Exploring Information Communication Technology and mobility linkage for smart and sustainable cities in developing countries

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Abstract

Mobility in developing countries like India is a challenge, Poor mobility influences both economy and environment of cities through loss in productive man hours and Gross Domestic Product (GDP) and exacerbates environmental degradation. Therefore, using a case study of an emerging Information Communication Technology (ICT) enabled city in India, this study examines the influence of the use of ICT in socio-economic activities and during travel on the travel pattern, economy and environment of the city. A survey research method and System Dynamics modelling approach were used. Findings revealed that definite linkage between ICT use and travel pattern exists. Significant increase in the use of ICT in socio-economic activities and during the travel in combination would enable reduction in trip generation and travel distance in the city. As a result, reduction in loss of man hours and loss of GDP of the city would be experienced. Furthermore, there would be appreciable decrease in vehicular emissions alleviating environmental pollution. The combined effect of the reduction in the mobility challenges, economic growth (GDP) on account of reduction loss of GDP and reduction in environmental deterioration can assist the cities to become smart and sustainable.

Keywords: Gross Domestic Product; Information Communication Technology; Mobility; Smart city; System Dynamics modelling; Vehicular emissions

1. Introduction

Many medium and large Indian cities are in transition. The economic reforms of the early 1990s assisted cities to garner investment from both domestic and foreign investors, which engendered higher economic opportunities. Paradoxically, it is also observed that they lack acceptable of living standards and acceptable levels of quality of life. There are challenges of housing shortage, lack of adequate water and sanitation facilities, lack of appropriate solid waste disposal, mobility challenges and traffic congestion and environmental pollution in the cities to name a few (Sankhe, Vittal, Dobbs, Mohan, et al., 2010 presented in McKinsey Global Institute report 2010).

Looking at the challenges the cities are facing and the potential they have, there have been concerted efforts to make the cities more liveable, smart and sustainable through various urban development and renewal schemes and programmes. Concerning to make the cities smarter and sustainable city in India, two of the issues stand out. First, there is a huge challenge in the mobility sector, i.e., sustainable and efficient local accessibility. Despite the various measures that have been taken to augment the transportation sector, such as, introduction of metro rails in many major cities, improvement of public transportation system and in some cases encouraging private taxi and auto (three wheeler passenger vehicles) operators, the ever increasing demand for movement have created chronic overcrowding and congestion, delay and some instances accidents. During peak hours the roads have found to be clogged and local trains and metros rails are swarmed with people a way beyond their capacities causing both safety and mobility challenges. Consequently, there has been loss of effective man hours (working hours by employees) and productivity. Besides, the huge demand for vehicular travel and plying of large number of vehicles resulting to huge carbon and other vehicular emissions is deteriorating the living environment. The second issue is the development of digital connectivity, i.e., Information Communication Technology (ICT) connectivity at a huge expense. Although, the cities are trying to enhance the ICT connectivity and use it to facilitate socio-economic and governance activities and to increase efficiency, their optimal use and effectiveness to ease mobility challenges have either been undermined or not explored. Some scholars like Das (2014a) and Emuze and Das (2015) argued that effective use of ICT socio-economic activities could aid to reduce mobility owes in the cities and in turn can engender smart and sustainable mobility (Das, 2014a; Emuze and Das, 2015). Consequent upon, as seen from the European and North American cities, effective use of ICT and smart and sustainable mobility can make the cities smart and sustainable. In the context of developing countries such as India smart and sustainable cities entail integration ICT and mobility to enhance economic performance, energy efficiency and reduce environmental pollution and provision of other basic infrastructures and amenities such that cities can become competitive at national and global level (Datta, 2015, Kitchin, 2014; Pruseth, Satapathy, 2015; PTI, 2015, Townsend, 2014).

Thus, mobility and ICT are found to be integral components of a contemporary city. Both influence the urban activities of people and consequently economic and environmental conditions of a city. Built infrastructure including mobility particularly road and rail infrastructure has a significant impact on the economy and environment of a city (Abraham, and Mario, 2015; Das, Sonar, 2013; Das, 2014a; Das and Emuze, 2014; Yigitcanlar, O'Connor, and Westerman, 2008). Similarly, ICT has influence on the business, labour productivity, and economy (Ponelis & Holmner, 2015; Roztocki & Weistroffer, 2009). In some cases, particularly in less developed countries, it is also used to compensate for lack of infrastructure and for social needs (Ponelis & Holmner, 2015). More importantly, it is acting as a driving force to transform the society and for economic growth of a city (Castells, 2000; Francis, Babajide & Niki, 2014; Hutto, & Giddens, 2000; Rantanen, 2001; Rogers, 1995; Rosenberg, 1972), although some researchers have reservations about the relationship between ICT and development.

Thus, it is argued that the interlinkage between ICT and mobility has a significant role to play in transforming a city. However, most of the researches in mobility issues are directed towards implication and development of physical infrastructure or application of ITS and ICT to solve transportation problems, particularly during the travel. While, ITS assists in among others the route choice; dynamic route and schedule of freight vehicles in congested urban area using real-time traffic information systems, and operation of traffic control systems, the challenge of trip generation remains the same.

