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Assessing the Role of Modal Shift in Minimizing Transport Energy Consumption, a Case Study of Kathmandu Valley

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Abstract:
With rapid growing economies and population, there is an increasing trend of expansion of urban sprawl and auto-mobilization, in the cities of the Kathmandu Valley. With the rise in travel demand, transport energy is becoming a major concern for planners and policymakers. This paper aims to study the transport energy of daily trips that constitute work and educational trips, in context of the Kathmandu Valley. The study demonstrates the applicability of a 4-step travel demand model for the assessment of energy-saving measures in urban transport system by formulating scenarios. The results show that currently, daily trips consume 3666 TJ annually. Cars and motorcycles contribute to most of the consumption, accounting for over 80% of the total transport energy. As a mitigation measure to reduce transport energy, the introduction of the efficient public transport system in the form of Bus Rapid Transit System (BRTS) along major corridors, could bring down transport energy consumption significantly. The paper concludes with the essence, to address the need for modal shift to the mass transit system, as a step towards the minimization of transport energy.

Keywords: Transport energy, Work trips, Educational trips, Kathmandu Valley, Public Transport

1 Introduction

Energy consumption and emissions from the transport sector continue to rise, adding to growing concerns about the environmental impacts caused by transport systems and related travel behavior and land-use patterns. Urban areas account for 75 % of global energy consumption and nearly 80 % of greenhouse gas emissions [1]. Growing urbanization and increase in urban sprawl also lead to a rise in urban transport energy consumption level with an increase in commuting distance. As per IEA [2], the transport sector accounts for up to 27% of the global energy demand. EIA [3] projects that world energy consumption will grow by 56 % between 2010 and 2040. Total world energy use rises from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040.

It is now a major concern to promote energy efficient transport system to minimize energy consumption and cut-down emissions. Transport is invariably deemed to be the most difficult and expensive sector to reduce energy demand and greenhouse gas emissions [4,5]. Mainly private motorized transport needs to be reduced, while the share of non-motorized and public transport (PT) must be increased to achieve energy efficiency [6]. The urban mobility patterns and related energy consumptions are affected by the dimension, density, design and the level of transport service within the city, as well as by socio-economic features [7]. Many of the previous studies showed that the most significant increase in fuel consumption and emissions is taking place in cities, where there is a rapid increase in urbanization and concentrated economic activities [8]. An effective way of reducing car dependency of the cities and the related energy consumption is to properly integrate land use and transport planning [9,10].

Urban policies, aiming at compaction and modal shift are considered important measures for saving energy from the transportation sector. Cities can become more compact or public transportation-oriented by prompting the actors of the urban system to modify their behavior; changing household locations, moving company office locations, and expanding transportation modes for a wider range of travel purposes [11]. Newman and Kenworthy [12] found that transport-related fuel consumption is reduced by urban density. The idea is that higher density increases the probability of shorter trips and the attractiveness and feasibility of walking and using public transport. This leads urban planners to favour mixed-use, transit-oriented compact cities as opposed to low density, car-dependent and sprawled cities [13].

It has become a major challenge for developing countries due to poor state of urban mobility as a result of rapid unplanned development. Thus, researchers and planners in the field of transport planning and management have continually sought effective methodologies for analyzing and solving urgent transport issues in these cities [14]. Advanced transport modeling approaches such as disaggregate activity-based modeling methods have been efficiently applied for the study and improvement of urban transport conditions in cities in developed countries, in attempts to analyze and resolve the urban transport problems [15]. However, valid analyses of the urban transport studies of developing cities remain very difficult, because elementary trip survey data are still quite scarce, and the available data mostly are of poor quality and often are not shared among planning agencies [16]. Thus, advanced modeling techniques, which usually require a more detailed trip and activity data, are very difficult to apply. Therefore, the conventional aggregate four-step modeling process, which is customarily estimated sequentially, is still the most widely applied method because of its practicability [17,18].

The objective of this paper is to analyze the influence of daily trips that includes work trips and educational trips, on urban transport energy consumption, in the context of the Kathmandu Valley. The study is aimed to demonstrate the applicability of an Urban Transport 4 step model for the assessment of energy-saving measures in urban transport system by the modal shift from private to public mode.

