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Journal Article

Urban Design and Planning

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ice | proceedings

Proceedings of the Institution of Civil Engineers

http://dx.doi.org/10.1680/jurdp.15.00015
Paper 1500015
Received 09/02/2015 Accepted 31/10/2015
Keywords: pollution/sustainability/transport planning

Designing and modelling Havana's future bus rapid transit

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A single bus route in Havana's bus system is modelled from the current position to a modernised bus rapid transit (BRT). The system is based on an expert-led visioning process and Cuba's official planning documents, which define the high-level design criteria and their objectives. Building on the experiences of BRT systems that operate in other Latin American cities, a conceptual design for Havana's BRT system is defined in terms of the key institutional, technical and financial frameworks, and physical criteria that need to be considered. Based on the application of the conceptual design for Havana's BRT, a model for a single BRT route was constructed and modelled for emissions and capacity. The current situation and a future BRT scenario are modelled using a single bus route. The scenarios demonstrate that the current bus route with a BRT system can lead to lower overall emissions. The model suggests that if properly designed, Havana's BRT system has a realistic potential for providing, in a cost-efficient manner, the improvements in accessibility, employment generation, fuel efficiency and air quality required for achieving Havana's sustainable transport vision. The study finds critical factors, including the finance and business operating model, capability and planning.

1. Introduction

A major visioning workshop was held in Havana that focused on the theme of sustainable and equitable transport by using a series of key questions for stakeholders. The outcomes of the workshop are described elsewhere (Warren *et al.*, 2015) and included transport visions, including bus rapid transit (BRT), trams, light rail, cycle schemes, pedestrian zones and congestion charging aligned to an overarching set of policy guidelines. This study considers one piece of those visions – BRT – and uses an incremental series of phase changes to derive the current emissions of the bus fleet and then models how these might change if a BRT system was utilised for Havana. The study also outlines some possible limitations for BRT systems and some possible suggestions for the way forward for a more sustainable transport public bus system for the capital city of Cuba. The study is a conceptual exercise to highlight the key elements for consideration in order to be successful. This study distils the extensive literature on BRT guidelines and case studies to present guidelines for the conceptual design of what could be for Havana the first formal, dedicated BRT line.

The BRT concept is as wide as the variety of existing systems, partly due to its flexible nature and adaptability. Generally, BRT systems are defined in terms of its characteristics as 'a high-quality bus-based transit system that delivers fast, comfortable and cost-effective urban mobility through segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. BRT emulates the performance and amenity of a modern rail-based transit system but at a fraction of the cost (Wright and Hook, 2007). The main features of BRT include: (*a*) central control, (*b*) mass transit image, (*c*) efficient bus operations, (*d*) performance- and customer-oriented management and (*e*) a commercial business model. The critical design elements are: (*a*) adequate station capacity and intersection control, (*b*) overall system capacity and (*c*) commercial speeds (Finn and Muñoz, 2014). A BRT is a high-quality customer-oriented public transport system that is fast, safe, comfortable, reliable and cost effective (UNH, 2013).

Havana's current bus system, *Sistema Metrobús*, is a conventional bus system, particularly inexpensive for users but the very low ticket price may also present future challenges. The context of transport provision in Havana is very peculiar, especially compared with other cities in Latin America. Due to the specificities of the socio-economic environment in Havana, the public transport system serves a limited amount of the potential travel demand of the city with an average of just 0·4 trips per person (Arias, 2014) undertaken daily in the city; Havanian officials call this unit 'the mobility index' (Arias, 2014). It is defined as the number of trips taken each day divided by the population and is usually lower than the overall supply. Total places (seats or seat km) supplied daily is higher, but due to systemic inefficiencies there is still unmet demand during peak hours. Typical daily demand for similar sized cities, such as San José, Montevideo, León, Curitiba and Caracas were 0·5–0·9 trips per person using the public transport (OMU, CAF, 2015, 2009). For Havana, this means that despite having high levels of health, education and cultural services and a wealth of activities, unless provided within short distances, the accessibility to these opportunities is limited. Responsibility for transport provision has been given to competing private providers as a way to tackle chronic problems of fuel theft within the context of limited fuel supply, but not necessarily as a strategy for improving transport service quality (Morris, 2014).

