The supply side strategies essentially rely on policies that affect the technology choices for consumers (e.g., for more efficient cars, cleaner fuels, etc.), as well as decarbonising the electricity.

	Demand	Supply
Transport	Transport demand management; speed limits; congestion pricing; fuel tax; public transport subsidy; promotion of non-motorized transportation; road tolls; parking fees; provision of eco-driving schemes.	Investment in mass transit system. Regulation and incentives for improvement of vehicle energy yields or low emission fuels. Facilitate inter-modal linkages application of information technology.
Land use	Land use planning; provision of basic services; property tax regimes to discourage sprawl.	Zoning regulation; town planning schemes; incentives for high density urbanization, regulation to discourage sprawl.

Figure 5: Demand and supply side interventions for low carbon Transport

Source: Climate change and urban transportation systems, Mehrotra et al., 2011

There are many categories of policy instruments that have been used by decision makers in many countries that have fostered sustainable transportation goals. Given the wide array of policy instruments available, myriad forms of combinations are possible and the potential for interaction between different instruments increases (Tanu Priya Uteng). Hickman and Banister (2007) argue that combinations of policies are required to significantly reduce CO_2 emissions, as individual policies are insufficient. The policy instruments are discussed in the following sections.

3.2.1 Planning instruments

City planning that helps reduce or optimize transport and encompass integrated land use and transportation planning. Singapore, Hongkong, Bogota and Curitiba are profound examples of remarkable land use planning. Whether it is the success of Bus Rapid Transit (BRT) in Bogota and Curitiba or mixed development in Singapore, these cities have shown that linking urban transport with land use planning, apart from reducing emissions can deliver multiple benefits in terms of improvement of public transport and reducing congestion. In a study in China's 35 major cities, it was found that an increase of 1,000 people per km^2 on average is associated with a reduction of CO_2 emissions per household of 0.424 ton from use of taxis and 0.837 ton from the use of buses (ADB, 2012) This may indicate shorter average travel distance and/or much more effective urban public transportation.

3.2.2 Regulatory instruments

Regulatory reforms may include mandatory emission norms for vehicles or a complete ban on certain kinds of vehicles. Restrictions to circulation have been widely implemented in towns and cities like Bogota, Sao Paulo, Athens. The short-term benefits are similar to road pricing schemes: reduced congestion and faster average speeds, leading to reduced fuel consumption and lower GHG emissions. The implementation of combined measures such as pedestrian pathways, BRT, car free days in Bogota and Curitiba is estimated to have reduced

CO_2 emissions by 318 tons per day from 1997 and decreased rapidly year by year.

In some EU countries, low-emission zones have been introduced in some cities. In these zones, vehicles or classes of vehicles that cannot meet a prescribed standard of emissions are prohibited entry. The Low Emission Zone (LEZ) in London was implemented in February 2008. The main objective of the scheme is to deter the most polluting diesel vehicles from driving inside Greater London. Low Carbon Fuel Standard introduced by the state of California in 2007 requires fuel providers to reduce GHG emissions of the fuel they sell. The programme intends to achieve a 10 per cent reduction in the carbon intensity of transport fuels by 2020.

Another way of controlling vehicle use is through restrictions on vehicle ownership. The only example of a direct quantity control of this sort is the Vehicle Quota System (VQS), a policy implemented in Singapore in 1990 and still in place today. Prospective vehicle owners are required to purchase a Certificate of Entitlement (COE), which is a licence that lasts ten years, except for taxis, for which it lasts seven. Traffic management measures include sophisticated traffic signal systems significantly increase the carrying capacities per lane of the affected streets, and thus reduce congestion and increase speed. However, it also makes car use more attractive, so that car use increases. The net GHG emission effect may, therefore, be small, perhaps even negative. In developed countries, traffic management measures have led to 2%–5% emission reductions overall (GTZ, 2013).

3.2.3 Economic instruments

Market-based approaches use economic incentives and/or disincentives to pursue a policy goal. The price mechanism serves as a vehicle for policy enforcement. Economic instruments can include emission taxes, congestion charges, or subsidies on the use of cleaner fuels.

The first and most prominent example of active road pricing was introduced in Singapore as congestion pricing for entering the

central business district during peak hours. this cordon pricing measure resulted in reducing the private car travel within the zone by 75%.road pricing scheme in London introduced in February 2003, under which vehicles travelling in daytime central London incur a charge of 16$ /day with revenues from the scheme used to improve public transport. The scheme resulted in an estimated 19% reduction in CO_2 emissions from road traffic and 20% reduction in fuel consumption.

3.2.4 Technology - Technological instruments are more effective when applied in conjunction with other policy instruments. These instruments often focus on cleaner fuels and efficient vehicle technologies.

3.2.5 Information - Information instruments include behaviour change campaigns, public information procurement and public acceptance monitoring. These are 'soft measures' sometimes used to complement other instruments. Bogota's car free day promotes bus and bicycle networks. Harmsen, van den Hoed, and Harmelink (2007) study the impact of the Eco-driving program in the Netherlands between 1999 and 2004 and find that, in that period, the program achieved reductions in fuel consumption of between 0.3 and 0.8 percent, equivalent to 0.1– 0.2 million tonnes reduction in CO_2 emissions. VMT (Vehicle Miles Travelled) reductions from car sharing have been found to be even more dramatic in Switzerland, where car owners who sold their vehicles and became mobility car-sharing customers reduced their annual mileage driven by 72%.

3.2.6 Voluntary Agreements- voluntary agreements are agreements between a government authority and one or more private parties with the aim of achieving environmental objectives or improving environmental performance beyond compliance to regulated obligations.

GTZ suggests developing countries to focus on short to mid-term measures which are low cost and "win-win," with the highest impact on CO2 mitigation at the same time leading to local economic, social, and environmental improvements.

4. Urban transport Policies in India

India signed the United Nations Framework Convention on Climate Change, and acceded to the Kyoto Protocol in 2002. Despite not having binding mitigation commitments as per the United Nations Framework Convention on Climate Change (UNFCCC), India has communicated its voluntary mitigation goal of reducing the emissions intensity of its Gross Domestic Product (GDP) by 20–25 per cent, over 2005 levels, by 2020. The Government formulated the National Action Plan on Climate Change (2008) that provides for eight missions to help the country adapt to the effects of climate variability and change. The National Mission on Sustainable Habitat which is a component of the National Action Plan for Climate Change emphasizes on Better Urban Planning and Modal Shift to Public Transport in order to reduce GHG emissions from the transport sector.

Numerous Legislative Acts have been enacted so far which have aimed at mitigating climate change and adapting to sustainable transport. Pertinent amongst them are listed as follows:

1. Air (Prevention And Control Of Pollution) Act, 19812. Environment (Protection) Act, 1986
3. Motor Vehicles Act, 1988
4. Energy Conservation Act, 2001
5. National Auto Fuel Policy, 2003
6. Jawaharlal Nehru National Urban Renewal Mission (JNNURM), 2005
7. National Urban Transport Policy, 2006
8. National Environment Policy (NEP) 2006
9. Integrated Energy Policy, 2006
10. National Action Plan On Climate Change (NAPCC), 2008
11. National Transport Development Policy Committee, 2010

One of the main short comings of the policy implementation in India is time gap between the framing of the policy and its implementation. For example **Jawaharlal Nehru National Urban Renewal Mission** (JNNURM) was a reform-driven, fast track, planned development program launched in 2005 with an initial mission period of seven years. The time frame was extended by two years in March 2012 due to delays in implementation. Land acquisition etc. The Energy Conservation Act, 2001 provides the much-needed legal framework and institutional arrangement for embarking on an energy efficiency drive. Under the provisions of the Act, **Bureau of Energy Efficiency** has been entrusted to set the fuel efficiency standards (similar to CAFÉ Standards) for passenger cars, to be implemented by MoRTH under Motor Vehicles Act, starting 2017.

National Auto fuel Policy, 2003 adopted a roadmap for progressively tighter fuel quality and vehicle emission standards through 2010.As a result of the implementation of this policy, vehicular emissions of particulate matter (PM_{10}) declined throughout the decade and growth in emissions of oxides of nitrogen (NO_x) slowed, even as the number of vehicles on the road doubled. Fuel conforming to BS (Bharat Stage) III was introduced in 13 major cities across the country from the year 2005 while BS II fuel was made available elsewhere. Whereas BS I fuel has been phased out and from April 2010 BS IV standard fuel has been implemented across the 13 major cities and BS III fuel is made available elsewhere.

National Urban Transport Policy (NUTP) was created to motivate the building of people centric urban transport solutions instead of focusing on improving the conditions for private motor vehicles, Promoting use of public transport, mixed land use and Priority to non- motorized transport are the main features of NUTP.

National Environment policy (NEP) recommended Formulation of a national strategy for urban transport to ensure adequate investment, public and private, in low pollution mass transport systems.

National Transport Development Policy Committee, 2010 recommended Tighter Bharat IV fuel quality standard to be implemented nationwide by the middle of this decade, with a target to reach Bharat VI by 2020 and Establishing a National Automobile Pollution and Fuel Authority (NAPFA) that will be responsible for setting and enforcing vehicle emission and fuel quality standards in India.

With a fragmented Transport Institutional Network in the country, the governance of the sector has been very complex. Although urban transport issues like vehicular emissions feature prominently in Government's policies such as the Ministry of Urban Development's National Urban Transport Policy (NUTP), the National Habitat Mission and the Report of the National Transport Development Policy, yet funding barriers, diffused responsibility between the Centre and the state governments are a constant hurdle in implementation. The government policies, as of now, do little to control personal vehicle ownership. The only dis- incentive for buying cars is the high cost of ownership and higher fuel prices compared to the cities in developed countries. (Verma et al., 2013)

5. Case study of Bangalore- Urban Transport Challenges

Bangalore is the most urbanized district in the state of Karnataka with 90.94% of its population residing in urban areas. With an economic growth rate of 10.3% p.a, it is one of the fastest growing cities in Asia. Bangalore recorded the highest population growth of 106% in the last two decades. Although Bangalore's rapid economic growth has substantially improved the local quality of life, yet challenging issues of urbanization, motorization, congestion & pollution looms over the development of the city. The transportation system in Bengaluru is far behind than what is needed to suffice the increasing urbanization. Personalized modes of transport have grown at a tremendous rate and two wheelers along with the cars almost comprise 90% of the total registered vehicular population in the city. Bangalore's rapid urbanization has given

rise to unprecedented growth in motorized vehicles. Higher income levels have made it possible for larger segment of people to own vehicles. Despite the inadequate road space in the city and higher cost of owning a vehicle, the number of passenger cars/personal vehicles has grown up by 106 % in just a span of four years from 2007 till 2011 as shown in Figure 6.
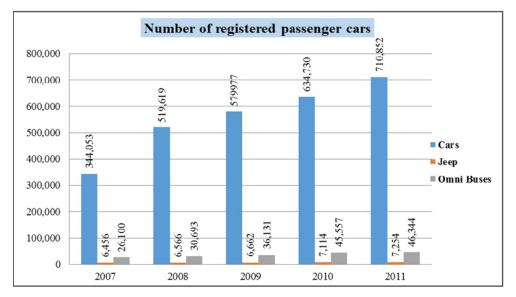
Figure 6: Growth of motorization in Bangalore

Source: Bangalore mobility indicators, 2011

Air pollution also remains a major concern in the city. Deterioration of air quality has been time and again attributed to rapid increase in population and consequent fuel combustion activities. The source apportionment study carried out by CPCB (Central Pollution Control Board) in 2011 in collaboration with Karnataka State Pollution Control Board under the National programme known as National Air Quality Monitoring Programme (NAMP). Table 1 shows the level of pollutants produced by each sector. NAMP attributes much of the air pollution to transport sector as shown below.

Table 1: Sectoral emissions in Bangalore

	PM_{10}	NO_X	SO_2
Transport	22.4	146.36	2.31
Road Dust	10.9	0.00	0.00
Domestic	1.8	2.73	0.68
DG Set	3.6	50.96	3.35
Industry	7.8	17.19	8.21
Hotel	0.1	0.20	0.02
Construction	7.7	0.00	0.00
Total	54.4	217.4	14.6

Source: CPCB 2011

5.1 Climate Change – Response and strategies

Climate change is most likely to aggravate the events like urban flooding. These impacts will be borne directly by the people of the city and also simultaneously hindering development. Given the increasing urban growth, ill planned infrastructure in the city, even a small amount of rain floods the motorways and brings the city to a halt.