Similarly, most of the ICT studies are concentrated on relatively few ICT issues, such as ICT adoption (Erumban, & Jong, 2006; Png, Tan, & Wee, 2001), diffusion and implementation (Roztocki, and Weistroffer, 2015) such as, e-participation initiatives and Internet diffusion (Foster, Goodman, Osiakwan, & Bernstein, 2004; Phang, & Kankanhalli, 2008). Besides, it is also observed that these studies are conducted primarily at the country or organization level (Roztocki, and Weistroffer, 2015) and not at the individual city or society level.

However, literature suggests that such linkages and their impact on economy and environment have not been explored explicitly so far, specifically in the context of cities in developing countries such as India. Particularly, the linkages between the local accessibility, travel behaviour of people, ICT use, and their influence on the economy and environment of the city have not been examined. Therefore, the objectives of the study are (1) to examine the relationship between the ICT use and travel pattern of the people and (2) to assess the impact of ICT use and consequent travel pattern on the economy (GDP) and environment (polluting emissions from the vehicles) in cities of developing countries by using a case study of an Indian city.

2. Case study: Pune city, India

The study area considered for this investigation is Pune metropolitan region (Pune city) of India. It lies between 18^0 32' North and 73^0 51' East and is located about 170.00 Kilo meters (Kms) South-East of Mumbai by road. It has a population of about 5.0 million (Census, India, 2011) and a land area of about 500 Sq. Kms. It is the seventh-largest city and the eighth largest metropolitan economy having highest per capita income in India with the least income disparity. Although, it is well known for its educational facilities and cultural attributes, it has become one of the most industrialised cities, particularly in the Western region of the country. Important industries in manufacturing, glass, sugar, forging, automobile and ICT sectors have been established in the city. The availability of adequate basic urban infrastructure facilities including existence of relatively better transport and communication services, presence of skilled manpower and its proximity to Mumbai (regarded as financial capital of India), have in particular helped establishment of a number of domestic and multinational ICT companies, attracted huge investment in this sector and emerged as an ICT hub in the country in recent years. The city has equally well established facilities for trade and commercial activities. It contributes about $48 billion per year to the GDP of the nation and offers opportunities for large scale employment generation (Silicon India, 2012). Thus, the city can be seen as a hub for extensive socio-cultural and economic activities.

However, the fast growth is creating pressure on the urban infrastructure, particularly in the transportation sector. Under public transportation system Pune has both bus and local train system. However, according to vehicle registration in Pune, 88.00% of the total numbers of vehicles are private vehicles, out of which 75.00% are motor cycles. Only about 0.80% vehicles are buses. Pune Managar Parivahan Mahamandala Limited (PMPML) operates about 1300 buses per day to facilitate local accessibility. Similarly, local trains (EMU) through its two lines connect the suburban and industrial areas in and around the city offering transportation facilities to about 100000 people per day.

Besides, the Bus Rapid Transit system known as Rainbow BRT was opened in August 2015. However, it is observed that the transportation system remained as a challenge in with regards to capacity, congestion, and safety. For, example, sometimes congestion becomes so acute on certain parts of the day that it might take as much as 3.0 hours to travel a distance of 5 Kms (Rangarajan, 2010) by road. These results to increase in travel time and delay and consequently loss of productive labour hours (man hours). Besides, the plying of huge amount of vehicles is endangering the city environment through carbon and other polluting matter emissions (Global Sustainable Systems Research Report, 2004). Thus, it is imperative to explore avenues to reduce vehicular travel and loss of productive labour hours, which otherwise would impact the economy and environment of the city.

3. Methods

3.1. Data and analysis

A survey research method followed by modelling by applying System Dynamics (SD) principles was used in this study**.** Household survey was conducted in the wards (administrative divisions) of six representative sub regions, such as, Pune Municipal Corporation in the South-east, Pimpri – Chinchwad Municipal Corporation in the North-west, Pune Cantonment Board, Kirkee Cantonment Board, Dehuroad Cantonment Board, and Dehu-a census town of the city. The wards for survey in the six sub-regions were selected based on their geographical locations, demographic characteristics, availability of industrial and other economic activity areas, density, and transportation connectivity. A total of 500 pre tested questionnaires were administered by using stratified random sampling process of which 459 were retuned (with a 92% response rate). Samples were spread over nine income range categories (varying between <0.005 million USD (<0.3 million Indian Rupees (INR)) to >0.4 million USD (>2.4 million INR) with increments of 0.005 million USD)) in appropriate proportions ranging between 16.20% for the lowest income level and 2.40% for highest income range with an average of 11.11% and median of 11.00% indicating suitability of the samples. Variables relating to the ICT accessibility, intensity of ICT use, influence of ICT on transportation and socio-economic activities (such as influence of ICT on travel pattern, number of trips, performing jobs through online system, and time saved in travel, etc.), perception of ICT use in future travel pattern and its impact on socio-economic activities are included in the survey questionnaires. Secondary data was collected from authentic published and unpublished literatures, reports and documents available at city, provincial and national level to supplement the survey data. Quantitative descriptive statistics analysis and Cronbach's alpha test of the data collected were conducted to observe the reliability of the data, t test (for $\alpha \leq 0.05$) for 95% confidence level and regression analysis were conducted to observe the relationship among the variables. Followed by SD modelling was develop to simulate the interchange among the ICT, mobility and economic and environmental variables in the city.

