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The physical and ecological space consumed by transport modes in Rajkot City, India

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Abstract

The space needed by various urban passenger transport modes varies greatly depending on the size and the speed of vehicles. Past studies have shown that public transport (PT) and non-motorized transport (NMT) can be up to 20 times more space-efficient compared to a typical car. This is of relevance in urban context where space is a constrained resource. Yet space used by transport modes is rarely assessed in the transport planning practice and there exists no standard method for quantifying the use of space in complex urban settings like that of developing cities. Three kinds of space usages can be defined for passenger transport systems: space used for travelling, space used for parking, and a broader ecological space, which combines the transport infrastructure space with the forest land required to absorb CO_2 emissions resulting from urban transport. This study proposes a method based on the space-time concept for quantifying the transport, parking and ecological space and compare them by modes. Transport planning scenarios developed for the Low-carbon Comprehensive Mobility Plan (LCMP) prepared for the city of Rajkot are used to demonstrate the method. The indicators show that significantly less space is used by transport in a scenario that promotes higher use of PT and NMT mode in comparison to business-as-usual scenario. This provides evidence that could contribute to alleviating chronic congestion expected from a car- and motorcycle-based transport development only. Overall, this research describes an assessment framework for low carbon transport development that would include spatial efficiency concerns.

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Keywords: space-time indicator, ecological footprint, sustainable transport planning

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1. Introduction

Transport infrastructure provision helps shaping spatial patterns of development, and more importantly, is a means for most residents to access their activity locations (Banjo and Dimitriou, 1983; Dimitriou, 2006; Geurs, 2006; Munshi and Brussel, 2004). From collector roads to urban highways, through arteries and parking lots, motorized modes rely on a wide infrastructure network. The efficient use of space is key in the global debate around the role of transport in progressing toward sustainable development (Banister, 2008). There is a wide disparity in provision of transport infrastructures among the most and least economically developed countries. In most developing countries, the access individuals have to transport infrastructures is characterized by spatial inequities between areas and among people (Knowles, 2006; Munshi, 2013). A large share of the developing countries population is poor and dependent on non-motorized transport (NMT) and public transport (PT) to access their desired activity locations.

Typical to many other developing nations, India has traditionally been known for limited transport infrastructure provision, with demand levels often surpassing transport infrastructure supply (Pucher et al., 2005; Tiwari, 2011). Transport planners have mainly focused on reducing road congestion and on accommodating the ever-increasing number of motorized vehicles. Transport planning thus far has therefore discriminately favored the use of cars (Tiwari, 2011). There has been a general failure to incorporate NMT in the transport planning process, and PT plans and provision are poor and not comprehensive (Munshi, 2013). Despite inadequate infrastructure provision, walking and NMT like bicycles and rickshaws, as well as motorized para-transit or public transport still dominate the urban transport in India. The proportion of NMT modes amount to 30-50% of the total trips made in urban areas, and public transport accounts for 15-60% of the trips, indicating an apparent disparity between the infrastructure space allocation for NMT and PT modes and their use (Tiwari, 2011).

The National Urban Transport Policy (MOUD, 2006) stresses the relevance of promoting NMT and PT modes. The intention is to retain the existing users and possibly entice present private motorized vehicle users to shift to NMT and PT modes. Most of NMT and PT users are captive users, unable to afford using other modes. Steadily rising per capita income in India is likely to grow by a factor of four in the next 20 years (Sankhe et al., 2010). Rise in income level and poor NMT and PT infrastructures have resulted in a surge in individual motorized vehicle ownership and use. Motorized two-wheelers and cars have been respectively growing at a rate of 15-20 % p.a. and 10-15% p.a. (Tiwari, 2011). The proportion of NMT and PT trips have consequently already started declining in most Indian cities. Despite good intentions, retaining the existing NMT and PT users may thus prove difficult, much less increasing their use. Providing infrastructures for NMT and PT modes is crucial in bringing individuals to deliberately choosing these modes.

The UN-Environments Promoting Low Carbon Transport project in India (2010-2014), aimed at tightening the bonds between India's national climate change policy and efforts to develop and improve urban transport systems. The project developed a business-as-usual scenario and low-carbon transport development scenarios for three case cities in India: Rajkot, Vishakhapatnam and Udiapur. The business as usual scenario predicts travel demand for year 2031 assuming urban development, economic growth and motorization follow current trends. The low carbon scenario includes land-use changes aimed at organizing the urban development around nodes with high job and housing densities, and other measures such as better PT and NMT infrastructures to encourage a higher use of non-motorized and public transport modes and shorter travel distances.

Rajkot, used as a case in this paper, is a second-tier Indian city located in the state of Gujarat in western India. Its estimated metropolitan area population is 1.2 million inhabitants (Munshi et al., 2014). This paper furthers the work done for Rajkot and evaluates the space used by transport in three configurations: the situation as of 2011, and two different transport development scenarios for year the 2031, the business-as-usual (BAU) and the Low-carbon Comprehensive Mobility Plan (LCMP) scenario (Munshi et al., 2014).

This paper presents a methodology for the spatial assessment of transport systems, and addresses the difficulty of transport space demand measurement in developing cities. Travel demand has been modelled and forecasted based on number of trips and distances travelled in the LCMP Rajkot report (Munshi et al., 2014). In this paper, travel demand is then converted into two spatial indicators: a space-time indicator quantifying the space-time used by transport modes, both while traveling and while parking, and a transport ecological footprint indicator. The space-time indicator quantifies the space consumed by different transport modes and in different scenarios. The ecological footprint of transport measures the travel demand's spatial cost in terms of forest land required to sequester transport-related carbon dioxide (CO_2) emissions in addition to the land required for transport infrastructure.