In June 2009 Government of Karnataka (GoK) constituted a Coordination Committee to oversee the state's response to climate change. . It assigned the mandate to prepare **the State Action Plan on Climate Change (SAPCC)** to Environmental Management & Policy Research Institute (EMPRI), Bangalore, which submitted its first assessment report in March 2012 The Plan suggests adaptive and mitigation measures to reduce the impact of climate change in Karnataka in different sectors. Though there is no stated mechanism in the draft to ensure evaluation and implementation of plans, the plan identifies the key sectoral issues, actionable points, implementation arrangement, stakeholders, capacity building needs and funding requirements. The plan suggests focus on piloting viable options for a sustainable larger-scale development of bio-fuel as a substitute for fossil fuels like diesel and petrol for use in vehicles.The urban transport sector though is not sufficiently addressed in the plan.

5.1.1 Energy consumption in Transport sector

The CPCB report (2010) mentions transport sector as a major sectoral contributor to PM_{10} and $PM_{2.5}$ concentrations in the city. According to the **Greenhouse Gas Inventory of Karnataka** (Karnataka State Pollution Control Board and Enzen Global Solutions Pvt. Ltd), greenhouse gas emissions as carbon-di-oxide equivalents from the road transport sector in Bangalore City during the period 2005 -06 were around **2.24 million tonnes**. It has been seen that emissions have almost doubled since 1997 (1.01million tonnes CO_2 equivalents) and will be doubled in the next ten years if the same trend continues (Bangalore Mobility Indicators, 2008).

Table 2: Energy consumption and emissions from the transport sector

Fuel type	Annual Consumption (Tonnes)	Energy Content (TJ)	GHG Emissions (Tonnes)		
			CO_2 (Tonnes)	CH4 (Tonnes)	N2O (Tonnes)
Gasoline	2,47,577	11,193	7,88,210	224	7
Diesel	4,82,632	20,203	14,60,728	101	12
Total Emissions			22,48,938	325	19

Source: Bangalore Mobility Indicators 2008

5.1.2 Policy instruments in Urban transport sector

The government policies in the transport sector in Bangalore , it can be said have so far not been instrumental in order to suffice urbanization and rampant vehicular growth.The road supply in terms of road length (metre) per population in the city is 1.20 which is lesser than that of smaller cities like Lucknow (1.83) and Guwahati (2.06). Though the city, also called as the Silicon valley of India is significantly building up its way in terms of economy, but in terms of road infrastructure it is incomparable with the likes of

OECD countries like US where the road length (m) per population is 21.39. The cost of bus travel is fairly high in the city than the other metropolitans in the country, making it unaffordable to some sections of the society. Though the travel cost per passenger km in proportion to GDP per capita (0.00055%) is far less than even in the developed cities like London (0.075%), the fact that presently the mode share of PT i.e bus in Bengaluru is 46.9% and that of cars is 7.4% indicates that bus transport is still the attractive mode of transport (Verma et al, 2013). Over the years the government has initiated actions that intended to delimit the vehicular growth. As a means of controlling personal vehicle growth,these policies have directly or indirectly addressed climate change.They are :

- Karnataka State Bio-fuel Policy 2009: Stipulates mandatory bio-fuel use by state departments as a part of a popularization strategy. It also sets 5% as a target for bio- fuel blending in 2012 which as of date was not achieved and 10% by 2017.

- In accordance with the National Bio-fuel Policy prepared by Ministry of New and Renewable Energy (MNRE) that proposed a 20% substitution of diesel by bio-diesel to be achieved in the year 2017, Bangalore Metropolitan Transport Corporation (BMTC) has introduced the usage of bio-fuel in part of its fleet.

- Department of Transport also initiated action to improve air quality in Bangalore. In 2001 it achieved passing of a Government Order prohibiting commercial vehicles older than 15 years. Although it has been 14 years since the order was enacted, on ground implementation has proved to be futile.

- The life time tax imposed on purchase of new vehicles in the state which is anywhere between 10-18% of the cost of vehicle has not been fruitful in containing the rapid vehicular growth.

- As Institutional reforms the state Government created Bangalore Metropolitan Land Transport Authority (BMLTA) & The Department of Urban Land Transport (DULT) to comply with the institutional reforms mandated by the NUTP and JNNURM. DULT has come up with Pedestrian and Parking Policy guidelines for the city, although the implementation is awaited.

- As an informatory instrument, DULT initiated Cycle day in the city as a means to promote non-motorized transport.

6. Conclusion

The foremost challenge that developing countries are facing in present times is of rampant urbanization and increasing transport activity. The linkage between transportation and GHG emissions makes it imperative to devise strategies that limit the emissions and simultaneously make the urban areas resilient to climate change. Through the review of the literature, it is observed that city specific approaches need to be developed to assess climate change and its impacts. Incorporating vulnerability assessment of the urban areas and economic assessment of the adaptation strategies will help overcome the present gaps. This paper has looked at different policy instruments that have been practiced in cities world over to ensure a more sustainable low carbon travel. The review has shown how countries like Singapore through well planned urban transport policies have made travel environment friendly and efficient in terms of energy demand. Through examples it is also observed that though cities enacted urban transport policies to reduce motorization, co-benefits of reduced vehicular emissions, better air quality were also achieved. The review of policy instruments suggest that policy instruments when applied in isolation tend to have a less pronounced effect on motorization. Instead it is imperative for countries or cities to develop a comprehensive package of policy instruments that are acceptable, feasible and are backed by strong political will. As can be seen in the case of Bogota where pro people policies rather than pro car policies resulted in it

being considered a precedent for sustainable transport world over. The examples demonstrate that policies that tackle major issues related toemission reduction should be coherent and integrated in order to reap maximum results. It is though necessary that strategies are selected depending on city specific conditions. Indian transport scenario presents a challenging opportunity to draw lessons and build on from such examples. India has a lot of scope in terms of important policy decisions to significantly alter the growing path of auto mobility. The coming decades will witness huge changes in terms of transport systems, new technologies, demographics etc. and any policy decision taken at this point of time has to ensure the envisaged growth along with proper and constructive investments in the transportation sector. The policies that have been reviewed so far have not been fruitful in limiting the use of personal vehicles nor have encouraged public transport. There has been no comprehensive economic evaluation of the policies in ascertaining their potential to reduce GHG emissions. Also it is observed that the complexity of the Institutional arrangement and governance of the transport sector has by and large been responsible for transport planning not being central to climate change concerns.

The review of policies related to urban transport and climate change in Bangalore city presents a conflicting approach between various stakeholders involved. It is understood that policy decisions have to be made that would encourage the use of public transportation and induce simultaneous reduction in personal vehicle growth. Decisions that include High priority bus lanes, Non Motorized Transport (NMT) infrastructure, congestion pricing, higher on street parking charges, cap on new vehicle registrations can help in mitigating the vast challenges in the present transportation scenario and addressing climate change concerns. For developing countries like India, policies that favour emission reduction yet do not compromise on economic growth and social equity need to be framed, evaluated and implemented on time to achieve sustainable transport and wider socio-economic benefits.

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A Multicriteria Decision Making Methodology for Selection of Suppliers In Sustainable Supply Chain

V Ravi[1]

Abstract : Liberalization, privatization, globalization of economies coupled with growing global population has resulted in various kinds of pollutions that can have a severe impact on environment and human life. The concept of sustainable supply chain increases in this regard. Sustainable development stands for not only meeting the requirements of present generation but also of future generations in meeting their own needs. A key issue faced by top managers in sustainable supply chain is selection of appropriate suppliers. Suppliers tend to have varied strengths and weakness on different parameters as quality, price, service, technical capability, financial strength, geographical location, reciprocal arrangements, etc., related to procurement process. But the selection of appropriate suppliers for a sustainable supply chain is a multi-criteria decision making problem containing qualitative and quantitative attributes. This study aims to efficiently assist the decision makers in determining the most appropriate suppliers in context of sustainable supply chain using a combination of analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS). A numerical example from a case company is included to demonstrate the steps of the proposed model.

Keywords:
Sustainable supply chain, suppliers,Analytical Hierarchical Process; TOPSIS.

1. Introduction

Supply chains have seen a radical transformation in their operation since the last decade due to number of factors. Increasing competition on a global scale, shortened product life cycles, changing preferences of customers, concerns to environment are some of them. Also, liberalization, privatization, globalization of economies coupled with growing global population has resulted in various kinds of pollutions that can have a severe impact on environment and human life. The concept of sustainable supply chain increases in this regard. Sustainable development stands for not only meeting the requirements of present generation but also of future generations in meeting their own needs. A key issue faced by top managers in sustainable supply chain is selection of appropriate suppliers. Supplier selection is one of the critical issues faced by operations and purchasing managers to maintain competitive advantage (Chen et al., 2006).

An organization has to take into consideration a number of actors for evaluation of suppliers. Here a careful analysis of the products/services offered by suppliers needs due consideration. Some of the important criteria are cost, quality, delivery, serviceability, geographical location, flexible working arrangements, credit strength, etc. A careful analysis of these factors reveals that supplier selection problems are a multi-criteria decision making problem that needs consideration of both tangible and intangible factors (Sarkis and Talluri, 2002). To these factors, if the concept of sustainability is also introduced, supplier selection process becomes more complex. Incorporation of strategic and sustainability factors into supplier selection problems builds long–term resiliency of a supply chain (Seuring and Muller, 2008; Zhu et al., 2008).

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In the recent years supplier selection with concerns to environment have gained prominence (Handfield et al., 2002; Sarkis, 2006). Hutchins and Sutherland (2008) report that supplier selection incorporating general sustainability issues and other social sustainability dimensions are scarcely found in literature. Sustainable development generally follows a triple- bottom line approach that takes economic, environmental and social development into consideration (Gauthier, 2005). Literature reveals that social factors as human right abuses, child labour, health and safety of staff and customers need to be added to supplier selection process (Rivoli, 2003).

The triple-bottom-line approach incorporating economic, environmental and social factors into supplier selection can result in increase of a company's image and would be beneficial for an organization in the long run. Selection of appropriate suppliers for sustainable supply chain is a key strategic issue for top management in an organization. A combination of multi-criteria decision making approaches using analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) has been used in research for selection of suppliers in sustainable supply chain.

This paper is further organized as follows. Section 2 provides the literature review related to methods adopted by researchers for supplier selection problems. The proposed TOPSIS-AHP method is discussed in section 3. In section 4, we apply the proposed method in company interested in selection of suppliers for sustainable supply chain. This is followed by discussions of this research and its applications.

2. Literature review

Literature review reveals that researchers have adopted different methods for selection of suppliers. Analytical hierarchical process (AHP) as a methodology has been used by researchers for selection of suppliers (Chan, 2003; Bayazit, 2005). Mandal and Deshmukh (1994) used interpretive structural model (ISM) for showing inter-relationships among different supplier

attributes and their levels of importance. Case based reasoning has been used for evaluation of supplier's environmental management performance (Humphreys et al., 2003). Choy et al., (2003a, 2003b) used artificial neural network and intelligent supplier selection relationship management for selecting and benchmarking potential suppliers. Liu et al., (2000) applied data envelopment Analysis (DEA) for evaluation of overall performances of suppliers in a manufacturing firm. Razaei and Davoodi (2011) used multi-objective programming for lot- sizing with supplier selection. Lee et al., (2009) used goal programming methodology for selection of suppliers in case of high-tech industry.

In addition, literature reveals that researchers have also used hybrid methods, i.e. combination of two or more multi-criteria decision making methodologies for selection of suppliers. Ghodsypour and O'Brien (1998) used a combination AHP and linear programming approaches for selection of suppliers containing tangible and intangible factors such that the total value of purchasing becomes maximum. Kannan et al., (2009) used a combination of ISM and TOPSIS methodologies in a fuzzy environment for selection of best third party reverse logistics providers. Haq and Kannan (2009) used AHP and grey relational analysis for selection of appropriate vendors. Zhang and Feng (2007) used fuzzy-AHP methodology for selection of third party reverse logistics providers. It is observed from literature review that there is not much work reported till date for selection of suppliers in context of sustainable supply chain using a combination of TOPSIS-AHP method and this research is an attempt in this regard.