2 Case Study

The study area for the research is the Kathmandu Valley of Nepal, that comprises of three districts, Kathmandu, the capital city, Lalitpur and Bhaktapur with a population of about 2.5 million as per the census of 2011 [19] and the total area of about 665 sq.km. Kathmandu Valley is the nation's main attraction center as it is the major hub of opportunities that include wide varieties of economic activities like job and business opportunities, industries and education. Work trip and education trips combined have a share of about 73% in Kathmandu valley and their share has increased significantly, overtime [20].

Growth in population has led to a sharp increase in travel demand. Urban mobility is affected by the unmanaged roads, increasing use of private vehicles (motorcycles and cars), low occupancy public vehicles (micro bus and tempos). Share of private vehicles in the trips is becoming more dominant. Roads are heavily congested, resulting in delays due to increased travel time, along with air pollution, noise pollution and other problems, resulting in inefficient urban mobility. The number of vehicles has increased drastically in the past few years. And more alarmingly, ownership of private vehicles is rising up rapidly (Table 1).

As per data of NOC [22], the national annual sale of petrol has risen from 31061 Kiloliter (KL) in the year 1993/94 to 283,567 KL in the year 2014/15 and that of diesel from 195,689 KL to 901,393 KL in the same period. The trend is clearly showing a steep rise in the consumption of fuels and transport sector is the main sector, where fuel is consumed heavily. 57 % of the total national petroleum products are used up by transport sector alone as reported by WECS [23]. Nepal does not have oil production and all commercial fossil fuels are imported from international markets. So, it has become a major concern to look for planners and policymakers, the ways to achieve energy efficiency in the urban transport sector, to cut down escalating energy demand.

3 Materials and Methods

3.1 Building of 4 step transport model

Urban Transport Model System (4-step transport modelling) consists of Trip Generation, Trip Distribution, Modal Split and Route Assignment. The framework of the transport model developed for this research is illustrated in Figure 1. There are 131 traffic analysis zones (TAZ) that are based on population census boundary. All the areas with forest, that are along the edge of the valley are excluded from the study area. Household survey was carried out in various locations of the study area, to collect travel characteristics data of workers and students for

Table 1: Vehicle Registration Data (Cumulative) for Bagmati Zone (1989/90 - 2016/17), Source: DoTM [21]

Year	Bus	Mini Bus	Car/Jeep/Van	Micro Bus	Tempo	Motorcycle	Others	Total
1989/90	797	1,028	9,868	-	507	18,594	3,812	34,606
1999/00	2,126	2,219	29,697	-	2,133	94,081	12,822	143,078
2009/10	6,140	5,784	68,132	1,440	2,515	394,420	27,704	506,135
2016/17	11,784	11,967	139,981	2,345	2,528	817,473	56,778	1,042,856