This paper starts with a literature review of previous transport spatial assessments in section 2. In section 3, the methodology used to quantify the space used by different transport modes is presented, as well as the ecological transport footprint calculation process. Results are presented and discussed in section 4, and suggested improvements to the methodology are offered in the conclusion section.

2. Passenger transport and urban space consumption

Transport is a derived activity required for people to access locations to pursue their main activities and meet fundamental human needs (Geurs and van Wee, 2004). Transport infrastructure requires dedicated city space, most often above ground. Because such infrastructure forms an essential and visible part of the cityscape, infrastructure choices can lead to long-term lock-ins in terms of transport choices. For example, adapting road supply as car traffic increases has been shown to often lead to more vehicles on the road and therefore to create more traffic in the long term (Dimitriou, 2006). The rise of individual motorized vehicle ownership promotes car-oriented transport planning, stigmatizing and reducing the use of other modes, which in turn fosters the path towards suburbanization, a car-based land use planning, urban sprawl and consecutively further increase in vehicle ownership. The Cycling Promotion Fund suggests the space occupied by 60 cars (about 70 persons) on-road can accommodate around 16 buses (about 380 persons) or about 600 bicycles[1]. Previous (but rare) studies have shown public and non-motorized transport can be up to 20 times more space-efficient per passenger than a typical car (Héran and Ravalet, 2008). A shift from car to NMT or PT can therefore theoretically contribute to freeing up precious city space.

Three kinds of space usages can be defined for passenger transport systems: space used for travelling, space used for parking and a broader ecological space, which combines the transport infrastructure space with the forest land required to absorb CO_2 emissions resulting from urban transports.

The space consumed by travelers has been theorized and quantified in the literature for the city of Paris (Héran and Ravalet, 2008). As the use of space varies with time, the assessment resorts to a dynamic indicator measuring the space-time consumed per trip. The calculation is based on travel diaries resulting from household surveys. The dynamic surface used by each mode is defined as the product of the mean effective lane width taken on-road by the sum of the average vehicle length and intervehicular distance. The space-time indicator has been first introduced in an attempt to compare spatial efficiency of different modes and to monetize transport space consumption (Marchand, 1984). Quantifying the space used on-road by vehicles is largely dependent on the definition of the surface used by moving vehicles. The calculation for Paris' case draws on the lane width, whereas in developing cities, traffic may be organized in a more condensed manner, with several vehicles occupying the same lane width, especially motorized two-wheelers which tend to slot into every available space.

Space used for parking, in the case of Paris, has also been estimated based on travel diaries, which determined the parking time spent between trips. Parking surface is taken as the size of the parking spot used, with three parking size distinctions: parking on-road alongside footpaths, private parking or parking on a parking lot. The lack of formal parking spaces in many Indian cities raises the question of the accurate dimension of a parking space to use when attempting the quantify the space used by parking vehicles (Barter, 2010).

Ecological space consumed by transport merges two elements (Nazelle et al., 2012): the "physical footprint", which is the total space allocated to transport in the city; and the "energy footprint" (Chi and Stone Jr, 2005), which is the forestry land required to absorb transport-related direct and indirect CO_2 emissions. Wackernagel & Rees (1996) estimated that indirect carbon emissions from road construction and maintenance are equivalent to 45% of the total annual fuel consumed for vehicle travel.

The quantification of the physical footprint of transport, comprising both the street network and public parking facilities, has been more extensively studied than the transport space consumed by travellers. Apel (2000) conducted a comparative study on the structure of the cities of Oldenburg (Germany), Delft (The Netherlands), and Denver

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[1] http://www.cyclingpromotion.com.au/content/view/566/9/

(USA). By estimating the space used by streets and traffic facilities, the research shows how car-based transport planning acts as a major root cause for expansion of settlement space, and goes on to suggest specific features of infrastructure network as well as population and job density distribution that would enable a reduction in the need for new settlement space. More recently, a case-study of Fribourg (Germany) put emphasis on the differences in space allocation within modes and the fairness issues implied (Gössling et al., 2016). The space dedicated to different mode categories in four neighbourhoods of the city – Wiehre, Herdern, Weingarten, Vauban – is measured through high-resolution satellite images. Without taking private parking into account, the study shows that the majority of the transport space is allocated to roads and public parking, with other areas – pedestrian-only areas, bicycle and walking areas, public transport lanes, bicycle lane, mixed use spaces – amounting to a minor share of the space. The differences between neighbourhoods epitomize the urban and transport planning trends of the construction period. The Wiehre and Herdern neighbourhoods were planned around 1900, a time when walkers were predominant, and therefore, allocate a large share of space to pedestrians. The neighbourhood of Weingarten was built in the 60's, when urban development was car-oriented. The neighbourhood of Vauban in the 90's was planned with an intention to shift towards sustainable urbanism, explaining a lower share of space dedicated to car transportation (Gössling et al., 2016). Likewise, Rajkot city's central area, constructed in the 18th century is characterized by narrow lanes for non-motorized travel. The outer part of the city, which has developed recently, is more car-oriented. As the city is still growing, there is a possibility to learn from the evolution and planning trends in Western cities and potentially leapfrog the car-oriented planning phase directly to a more sustainable urbanism phase.

3. Methodology

3.1. Overview

The methodology developed (Figure 1) aims firstly at quantifying the space-time used by passenger transport modes, both for parking and on-road, using an approach adapted from Héran & Ravalet (Héran and Ravalet, 2008) and extended to the BAU and LCMP scenarios forecasts. Applying space-time measurements on future transport development scenarios is the main methodological contribution of this paper. The second part of the methodology consists of estimating the ecological footprint of transport as introduced by Chi & Stone (Chi and Stone Jr, 2005).