3. TOPSIS-AHP Method

As discussed, it can be seen that supplier selection in context of sustainable supply chain is a strategic decision making problem that calls for consideration of both tangible and intangible factors. Many attributes of supplier selection as cost, quality, reliability, pollution, resource consumption, healthand safety of staff and customers, etc., are qualitative and quantitative in

nature. One of the advantages of AHP methodology is that it can be used to deal with tangible and intangible factors in the light of subjective judgments in the process of decision making (Saaty, 1980). TOPSIS method simultaneously considers the distance to the ideal solution and negative-ideal solution for each alternative and helps to select the closest relative to the ideal solution as the best alternative (Hwang and Yoon, 1981). Thus, in order to reap advantages associated with both of these methods, a combined multi-criteria decision making methodology using AHP and TOPSIS has been used in this research for selection of suppliers in the context of sustainable supply chain. This methodology is illustrated in the following steps:

Step 1:A decision matrix 'D' having 'n' criteria/ attributes and 'm' alternatives is represented as:

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & \cdots & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Here x_{ij} is the performance of ith alternativewithrespect to j^{th} attribute.

Step2 : The normalized decision matrix for the above matrix is obtained as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \text{ where } j = 1, 2....n \quad (2)$$

Step3: In this step, the relative importance of various attributes with respect to overall objective be determined. Weightages to attributes according to their importance needs to be given. In this research we have used nine-point preference scale of Saaty (1980) for construction of pair-wise comparison matrices. Reflexive property between the criteria is also taken care by this scale. For example, if a criterion 'A' is 7 times more important compared to another criterion 'B', then 'B' will be 1/7 times as important as 'A'.

Let Brepresent an n x n pair-wise comparison matrix,

$$B = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix} \quad (3)$$

In this matrix, diagonal elements are self-compared. Thus these elements in equal importance.

Thus, $b_{ij}=1$, where i=j, i, j=1, 2….n.

The importance degree of considered attributes is calculated using normalization of the geometric mean (NGM) method in this research. If $w_{i\ denotes}$ the importance degree for the ith attribute, then:

$$w_i = \frac{\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}, \text{ i, j = 1, 2……n.} \quad (4)$$

Consistency check is carried out for ensuring that the pair-wise comparison matrix done is reasonable and acceptable.
Let P denote an n-dimensional column vector that is used to describe the sum of weighted value of importance of degrees of attributes. Then,

$$P= [P_i]_{n \times 1} = BW^T, \text{ i= 1, 2, …..n} \quad (5)$$

where :

$$BW^T = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1, & w_2, & \cdots & w_n \end{bmatrix} = \begin{vmatrix} p_1 \\ p_2 \\ \cdots \\ p_n \end{vmatrix} \quad (6)$$

Consistency values of attributes can be represented by vector:

$PV = [pv_i]1xn$ with a typical element pv_i defined as: $pv_i = (p_i/w_i)$, i= 1, 2,…n.

Care should be taken that inconsistency among pair-wise comparison matrix is avoided.

Saaty(1980) has suggested use of maximum eigen value (λ_{max}) to calculate the effectiveness of the judgment for this purpose.

λ_{max} is calculated as:

$$\lambda_{max} = \left(\frac{\sum_{i=1}^{n} pv_i}{n} \right), i = 1, 2 \ldots n \quad (7)$$

Consistency index (CI) is estimated as:

$$CI = \left(\frac{\lambda_{max} - n}{n-1} \right) \quad (8)$$

Consistency ratio (CR) is used as a guide for checking consistency of evaluation. CR is calculated as:

$$CR = \frac{CI}{RI} \quad (9)$$

Where RI denotes average random index (Saaty, 1980). The evaluation of importance of degrees of attributes is considered reasonable if value of CR is below 0.10.

Step4: By multiplying each column of the matrix r_{ij} by weight w_j, the weighted normalized matrix is obtained as:

$$v_{ij} = w_j. \; r_{ij} \quad (10)$$

Step5: Here the ideal solutions (v^+) and negative ideal solutions (v^-) are calculated as follows:

$$(11)$$

$$v^- = \{v_1^-, \; v_2^-, \; \ldots, \; v_n^-\} = \left\{ \left(\min_i v_{ij} | j \in J \right) \left(\max_i v_{ij} | j \in J' \right) | i = 1,2\ldots m \right\}$$

$$(12)$$

Here J and J' are associated with beneficial and non-beneficial attributes respectively.

Step6: The Euclidean separation distance between the ideal solution (S_i^+) and negative idealsolution (S_i^-) for each alternative is calculated as:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2}, \; i = 1, 2, \ldots m \quad (13)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2}, \; i = 1, 2, \ldots m \quad (14)$$

Step 7: The relative closeness to the ideal solution of each alternative is calculated as:

$$C_i = \left(\frac{S_i^-}{S_i^+ + S_i^-} \right), i = 1, 2, \ldots \ldots m \quad (15)$$

Step 8: Alternatives under consideration are ranked in descending order of C_i^*. A larger value of C_i^* indicates better performance of alternatives.

4. Illustrative example of proposed model applied to a case computer company

The TOPSIS-AHP method presented in this research has been evaluated in an actual computercompany, which was interested in the selection of suppliers in their organization.The company had 6 potential suppliers (A, B, C, D, E and F) and the best one among them was to be chosen. The case company identified ten important attributes relevant to sustainability as they deemed it necessary for suppliers that they intended to choose. These attributes were quality of products delivered (QTY), price (PRI), timing of delivery (TIM), using new technologies (UNT), information sharing (INS), financial stability (FSY), health and safety of staff and customers (HSY), customer privacy (CPY), environmental management system (EMS) and resource consumption (RCN). Among these attributes QTY (in defects per million opportunities (DPMO)), PRI (in rupees), TIM (in days), RCN (lakh gallons of water per month) are quantitative in nature having absolute numerical values. Attributes UNT, INS, FSY, HSY, CPY, and EMS have qualitative measures and for these a ranked value judgment on a scale of 1-5 (here 1 corresponds to lowest, 3 is moderate and 5 corresponds to highest) is suggested. Attributes QTY, UNT, INS, FSY, HSY, CPY and EMS are beneficial attributes were high values are desired. Whereas attributes PRI, TIM and RCN are non-beneficial attributes for which low values are preferred. Also, as QTY is measured in defects per million opportunities, low values of them are preferred. The data for all suppliers with respect to various attributes are given in Table 1.

Table 1: Data for all suppliers with respect to various attributes

Supplier	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	900	13	50	5	4	3	5	3	4	24
B	233	10	45	4	3	4	5	4	5	35
C	500	10	35	4	2	3	2	5	3	32
D	450	11	40	3	5	5	4	3	2	28
E	300	11	25	3	4	5	3	4	5	25
F	100	12	30	4	4	4	5	4	5	23

The analysis and the implementation of the TOPSIS-AHP model are presented in the following steps:

Step1: Based upon the information available, the decision matrix is constructed which represents the performance of various reverse logistics providers with respect to different attributes:

$$
\begin{array}{c}
 \\
A \\
B \\
C \\
D \\
E \\
F
\end{array}
\begin{pmatrix}
QTY & PRI & TIM & UNT & INS & FSY & HSY & CPY & EMS & RCN \\
900 & 13 & 50 & 5 & 4 & 3 & 5 & 3 & 4 & 24 \\
233 & 10 & 45 & 4 & 3 & 4 & 5 & 4 & 5 & 35 \\
500 & 10 & 35 & 4 & 2 & 3 & 2 & 5 & 3 & 32 \\
450 & 11 & 40 & 3 & 5 & 5 & 4 & 3 & 2 & 28 \\
300 & 11 & 25 & 3 & 4 & 5 & 3 & 4 & 5 & 25 \\
100 & 12 & 30 & 4 & 4 & 4 & 5 & 4 & 5 & 23
\end{pmatrix}
$$

Step2: The decision matrix is normalized using equation (2) as shown below:

$$
\begin{array}{c}
 \\
A \\
B \\
C \\
D \\
E \\
F
\end{array}
\begin{pmatrix}
QTY & PRI & TIM & UNT & INS & FSY & HSY & CPY & EMS & RCN \\
0.7561 & 0.4731 & 0.5307 & 0.5241 & 0.4313 & 0.3000 & 0.4903 & 0.3145 & 0.3922 & 0.3478 \\
0.1958 & 0.3639 & 0.4777 & 0.4193 & 0.3235 & 0.4000 & 0.4903 & 0.4193 & 0.4903 & 0.5071 \\
0.4201 & 0.3639 & 0.3715 & 0.4193 & 0.2157 & 0.3000 & 0.1961 & 0.5241 & 0.2942 & 0.4637 \\
0.3781 & 0.4003 & 0.4246 & 0.3145 & 0.5392 & 0.5000 & 0.3922 & 0.3145 & 0.1961 & 0.4057 \\
0.2520 & 0.4003 & 0.2654 & 0.3145 & 0.4313 & 0.5000 & 0.2942 & 0.4193 & 0.4903 & 0.3622 \\
0.0840 & 0.4367 & 0.3184 & 0.4193 & 0.4313 & 0.4000 & 0.4903 & 0.4193 & 0.4903 & 0.3333
\end{pmatrix}
$$

Step3: In this research, four experts two from the computer hardware industry and other two from academia were consulted for making pair-wise comparison of attributes. Two industry experts were the senior managers of different companies in operations area. These experts from industry and academia were well conversant with concepts of sustainable supply chain management having an experience of over ten years in this area. The pair-wise comparison matrix as given by experts is:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
QTY	1	4	1/3	1/2	5	5	5	7	1/2	1/5
PRI	1/4	1	1/3	1/4	3	4	5	5	1/5	1/5
TIM	3	3	1	3	5	5	6	7	1/3	1/4
UNT	2	4	1/3	1	5	5	6	8	1/3	1/4
INS	1/5	1/3	1/5	1/5	1	3	4	4	1/6	1/6
FSY	1/5	1/4	1/5	1/5	1/3	1	2	3	1/6	1/7
HSY	1/5	1/5	1/6	1/6	1/4	1/2	1	3	1/7	1/8
CPY	1/7	1/5	1/7	1/8	1/4	1/3	1/3	1	1/8	1/7
EMS	2	5	3	3	6	6	7	8	1	3
RCN	5	5	4	4	6	7	8	7	1/3	1

The normalized weights of the attributes computed using equation (4) are: QTY= 0.0996, PRI=0.0577, TIM=0.1442, UNT =0.1158, INS=0.0377, FSY=0.0263, HSY=0.0204, CPY=0.0145, EMS=0.2486 and RCN=0.2353.

λ_{max} value is 11.33211and that of CR is 0.099,

which is less than allowable value of 0.10. Thus, there are total consistencies in judgments made by experts and the pair-wise comparison matrix is free from any undue bias.

Step4: The weighted normalized matrix is computed as:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	0.0753	0.0273	0.0765	0.0607	0.0163	0.0079	0.0100	0.0046	0.0975	0.0818
B	0.0195	0.0210	0.0689	0.0486	0.0122	0.0105	0.0100	0.0061	0.1219	0.1193
C	0.0418	0.0210	0.0536	0.0486	0.0081	0.0079	0.0040	0.0076	0.0731	0.1091
D	0.0377	0.0231	0.0612	0.0364	0.0203	0.0132	0.0080	0.0046	0.0488	0.0955
E	0.0251	0.0231	0.0383	0.0364	0.0163	0.0132	0.0060	0.0061	0.1219	0.0852
F	0.0084	0.0252	0.0459	0.0486	0.0163	0.0105	0.0100	0.0061	0.1219	0.0784

Step5: Using equations (11) and (12) the ideal (best)and negative-ideal (worst) solutions are calculated as: v_1^+=0.0084, v_2 =0.0210, v_3 =0.0383, v_4 =0.0607, v_5 =0.0203, v_6 =0.0132, v_7^+=0.01, v_8^+=0.0076, v_9^+=0.1219, v_{10} =0.0784 and v_1 =0.0753, v_2 =0.0273, v_3 =0.0765, v_4 =0.0364, v_5^-=0.0081, v_6^-=0.0079, v_7^-=0.004, v_8^-=0.0046, v_9^-=0.0488, v_{10}^-=0.1193.

Step6: The Euclidean separation distances are computed using equations (13) and (14) as : s_1^+= 0.08148, s_2 = 0.05437, s_3 = 0.07094, s_4 =0.08735, s_5 =0.03089, s_6 =0.01578 and s_1^- = 0.0669, s_2^- = 0.0936, s_3^- =0.0504, s_4^-=0.0493, s_5^-=0.1030, s_6^-=0.1127.

Step7: The relative closeness to the ideal solution

of each alternative is calculated using equation (15) as: C_1=0.4507, C_2=0.6325, C_3=0.4152, C_4=0.3607, C_5=0.7692, C_6=0.8771.