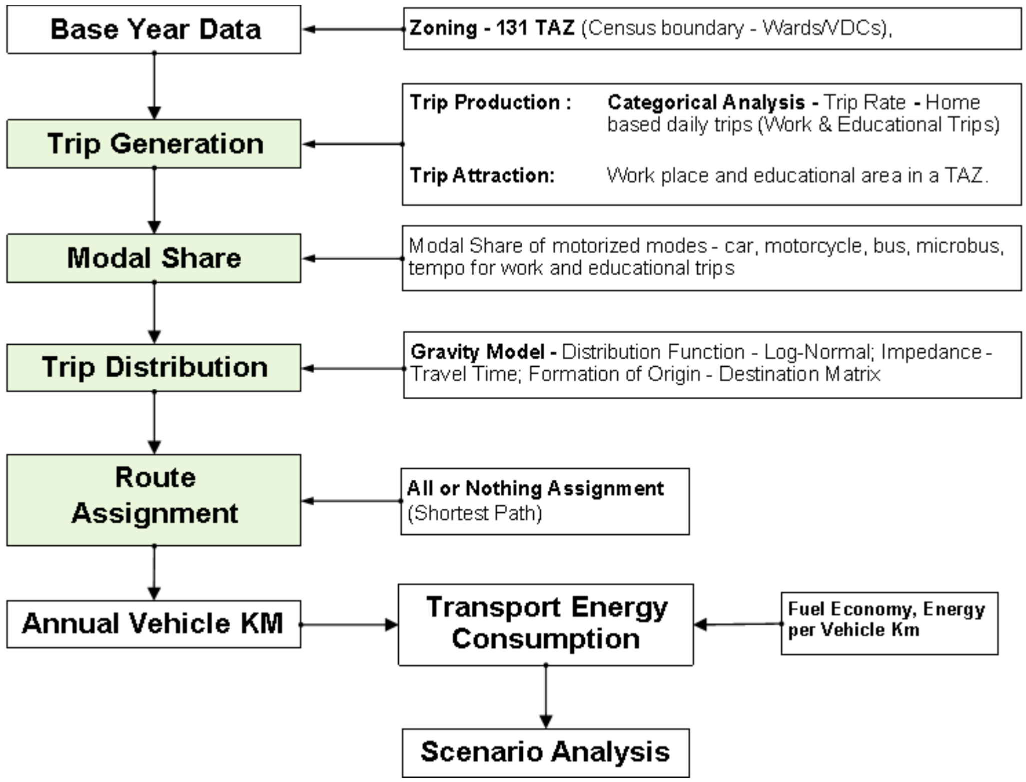


Figure 1: Framework of Transport Model

commuting their work and educational trips respectively. Sampling was done using stratified proportionate random sampling, to have coverage over the study area, in proportionate to the number of households, by diving the survey area into several zones. In total, data was collected from 2300 households, that includes travel data of 2659 educational trips and 3602 work trips, collected from household members, who are students and workers. For the model, only trips made by motorized modes were included. Non-motorized modes were excluded in the model as these are presumed to be intrazonal and do not contribute to transport energy consumption and thus, they were not included in the model. OmniTRANS software was used for transport modeling and for visualization, Geographic Information System software - QGIS and ArcGIS were used.

Trip Generation: Trip generation consists of trip production and attraction. The number of work and educational trips from each TAZ were derived from category analysis for trip production. Work trip rate and educational trip rate were obtained from Household survey data. For trip attraction, the basis was the area of workplace and educational institutions in each TAZ, which were obtained from secondary sources, mainly from Open Street Map database.

Modal Share: Share of each mode was obtained from household survey data for work and education trips. For each mode, trip distribution and trip assignment were carried out, separately.

Trip Distribution: For distribution of trips, gravity model (Equation 1) was used, with standard distribution function as in Equation 2 [24], with travel time as impedance. Travel time for each mode was calculated based on the average journey speed of the mode (Table 3).

$$T_{i,j} = a_i b_j P_i A_j f(c_{ij}) \tag{1}$$

$$f(c_{ij}) = \alpha e^{\beta . ln^2(c_{ij}+1)} \tag{2}$$

where,

C_{ij} = Cost for traveling from zone 'i' to 'j' (travel time)

α, β = Parameters of the impedance function

For estimation of parameters, model calibration was done, by comparing average trip length and using coincidence ratio. Observed and estimated average trip lengths were made within 5 % difference. Coincidence ratios were used as a measure of how close the estimated trip frequency distribution is to the observed distribution for each mode. It varies from 0.7 to 0.8 for different mode. For all motorized modes, intrazonal trips were restricted, assuming that, these trips belong to non-motorized modes.

Trip Assignment: For this research, All or Nothing assignment has been used in traffic flow assignment, which assumes that people take the shortest route from an origin to a destination. Trip assignment validation involves comparing model generated link volumes compared to traffic counts. The model was validated using traffic counts for each mode, taken at major road segments. The difference was calculated between observed and estimated values and it varies from 5 to 20%.

Scenario Analysis: Scenarios are a commonly employed technique for evaluating the merits and effectiveness of alternatives. The model was developed for the base scenario and proposed scenarios to assess transport energy consumption pattern.