3.2. Modelling

A conceptual model by using SD modelling principles (Coyle, 1996; Forrester, 1968; Sterman, 2000; Sterman, Forrester, Graham, and Senge, 1983) was developed to understand the causal feedback mechanisms among the influential variables. The city was considered as the system or environment. The influential variables, their positive and negative influences on the related factors and the causal relationships among them were used to develop the conceptual SD model. The causal relationships were developed based on the evidences observed from the literature, and discussions and experiences of the professionals surveyed. The economy in terms of GDP and employment in man hours; vehicular travel distance and environmental pollution (in terms of carbon emissions (CO), Volatile Organic Compounds (VOC), Nitrogen Oxide (NOx) and Particulate Matters (PM) were considered as the measured parameters. ICT use and its influence on travel pattern and socio-economic activities were considered as decision variables for exploring policy interventions. On the premise of the conceptual model a quantitative SD model was developed and simulated to compute the predicted GDP and level of emissions of different polluting matters under different scenarios of ICT use and its influence on mobility and to evolve strategic interventions to improve the economic, mobility and environmental scenario in the city. While developing both the conceptual and quantitative models experts and professionals were consulted through semi structured interviews in an iterative and reflexive manner (Day, and Bobeva, 2005; Donohoe, and Needham, 2009; Pandza, 2008).

3.2.1 Conceptualisation of the model

It is well established that economy, mobility and environment are some of the most important components of a smart and sustainable city (Das, Emuze, 2014; Giffinger, 2007; Giffinger, Fertne, Kramar, Kalasek, Pichler, and Evert, 2007; Komninos, 2002; Lombardi, 2001. Nijkamp, and Kourtik, 2011; Shapiro, 2008; Van Soom, 2009). Although, many Indian cities are showing substantive economic growth, yet they are facing irreplaceable mobility and environmental challenges. Increase in population and urban activities have created a huge demand for vehicular travel, which consequently have created both mobility and environmental challenges. As shown in Figure 1 it is observed that urban activities demand for physical travel. The demand for physical travel on account of inefficient transportation system and poor mobility leads to increase in travel time resulting to loss of labour productivity (in terms of effective man hours) of the employees. Reduction in effective man hours ultimately impacts GDP negatively leading to loss of GDP of the city through a disruptive causal feedback mechanism B1. Similarly, demand for physical travel leads to increase in vehicular travel, which produces large scale vehicular emissions (polluting gases and particulate matters), which affect the environmental health of the city through disruptive feedback mechanism B2.

However, it is envisaged that if ICT is used effectively in the day to day urban socio-economic and transportation activities, it will lead to reduction in the travel time, which consequently will increase the effective man hours or labour productivity hours. In other words, it can reduce the loss of effective man hours. As a result, there shall be a reduction in the loss of GDP or positive contribution to the GDP growth through reinforcing feedback mechanism R1. Further, ICT use in daily urban activities like jobs, shopping, commercial and civic activities can reduce vehicular trips as well as vehicular distances to be travelled, unless highly warranted. Consequent upon which a reduction in the vehicular emissions shall be experienced, which shall result to healthy environment in the city through a feedback mechanism R2. Therefore, it is seen that while disruptive mechanism B1, and B2 are causing economic, mobility and environmental challenges respectively; reinforcing mechanisms R1, and R2 can balance the negative influences of the disruptive mechanisms as well as strengthen the economy, mobility and environment respectively through enhancing GDP, reducing trips, travel time and vehicular travel distance, and reducing the vehicular emissions. Thus, with the use of ICT, leading to improvement in mobility, increase in GDP and creation of healthy environment a city can be transformed to a smart city.