Step8: Based on the relative closeness values, the case company can choose suppliers for their operations as F-E-B-A-C-Din decreasing order of preference. It is emphasized here that these results should be seen in the light of the characteristics of the case company and the inputs provided experts in the pair-wise comparison of attributes.

5. Conclusion

The selection of the suppliers for sustainable supply chain is a strategic level decision that

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needs to be taken by top management of companies. With increase in environmental and social issues becoming relevant, selection of suppliers practicing these principles is to be preferred and this research assumes significance in this regard.

The TOPSIS-AHP method presented in this paper can be helpful for selection of appropriate suppliers as it relates various attributes with alternatives available to the decision maker. The proposed model not only guides decision makers for selection of appropriate suppliers but also enables them to visualize the impact of various criteria on the alternatives while arriving at the final solution. One of the important contributions of this research is that it can simultaneously take into account any number of qualitative and quantitative attributes and gives a logical approach for selection of suppliers.

This research has a few limitations also. While using AHP methodology, the pair-wise comparison of attributes affecting supplier selection was subjectively performed by experts from industry and academia. An experts' knowledge and familiarity with the firm and also biasing of experts to some of these attributes might have influenced final results. In this research, we have attempted to minimize this limitation through consistency ratio check (Saaty, 1980).

Extensions to this research are also possible. Analytical Network Process (ANP), a more advanced approach that can consider complex interrelationships among decision levels and attributes could be attempted. User friendly software could be developed on basis of the proposed model.

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Space Technology and Knowledge Management in Agriculture

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Introduction

Knowledge Management comprises of a range of strategies and practices used in an organization to identify, create, represent, distribute, and enable adoption of insights and experiences. Such insights and experiences comprise knowledge, either embodied in individuals or embedded in organizational processes or practice (National Institute of Extension Management; Govt. of India). The asymmetry and poor communication of knowledge among and between farmers, and those who produce of farm related knowledge, has often considered as big hindrance to the proper development of agriculture in developing countries. Knowledge management can play a pivotal role in enhancing agricultural productivity and addressing the problem of knowledge asymmetry. It will facilitate appropriate knowledge and information to reach farmers in a timely manner. Such delivery of knowledge and information undoubtedly minimizes the risk and uncertainty among farmers who face multiple levels of problems from production to marketing of their produce.

The attainment of effective knowledge management in the agriculture sector requires the systematic and continuous interaction of stakeholders that include farmers, farmer organizations, research scientists, policy makers, extension agents and the private sector among others (ASARECA, 2010). Appropriate institutions are required for generating, capturing, and disseminating knowledge and information. Information and Communication technology (ICT) based institutions can play a critical role in facilitating rapid, efficient, and cost effective knowledge management. The information and communication technology advances in space research can play a tremendous role in socioeconomic development of a nation. It can be instrumental in disseminating knowledge of any kind to the rural masses and thereby can act as a catalyst to development. The Indian Space Research Organization (ISRO), with the aim of disseminating knowledge to the rural masses, envisaged the concept of Village Resource Centre (VRC) in 2004. The VRCs programme of ISRO is in association with non-governmental organizations (NGOs)/Trusts and state/central government agencies, and is connected to the knowledge-generating institutions like universities, public research institutes, healthcare centres, etc. The VRC is a totally interactive 'Very Small Aperture Terminal; (VSAT) based network. The objective of the study is to understand the effectiveness of Village Resource Centers in Knowledge management among farmers. The specific objectives of the study are i) to analyse the changes in knowledge capability of farmers' ii) to understand the changes in innovative capacity of farmers and iii) to understand the skill capacity of farmers.

Review of Literature

Knowledge management primarily includes sharing, exchanging and dissemination of knowledge. The central purpose of knowledge management is to transform information and ideas into valuable output (Metcalfe, 2005). The important distinction in knowledge management is between explicit knowledge (which can formally communicate through a structured language) and tacit knowledge (gain through

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personal experience and involvement) (Polanyi, 1966). A large part of knowledge is not explicit but tacit (Schreiber et al., 1999). Fostering a dynamic interaction between tacit and explicit knowledge, therefore, generates new forms of knowledge vital for improved knowledge utilization (Nonanka and Takeuchi, 1995). An effective strategy for knowledge management in agriculture should bring the knowledge creators, innovators, extension experts and farmers together in all the knowledge management phases from knowledge creation to utilization. Any attempt at bridging the knowledge divide between the different stakeholders must be rooted in a knowledge management model that recognizes the significance and complementary roles of both tacit and explicit knowledge in decision-making (Boateng, 2006). Effective knowledge management can increase the profitability of any organization (Probst, Raub and Romhardt, 1999). The emergence of Information and Communication Technologies (ICT) in the last few decades has opened new avenues in knowledge management that could play important roles in meeting the prevailing challenges related to sharing, exchanging and disseminating knowledge and technologies.

Agriculture is an important sector of Indian economy. More than 70 per cent of the population depends upon agriculture and it contributes about 17 per cent of national income. Transfer of relevant knowledge to small and marginal farmers can help them to improve their yields and get better market prices. ICT can play a crucial role in benefiting the resource-strapped farmers with up-to-date knowledge and information on agricultural technologies, best practices, markets, price trends, and weather conditions. The experiences of most countries indicate that rapid development of ICT, which facilitates the flow of data and information, has tremendously enhanced the knowledge management practice in agriculture. In agriculture, extension activities are necessary to transfer information from global knowledge base and from local research to farmers, enabling them to clarify their own goals and possibilities, educating them on how to make better decision, and stimulating desirable agricultural

development (Van der Ban and Hawkins 1996). Lack of information can cause vulnerability. However, institutional systems can act to reduce risk and protect livelihood assets (Jock Anderson, John Dillion and Brian Hardaker 1977).

The Indian Space Research Organization (ISRO), with the aim of disseminating knowledge to the rural masses, envisaged the concept of Village Resource Centre (VRC) in 2004. These centres aim to accelerate farmers' education, facilitate technology transfer and technological development, develop skills of agricultural labour, and enhance continuously the learning process of all farmers, and thus help in increasing their earnings and professional capacities. Village Resource Centers are a peculiar type of institutions clubbed with technology and can be called 'Technology institution' where, they can influence the production possibility curve as well as the physical quality of resources. VRC's are the centers of knowledge management, where they manage the raw information from different agencies and stakeholders, synthesize and add value before they deliver it to the end users. ISRO's VRCs programme is in association with Non Governmental Organizations (NGOs)/Trusts and state/central government agencies, and is connected to knowledge producing institutions like Universities, government research institutes, hospitals, etc. The VRC is a totally interactive Very Small Aperture Terminal (VSAT) based network. These nodes can be further extended using other technologies like Wi- Fi, Wireless and Optical Fibre. The extensions may serve as the local clusters around the areas where the VRC is located.

Methodology

The study is based on both primary and secondary data. The field of study for collecting primary data is Meppadi (11°33'38.24"N, 76° 8'31.32"E) in Wayanad district of Kerala. VRC in Kerala has been organised by ISRO in collaboration with Kerala State Planning Board since 2006 and generally known as the ISRO-KSPB Network. In Meppadi, VRC has equipped withinternet powered computer, powerful camera, speaker, tele-medicine related equipments etc and

conducts both online and offline classes for farmers. Through internet, the local people are able to get class from the experts from the various points like universities, hospitals, agriculture offices etc. In addition to the teleconferencing programmes, additional features such as offline programmes, soil testing and dissemination of weekly weather advisories have been done for the benefits of the farmer community. Coffee based farming system is a notable feature of Wayanad. Coffee in Wayanad (66,999 ha.) shares 33.65 per cent of the total cropped area in the district and 78 per cent of the coffee area in the Kerala state.

A detailed survey has been conducted at Meppadi during the months of September and October of 2011 and primary data collected from 170 VRC attending (VRC A) Meppadi coffee planters, 170 VRC non-attending (VRC NA) Meppadi coffee planters and 170 VRC non- attending (VRC NAN) coffee planters as Control Group from a neighbouring panchayats such as, Ambalavayal, Mooppanadu and Vaithiri. The geographic, climatic and demographic features of these neighboring panchayats are almost similar and comparable with that of Meppadi. The Control Group is selected to distinguish between the effects of VRC from other related institutions like, Village Office, Panchayath Office, Agricultural Office etc. in the region.

Descriptive Analysis

There are several factors which can influence the agricultural production and productivity of an economy. A good knowledge on the exact production techniques enables the farmers to increase productivity. In this sense, the services of knowledge provision by village resource centers should have a positive impact on crop production and productivity. Space technology and information communication technologies (ICTs) are the state-of the-art technologies of modern civilization. The potential benefits of knowledge are actualized only when these are successfully disseminated to a large number of end-users. Generally the benefits that right knowledge brings- in are normally accessed by the few rich with relatively high absorptive capacity. Hence, the ultimate benefits of a new knowledge can

contribute to economic growth and development only when it is correctly and successfully transferred and applied by a large number of end-users.

The economic development involves the mastering of new ways of doing things and breaking away from the circular flow of economic activities. The mastering new ways of doing things implies transition of an economy from low value-addition to high value-addition activities. Farmers can also improve and enrich their existing indigenous (tacit) knowledge not only through the interaction with modern knowledge, but also by sharing experience with other farmers. However, in order to scale up knowledge to other farmers, the knowledge and information needs to be codified, made explicit, and upgraded or modernized with research- based evidence. Because of the sharing of experiences at local level by farmers, dissemination of information / knowledge through VRCs is also leading to the creation of new knowledge.

Knowledge capability of farmers

Indian agricultural sector has been characterised by low productivity growth despite periods of strong growth in the past. Serious challenges must be addressed in order to achieve faster productivity growth. These include infrastructure constraints, supply chain inefficiencies and significant problems in the diffusion of and access to information (Mittal et al., 2010). From the field it is observed that, the shortage of the labourers and the high wages have forced the farmers to employ new technological equipments. In this context, the scope of the knowledge of farmers, their effort to assimilate the new knowledge and application of such knowledge is important. It is also understood from the study area that the farmers are keenly interested in increasing their knowledge day by day and in many cases they gain new knowledge as a result of trying to increase their income from farming.

Agricultural innovation literature suggests that awareness and knowledge of a new technology is the first step in the adoption process (Rogers, 1995). Usually farmers plan agricultural

production with the instruments of their knowledge. VRC is essentially a knowledge provider to rural population. Knowledge needs of the farmers and other stakeholders fell broadly under the areas like weather forecasts, harvest and post harvest technologies, marketing information, government schemes including subsidies, issues relating to the package of practices etc (Kareemulla, 2012). In the examination of VRC's relative role and capabilities as an institution that enter in partnerships and linkages with other regional institutions to promote innovation, it is essential to have a basic idea on peoples' accessibility to modern ICTs and conventional information sources. Knowledge/technology transfer approach is given thrust to "trickle down" flows of information from experts to farmers. The project also emphasizes the importance of interactive, mutual learning between formal and informal knowledge/technology sources and stresses their linkages with farmers so that they actively participate in rural(agricultural) development. The survey data from Meppadi (Table 1) shows that the VRC attendees have relatively good access to both modern ICTs and conventional information sources such as news papers and agricultural magazines.

Table 1. Access to Information			
Sources	**VRC Attendees**	**VRC Non Attendees**	**VRC Non- Attendees of Neighbouring Villages**
Telephone	82 %	76 %	68 %
Mobile Phone	96 %	93 %	78 %
Internet Connection	8 %	3 %	4 %
Newspaper	63 %	48 %	38 %
Agriculture Magazine	32 %	14 %	3%

Source: Primary Survey

In agriculture, extension activities are necessary to transfer information from global knowledge base and from local research to farmers, enabling them to clarify their own goals and possibilities, educating them on how to make better decision, and stimulating desirable agricultural development (Van der Ban and Hawkins 1996). To warrant this transition the capabilities for innovation have to be strengthened. It implies the ability of a local economy to adapt to the new market and technological opportunities through innovation. Development is not merely introduction and adoption of knowledge, it requires co-evolution of institutions. Lack of information can cause vulnerability. However, institutional systems can act to reduce risk and protect livelihood assets (Jock Anderson, John Dillion and Brian Hardaker 1977). The following table shows that VRC attendees have improved awareness about factors affecting productivity of Coffee in Meppadi.