3.2 Calculation of Annual Transport Energy

Total energy consumption was calculated for each mode and then it is summed to get total transport energy. Vehicular distance for each mode was derived from the route assignment step of the model. Transport Energy for one-way trip from home to destination was obtained using Equation 3 and then it was converted to annual energy, as shown in Table 2.

$$TE_{one-way} = \sum_{i-1}^{n}\sum_{j=1}^{n} V_{i,j} \times E_j \tag{3}$$

where,

$V_{i,j}$ = Vehicular distance for trip purpose 'i' (work/ educational trips) for mode 'j' (motorized modes)

E_j = Energy consumed per km by a mode (Table 3)

Energy figures for all modes are only for the operational phase and do not cover those used up during other stages of its lifecycle. Table 3 shows the mean energy consumption for different modes obtained from various sources. The variation of vehicle type within a mode category is not shown. For instance, there are different kinds of bus operating and all these are aggregated into one group with the average figure of fuel economy. Same applies to other modes as well. For car and motorcycles, fuel economy is obtained from household survey data, and for bus, it is from the survey of bus drivers. For tempo, which is a three-wheeled electric vehicle, having a maximum capacity of ten passengers, is operated as a public vehicle along specific routes. For fuel economy, data obtained from survey, is only an approximate figure. However, it still reflects local driving conditions, as standard figures of fuel economy are often high, which does not consider actual driving conditions. For walking and bicycle, energy consumed is taken as zero.

3.3 Limitations of the model

For the trip distribution model, due to the unavailability trip attraction data, area of workplace and educational institution in each TAZ, has been used as a basis for trip attraction. As these are the approximate ways of processing the data, it could have an implication on the accuracy of the resulting trip distribution. For accurate trip attraction results, a survey is required to be done for trip attraction as well. For modal split, as discrete choice models were not used, the share of each mode was derived from the household survey data and for each mode, trip distribution and trip assignment were done separately. The shortest path method, used in the trip assignment, neglects the congestion effect, thus giving a fairly accurate flow pattern. The average journey speed data, obtained from the household survey, is the average speed of travelling, derived for each mode. The use of same speed data for all the road segments, ignores the variation of travel time across different road segments.

4 Scenario Analysis

4.1 Base Scenario

Base scenario presents the current situation of the transport system, for the base year, 2017. Private vehicles have a high modal share, nearly 50%, and public transport has about 31% and non-motorized modes, about 19% for daily trips (Table 3). Average trip distance for motorized modes is found to be 4.59 km. From the result of the model, total annual transport energy consumption for work and education trips combined, is found to be 3,666.9 TJ in the base scenario (Table 5). When analyzing the energy consumption by mode, private vehicles have quite

Table 2: Calculation of Annual Transport Energy Consumption

SN	Particulars	Energy	Calculation	Remarks
1	Daily one–way Energy	E_1	From Equation 3	
2	Daily two-way Energy	E_2	E_1 x 2	Assuming that, commuters travel same way in returning home, as going from home to work place or to school
3	Annual Energy Consumption	E_3	E_2 x 280	Average number of working days in a year is derived by deducting Saturdays and public holidays.

Table 3: Vehicle Efficiency

Mode Category	Travel Mode	Modal Share [1]	Fuel Economy (km/L)	Average Occupancy [2]	Average Journey Speed (km/hr)[1]	Fuel	Energy Density (MJ/L[3])	Energy per km (MJ/km)	Energy per Passenger -km (MJ/p-km)
Private	Car	13.2%	10.0 [1]	1.80	15	Gasoline	34.56	3.46	1.92
	Motorcycle	35.7%	31.0 [1]	1.50	20	Gasoline	34.56	1.11	0.74
Public Transport (PT)	Bus	25.9%	3.5 [2]	35.00	12	Diesel	38.77	11.08	0.32
	Microbus	4.6%	7.5 [2]	15.00	13	Diesel	38.77	5.17	0.34
	Tempo	1.6%	0.18 kwh/km[4]	8.00	13	Electricity		0.65	0.08
Non-Motorized Transport (NMT)	Walking	18.4%							0
	Bicycle	0.7%							0

Source: [1] Household Survey, [2] Roadside Survey, [3] The Engineering Toolbox [25], [4] Moulton and Cohen [26]

Table 4: Daily Energy Consumption (One-way)