A new BRT system can be a tool for transforming mobility services in cities, especially in developing countries, and a first step for designing it is the understanding of structural transport problems that the city is facing. Understanding the structural problems will facilitate the definition of a vision of how the mobility service will be when the critical transport issues are solved. The exercise of understanding the structural causes of transport problems needs a thorough analysis that goes beyond the common identification of symptoms of problems to go to the actual main causes. For brevity refer to Gugger and Spörl (2008) for a comprehensive list of transport-related issues or Piercy *et al*. (2010) for a historical perspective on the transport policy in Havana. The transport situation in Havana is detailed in the following section.

2. Havana: geography and transport

Havana's main bus system is characterised in Table 1, which highlights the input variables used in the model in this study. The network uses 18 main routes that feed in all directions towards the centre of the city along with a single system travelling around the peripheral 'ring'. Havana's unique position means that the city is split into zones partly determined by the sea and bay and also according to where major points of activity lie, making the polycentric city travel patterns distinctive. A challenge in modelling the bus system in Havana arises from the lack of precise data, and in some instances this study assumes certain baseline conditions. Figure 1 shows the city limits of Havana and each of the municipalities and their respective population densities. The central city 'hot spot' represents 26%

Parameter	Key value
Bus fleet, fuel consumption and emission levels	450 diesel-powered units, with a mixed fleet using single articulated and biarticulated bodies with reported consumption of 1·46–2·0 km/1 litre, emitting 1335–1830 g/km (carbon dioxide)
Average speed	20 km/h (estimated)
Route description	Average route length 18–25 km with bus stops every 1 km, using 18 routes with six operating depots, with supporting feeder routes and other networks. All buses operate in mixed traffic with no dedicated lanes
Passenger amenities	Limited use of bus shelters, low level of signage, basic maps and scheduling information
Passenger capacity and daily demand	125 seats or places/bus typically serving 860 000 passenger trips/d
Operating day	17 h/d (06·00–23·00 for most routes) normally for 285 d/year
Fare system	Cost 0·40 CUP/ticket, exact fare required, with fare conductors on each bus (0·40 CUP = 0·015 USD)
City population, area and density	2 117 343 citizens; 727 km^2; 2907/km^2

Sources: Arias (2014), Contreras *et al*. (2014) and DPPF (2014)

Table 1. Description of the current Havana Metrobus network and Havana City (2012)