The two indicators flow from the scenarios in the LCMP project, which included household surveys and future transport demand projections. The LCMP transport model predicted socio-economic and land-use transitions of the urban area (Munshi et al., 2014). Household surveys consisted of revealed and stated preference surveys, enabling the forecasting of mode-choice and distance travelled changes as a result of new infrastructure provision. The model was developed for 2011 and calibrated using on-ground traffic surveys.

Travel demand is the main input of the space-time consumption indicator. Rajkot is divided into 23 wards, for which the space-time used by transport is calculated and then aggregated into a city-level indicator. The indicator measures the space-time consumed for traveling and parking by modes and scenario, in km^2/h averaged on a day. A major issue in defining the transport physical footprint in India is the sometimes unclear definition of infrastructure delimitations, with a mix use of the road space by hawkers and a large share of unmettled roads (Munshi et al., 2014).

The transport ecological and physical footprint estimates the dimension of the traffic facilities according to land-use data from the Rajkot Municipal Corporation. The ecological footprint is given in km^2 and encompasses both the physical and energy footprints. This is computed as forest land required to sequester transport-related CO_2 emissions and has been estimated globally by Wada (1994). A recent study by Rizvi et al. (2016) evaluated the absorption capacity of several forests in India, establishing for the forest in the Junagarh district, Gujarat, a yearly value of 550 tons of CO_2 sequestered per km^2. Forest's CO_2 sequestration capacities are however, complex to quantify as many factors such as the flora type and the forest management approach need to be taken into account. The energy footprint is derived from the travel demand and fuel consumption assumptions elaborated in the LCMP. The energy footprint includes an emission adjustment factor accounting for road construction and maintenance. A value of 1.45 is applied, based on the literature on transport ecological footprint (Wackernagel and Rees, 1996). The absorption capacity of the local forest land is taken from Rizvi et al. (2016)

The space-time used by transport is measured for the base-year 2011, as well as for two transport development scenarios for year 2031, BAU and LCMP. Similarly, the forest land required to absorb CO_2 emissions is evaluated per scenario. The transport physical footprint is based on what has been proposed in the LCMP Rajkot report (Munshi et al., 2014).

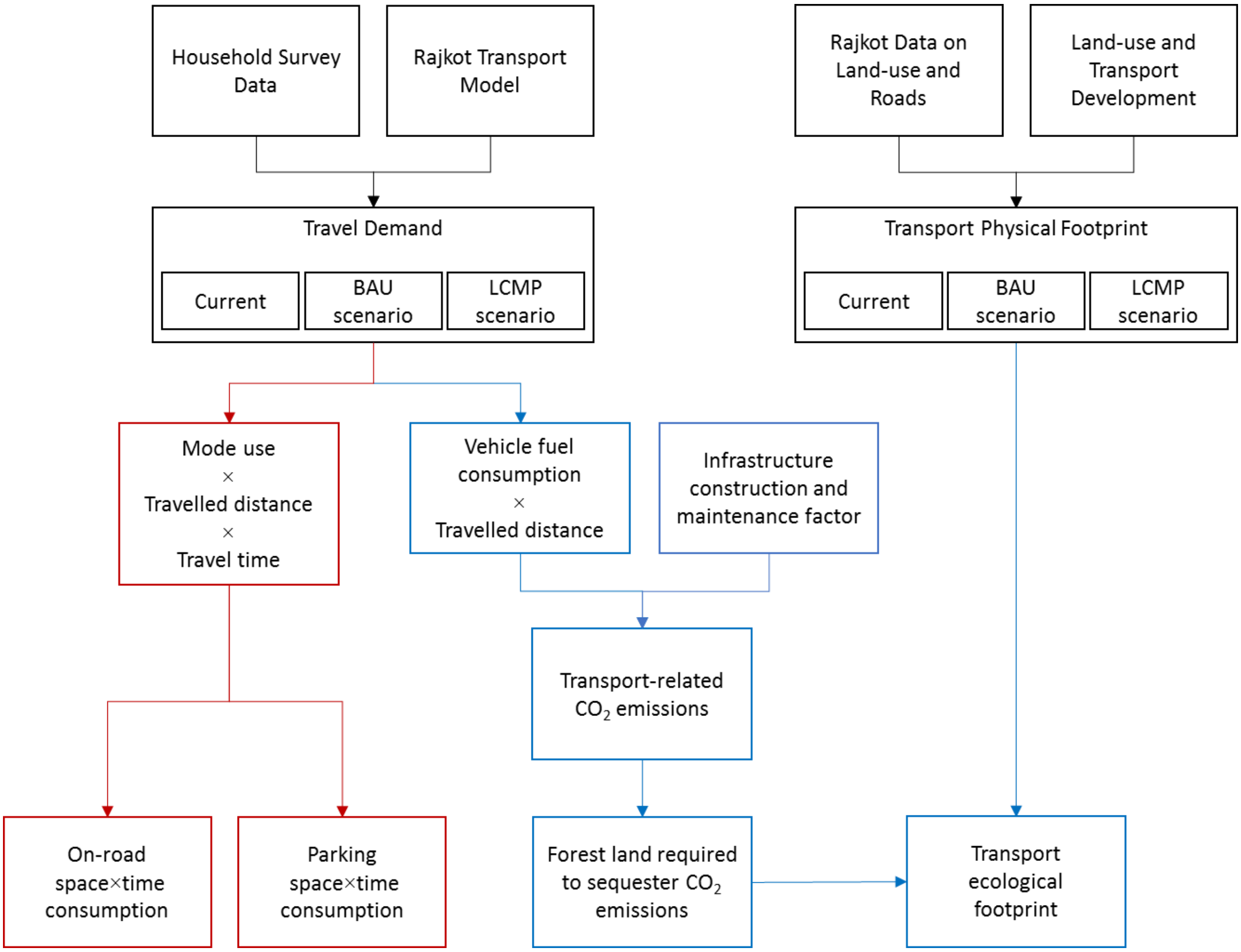

Figure 1: Transport space-time consumption and ecological footprint. Outlined in black: input data from previous studies (Munshi et al., 2014). In red: methodology for space-time consumed by transport developed for this research. In blue: ecological footprint methodology proposed by Chi & Stone (Chi and Stone Jr, 2005).