Table 2	Factors Influencing Productivity		
Factors	**VRC Attendees**	**VRC Non- Attendees**	**VRC Non- Attendees of Neighbouring Villages**
No response	12.1 %	5.5 %	4.8 %
1.Weather	49.1 %	61.9 %	92.2 %
2.Improved Access to Knowledge	6.4 %	1.9 %	-
3.Market Price	16.2 %	12.5 %	2.4 %
4.Labour	5.8 %	12.5 %	-
5.Other	0.6 %	0.6 %	0.6
1 & 2	3.5 %	1.3 %	-
1 & 3	4.6 %	1.3 %	-
1 & 4	1.7 %	2.5 %	-
Total	100 %	100 %	100 %

Source: Primary survey

The above table reveals that, even though majority of farmers are still weather dependent, VRC attendees are less dependent because of their awareness about alternate sources of irrigation. However, we can identify three distinguishing features of VRC attendees that make them innovative; (i) survey data indicates VRC planters are relatively less weather dependent while comparing with other two groups, (ii) VRC planters recognises knowledge as an important factor that determine productivity, and (iii) VRC planters are more market oriented as they conceive price as a dependent variable.

In order to understand the level of knowledge of farmers we are taking a case of pest management.

Pest management is embarked upon for the promotion of yields of crops (Ofuoku et al 2009). The uniqueness of VRCs is the knowledge connectivity between experts at Universities, research institutes and medical colleges with village community. An important actor in the concept of VRC is (agricultural) University, for which space technology serves as a platform for linkage and dissemination of knowledge from their research to the local community. Accordingly, VRCs support universities in discharging their third role- i.e. (regional) economic development. One of the main reasons for decline in coffee productivity is pest diseases. It is also noted that there had been many VRC classes regarding pest management in Meppadi, Wayanad.

Table 3. Total Programmes on Pest Management by Various Agencies / Institutions in Meppadi between 2007 & 2011	
Agents \ institution	Total programmes
Regional Coffee Research Station (RCRS)	18
Indian Institute of Spices Research (IISR)	17
Kerala Agriculture University (KAU)	11
Krishi Vigyan Kendra (KVK)	5
Regional Agriculture Research Station (RARS)	5
State Planning Board (SPB)	1
Total	57

Source: Primary survey

Berry borer and mealy bugs are the two major pests found in Meppadi that had adversely affected coffee productivity. In order to understand the knowledge on pest management specifically, in case of berry borer and mealy bugs, we framed different set of questions that test respondents' degree of understanding or knowledge on the corresponding facets. The field investigators were also trained on the concept of pest management and on evaluating farmers' response to each set of questions. Four degree or scales such as 'perfect knowledge', 'incompletek-nowledge', 'not sure' and 'ignorant'

were prepared to classify respondents according to their knowledge on certain facets of pest management. It is observed that perfect knowledge about pests that affect more frequently is high among the VRC attendees (Table 4); around 75 percent of them have perfect knowledge on pests which affects their plantation. 24.5 percent of them have an incomplete knowledge about them. In case of VRC non-attendees in Meppadi, 37.5 percent have perfect knowledge but 42.5 percent have an incomplete knowledge and 4.4 percent are ignorant.

Table 4. Knowledge on Pests that affect more Frequently			
	VRC Attendees	VRC Non-Attendees	VRC Non-Attendees of Neighbouring Villages
Perfect Knowledge	74.9 %	37.5 %	4.8 %
Incomplete Knowledge	24.5 %	42.5 %	62 %
Not Sure	0	15.6 %	21.1 %
Ignorant	0.6 %	4.4 %	12.1 %
Total	100 %	100 %	100 %

Source: Primary Survey

From the table it can be said that VRC attendees have comparatively better knowledge regarding what kind of pests affect their plantation frequently. It is also observed that VRC attendees (Table 5) have better knowledge on the symptoms and where pests affect the plants.

Table 5. Knowledge on Symptoms & where it affects the Plants			
	VRC Attendees	VRC Non-Attendees	VRC Non-Attendees of Neighbouring Villages
Perfect Knowledge	68.4 %	34.4 %	5.4 %
Incomplete Knowledge	30.4 %	45.0 %	62.0 %
Not Sure	0.6 %	5.6 %	18.7 %
Ignorant	0.6 %	0	13.9 %
Total	100 %	100 %	100 %

Source: Primary Survey

The survey has also observed that 62% of VRC attending farmers in Meppadi have perfect knowledge about pest control methods (Table 6). 34.5 percent have incomplete knowledge, 3 percent are not sure about this and only 0.6 percent is ignorant. In case of VRC non attendees in Meppadi, 20.1 percent have perfect knowledge, incomplete knowledge - 46.1 percent, not sure - 23.4 percent and 10.4 percent are ignorant.

Table. 6 Knowledge on Pest Control Methods			
	VRC Attendees	VRC Non-Attendees	VRC Non-Attendees of Neighbouring Villages
Perfect Knowledge	61.9 %	20.1 %	1.2 %
Incomplete Knowledge	34.5 %	46.1 %	68.3 %
Not Sure	3.0 %	23.4 %	17.1 %
Ignorant	0.6 %	10.4 %	13.4 %
Total	100 %	100 %	100 %

Source: Primary Survey

65.3 percent of VRC attendees have adopted right prescribed pesticides and observed improvement in productivity after using pesticides (Table 7). However, only 4.4 percent VRC non attendees in Meppadi and 5.8 percent of neighbouring villagers reported adoption and positive impact in productivity.

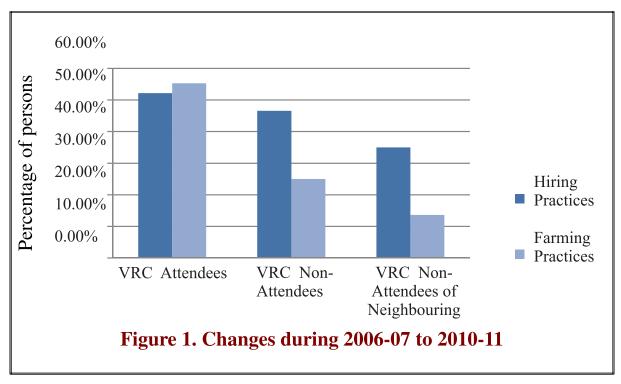| Table .7 Adopted Right Pesticides and Observed Impact on Productivity			
Yes/No	VRC Attendees	VRC Non-Attendees	VRC Non-Attendees of Neighbouring Villages
Yes	65.3 %	4.4 %	5.8 %
No	34.7 %	95.6 %	94.2 %
Total	100 %	100 %	100 %

Source: Primary survey

In short, the VRC attendees have perfect knowledge regarding what kind of pests affect their plantation, its symptoms, where its affects and what sort of methods to be adopted to control pests. They can also identify the pests in the early stage. However, only less percentage of VRC non-attendees posses this knowledge.

Changes in Innovative capacity of farmers

An innovation system may be defined as comprising the organizations, enterprises, and individuals that together demand and supply knowledge and technology, and the rules and mechanisms by which these different agents interact (*World Bank,* 2006:5). It extends beyond the creation of knowledge to encompass the factors affecting demand for and use of new and existing knowledge in novel and useful ways. Therefore, Innovation depends upon dynamic interactions among actors such as firms, government agencies, universities, and research institutions that result in systemic learning and capacity building. With the use of space technology tools, the Village Resource Centres can act as a critical link between knowledge production institutions and society.

The innovative changes are discussed in terms of changes in farming and hiring practices; subsequently changes in farming practices are discussed in terms of changes in existing farming practices and adoption of entirely new process or varieties. In the field, the study could observe that innovative changes in farming practices as a result of new knowledge and learning is followed by naturally subsequent changes in labour hiring practices. The changes in farming practices include both changes in existing farming practices and adoption of new farming practices. Figure 1 exemplifies the innovative changes adopted by the VRC attending and non-attending planters in Meppadi and neighbouring villages during last five years. It is evident that whilst around 55 percent of Meppadi VRC planters have undertaken changes in farming practices, only 25 percent of non VRC Meppadi planters and 13.6 percent of non VRC planters in neighbouring villages have undertaken changes during last five years.

Figure 1. Changes during 2006-07 to 2010-11

Source: Data from Primary Survey

Fifty five percent of VRC attendees and twenty five percent of VRC non attendees in Meppadi have made innovative changes in farming practices. These changes can be of two types; (i) changes in existing farming practices and (ii) adoption of new varieties and farming practices. Table 8 depicts the major changes adopted in existing farming techniques by each group during the last five years. The changes are reported under each major category for three different groups. It is evident that most of the changes are in weeding, fertilizer, and irrigation techniques. However, the intensity of changes varies extremely across three different groups of planters.

Table. 8 Changes in Existing Farming Practices (from 2006-07 to 2010-11)			
Farming Practices	**VRC Attendees**	**VRC Non- Attendees**	**VRC Non- Attendees of Neighbouring Villages**
Weeding	46.1 %	19.8 %	2.1 %
Fertiliser Application	45.1 %	20.61 %	7.4 %
Irrigation	39.9 %	16 %	1.1 %
Pest Management	30.3 %	13.7 %	0.5 %
Harvesting	21.4 %	9.2 %	1.1 %
Post Harvesting	11.2 %	4.6 %	1.1 %
Others	3.9 %	2.3 %	6.4 %

Source: Primary Survey

The main incentives or motivations for these kinds of changes of both VRC attendees and non attendees are showed in the following table:

Table 9. Reasons for Introducing Changes in Farming Practices			
Major Reasons	**VRC Attendees**	**VRC Non- Attendees**	**VRC Non- Attendees of Neighbouring Villages**
New Knowledge	83 %	53 %	33 %
Less Remuneration	2.3 %	7 %	5.3 %
Pests & Diseases	5 %	20 %	22.3 %
Financial Difficulties	1.2 %	-	5.3 %
Labour Shortage	4.8 %	7 %	11.7 %
Others	0	0	10.6 %
Both New Knowledge & Less Remuneration	3.7 %	13 %	11.7 %
Total	100 %	100 %	100 %

Source: Primary survey

Out of the total VRC attending planters, 83 percent reported acquisition of new knowledge is the main reason for adopting changes in their farming process. The innovative changes in farming practices can be of two types; (i) changes in existing farming practices and (ii) adoption of new varieties and farming practices. Table 10 reports frequencies of adoption of new varieties and/or plants, and new processes by the three different groups during 2008-09 to 2010-11.

Table 10. Innovative methods adopted (from 2008-09 to 2010-11)			
Frequency of Changes	VRC Attendees	VRC Non-Attendees	VRC Non- Attendees of Neighbouring Villages
New Variety / New Plants			
1	43	20	7
2	29	7	0
3	16	4	0
4	14	5	0
5	12	5	1
Total	265	91	12
New Process			
1	19	2	7
2	8	3	3
3	5	0	5
4	4	3	0
5	21	7	0
Total	171	55	28

Source: Primary survey

The first section of Table 10 reports the frequencies of varieties or plants, and the numbers of adoptions under each frequency. It can be read from the table that 43 VRC attendees have adopted of one variety, but 20 and 7 persons in case of non attendees in Meppadi and neighbouring panchayats respectively. Among the VRC attendees 29 persons adopted 2 varieties, 16 persons adopted 3 varieties and number of persons adopted 4 and 5 varieties are 14 and 12 respectively. The innovative methods are consisting of two types: - one is new to the farmer but practised in locality, and the other is new to both the farmer and locality. The innovation that is both new to the farmer and region is considered to be more radical, whilst the innovation that is new to the farmer but that already exists in the region is relatively more with imitation features. The study has also observed that VRC attendees spent 18.5 percent of total agricultural expenditure for the innovative methods. Of which, 14.4 percent for introducing a method, which is new to the farmer but practised in that region and remaining expenditure used for the method, which is new to both farmer and region. The VRC non-attendees in Meppadi and Neighbouring villages spent 9.3 percent and 11.9[1] percent of total agricultural expenditure for new innovative methods. In short, as expected VRC attendees are devoting relatively higher percentage of their total outlay towards innovative activities, and this substantiates our earlier findings.