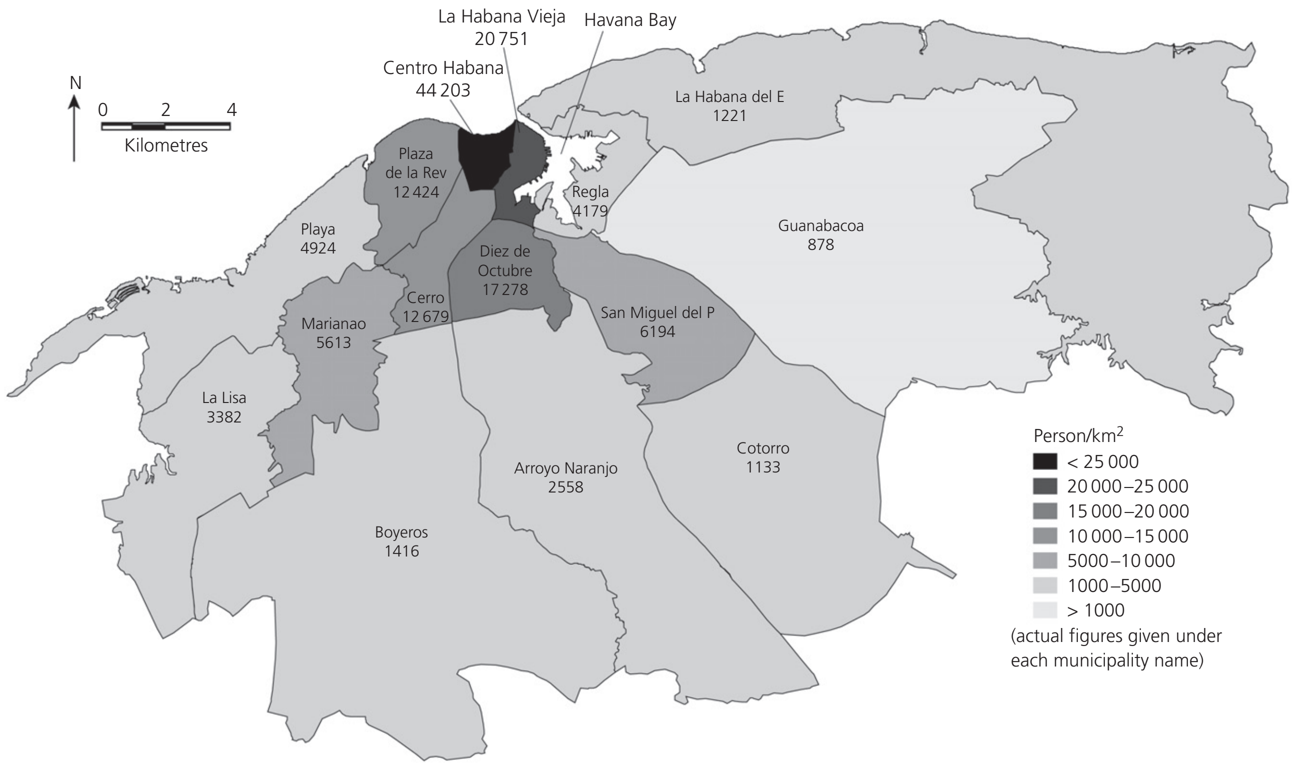

Figure 1. Havana's municipalities and population densities (adapted from DPPF, 2014)

of the population and contains about 37% of employment, creating strong travel destination demand (DPPF, 2014) with many final destinations being in Centro Habana or La Habana Vieja. A large portion of daily movement (22% of all trips) is concentrated in the old city centre. Approximately another 60% of the trip movements lie in the peripheral area and represent people moving around at the edges of the city with another 18% of movement being radially in direction with people heading into the city from the edge or periphery. Havana's movements are frequently termed as being polycentric as motivation for trips is typically from one centre to another.

A mobility index of 0·4 trips/population is met according to the data in Table 1, and it is assumed that demand is much higher than the current supply (Arias, 2014); previous historic levels in the mid-1980s reached 2·1–2·2 trips/person, each day, and it is commonly acknowledged that the demand for transport is much higher than current supply (Mesa-Lago and Pérez-López, 2013). Supply levels of buses were ~2000 and trips supplied peaked at daily trip levels of ~4·3 million passengers during 1984–1987. To achieve higher levels of supply and improve the quality of the service, Havana has as part of its project for restructuring bus-based urban transport a definition of a network with three hierarchies of services: (*a*) main roads network that covers all the city with 18 lines and express and super-express services (known as 'Metrobus'), (*b*) a feeder network and (*c*) a complementary network for sporadic special events. Hence, the BRT systems should be conceived as a 'door-to-door' mobility solution that is part of the defined multimodal system. The feeder network is called '*Omnibus Metropolitano*'. Figure 2 shows all of the public bus routes for the 'Metrobus' and 'Omnibus' along with the airport (in Boyeros), the main bus station and the rail station.

Transport supply is far lower than demand from Havanians, as noted previously, due to many factors. Some transport officials (Arias, 2014) have implied that even if bus-based transport supply would double, or even triple, compared with the current levels, that occupancy would remain high and the majority of places would be filled. It would appear that many city dwellers simply forego some trips or shift to another mode, such as walking or using collective taxi modes, if they cannot get or wait for the bus. Modal splits and trip behaviour are not currently known for Havana, with the last published citywide mobility survey taking place in the early 2000s. A survey was undertaken in 2014 and the results are being formalised during the time of this study. Previously, the city was characterised by high bus use and walking, along with high use of collective