Travel Mode	Daily Vehicular Distance (km)	Energy per km (MJ/km)	Total Energy (MJ)	Total Energy (GJ)	Percentage
Car	726,591.8	3.46	2,514,007.5	2,514.0	38.4%
Motorcycle	2,702,703.7	1.11	3,000,001.1	3,000.0	45.8%
Bus	74,290.4	11.08	823,137.4	823.1	12.6%
Micro	39,135.8	5.17	202,332.2	202.3	3.1%
Tempo	13,057.6	0.65	8,487.4	8.5	0.1%
	Total Energy Consumed:		**6,547,965.6**	**6,548.0**	

Table 5: Annual Energy Consumption

SN	Particulars	Notation	Total Energy	Calculation
1	Daily Transport Energy (One–way) GJ	E1	6,548.0	From Table 4
2	Daily Transport Energy (Two Way)	E2	13,095.9	E1 × 2
3	Annual Energy Consumption	E3	3,666,860.7	E2 × 280
4	**Annual Energy Consumption (TJ)**	**E4**	**3,666.9**	E3 / 1,000
Energy Units - MJ: Mega Joule; GJ: Giga Joule; TJ: Tera Joule				

a high figure. Motorcycle contributes to about 46% share and car, 38% (Table 4). In contrary, public vehicles have far less share, only about 16%, combined.

4.2 Proposed Scenarios

Public transports can help reduce transport energy significantly if more commuters start to use them. Bus Rapid Transit system (BRTS) is a high-quality bus-based transit system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated lane or right-of-way. It combines the best features of metro rail with the flexibility and cost advantage of road transit system [22].

Kathmandu Sustainable Urban Transport Project (KSUTP), initiated by the Government of Nepal (GoN) and Asian Development Bank (ADB) has identified major routes for public transport for efficiently operating public transport system. As in this research, the route feasibility study is not within the scope, the primary PT routes (Figure 3), proposed by KSUTP has been used for the formulation of scenarios, and these are identified as BRTS routes. For formulating scenarios, it was proposed to have improved public transport system with Bus Rapid Transit System (BRTS) along the BRTS routes, with following features:

High Occupancy, Mass Transit Service along primary routes, as proposed by KSUTP.

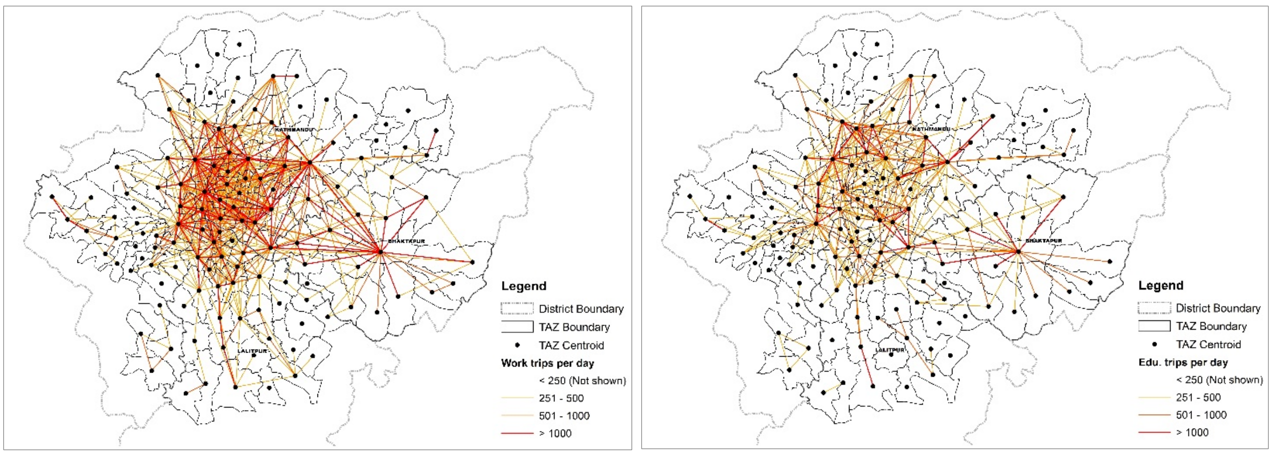
Average Occupancy: 50

Energy Consumption by BRTS bus: 12.9 MJ per km (3 km per liter). It is derived from the average fuel economy of currently operating high occupancy bus, of Sajha Yatayat, one of the operators of public transport in Kathmandu Valley TAZs, that have their centroid within 1 km from the route are assumed to the zones accessible to BRTS, for both origin and destination. There are in total 50 traffic analysis zones that are within 1 km buffer range from the BRTS route. These are the zones, supposed to be within the service area of the BRTS.