With regard to hiring practices, almost 53 percent of VRC attendees in Meppadi changed their hiring practices. It is 46.6 percent and 35 percent in case of VRC non attendees in Meppadi and neighbouring panchayats. It indicates that changes made in hiring practices are comparatively higher in case of VRC attendees. It is also noted that the demand supply gap is higher among the VRC attendees than others. The study observed that the supply gap in plantation labourers has a significant negative effect on innovation activities of planters. It is evident that those farmers who have adopted large number of innovations in terms of new processes and varieties have faced higher shortage in labour supply. Those planters are primarily VRC attendees. This labour shortage naturally has increased local wage rate and hence labour productivity, which naturally squeeze the profitability of innovation and thus hamper incentives for innovation.
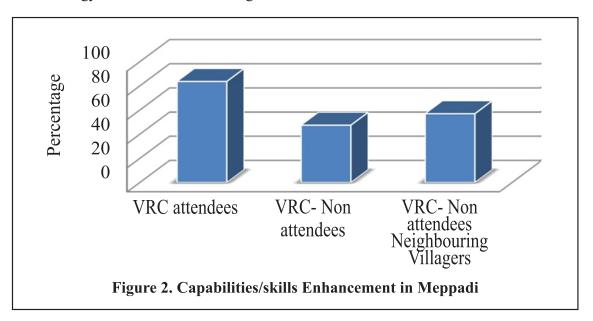
[1]However, the average total expenditure per hectare is relatively much lower for VRC non attendees particularly for planters in neighboring villages. Without this 'base effect' the percentage of expenditure on innovative practices would be higher than the figures in table.

Changes in Skill Capacity of farmers.

For the rural people, technological inclusion is enhancing of absorptive capacity and thereby increasing their capacity to participate in more economic activities. Technology allows the rural people to get more access to knowledge and resources and thereby helps them to get more economic benefits. Located close to the rural community, these VRCs bring together national and local government organizations, and local people. These centres aim to accelerate farmers' education, facilitate technology transfer and technological development, develop skills of agricultural labour, and enhance continuously the learning process of all farmers, and thus help in increasing their earnings and professional capacities.

The most striking result is 83.6 percent of VRC attendees in Meppadi have improved their skills after participating in organisations. Among the VRC non attendees in Meppadi 47.4 percent have improvements in their skills and the corresponding percentage was 56.9 among the non attendees of neighbouring villagers.

Figure 2. Capabilities/skills Enhancement in Meppadi

In Meppadi, 83.6 percent of VRC attendees reported improvements in skills, the main one being that of training and leadership quality. 42.9 percent of VRC attendees got training, 16.5 percent improved leadership quality and 7.1 percent gained both training and leadership quality. 6 percent could convey their needs, 2.1 percent got ability to oppose social evils and 2.5 percent got specific skills in agriculture as a result of participation in organisations.

Table 11.	Improvements in Skills		
	Meppadi		
	VRC	Non-VRC	Neighbouring Villagers
1.Training	42.9 %	15.1 %	13.8 %
2.Leadership Building	16.5 %	17.1 %	36.5 %
3. Ability to Articulate needs	6 %	4.4 %	1.8 %
4. Fight against Social Evils	2.1 %	-	4.8 %
5. Agricultural Production	2.5 %	1.8 %	-
1 & 2	7.1 %	2.2 %	-
1 & 3	3.6 %	3.4 %	-
2 & 4	2.9 %	3.4 %	-
Total	83.6 %	47.4 %	56.9 %

Source: Primary Survey

In the case of VRC non attendees in Meppadi, 15.1 percent got training, 17.1 percent have improvement in leadership quality and 2.2 percent got both training and leadership quality. 4.4 percent got ability to convey their needs and 3.4 percent both training and ability to convey their needs. And another 3.4 percent informed both improvements in leadership quality and ability to oppose social evils. 5.1 percent reported both improvements in leadership quality and got information regarding agriculture production. Among the neighbouring villagers, 36.5 percent reported improvement in their leadership quality, which is primarily because of their association with NGO's. The study has observed that 19.5% of VRC Non- attending neighbouring villagers have membership in Self Help Groups of NGO's and only 7.5% of VRC attendees have VRC attendees have membership in NGO's. A lion share of VRC attendees as well as non attendees is also affiliated to other local organisations, whilst this phenomenon is quite prominent in Meppadi, owing to the sociological peculiarities of Kerala society. It is also evident that the primary motive to join a social network or organisation is social as well as economic benefit, and eventually people have experienced enhancement of skills and capabilities.

Conclusion and Policy implications

This study began with a goal to understand the outcome of new developmental intervention; i.e. Village Resource Centres with their linkages with a set of regional research institutions on one hand, and local farmers on the other hand. The economic development involves mastering of new ways of doing things and breaking away from the circular flow of economic activities. The mastering new ways of doing things implies transition of an economy from low value-addition to high value-addition activities. Development is not merely introduction and adoption of knowledge; it also requires co-evolution of institutions. Improving productivity and quality requires a functioning system of technology generation and transfer and a means to implement these technologies. The study clearly found that VRC attending farmers have better

knowledge, innovative capacity and enhanced skill capabilities than VRC non - attending farmers. The effect of VRC in Meppadi region has been isolated by using a control group of VRC non-attending population from neighbouring villages. The study results reveal that, even though there were plenty of development institutions like Village Panchayath, Krishibhavan etc, VRC has played a vital role in enhancing the level of knowledge, innovativeness and skill among farmers in Meppadi region. To enhance the positive effects of VRCs as highlighted by this study, it is proposed that a specific body is to be established so as to bring any local specific problem to the notice of resource centers on time, and instant transfer of solutions to such problems. The study has also taken into note that interaction between farmers particularly VRC attendees and non-attendees is a requisite for the success at community level. Therefore, one should identify the centre of the social network under each VRC and efforts should be given to make centre more active and form linkages with maximum number of nodes (farmers). The study asserts this initiation will result in a Public Private People Participation model. Moreover, such PPPP model should also plan on delivering information at door step.

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Literary and Artistic Creativity to Augment Technical Innovations

Gigy J. Alex[1]

Abstract : Science and Technology, and Art and Literature are not two distinct polar opposites, but that which complements each other. As disciplines science and technology, like arts and literature need imagination and creativity. This fact is quite relevant when we look at the polymaths of the renaissance age. They never approached these disciplines on varying temperaments. Leonardo da Vinci was an undisputed expert who managed to blend the three disciplines, science, engineering and arts. He had an artistic eye of everything, along with the scientist's spirit to look at the minutest with keen precision.

Creative perusal of talents helps technologists and scientists to have a wider perspective of things and in considering everything in a global perspective. It will boost the imagination and also help the scientists/ engineers in multitasking things. Oliver Sacks who is known as the Poet Laureate of medicine is a man who excelled in medical field and also a famous writer, neurologist and a bestselling author.

This study shows how literature and artistic commitments help in increasing the technical efficiency and in eradicating lethargy and boredom. Even when they are saddled with jobs that expect a different work ethics and meticulous time management, there are good numbers of people employed in various technical and technological innovation centers and, engaged in research and development, who make use of their innovative creativity and love for literature to improve their performance at their career level.

This paper looks at how artistic and literary creativity help a scientific community to be more innovative and how they promote a sustainable and holistic development.

Key words
Scientific spirit, creativity, literature, arts, technical efficiency

"The greatest scientists are artists as well."
Albert Einstein (Calaprice 245)

Quite often it is the imaginative visions of the future rooted firmly in a reasonable social cause that compel most of the scientists and technologists to come up with innovations. These visions and hopes regarding the future get reflected in several media in different manifestations. In the global world where the information technology and communication have developed to such a great extent, these visions are always reflected in the social media, network groups, print and digital media, thereby become more fluid and are always at war with the boundaries and fixities of the world.

Studies have shown that when people are given enough time to exercise their creative and artistic outputs, it will help in the development of their personality and thereby it will boost their technical innovations. It is an aid which compels them to increase their output and productivity in their careers also. A lot of significant research work has been going on in this area for the past few years. Quite often critics consider Raymond B. Cattell's 1987 book Intelligence: Its Structure, Growth and Action published by Elsevier Science Publishing Inc, as one of the key

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text that explains the link between intellect and achievement based creativity. Duke University Press has published a book in 1976 written by Albert Rothenberg and Carl R. Hausman, The Creativity Question. Rothenberg and Bette Greenberg had already published The Index of Scientific Writings on Creativity: Creative Men and Women in 1974. In these works and the studies that followed later, creative people are often considered as more intelligent than less creative people. Annual Review of Psychology has published an article, "Creativity, Intelligence, and Personality" by Frank Barron and David M. Harrington, where they have thoroughly established an authentic definition of creativity as "(i) as socially recognized achievement in which there are novel products to which one can point as evidence, such as inventions, theories, buildings, published writings, paintings and sculptures and films; laws; institutions; medical and surgical treatments, and so on; and (ii) creativity as an ability manifested by performance in critical trials, such as tests, contests, etc, in which one individual can be compared with another on a precisely defined scale."(5)

American psychologist and psychometrician who is currently the Professor of Human Development at Cornell University, Robert J. Sternberg has analyzed three interacting aspects that help in the successful application of intelligence within a society. They are (i) "analytical skills that helps individuals to evaluate, judge, or critique information, (ii) practical abilities that create an optimal match between individual skills and their external environments, (iii), creative intelligence that involves maximizing experience in order to generate new products, solve relatively novel problems, and quickly automatize procedures" (68).

The research and studies conducted by all these eminent psychologists strongly emphasize the fact that creative people manifest unusual combinations of creativity, intelligence and personality. As personalities who beautifully linked artistic creativity and scientific aptitude, a single variety of creativity is a myth. They effectively handled the multitasking, taking care of their respective professions, and their artistic pursuits and literary creativity which helped in being sharper and keener in their profession. A lot of studies are going on to analyze the creativity of scientists and their outcome, but very few studies were conducted to understand the relationship between artistic and literary pursuits and their relationship with the success or productivity of a scientist. Juha T. Hakala's book The Art of Scientific Discovery- Creativity, Giftedness and the Nobel Laureates (2013) analyses the link between a scientist's talents and giftedness and his scientific pursuits.

Most of the inventions made by man resulted from his curiosity and his excellent extrapolation of imagination. This fact is being proved by many of the science fiction movies and stories. Modern science can be considered as an extension of man's earnest urge to know about the universe. This urge is reflected in literature. There are people who are passionate about artistic performance also. If enough opportunities are given to our scientific and technical community to explore the world of art and literature it will definitely enkindle their scientific spirit too. This is quite evident when we look at the innovative achievements of people like, Steve Jobs, Jay Silver, etc.

It is the love for the unknown, the curiosity and earnest urge to explore the unexplored that compel the scientists to pursue their subject of interest. It is this very subject that inspires the poets and writers too. Through their work and passionate journey they give a structure and a pattern to their thought process and what they explored. This is beautifully elucidated by the Nobel Prize winning poet Czeslaw Milosz, "the incessant striving of the mind to embrace the world in the infinite variety of its forms with the help of science or art is, like the pursuit of any object of desire, erotic. Eros moves both physicists and poets" (Lee Gutkind 16). Both the evolutionary biologist and the poet participate in the inherent tendency of nature to give rise to pattern and form.

Jonathan Holden, Poet Laureate of Kansas, was a Maths teacher before becoming the Professor of English at the Kansas State University. For him, of all the written languages, Mathematics is "the most visual, the least oral and the language closest to silence" and Science, "in its true essence is the concentrated truth, applicable to many situations," closely related to our lives (771). He also says that when these two disciplines, science and literature, blend together, the suggestive techniques of literature and the language and legends of scientists act upon the human mind so that they will get a liberated sense of truth and reality.

Miroslav Holub one of the most internationally well-known Czech poets, was an immunologist and his works were heavily influenced by his experiences. He wrote many poems applying his scientific knowledge to poetic effect. His scientific knowledge, following the very same tradition of literature, makes use of words to measure a definite and concrete data. He says in an interview how practising as an immunologist helped in exuding the writer in him. For him "Science presents a firm ground for all personal feelings, a sort of safe existential ground. A scientific worker writing poetry does not see (perceive, feel, sense) the abyss. He is not happy, but he is less desolate and, in many instances, also less neurotic" (Interview with Czech Poet Miroslav Holub).

William Carlos Williams, another English poet was a medical practitioner before he took poetry as his vocation. He published his first collection of poems, Poems (1909), after he took his medical degree in the year 1906. He produced the most captivating collection of poems while he was a doctor in Rutherford. He explains how his vocation as a poet compliments his work as a physician. He says, "One occupation complements the other, they are two parts of a whole, it is not two jobs at all, one rests the man when the other fatigues him" (122).

To many of these writers, writing poetry is an impulse similar to a scientific pursuit where the grandeur and excellence of a scientific theory or hypothesis is equally get represented through the apt selection and coalition of words and thoughts. The scientists and artists or writers are always impelled by this sense of wonder and awe regarding the universe, and they always contemplate on how to recreate the world and all that is included in it. The profession of neither the scientists nor the poets can fully reveal the secrets of universe, but they can definitely lay bare the beauties and wonders of nature before us to appreciate and nurture.