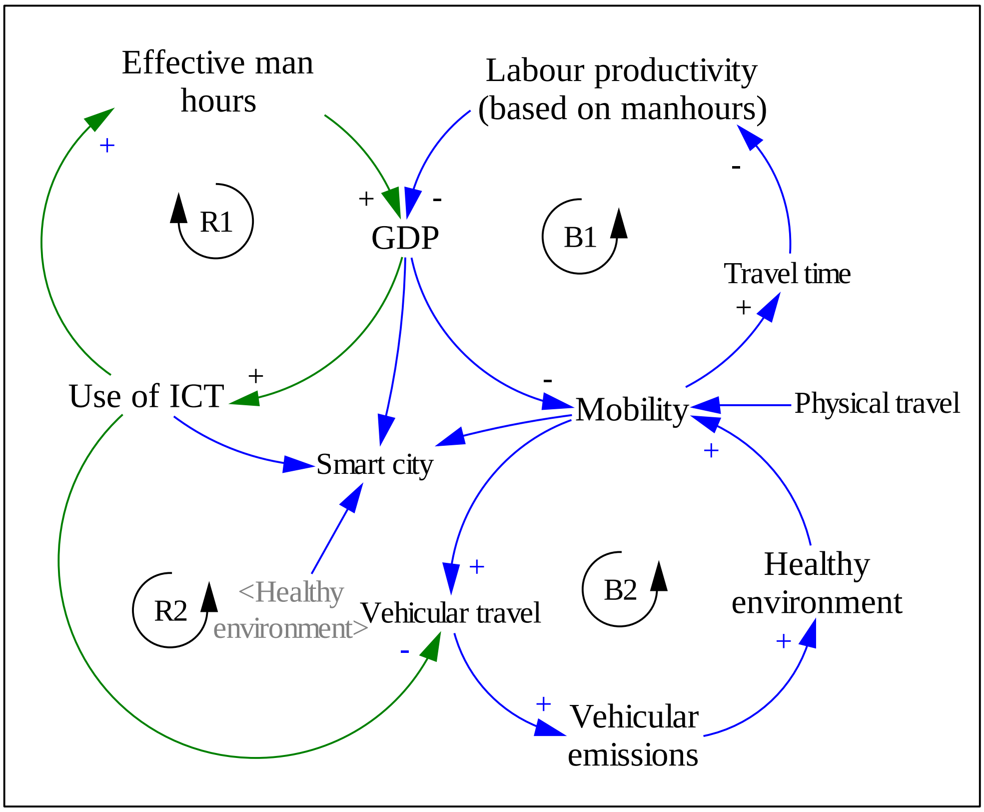

Figure 1 Causal feedback relationship among ICT, and influential mobility, economy and environmental variables

3.2.2 Model development and simulated scenarios

By considering the postulated feedback mechanisms as dynamic hypotheses a quantitative SD model was developed and simulated to observe the influence of the major variables, such as, effect of the use of ICT in urban activities particularly in the socio-economic activities on the mobility, consequent effect on GDP and environment of Pune city. GDP of the city, vehicular travel distance and environmental pollution in terms of CO, VOC, NOx and PM are considered as measured variables. Population, Normal man hours and trips generated are considered as stocks. Population growth rate (a function of birth, death, immigration and out migration), normal man hour growth rate (as a function of work force and work hours) and vehicular trip generation rate (as function of workforce (employees in the organised sector), trips per workforce, and ICT use are the three rate variables. Variables related to travel pattern (reduction in trips, predicted trips, reduction in travel distance, speed), GDP (loss of man hours, actual man hours, saving in man hours because of ICT use and reduction in travel distance, normal GDP, actual GDP due to loss in GDP, predicted GDP on account policy interventions), and environmental polluting emissions (normal CO, VOC, NOx and PM emissions and predicted CO, VOC, NOx and PM emissions on account of ICT use and change in travel pattern) are the auxiliary variables.

The established model was validated before used for simulation. It was tested to ensure that sufficient confidence in the model is attained. Structure verification test, algorithm check and behavioural validity tests were conducted and requisite adjustments were made to achieve the confidence in the model. Structure verification and algorithm check were conducted by checking the causal feedback relationships and correctness of mathematical equations respectively. Behavioural veracity of the model was tested by comparing the model results with the actual data available for the year 2011 to 2015. The variation is observed to be marginal (between 4.80% and 8.90%) showing behavioural validity of the model. In addition to this, experts were consulted to make adjustments and fine tune the model. The validated model was simulated to compute the measured variables under different simulated scenarios as given in Table 1.

Table 1 Simulation scenarios

Sl No.	Simulation conditions of Variables	Variation in conditions in the feedback mechanisms
1	Normal scenario	as in current situation
2	Intensity of ICT use for socio-economic activities (for reduction in travel needs)	Minimum increase of 1 of to 8 hours increments of 0.5 hours from the current level
3	Intensity of ICT use for changes in travel pattern during travel	Minimum increase of 10% up to 60% from the current level with increments of 5%

4. Results, Discussions and Implications

4.1 ICT use and travel characteristics in the city

Statistical analysis revealed that effective ICT use of households' increases with the increase in income. It ranges from 0.75 hours to 5.4 hours from lowest income to highest income level. Similarly, it is indicated that the number of trips per household increases with income, although average distance travel per trip varies. On an average the number of trips per household in the city is 7.25 trips with average distance travel of 17.95 Kms per trip. It is also revealed that with the use of ICT the average trips reduction and distance travelled by households envisaged are 13.33% and 22.59% respectively.

4.2. Relationship between Income, ICT use and travel characteristics

Significance test (t test) was conducted to check the relationship between income and ICT usage and various travel characteristics of the city and the T index values and p values. It is revealed that the relationship between income and ICT usage, number of trips, average distance travelled by households, reduction of trips and reduction of distance are significant for $\alpha \leq 0.05$. Similarly, it is also indicated that significant relationships exist between ICT use and number of trips, average distance travelled, reduction in trips and reduction of distance (for $\alpha \leq 0.05$). This implies that if effective ICT use is done it would lead to reduction of trips and consequent reduction in distance travelled. Besides, the test results show that number of trips and distance travelled and reduction in trips and reduction in distances are significantly related, which implies that people generating more trips travel more distance and would like to reduce both the trips and distances travelled. The regression analyses between various parameters also show that ICT use in the city substantially increases with the increase in income level. With ICT use varying from 0.75 hours to 5.4 hours reduces trips from 2.00%up to 22.00%. Similarly, intensity of ICT uses from 10.0% to 60.0% during the travel would reduce the travel distance by 6.55% up to 25.91% (see additional materials). Also ICT use will save travel time per household from 0.32 hours up to 2.33 hours per day. Thus, it is revealed that ICT use can assist in significant reduction in trips, travel distance and save travel time in the city.