3.2. Space-time used on-road

3.2.1. Methodology summary

The space-time indicator applies the concept developed by Héran & Ravalet (2008) to the specific case of Rajkot and combines both current and projected trip data for the transport development scenarios. Four main variables have been defined to assess the space-time used on-road (Figure 2):

- Number of vehicles of mode x on a road segment ab, N_{ab}^{x}
- Space used by a vehicle of mode x at a mean speed $\bar{v}_x$, $\bar{s}_x$
- Time spent by vehicles of mode x on a road segment ab, t_{ab}^{x}
- Overall space-time consumed by vehicles of mode x in a ward I, α_I^x

3.2.2. Number of on-road vehicles

The number of vehicles on-road is obtained from the transport model, which produces daily passenger trips. The number of vehicles on each road segment is obtained by dividing the latter with vehicle occupancy ratios, available for Ahmedabad (Munshi, 2013). Vehicle occupancy ratios are taken from a study on built form and travel behaviors in Ahmedabad, India by Munshi (2013). The number of vehicle of mode x on-road segment *ab* is given by:

$$N_{ab}^{x} = \frac{f_{ab}^{x}}{R_x} \tag{1}$$

Where N_{ab}^{x} is the number of vehicle of mode x on-road segment ab, f_{ab}^{x} is the daily passenger trips travelled by mode x on-road segment ab, and R_x the occupancy ratio of a vehicle of mode x.

3.2.3. Space used by the different vehicles

The space used on-road by moving vehicles is a function of speed. The relationship between the dynamic space consumed by a vehicle and its speed has been established for a case-study of Hanoi (Vietnam) (N. Y. Cao, K. Sano, 2012). Contrary to the space consumption defined in the Paris case by Héran and Ravalet (2008), which employs lane width and reglementary intervehicular distance, the dynamic space consumed for Hanoi's case-study was evaluated empirically based on traffic videos. Dynamic spaces for vehicles in Rajkot (Table 1) is defined based on the city's average speed by mode, and for pedestrian, the work of Fruin (1971) on pedestrian flows is used as a reference.

Table 1: Average speeds in Rajkot and corresponding mean effective space per transport mode (Fruin, 1971; N. Y. Cao, K. Sano, 2012)

Transport mode	Mean speed $\overline{v_x}$ (km/h)	Mean effective space $\overline{s_x}$ (m^2)
Car	22	20
Bus	16	55
Auto rickshaw	16	15
Motorized Two-wheeler	16	2.5
Bicycle	11	3.9
Pedestrian	4.7	1.4

3.2.4. Time spent on-road

The time spend on-road by a specific vehicle is determined by its speed and the distance travelled, calculated as:

$$\mathrm{t}_{\mathrm{ab}}^{\mathrm{x}} = \frac{\mathrm{l}_{\mathrm{ab}}}{\overline{\mathrm{v}_{\mathrm{x}}}} \tag{2}$$

Where l_{ab} is the length of road segment ab, $\overline{v_x}$ the average speed of mode x on Rajkot and t_{ab}^{x} the time spent on-road segment *ab* for a vehicle of mode x on a day.

3.2.5. Space-time consumed on-road in a ward

The space consumed by the total number of vehicle of mode x traveling in ward *I*, is given by equation (3):

$$\alpha_I^x = \sum_{(a,b)\in I} \overline{s_x} \times N_{ab}^{x} \times t_{ab}^{x} \tag{3}$$

Where α_I^x is the space consumed by the total number of vehicle of mode x using road segments of ward *I*, $\overline{s_x}$ is the mean effective space consumed by a vehicle of mode x at speed $\overline{v_x}$, N_{ab}^{x} is the daily number of vehicles of mode x on-road segment ab and t_{ab}^{x} the time spent on-road segment ab for a vehicle of mode x.

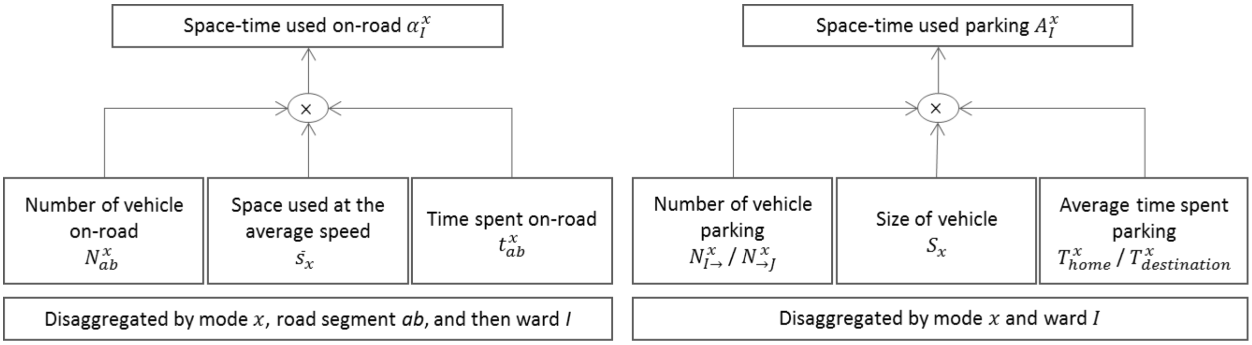

Figure 2: Space-time used on-road (left) and parking (right) calculation methodology