In Cross-Pollinations: The Marriage of Science and Poetry (2004), the ethno biologist and poet Gary Paul Nabhan examines the space where poetry and science meets and begins his book with this quote by photographer Paul Strand: "The true artist, like the true scientist, is a researcher using materials and techniques to dig into the truth and meaning of the world in which he himself lives, and what he creates, or better perhaps, what he brings back are the objective results of his explorations" (3). He believes that exchange of ideas between science and poetry nurture the discovery of new meanings and identities. He says; "I felt free to move between the practices of field science and the literary arts without being hampered by disciplinary boundaries" (9).

As it is rightly contented by poet and cognitive scientist Pireeni Sundaralingam who explores the nature of interactions between the two disciplines, poetry and science, though our current culture tends to treat the disciplines science and poetry as if they were "mortal enemies," we have to consider them "in terms of the variety of relationships that have evolved between species in the organic world" (Science and Poetry: Predation or Symbiosis?). It is these relationships that originated as a result of the close association between science and art that help any scientist or artist to chisel out new meanings and new vistas in the respective research field.

The zoologist turned novelist Vladimir Nabokov once posed a question, "Does there not exist a

high ridge where the mountainside of 'scientific' knowledge joins the opposite slope of 'artistic' imagination?"(Nabokov 330). He comes with an answer in his book Speak, Memory, where he says, "there is . . . in the dimensional scale of the world a kind of delicate meeting place between imagination and knowledge" (Nabokov 166). For him reality is a very subjective affair, and it is a kind of gradual accumulation of "information and specialization" (Alexandrov 33). He, as a poet arrived at this truth during the course of his life as a zoologist who observed and studied butterflies and later inspired by the very same observation to look at nature and write poems.

Tomas Transtromer, the 2011 Nobel Prize Winner and the great writer who passed away recently was a psychologist for more than fifty years. He balanced his occupation and passion to such an extent that he was considered as the most celebrated poet of Sweden and also as an excellent psychologist. His job as a psychologist at the Institution for Psychometrics and at Roxtuna, a youth correctional facility was exemplary.

Stanislaw Lem, one of the prominent science fiction writers of all time from the Soviet bloc, started his career as a redactor of contemporary western articles on science for a journal. There he was reading and editing number of science articles and the expertise in that particular field later compelled him to come up with novels like Solaris (1961), The Investigation (1959) of great depth and intensity.

These are writers who were doing other jobs to support them, or as their professions. There are people who made of their technical expertise to produce great master pieces of all time. Their knowledge and learning in the concerned disciplines helped them to come up with great master pieces. They complement each other in producing great literature of all time. To list a few in this area; Robert Heinlein, renowned science fiction writer, Isaac Asimov, the one who introduced the three principles of Robotics, Oliver Sacks, the internationally renowned neurologist.

Robert Heinlein who is considered as the dean of science fiction writers was a naval engineering graduate from the U. S Naval Academy, Maryland. His experiences along with this passion for science and an irreconcilable imagination compelled him to write stories of great craftsmanship.

Isaac Asimov, who is known as one among the big three's of Science fiction was a Professor of Biochemistry at the Boston University School of Medicine. Though he was approached by the US Defense Advanced Research Projects Agency (DARPA) for the development of new technologies for the military he declined it, but later submitted a paper "On Creativity", explaining how government can encourage people to come up with ideas which can be developed by government funded agencies. This experiences and information he gathered from all these sources, and his expertise as a professor of Biochemistry helped him a lot in producing great works of literature.

Oliver Sacks who passed away recently on August 30, 2015 at the age of 82 was an eminent neurosurgeon, a great physician, and a prolific writer. He always gained the greatest impetus of writing from his patients, their illness and their experiences. His cure was his writings. It is his experiences and life with the survivors of 1920s sleepy sickness, encephalitis lethargica, which formed the basis of his book Awakenings (1973). Some of his other works that were inspired by his patients include; The Man who Mistook His Wife for a Cat (1985), An Anthropologist on Mars (1995), Seeing Voice (1989), The Island of the Colorblind (1997), etc.

As a writer and a scientist, the greatest maestro of all time, Carl Sagan whose sense of inquisitiveness and wonder at nature and all it encompasses made him an astronomer, and a great writer. He was a full time Professor at Cornel University, was an advisor to NASA, and also associated with the US Space programme since its beginning. His most noted works include; Cosmos, Pale Blue Dot (1994), Broca's Brain (1979), The Dragon's of Eden (1977), etc.

One cannot make a study on scientist and artists without considering Einstein. "If I were not a physicist," he once said, "I would probably be a musician. I often think in music. I live my daydreams in music. I see my life in terms of music.... I get most joy in life out of music" (Calaprice 155). This is what Einstein says about his preoccupation with music which was always for him an abode of peace and contentment. Einstein always recognized an unimaginable connection between music and science, as something that give harmony and order to something really chaotic. Regarding the role of creativity in science and technology, one always think about Einstein's notion regarding imagination. He says, "Imagination is more important than knowledge" (Calaprice 10).

Arthur I. Miller while analyzing the life and works of Einstein and Picasso in his book, Einstein, Picasso: Space, Time and the Beauty That Causes Havoc (2001) says that for both of them art and science prided a channel to explore the world beyond their sensory perception and appearance. They proved during the culmination of creative process; the boundary between art and science eludes and they merge together producing the paramount beauty.

Jay Silver, founder director of JoyLabz and Maker Research Scientist at Intel Labs is the co-inventor of MaKey MaKey and Drawdio. For making his invention kit he was inspired by the British sculptor, photographer and environmentalist, Andy Goldsworthy. Jay Silver considers him as "an artist who, like ghost in to the woods and organizes natural elements in to beautiful art work that you didn't even know was there he just makes it a reality so all those thing kind come together at the same time and there are hacking like a museum exhibit or something how do you how do we get a button to push a computer without a being a keyboard we have to take a part keyboard solder on to this leads into a" (Insights into a Brilliant World).

David Eagleman, American writer and neuroscientist admits the fact that "good science and good art are the same" (To innovate, scientists and engineers find inspiration in the arts). He acknowledges the creative process that is involved in both science and art and says "A good creative person, scientist or artist, generates lots of ideas and has the capacity to throw a lot of them out." This is the reason why programmes like PopTech associate with various internationally known reputed universities and agencies so that they can provide a common forum to artists, writers, businesspeople, scientists, and social innovators which will make possible all sorts of productive collaborations.

Ed Belbruno is a passionate painter and a great mathematician. He was assigned to find trajectories for the Galileo mission to Jupiter. While finding the trajectories to Jupiter, and to compile the data of those trajectories to a spread sheet he realized that it was not an easy task. He started doing paintings to express him and suddenly envisioned an element of reality that he hadn't seen earlier. Applying the Van-Gogh style for the earth moon system in the brush strokes he saw a route to the moon and that paved the way for the first ballistic capture orbit to the moon with a painting. This story is a central part of the new documentary, Painting the Way to the Moon, and it explicitly depicts how one can intertwine art and science.

A list of internationally known personalities who are scientists and artist/writers is below:

	Helen Beatrix Potter	English Author and Natural Scientist
	Alexander Borodin	Russian Composer and Chemist
	Greg Graffin	Singer and Professor
	Brian Cox	Key board Player and Particle Physicist
	Dr Palash Sen	Indian singer, songwriter, musician, composer, actor and a medical doctor
	Mira Aroyo	Vocalist and geneticist
	John A. Wood	Scientist and painter
	Punathil Kunjabdulla	Writer and doctor
	Ed Belbruno	Mathematician and painter
	Diane Nalini de Kerckhove	Physicist and Jazz Singer
	Tom Scholz	Engineer and Guitarist
	Dan Snaith	Mathematician and Musician
	Milo Aukerman	Singer and Biochemist
	Brian May	Astrophysicist and Musician
	Carlos Prieto	Engineer and Musician
	Vilayannur Ramachandran	Neuroscientist and writer (articles on neuroscience)
	William James Hung	Technical crime analyst and singer
	Karim Elmahmoudi	Aerospace Engineer and Composer

For these people who decouple their passion and their profession, one complements the other. At times the work pressure instigate them to concentrate more on their passionate rooming, and sometimes it is the demand of time and work that forces them to spend more time to look at these works of art in a new sense. As scientists and as artists they are enthusiastically committed to discover new things. For them each of the discoveries and findings give them a sense of exhilaration where as their artistic or creative ruminations give them a sense of liberation. Science and art always present before us a sense of boundless scopefor searching and finding new truths and revelations about the universe and its infinity. They are always in a symbiotic relationship.

Currently there is a strong insurgence of collaboration of multiple disciplines in Universities, and R&D agencies. This merging of technology and science with art and literature could lead to the pop up of original ideas, more feasible products and services that can satisfy the people on artistic and practical levels. This will make the people more broadminded and happy.

Scientists or artists or writers will break away the shell within which they are engaged themselves with their research, ponderings and observations to come out and look around themselves and it will definitely make them more approachable, more humane, and more responsible. This could be the reason for the new insurrection in the national movements in the US for incorporating an A-for Arts into the STEM plan of education, science, technology, engineering, and math. Congresswoman Suzanne Bonamici, on February 6, 2013, asked "witnesses about the importance of STEAM (science, technology, engineering, arts, and math) education before a hearing of the U.S. house committee on science, space and technology" (Turning STEM into STEAM). Ultimately this coalition of disparate disciplines will equip us to face the world in a more invigorated spirit and confidence. This intellectual spirit will make the world around us more beautiful and more perfect.

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Indian Space Programme – Touching Lives

Jaya G Nair[1], S. Sridharan[1], S Aravamuthan[1]

Abstract : The Indian Space Programme has deployed space-based applications in a variety of fields, including communications, remote sensing, cartography, television broadcasting, disaster management and telemedicine, benefiting all sections of the society. The space programme has also built synergy in industrial development in the country. A number of technologies developed have been transferred to Indian industries. In addition, a significant number of technology spin-offs have lead to applications of societal benefit, in areas unconnected with the Space Programme. Artificial Polyurethane (PU) foot, Fire extinguishing powders, PARAS 3D software (Parallel aerodynamic simulator) for Computational Fluid Dynamics simulation with parallel computing, Liquid Level Sensor and Silica Cloth are some examples. The paper briefly describes some of these important developments which have been able to find applications offering significant benefits to the society. Thus the Space Programme has been able to touch the lives of the common Indian in myriad ways.

Keywords

ISRO, spin-offs, technology transfer, tele-education, radar, poly-urethene, navigation, GAGAN.

1.0 Introduction

The Indian Space Programme was initiated more than five decades ago, with the primary objective of utilizing space technology for socio-economic development of the country. Since then, it has achieved many milestones, from launching sounding rockets to exploring Mars [5]. A large number of satellites have been deployed into orbit and a number of space-based applications have been built using them. These applications help percolate the benefits of space technology to the lives of the common man in a number of ways, viz. in the areas of communications, remote sensing, agriculture, fisheries, cartography, television broadcasting, disaster management, tele-education and telemedicine. In addition to this, there have also been other facets in the influence Space Programme has been able to make in the society. The contribution of Indian Space Programme to the growth of industries in the country is notable. Certain 'spin-off's of space technology abound in our daily life as little gadgets or techniques that make our lives a lot simpler and which had their origins in ideas intended not for general usage. The body-hugging form of a car seat is typical of how space science has enhanced our comfort levels while driving. The seats were originally designed for NASA spacecraft based on the natural posture a human body assumes in a micro-gravity environment. There are many similar spin-offs from the Indian Space Programme that have touched the life of the common man. A few of these are highlighted in this paper.

2.0 Industry participation

Indian Space Research Organisation (ISRO) has always laid emphasis on development of indigenous technology. The space programme has built synergy in industrial development in the country and built a strong partnership with Indian industries. More than 500 small, medium

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and large scale Industries participate in the Space programme in the form of engineering hardware development, supply of materials, mechanical fabrication, development of electronics components and software, testing and other services. Almost 60% of the money spent on a launch vehicle flows to Indian Industries. Tele- education and tele-medicine are examples of recently deployed space-based applications where almost 100% of the ground segment equipments and services have been developed by Indian Industries [2].