For the scenario analysis, trips were categorized into three sets, as follows:

U: Universal set: This includes the trips in all zones. The total Origin-Destination (O-D) pairs generated is 131 × 131, that equals to 17416 O-D pairs for each mode (Figure 2).

S: Subset of U: This includes the trips between the 50 TAZs, that have their centroid, within 1 km buffer from the BRT route. The O-D pair for this case is 50 × 50 i.e. 2500 O-D pairs for each mode (Figure 3).



(a) (b)

Figure 2: Desire Line Diagram (a) Work Trips, (b) Educational Trips (Universal Set: U)

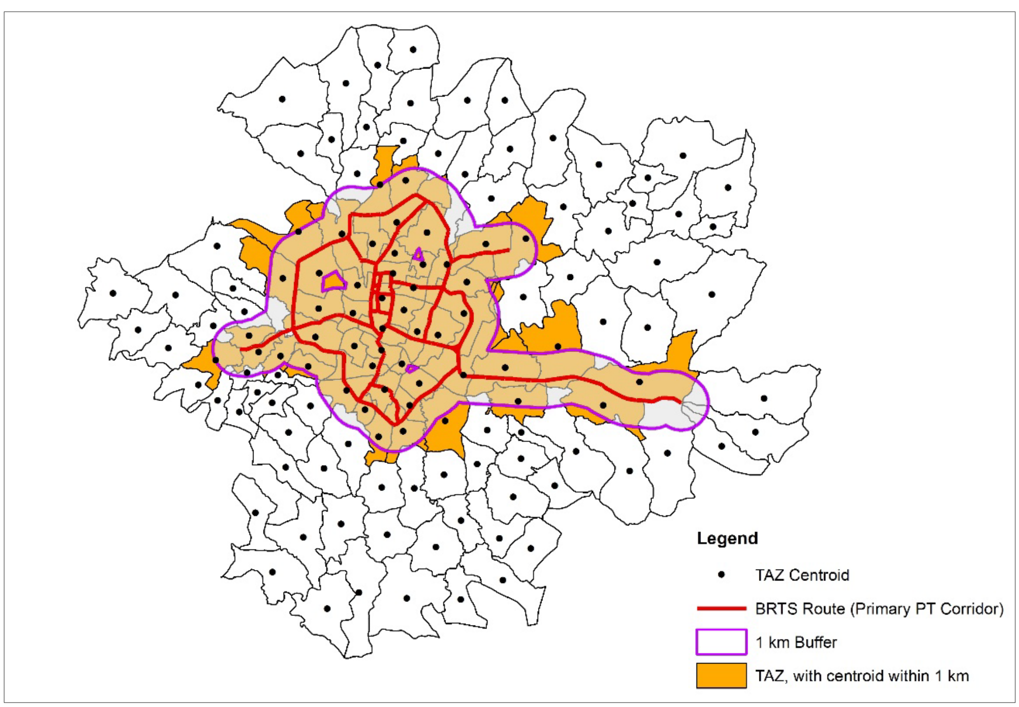


Figure 3: BRTS Route and TAZs within 1 km

S_{Pr} : Subset of S: This is the subset of S, that includes all trips between the 50 TAZs for private modes. It is only on this subset, that the modal shift was applied for the scenario analysis

Based on the potential shift to public transport from private modes, two scenarios were formulated. The purpose of the formulation of scenarios is to estimate the reduction in transport energy consumption when shifting from private to the new BRTS system. Modal shift is applied to Subset: S_{Pr}, that constitute all trips of all private mode along the corridor zones. The possibility of the BRTS use via feeder mode was not taken into account, which in reality, may constitute some portion of the BRTS trips.

4.2.1 Scenario 1: Shifting to BRTS from private modes, based on willingness to shift

From the household survey, it was found that 55.6 % of the car users and 72.2 % of the motorcycle users are willing to shift to public transport, if service is good enough, in terms of punctuality, comfort and safety. Assuming that, the new proposed BRTS meets their expectations, the shift is assumed to be the same in this scenario. All existing buses would be replaced by BRTS in its route. However, the share of other public modes microbus and tempo, is assumed to be same.