3.3. Space-time used for parking

3.3.1. Methodology summary

Four main variables define the space-time used parking (Figure 2):

- The number of vehicles of mode x parking in the “home” ward I and “destination” ward J, $N_{I\rightarrow}^x$ and $N_{\rightarrow J}^x$
- The space used parking by a vehicle of mode x, S_x
- The time spent parking by vehicles of mode x in the home ward and destination ward, T_{home}^x and $T_{destination}^x$
- The overall space-time consumed parking by vehicles of mode x in ward I, A_I^x

3.3.2. Parking space

The parking spaces have been taken as the averages referenced by the Institute for Transportation & Development Policy (ITDP India)[2] (Table 2). The parking time and the number of vehicles are computed assuming pendular traveling patterns as suggested by the transport model. The parking dimensions used in this study are on the lower side in comparison to typical parking space allocation in Western cities, for example, in United Kingdom the typical car parking size[3] is 6 m x 3.2 m. The values used in this study reflect the ground realities in Indian cities, where vehicles are parked in a compact manner.

Table 2: Average parking dimensions (Khanorkar et al., 2014) and Institute for Transportation & Development Policy (ITDP)[2]

Vehicle type	Average length (m)	Average width (m)	parking space (m^2)
Car	5.0	2.0	10.0
Bus	15.0	2.8	42.0
Auto rickshaws	3.0	1.8	5.3
Motorized Two-wheelers	2.0	1.0	2.0
Bicycle	2.0	0.5	1.0

3.3.3. Cars, motorized two-wheelers, and bicycles: parking time and fleet size

The parking time for cars, motorized two-wheelers and bicycles is taken as the mean parking time at home and at the primary destination from the travel diaries of the household surveys. Projected parking times have been assumed

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[2] https://go.itdp.org/display/public/Equivalent+car+space+%28ECS%29+conversion+factors

[3] https://www.planningni.gov.uk/index/policy/supplementary_guidance/dcans/dcan11_draft/dcan11_draft_design/dcan11_draft_reserved.htm

similar as in the base year. To fit the forecasting framework, and contrary to the parking space consumption methodology developed on Paris case by Héran and Ravalet (2008), average time values for pendular commuting are taken, regardless of potential trip chains. The total space used for the parking of mode x in ward I is the sum of the space used by vehicles of residents parking in the specified ward, and vehicles of travelers at the destination ward:

$$A_I^x = S_x \times N_{I\rightarrow}^x \times T_{home}^x + S_x \times N_{\rightarrow I}^x \times T_{destination}^x \quad (4)$$

Where A_I^x represents the space used for the parking of mode x on ward I, S_x the space required for the parking of one vehicle of mode x, T_{home}^x the average parking time of mode x (car, two-wheelers and bicycles) on a day in the residence location, $T_{destination}^x$ the average parking time of mode x on a day at the primary destination location, $N_{I\rightarrow}^x$ the number of vehicles of mode x traveling from ward I on a day, and $N_{\rightarrow I}^x$ the number of vehicles of mode x traveling to ward I on a day. Equations (5) and (6) show how $N_{I\rightarrow}^x$ and $N_{\rightarrow I}^x$ have been determined:

$$N_{I\rightarrow}^x = \sum_{a\in I,\ b\notin I} N_{ab}^x \quad (5)$$

$$\mathrm{N}_{\rightarrow \mathrm{I}}^{\mathrm{x}} = \sum_{\mathrm{b}\in \mathrm{I},\ \mathrm{a}\notin \mathrm{I}} \mathrm{N}_{\mathrm{ab}}^{\mathrm{x}} \quad (6)$$

Where N_{ab}^x is the number of vehicles of mode x on-road segment ab in a day.

Contrary to cars, motorized two-wheelers and bicycles, auto rickshaws and public transport travels are not characterized by daily commuting times and are thus modelled separately.

3.3.4. Auto rickshaws and public transport: parking time and fleet size

Auto rickshaws serve as a substitute for taxis or missing public transport, and the same vehicle is in operation for several hours per day. The average daily operation time of auto rickshaws is taken as ten hours (Shlaes and Mani, 2013). The number of auto rickshaws for the base year is issued from municipal vehicle registration data, and adjusted to the projected travel demand for the BAU and LCMP scenarios.

An average of six hours of daily operation time is taken for buses. The bus fleet size requirements have been determined in the LCMP project (Munshi et al., 2014) and was therefore used for the LCMP scenario, and values were adjusted to the travel demand in the BAU scenario.

3.3.5. Transport ecological footprint

The transport ecological footprint is built according to a standard methodology described by Chi & Stone (2005). It combines the transport physical footprint, which is the space allocated to transport in the city, and the energy footprint, which is the forest space required to sequester transport related CO_2 emissions (Chi and Stone Jr, 2005). The physical footprint consists of the actual dimension of the road network based on a dataset from Rajkot Municipal Corporation on Land-use and Roads. The energy footprint builds on the CO_2 emissions calculation undertaken in the LCMP project, which itself is based on travel demand projections. Transport-related emissions volume is then adjusted to take into account infrastructure construction and maintenance, then converted into a land value based on the absorption capacity of a forest site nearby Rajkot in the Junagarh district (Rizvi et al., 2016). For illustrative purposes, the Rajkot forest area is used as a benchmark for putting the city’s ecological footprint in context.