4.3. Insights from simulated SD model results

The model was simulated to observe the behaviour of the travel pattern, economy and environmental attributes of the city under different perspective scenarios from the base year 2011 up to a projected year 2031. Travel pattern was examined by the number of trips generation, vehicular distance travelled because of the trips generated and reduction in trips generation and distance travelled. Economy was measured by the man hours saved and GDP. Environmental attributes were measured by the emission of Carbon (CO), Volatile Organic Compounds (VOC), Nitrogen Oxide (NOx) and Particulate Matters (PM) because of vehicular movement in the city. Although, several simulations were conducted by considering the variables individually and in combination and changing the inputs in increments, only four scenarios, such as, (1) normal scenarios (i.e., current scenario will continue), (2) enhancement in ICT use to 5 hours more than the current level in the daily activities (scenario 1), (3) enhancement in the intensity of ICT use during travel to 50.00% more than the current use, (scenario 2), and (4) combination of enhancement in ICT use to 5 hours more than the current level in the daily activities and enhancement in the intensity of ICT use during travel to 50.00% more than the current use (scenario 3) were considered for analysis and presented in the following sections .

4.3.1 Trip generation and vehicular distance travel

Figure 2 presents trips generated under the four simulated scenarios per year. It is revealed that if the normal scenario continues the trip generation will continue to grow at a faster rate and will reach about 5129139761 trips in the year 2031. It is also seen that although reduction of trip generation shall be experienced under all the three perspective scenarios (1, 2, and 3) of enhancement of use of ICT, the reduction will not be appreciable under the scenarios 1 and 2. However, under the combined scenario of enhancement of ICT use in daily socioeconomic activities and increase in intensity of ICT use during travel, there will be appreciable reduction (31.75%) in trip generation (Table 2). The vehicular distance travel per year follows the similar trend (Figure 3). It will grow at a very high rate under normal scenario and will reach $9.65*10^{10}$ Kms per year. The results also show that there shall be reduction of vehicular distance travel under the three perspective scenarios of ICT use. However, appreciable reduction of about 31.75% (Table 2) will be experienced under the combined scenario (scenario 3). Therefore, it is revealed that under the normal scenario and isolated scenarios of ineffective ICT use in the city will not assist in appreciable reduction in trip generation and vehicular distance travel by people in the city; however significant reduction in trip generation and distance travel can be expected under the combined scenario of high intensity ICT use in daily activities and during the travel.