Comparing Transport Energy of two scenarios, overall

Overall, when we consider trips of all of 131 TAZ (Universal set: U), it is showing a difference of 20 % reduction in annual transport energy consumption (Table 6), due to shift from private to BRTS. This comparison is for all areas in the valley and not all zones have the BRTS, accessible. So, the difference is not explaining the net change. For those trips, not affected by the new system, the transport energy remains the same in both scenarios. For those zones, not in access with the new system, no change is observed in their trip characteristics, in both scenarios. Also, trips that take place from the corridor zone to off-corridor zone and vice versa are not affected.

Comparison Transport Energy for trips along the corridor zones

To have a clear understanding behind the change, it is necessary to identify the trips having both origin and destination within 1 km from the BRTS route i.e. Subset S, that includes only the trips along corridor zones (50 zones) as shown in Figure 3. When the comparison is made for only these trips, there is a considerable difference of 44% reduction with respect to base scenario, reducing annual transport energy from 1686.3 TJ to 739.6 TJ (Table 6).

4.2.2 Scenario 2: 90% modal shift

In this scenario, a hypothetical situation, whereby an ideal scenario was proposed, assuming that 90 % the private vehicle users shift to BRTS, since achieving 100 % is never possible. In this case, there is a reduction by 28% overall and by 62 % for trips along 50 TAZs with access to BRTS, when comparing with the base scenario.

5 Discussion and Conclusion

In this paper, 4 - step urban transport model was developed to predict the travel pattern of work and educational trips and to assess transport energy by analyzing scenarios. With growing population, the cities within valley there is a sharp rise in travel demand. Introduction of a mass transit system such as BRTS can be regarded as a step towards a sustainable transport system in terms of cost-effective solutions for minimization of transport energy and less impact on the environment. Its implementation is expected to improve the transport system of the Kathmandu Valley. With its good service in terms of timely service, reasonable fare and good comfort level, as compared to the existing bus service, more people are expected to use the newly proposed system, once the service is in operation. The service should mainly target work trips and educational trips, as these trips have a significant share and the valley is and will be the main center for employment and educational opportunities.

Table 6: Scenario Analysis

S. N	Scenario	Trips: Overall (Univ. Set- U: 131 × 131)			Trips: Subset – S (50 × 50)		
		Annual Energy Consumption (TJ)	Difference		Annual Energy Consumption (TJ)	Difference	
			TJ	%		TJ	%
1	Base Scenario	3,666.9			1,686.3		
2	Scenario 1 (Willingness to Shift)	2,927.3	739.6	20%	946.7	739.6	44%
3	Scenario 2 (90% Shift)	2625.4	1041.4	28%	644.9	1041.4	62%

The result of the base scenario shows that currently, daily trips consume 3,666 TJ annually. Cars and motorcycles contribute to most of the consumption, accounting for over 80% of the total transport energy. Accessibility to public transport and its level of service, have an important role to play in its ridership. More is the ridership; more is the reduction in energy consumption. 90% shift from private to BRTS can reduce annual transport energy consumption by 62 % on trips along the zones with access to the service. This may be difficult to achieve. However, as per the current willingness to shift, the reduction can be up to 44 % as revealed by scenario 1. For further reduction, the routes are to be expanded to other areas as well. This increases the accessibility of the service to more commuters and accordingly share of the bus can be expected to rise. So, route feasibility studies are to be made intensive and accordingly new mass transit bus routes are to be identified. For more shift, bus service should be providing good service to the public, in terms of timely service, comfort and safety. If all these conditions could be fulfilled, the outcome will certainly be beneficial, that will help to reduce transport energy to a much greater extent.

6 Further Research

In this paper, only work trip and educational trips are analyzed, to study the travel pattern and travel energy of daily trips. Other trip purposes and freight transport were not included in the study, which will also have some share of transport energy consumption. The shift to non-motorized modes of transport can also help to reduce transport energy, which has not been discussed in this paper. The transport model could further be improved with additional surveys and the availability of more data.

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