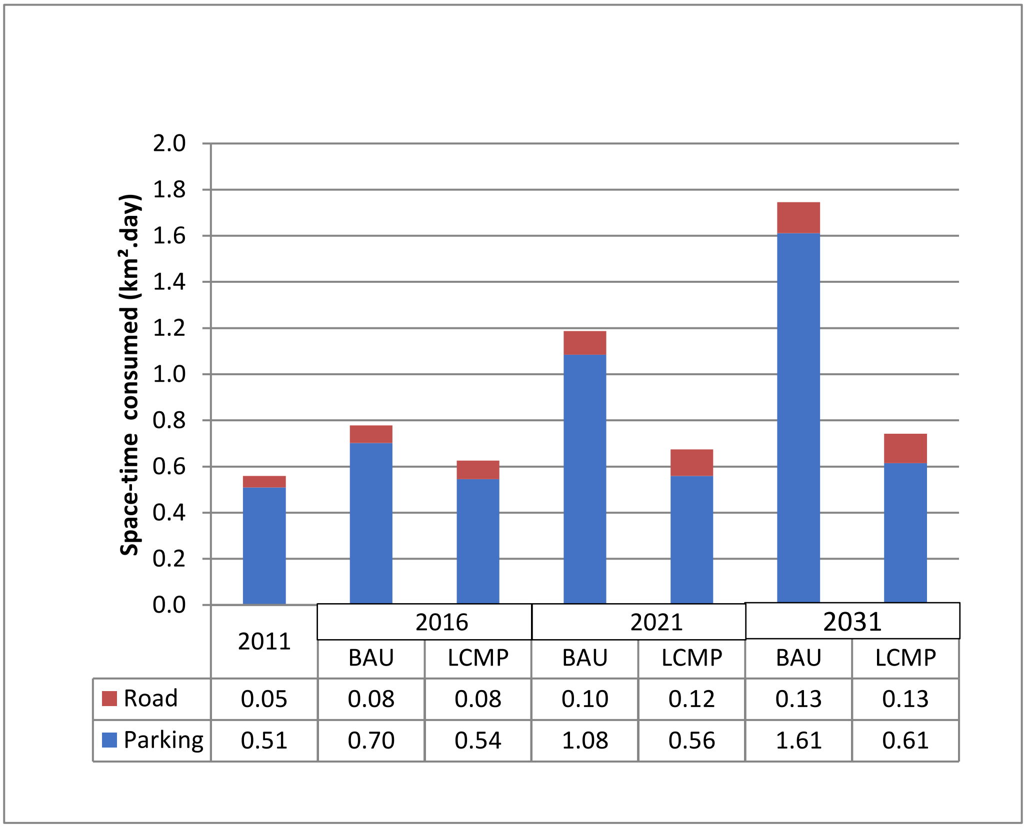
4. results

4.1. Space-time consumption on-road and parking

The space-time consumed by transport is expected to multiply by a factor of three in year 2031 if the current motorization trends remain (Figure 3). The parking space-time accounts for most of the total space-time used by transport in both scenarios. The LCMP scenario is able to meet the anticipated space used by transport and shows a potential reduction by half by 2031 compared to the BAU scenario. This mainly comes from the LCMP scenario cutting down the use of individual motorized vehicle, enabling a shift to NMT and PT modes, which are low space-time consuming modes. Moreover, the urban space-time consumed turns out to be more evenly distributed between modes in the LCMP than in the BAU and base-year scenarios (Figure 4). In the BAU and base year scenarios most of the space is used by motorized vehicles, whereas in the LCMP scenario NMT and PT take a higher share of transport space use.

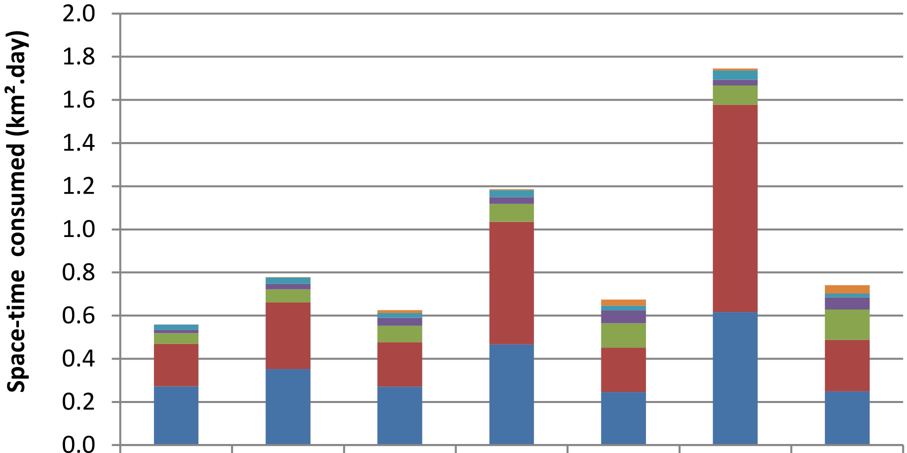
The mobility levels in the BAU and LCMP scenarios are fairly similar, at around 20 million passenger kilometers travelled per day according to the transport model by Munshi et al. (2014) The shift from individual motorized modes to NMT and PT modes is thus not decreasing the mobility in the LCMP scenario, indicating no direct correlation between the mobility level and the space consumed. The ratio of passenger kilometers travelled and space used is respectively the lowest for buses, followed by pedestrians, cycles, motorized two-wheelers, and cars, a ranking consistent with previous studies (Héran and Ravalet, 2008).

The geographically disaggregated values in Figure 5 localize the distribution of the space released in a LCMP transport development compared to a BAU scenario. The shift to low space-time consuming modes expected to take place in the LCMP scenario decreases the space-time consumed in all areas. More space is expected to be released in the peripheral areas as the LCMP hinges upon a compact city development model.