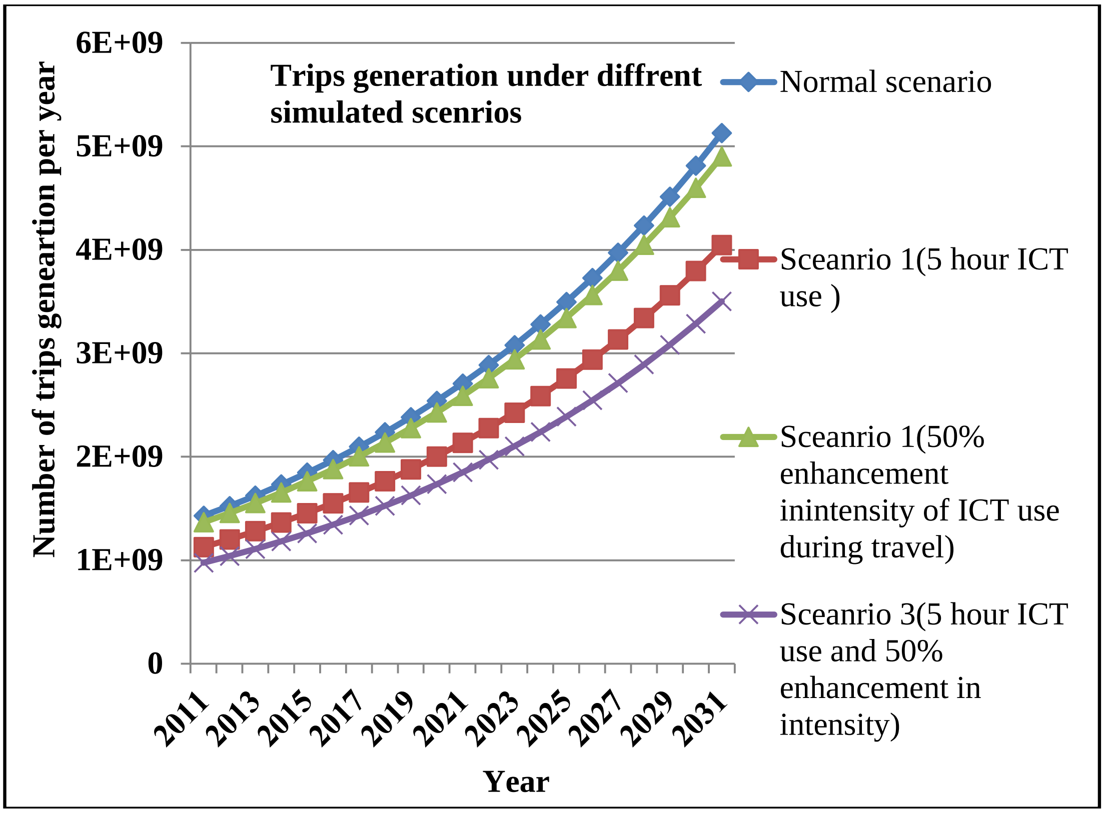

Fig. 2. Trips generated per year under different simulated scenarios

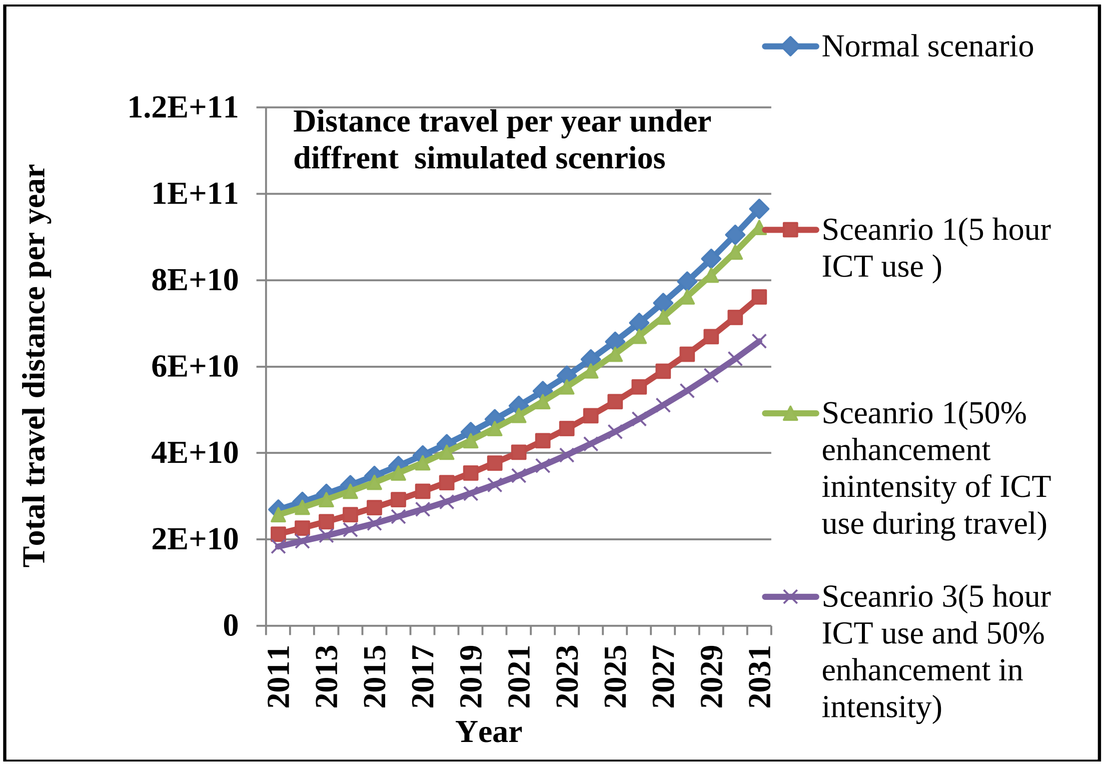

Fig. 3. Distance travelled per year under different simulated scenarios

4.3.2. Man hour and GDP

Figure 4 shows man hour losses and saving in man hour under different scenarios of ICT use. It is observed that there is an appreciable man hour loss because of challenges of travel in the city, which is expected to continue over the period 2011 to 2031. About 1397363592 man hours will be lost under normal scenario in the year 2031. However, the results revealed that (Figure 4 and Table 2), there shall be increase in savings in man hours over the projected year under the three scenarios of ICT use. While the reduction of loss or saving of man hours is not much appreciable under scenario 2 (only 10.18%), it will be highly appreciable under scenario 1 (48. 69%) and scenario 3 (73.04%). This implies that if ICT is enhanced for socio-economic activities or both socio-economic activities and during travel in combination then appreciable reduction in the loss of man hours can be achieved. ICT use during travel alone, in other words ITS alone would not able to reduce loss of man hours in the city.

The trend of GDP is presented in Figure 5. It shows that there is a significant gap between normal expected GDP and actual GDP. The actual GDP in the city will be much lower compared to Normal GDP that is expected if no loss in man hours occurs. This implies that there is significant loss of GDP in the city because of loss of man hour on account of travel patterns. However, it is also seen that under the different scenarios of ICT use, there shall be increase in GDP (or reduction in loss of GDP) over the actual GDP (Table 2). The GDP may increase from 1.64% (scenario 2) to 11.58% (scenario 3) over the actual GDP. This implies that the reduction of loss of GDP from the normal scenario will vary from 87.78% to 96.34%. So the combined scenario of appreciable use of ICT both in socio-economic and during travel will engender significant reduction in loss of GDP on account of loss of man hours in the city.