ISRO has also contributed for capacity building and nurturing the Indian industries through technology transfer, consultancy, funding and infrastructure development. So far, ISRO has developed and transferred about 300 technologies to industries in the fields of electronic and computer based systems, specialty polymer chemicals and materials, electro optical instruments, mechanical equipments and ground systems. Many of the industries have been able to supply products developed using these technologies to users other than the Space Programme. Thus a large sector of general engineering users have benefited from the space programme.
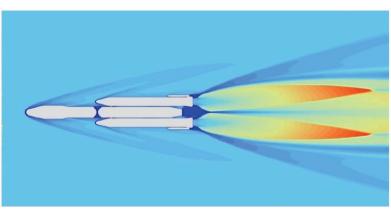
3.0 Technology products

A number of technology and products primarily developed for space programme have also benefited users from other disciplines. These include products realized in mechanical systems, materials, chemicals, electronics, software etc which find use in general applications and for general users.

3.1 PARAS-3D - Parallel aerodynamic simulator software

PARAS 3D is a general purpose flow analysis and simulation software developed by ISRO, is an example in this regard [4]. The features of the software include fully automated grid generation, ability to handle complex geometries, interfaces for CAD geometries, adaptive grid refinement etc. The software runs on computer system named SAGA (Super Computer for Aerospace with GPU Architecture) configured in- house with Linux OS using open source components. The software uses three technologies for high performance computing namely distributed computing, shared memory computing and GPU accelerators. This facility together with PARAS-3D software helps solve Computational Fluid Dynamics (CFD) problems in a very cost effective manner with considerable reduction in execution time. The facility is being successfully applied to a number of complex practical problems in the aerospace domain.

This software is extensively used for aerodynamic design and analysis, to continually refine and improve design prediction capabilities. The software is today being used by other institutions like DRDL, ADA, ADE and IISc in addition to ISRO. The software is implemented in the Space Technology Cell in IISc Bangalore for use of student and research community. The software is being extensively used for design studies by institutions in the strategic sector.

3.2 GAGAN (GPS-Aided Geo-Augmented Navigation)

GAGAN is an indigenous navigational guide system developed by ISRO in association with AAI (Airports Authority of India) with a view to assist aircraft in accurate landing and take-off even during very poor visibility conditions.

3.3 IRNSS (Indian Regional Navigation Satellite Systems)

To implement India's own navigation system, ISRO is realizing Indian Regional Navigation Satellite System (IRNSS), a constellation of seven satellites of which four are already placed in the orbit. Its area of coverage is the Indian sub-continent and 1500 km beyond Indian boundaries, mostly focusing on SAARC region, with an accuracy of less than 20m. It will provide terrestrial, aerial and marine navigation, support disaster management, vehicle tracking and fleet management, integration with mobile phones, mapping and geodetic data capture.

4.0 Spin-off Products

Technologies developed originally for the Space Programme have found novel applications in totally unconnected fields, with significant benefits to society. A few examples are highlighted in this section [5].

4.1 Artificial Polyurethane foot

Polyurethane (PU) technology was developed using microcellular polyurethane foam for insulation, damping, acoustic protection and other lightweight applications in launch vehicles. The development of PU foams has resulted in an important spin off in the form of artificial foot prosthesis. The PU foot underwent extensive field trials and modifications in collaboration with Government Medical College, Thiruvananthapuram. Subsequently, this was fitted to many amputees successfully. The PU foot developed by ISRO has numerous advantages over the traditional artificial foot. The prostheses are made of variable density microcellular elastomer. It has natural looks, is lightweight, flexible, comfortable, slip resistant and more durable and has leverage, balance etc and is easy to manufacture in large quantities. The average weight of the foot is about 500 gm. Amputees especially among the poor and needy in the country have benefited from the prostheses replacement.

PU foot

4.2 Search and Rescue Beacon

Technology developed for communication devices for launch vehicles have led to the development of beacon systems deployed in Search and Rescue Systems [3]. A Search and Rescue Beacon is an affordable and technically advanced electronic device that helps in locating and rescuing people in distress, by making use of satellite communication. The beacon, carried by the users in distress, transmit encoded digital messages that contains information about the
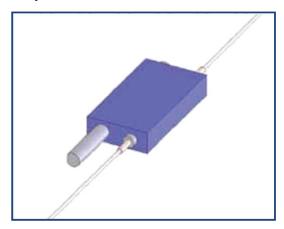

COSPAS-SARSAT System Overview

beacon, such as its unique identification number, country where the beacon is registered etc. along with current location of the beacon. The beacon gets location information from Global Positioning System (GPS). Various search and rescue satellites under the international Search and Rescue system called COSPAS-SARSAT network receive the transmitted signals. The messages are processed and retransmitted to different ground stations. These dedicated ground stations receive the message and alert the rescue centres nearest to the spot of user. The rescue centre in turn initiates the rescue operations. The beacon can be used in sea, on difficult terrains on the land and in air.

4.3 Fibre Optic Liquid Level Detector

Cryogenic fluids such as liquid Nitrogen, liquid Oxygen, liquid Hydrogen and liquid Helium find extensive applications in aviation, space technology and scientific research. ISRO at its Liquid Propulsion Systems Centre in collaboration with Indian Institute of Science (IISc) has developed a novel 'Fibre Optic Liquid Level Detector', which finds wide industrial and commercial applications [1]. Fibre optic devices sense the liquid levels typically through principles of reflection/refraction and they facilitate non-invasive level detection at an extremely high speed.

The device is simple in construction, robust in operation, easy to manufacture in large scale and is industrially viable. It is suitable for a variety of fluids and provides very fast responses. Traditional methods have high costs, slow response, heavy weight and have potential "electric spark hazard" which poses questions on their reliability, especially when used in detection of the liquid levels in fuel tanks in aerospace industry.

Fiber optic liquid level detector

The product can be used to detect the liquid level of any transparent fluid. The optical design approach ensures an electrically passive and inherently spark-free sensing operation. In explosive environments, such features help to realize a safe operation with increased efficiency and reduced maintenance loads. Some of the potential areas of use are as follows :

- The device finds application as "Green Monitoring Device", in a variety of areas especially for sensing and controlling the quality and quantity of fuels, thereby contributing towards monitoring for environmental pollution control.

- Handling of petrochemical and chemically harsh liquids during storage and bulk transportation.

- As a "built in device" in tanks of various sizes for detection of quantity of residual fuels in a more accurate manner.

- Reliable monitoring of fluids quantitatively during filling or emptying of tanks at high flow rates.

4.4 Lower Atmospheric Wind Profiling (LAWP) Radar

The Lower Atmospheric Wind Profiling Radar (LAWP) developed by ISRO provides data to study the dynamics of the lower atmosphere (up to 5 km) [1]. A coherent-pulse Doppler-radar, it is one of the most suitable remote sensing instruments for observing height profiles of three components of wind velocity vector, including the vertical velocity, with high time and height resolutions without the influence of weather conditions. The salient features of LAWP include simplified active aperture, solid state transmit receive modules, calibration free passive BFN (Beam forming network), direct IF (Intermediate Frequency) digital receiver, pulse compression, continuous operation capability and easy transportability.

LAWP Radar

LAWP radar is a potential tool to carry out research studies such as atmospheric boundary layer (ABL) dynamics (winds, turbulence structure), seasonal and inter annual variations, interactions between the ABL and the free troposphere, vertical profiles of precipitation, bright band characterization, monitoring the height of the melting layer and the vertical extent of hydrometeors, raindrop size distribution, etc. Operational field of applications include improved short- range forecasting, numerical weather prediction models, air pollution, civil aviation and flight planning, identification of atmospheric ducts, air pollution prediction, wind shear monitoring, temperature profiling in the radio acoustic sounding system mode etc.

4.5 Silicone polymer based Thermal Protection Systems (TPS)

SSF P70 is a low density Thermal Protection System (TPS) based on silicone polymer, with micro-balloon and other fillers as compounding ingredients [1]. This thermal protection system is room temperature curable and can be applied by brushing and spraying techniques. The remarkable features of this system includes simplified and cost effective process, low density of 0.38 g/cc, lower thermal conductivity and high specific heat. It has flexibility with respect to application procedure such as spraying and brushing, compatibility with wide variety of substrates including metals, composites etc and excellent ageing behaviour, making it suitable for long term application with no deterioration of properties for more than two years. The system can be tailored for use as coating on metal substrates for outdoor use.

4.6 Fire extinguishing powders

One of the widely used ISRO products is fire extinguishing powders - 'OLFEX' for flammable liquid and gas fires and Ternary Eutectic Chloride (TEC) powder for metal fires. OLFEX is a reaction product of urea and potassium bicarbonate and is used for extinguishing oil fires. TEC powder is an effective and efficient dry powder which is suitable for extinguishing fires involving reactive metals like magnesium, sodium, zirconium, aluminum etc. The performance of OLFEX is quite comparable with imported powders for similar applications. This technology exhibits excellent fire knockdown efficiency in addition to superior water repellency, flow characteristics and shelf life. Both these powders have been extensively tested by various competent and independent agencies.

4.7 Silica Cloth

Silica cloth developed by ISRO, named ISROSIL, is being used by industries for insulation and thermal protection for non metallic bellows, wrapping for pipes, cables and hoses, vertical strip furnace curtains, seals and gaskets etc. This environmentally approved asbestos free material provides high thermal, electrical and acoustic protection. This flexible textile product is available in various forms such as fabrics, tapes, sleevings, ropes, threads etc. This has been successfully used as thermal blankets in industries dealing with high temperature and corrosive applications.

4.8 Adhesives

Adhesives developed by ISRO for its own applications include both structural and non-structural adhesives. These adhesives can find

varied applications in automobile and other engineering industries. The use of adhesives, for joining, fixing and sealing, in the automobile industry is on the increase mainly due to its inherent advantages. The main advantages are improved stress distribution, weight saving, noise and vibration reduction, corrosion prevention, ease of joining dissimilar materials, sealing of joints, improved stress distribution and aesthetic appearance.

4.9 Doppler Weather Radars

Doppler Weather Radar (DWR) provides precise advance warnings, enhancing the lead time for saving lives and property in the event of natural disaster associated with severe weather. The salient features of DWR providing quantitative information about the intensity and radial velocities of cyclones, area rainfall rate & accumulation, substantially increases the lead time for cyclone warning and remedial measures. These help identify accurately the threatened areas, improves the accuracy of mesoscale rainfall estimates for flash flood warning and improves the understanding and forecasting of thunderstorms, hailstorms, tidal waves, wind turbulence and shear, visualization of storm structure etc.

5.0 Support of Space products and services to various other sectors

Space-based applications provide value-addition in many sectors which are not directly connected with the fields of science can technology. A few of these areas are discussed in this section [5].

5.1 Education and infrastructure

Satellite based data and applications support a large range of local services as diverse as customs and border control, city planning, distance learning, disaster relief, search and rescue, biotechnology and health care. Tele-education supports both distance education for students as well as continuing education for professionals. ISRO has supported various student experiments in the area of payloads and satellites. A number of student satellites have been launched on board

PSLV. Study of satellite imagery and microgravity research have lead to new discoveries. Studies made towards Space applications have contributed to R&D in fields like bone loss/osteoporosis research, vaccine research, energy research, disease prediction and monitoring, etc.

5.2 Travel and Entertainment

Space products and services play an important role in travel and the entertainment industries, such as direct-to-home television, television content, distribution to hotels, computer reservation services, satellite radio, digital movies, digital content to cell phones and GPS-based services.

5.3 Energy resources and environment management

Remote sensing satellites provide a wide view of earth that enables applications in local and regional levels in the areas of energy resources and environmental management. Weather monitoring and forecasting, resource exploration and exploitation etc are among some of the applications.

5.4 Transportation, logistics and manufacturing

A wide range of industries viz. shipping, airlines and terrestrial public transportation utilize several space technology-based applications in services like air traffic control, inventory control, package tracking, warehouse inventory management, etc.

5.5 Retail, finance and corporate services

This sector includes businesses engaged in sales, financial transactions, manufacturing and other enterprises requiring connections among distributed locations, supported by Satellites. Direct to homeinternet, video conferencing, tele-training, e-commerce and video surveillance utilize space-based services.

6.0 Conclusions

Indian Space Programme is continuing in its

mission to bring the benefits of space technology to soceity, by embarking upon missions to continue the applications and services already provided as well as embarking upon new missions, both to improve the services as well as to build new applications. Developments in Indian Industry have also occurred with synergy alongside the Space Programme. While the technology and applications developed benefit directly, spin-offs from space technology are also significant. Many products have been developed which find applications in a plethora of fields unconnected with space technology. A few of these products have been looked into here. This is a continuing saga and more and more of such applications are awaited. Thus in direct and indirect manner, the Indian Space Programme touches the lives of the common man in myriad ways.

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