	2011	2016		2021		2031	
		BAU	LCMP	BAU	LCMP	BAU	LCMP
🟥 Road	0.05	0.08	0.08	0.10	0.12	0.13	0.13
🟦 Parking	0.51	0.70	0.54	1.08	0.56	1.61	0.61

Figure 3: Space-time consumed on-road and parking



	2011	2016 BAU	2016 LCMP	2021 BAU	2021 LCMP	2031 BAU	2031 LCMP
🟧 Buses	-	0.00	0.01	0.00	0.03	0.01	0.04
🟦 Auto-rickshaws	0.02	0.03	0.02	0.03	0.02	0.04	0.02
🟪 Pedestrians	0.02	0.03	0.04	0.03	0.06	0.03	0.06
🟩 Bicycles	0.05	0.06	0.08	0.08	0.11	0.09	0.14
🟥 Cars	0.20	0.31	0.21	0.57	0.21	0.96	0.24
🟦 Motorized two-wheelers	0.27	0.35	0.27	0.47	0.25	0.62	0.25

Figure 4: Space-time used by modes and scenarios

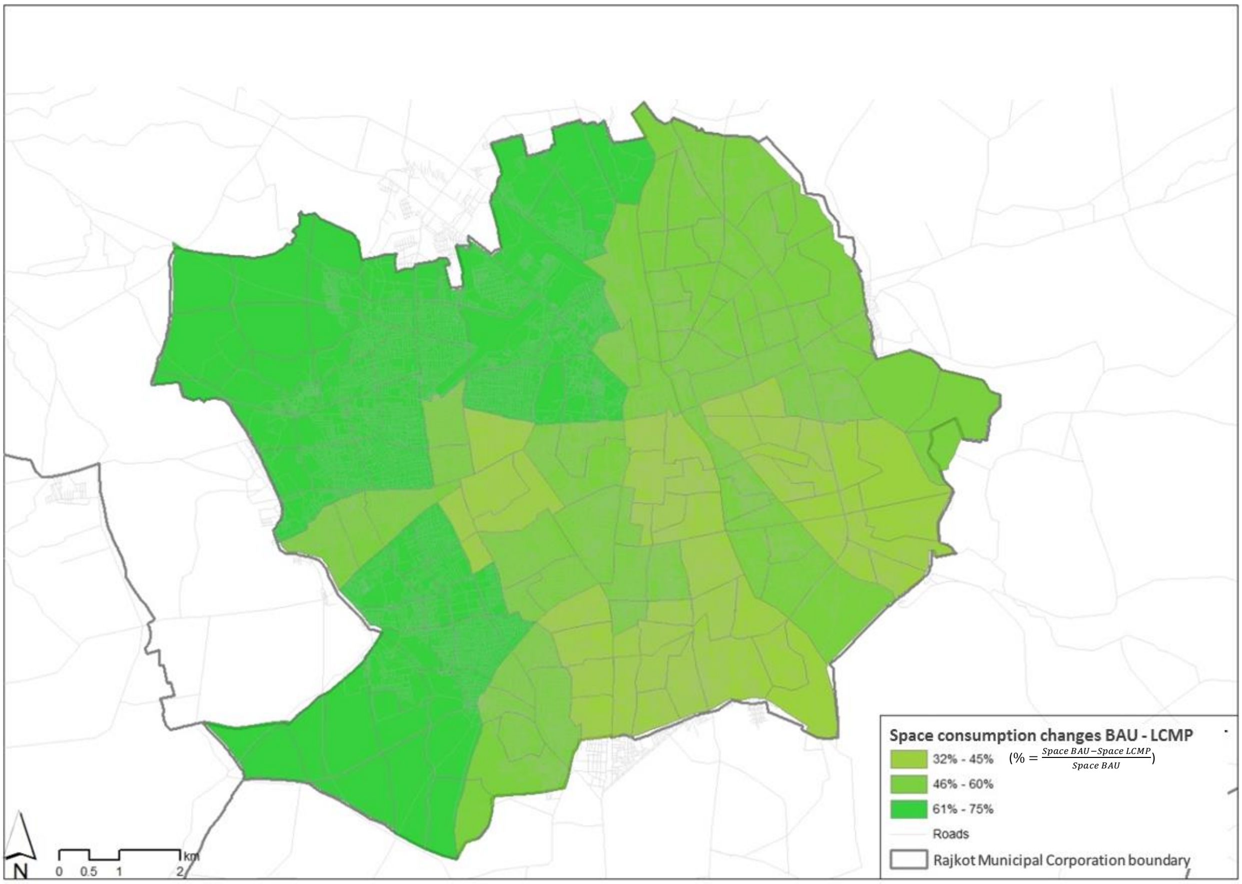


Figure 5: Localisation of the space consumption changes in the low-carbon mobility plan compared to the business-as-usual scenario (percentage reduction in space consumption from BAU to LCMP scenarios).

4.2. Transport ecological footprint

The transport ecological footprint estimates the space that would be required to sequester CO_2 emissions from transport. The physical footprint, estimated for the base-year only, represents only a small share of emissions compared to the energy footprint (Figure 6). The LCMP transport system relies on low-carbon modes, enabling the predicted (and considerable) expansion of the energy footprint of a BAU scenario to be lowered.

The transport ecological footprint raises the question about a possible ecological spatial *threshold*. The Rajkot district has a forest area of 166 km^2 (Government of Gujarat, 2016). Under the current methodology, the ecological footprint would reach the absorbing capacity of the area for the base-year, and would exceed it in all scenarios (illustrated by the green dotted line in Figure 6).