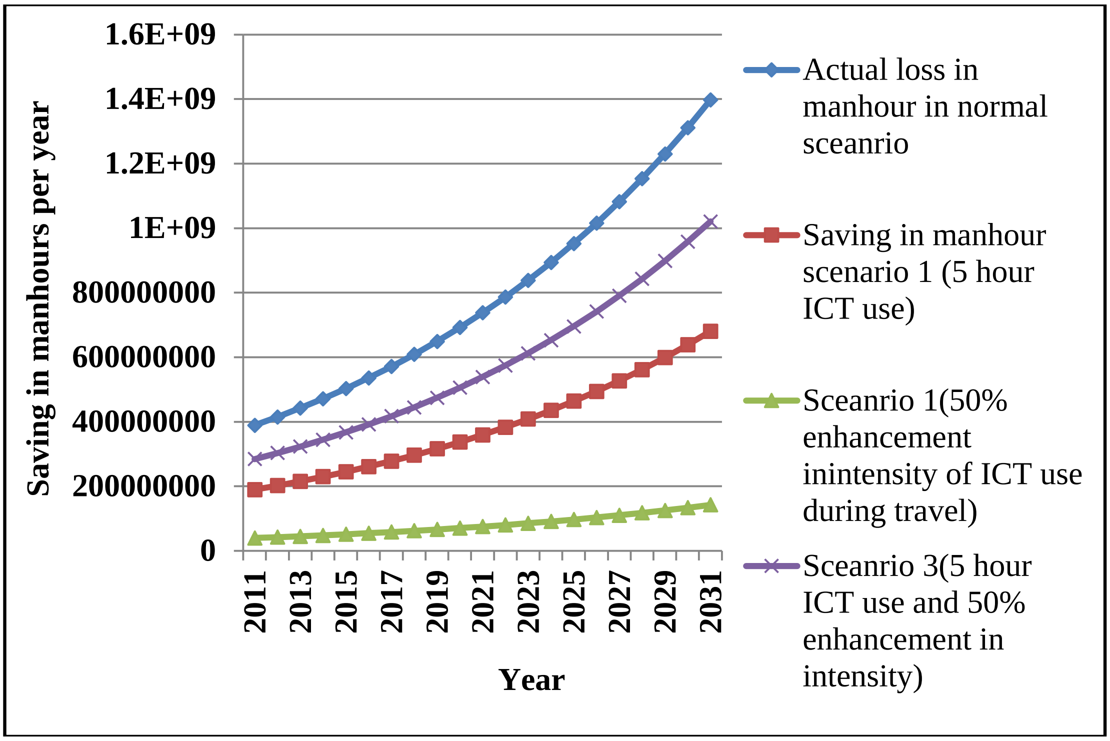

Fig. 4. Saving in man hours per year under different scenarios

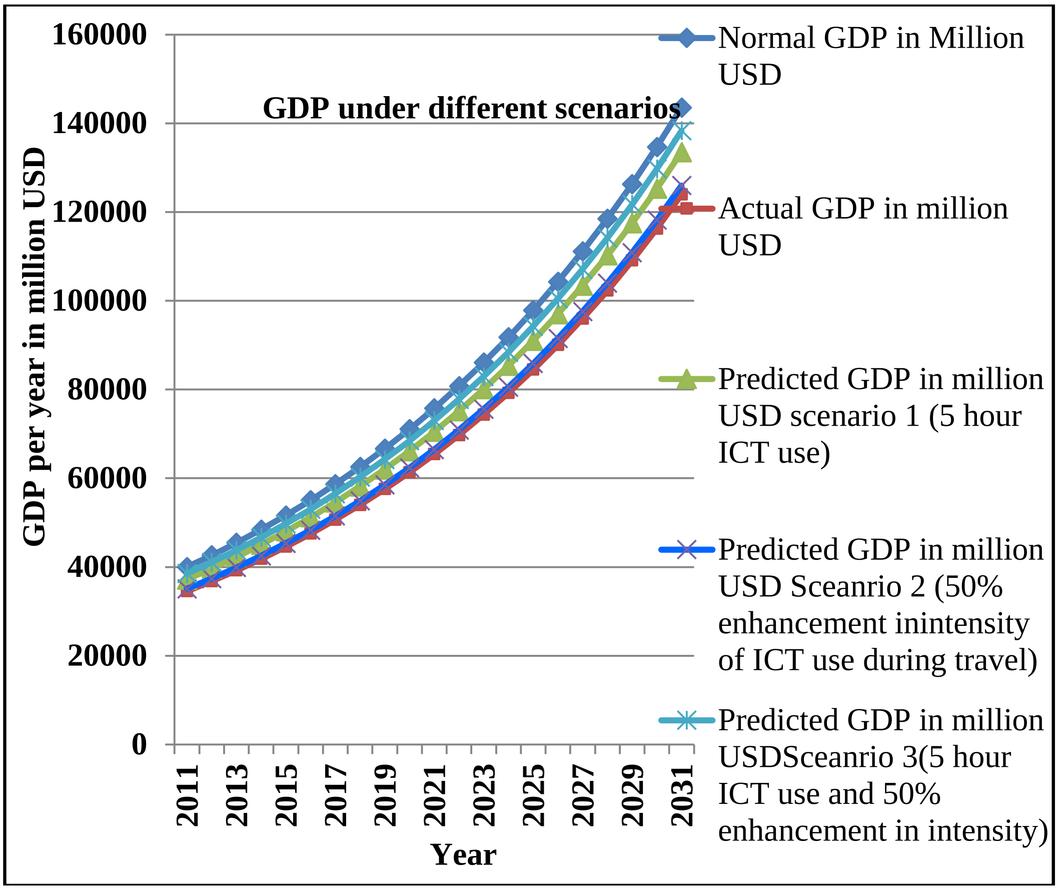

Fig. 5. Normal, actual and predicted GDP under different scenarios

4.3.3. Environmental pollution because of vehicular emissions

Figure 6 present the various emissions that occur from vehicular movement in the city. It is revealed that if the current scenario continues the CO, VOC, NOx and PM emissions will reach 1383569.07 tons, 434836 tons, 59295.82 tons, and 15812.22 tons respectively in the year 2031. However, if substantial ICT use is enhanced in the city then the vehicular emissions will reduce significantly, i.e., a reduction between 4.62% to 21.72% (Table 2) is expected under different scenarios.