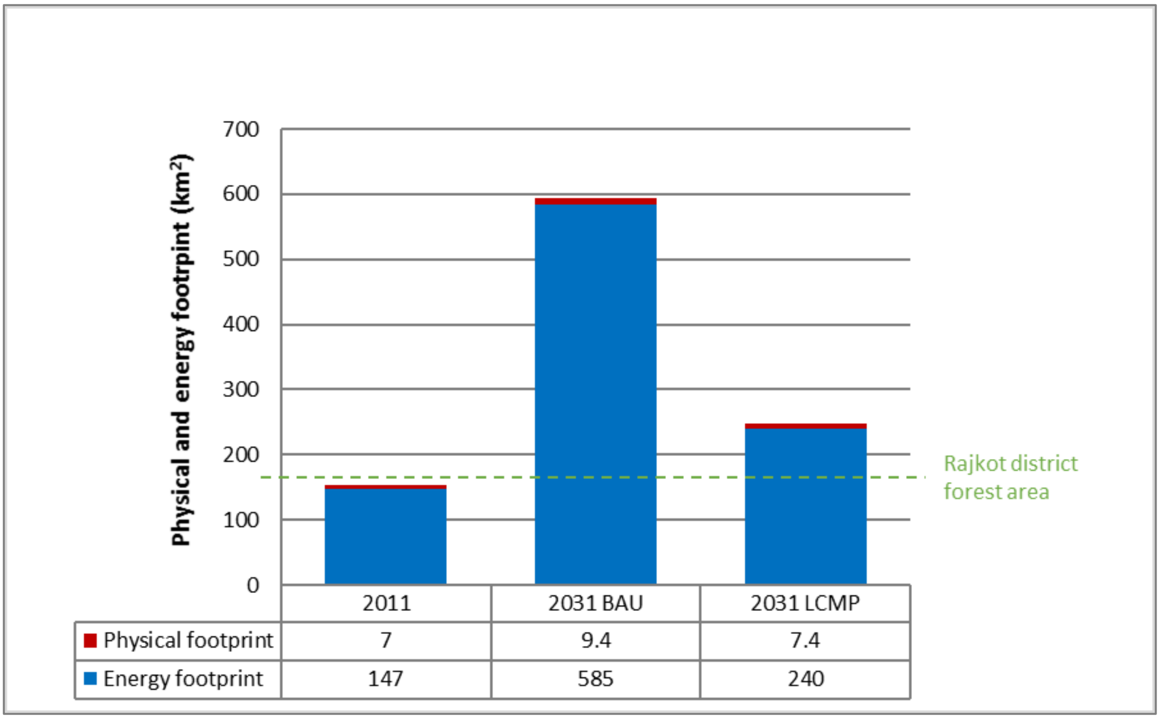


Figure 6: Transport ecological footprint and CO2 absorption threshold based on existing forest area in Rajkot district (green dotted line)

5. Conclusion

There is little empirical evidence available in scientific literature on time and space used by different transport modes. The objective of this paper was to investigate space-time consumption and assess whether investments in NMT and PT lead to more efficient and sustainable transport space planning and infrastructure provision. The analysis builds on the transport model developed for Rajkot City by UNEP’s Promoting Low Carbon Transport project.

In doing so, this paper presents a methodology to quantify space used by modes through time, which can be applied in complex Indian urban settings. The space-time consumed by vehicles while travelling on-road and when parked give a good indication of differential space consumption by modes. It is clear from the work presented here that in Rajkot cars consume a significant proportion of road and parking space, but provide mobility to only a few, whereas walking provides mobility to a large section of population while consuming very little road space.

In dense urban settings like in Rajkot, physical space is scarce and policies should therefore aim for optimal use. Based on low carbon mobility plans prepared for Rajkot, it can be established that if adequate and properly designed infrastructure is provided for NMT, a large section of existing NMT mode users can be retained and some of the non-users can shift to these modes. The space-time consumed results (Figure 4) show that more mobility can be provided in the city with little addition to overall transport space. As motorized transport modes emit between a quarter and a third of total CO_2 emissions, the ecological footprint indicator is used to indicate the amount of forest area required for sequestering these emissions. From the ecological transport footprint (Figure 6), it is obvious that without intervention to support sustainable transport modes like NMT and PT, CO_2 emissions are likely to increase beyond the CO_2 sequestering capacity of the Rajkot district. This has strong negative implications for climate policy.

The presented methods can be improved further by incorporating actual travelling speeds instead of average speeds, which would take into account the effect of congestion and potentially play a significant role in travelling time calculations. The dynamic space determination reference used (N. Y. Cao, K. Sano, 2012) may also gain from a more precise and empirically-derived methodology on dynamic space values for the Indian context, especially for motorcycles. The parking fleet size considers travelling vehicles only, inferring that there are no more vehicles than the ones used daily, which may underestimate the actual number of parked vehicles. The baseline model could overall be verified via traffic counts. The road occupancy ratio calculated for year 2011 in this model is comparable to the one calculated in the Paris' case study (Héran and Ravalet, 2008) when taking similar parameters (vehicle size namely), expressing quantitatively sound results.

For the ecological transport footprint, accurately assessing local forest absorption capacity demands a detailed knowledge of numerous parameters such as forest management and the type of soil and biomass. Nevertheless, the methodology implemented uses a carbon sequestration value within the range of potential values for Indian small holding agroforestry systems (Dhyani et al., 2009). Emissions from road construction and maintenance are derived using global adjustment factors (Wackernagel and Rees, 1996) that could be further adjusted the local context.

In conclusion, the approach presented here is a model designed to draw attention towards differential space-time consumption by transport modes and can be used by urban and transport planners in its present form to account for the important issue of space in future transport infrastructure assessment and decision-making processes.

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