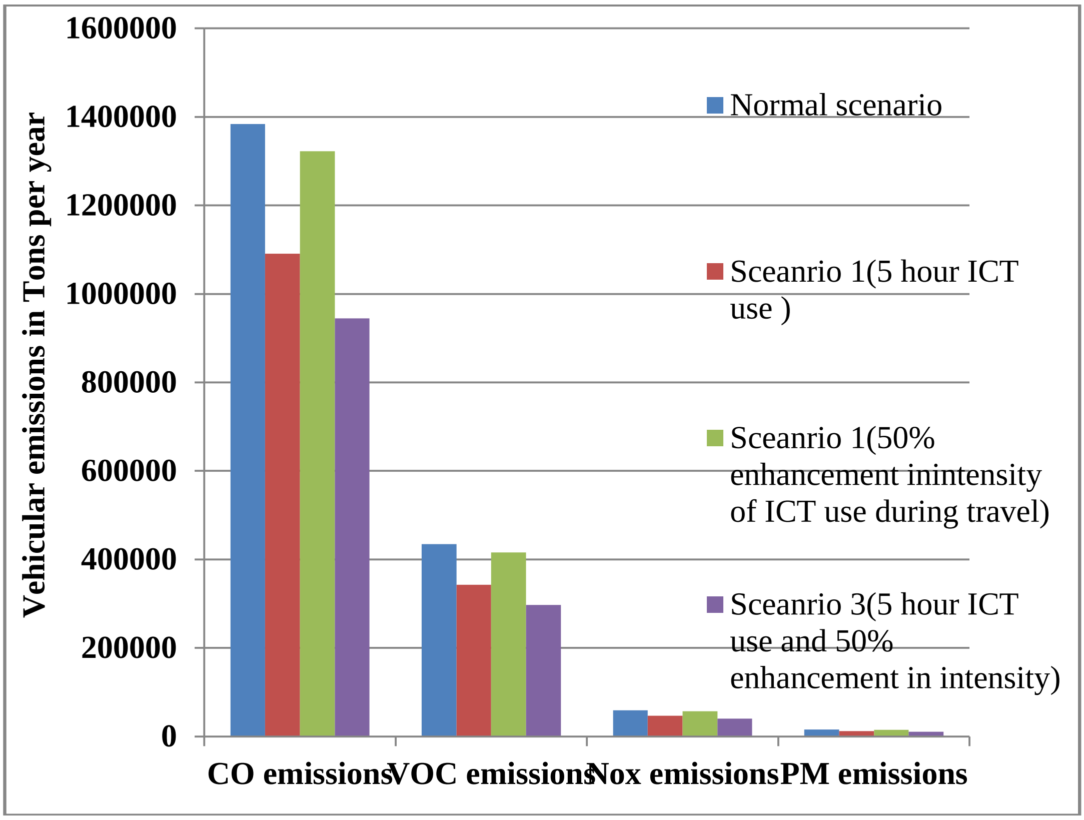

Fig. 6. Vehicular emissions under different scenarios

Table 2 Comparative scenarios of change in travel pattern, reduction in loss of Man hour, reduction in loss of GDP, and reduction in Vehicular emissions

Parameters	**Scenario 1**	**Scenario 2**	**Scenario 3**
Reduction of trips and travel distance	21.15%	4.4%	31.75%
Reduction in loss of man hours	48.69%	10.18%	73.04%
Increase in Predicted GDP over the actual GDP (Reduction of loss of GDP from normal scenario)	7.73% (93.03%)	1.64% (87.78%)	11.58% (96.36%)
Reduction in Vehicular emissions from Normal scenario	21.15%	4.62%	31.72%

5. Conclusions

In the current scenario, many cities in India are facing mobility and environmental challenges, although they offer significant opportunities for economic development through both industrial and service activities. Particularly, the overcrowding of public transportation system, use of private vehicles, large scale use of three wheeled and two wheeled vehicles and consequent congestion and delay are visible. The inefficiency in mobility in the cities leads to the loss of man hours, in other words loss of labour productivity hours besides causing environmental ailments in the cities. In the wake of such a scenario, the recent initiative of the Government of India to transform the cities to smart cities despite obvious socio-economic, political and technological challenges holds promise. However, development of plausible policy intervention measures necessitates the exploration of the inter-linkage among the influential variables and attributes of the cities. Therefore, this investigation examined the inter-linkage between the ICT use and travel pattern of the people and assessed the impact of ICT use on the travel pattern, economy (GDP) and environment in Indian cities by considering a case study of Pune city because many of attributes of Pune offer opportunities to transform it to a smart city. A survey research method and SD modelling approach based on the principles of causal feedback mechanisms were used for this purpose. The findings revealed that there exists definite linkage between ICT use and travel pattern in the city. Significant enhancements of ICT use in socio-economic activities of the people and enhancement of ICT use during the travel in the city in combination would reduce the number of trip generation and travel distance in the city. This would lead to reduction in loss of productive man hours and in consequence reduce the loss of GDP of the city, which would occur otherwise in the normal conditions. Furthermore, because of the reduction of trips generation and travel distance, appreciable decrease in vehicular emissions will be experienced.

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