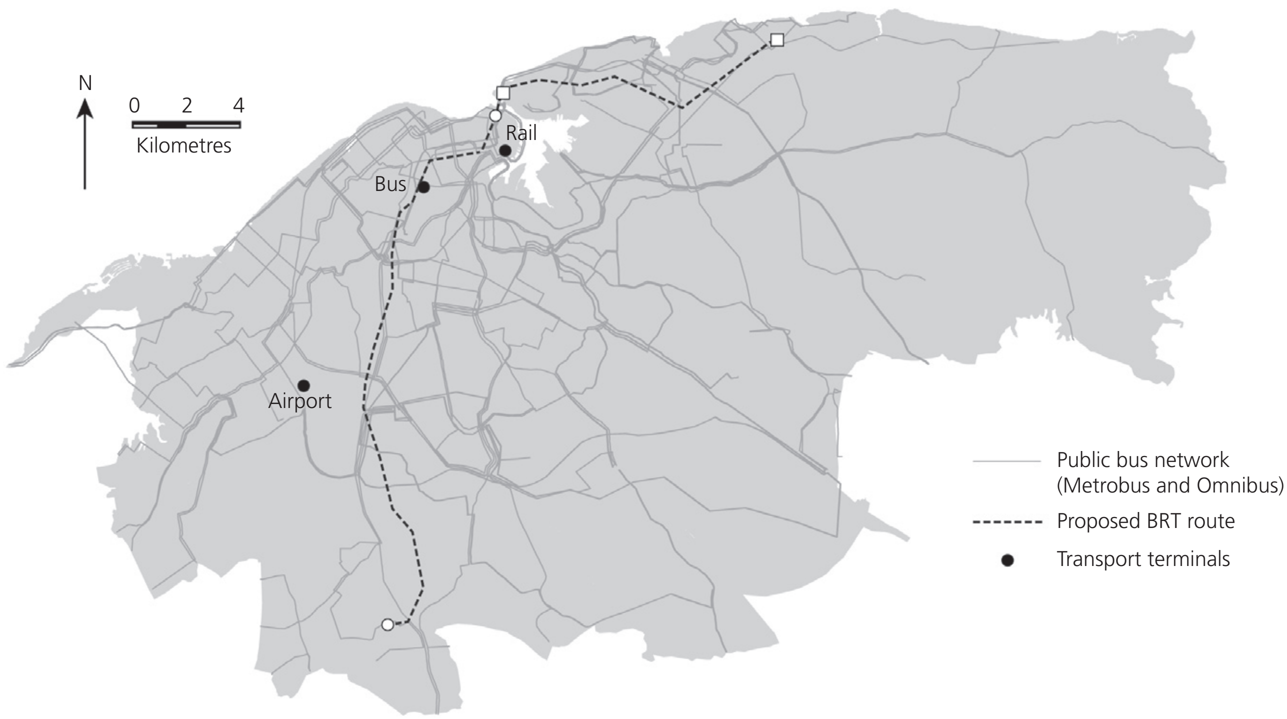

Figure 2. Map of main bus routes

taxis. Both bus and taxi passengers in 2014 were significantly higher than the previous year (ONEI, 2015), so it might appear that walking trips may be decreasing.

The proposed BRT system is shown as a dotted line running from Santiago de las Vegas (Boyeros) to the south of the city towards the bus station in the north and then onto Parque Fraternidad, which is a significant destination. The route then passes through the tunnel under Havana Bay heading due east towards Alamar (La Habana del Este) shown by the line ending in open squares. In this study, the 'southern' leg of the bus route is modelled to reach the city centre and this is ~26 km shown by the dotted line ending with open circles; the entire line is 37 km. Parts of this route are currently served by Metrobus and this study estimates the current situation in this mobility corridor. The following section explains the need for a functional model with respect to implementation of a BRT system to replace or 'upgrade' the current scenario.

3. Functional model for BRT

The functional model refers to an overall idea of how the system will function and assists with the general planning of a BRT, system as well as contributing to the overall design principles ultimately required for a successful system. For example, some of the first BRT systems were defined to function as feeder–trunk systems but this is not the only design alternative. The options for functional designs are related to whether the system is a trunk–feeder system or if it has direct services, or if it is just one corridor or a network of corridors integrated with several service hierarchies that connect the main corridors or the main areas (e.g. perimeter routes between integration stations or 'inter-neighbourhood routes') and different modes. If the premise is to design a citywide integrated transport system, then functionality is not really a question of choosing one over the other but rather identifying the conditions and the location in the city whereby one 'sub-system' performs better than the other. It is very likely that in order to achieve complete coverage of demand a combination of the mentioned options will be needed. Trunk–feeder services gain efficiency by separating two services that provide different functionalities which have different operational conditions. Feeder services operate in low-density areas, with smaller vehicles that serve the functionality of collection/distribution of passengers. Trunk services connect low-density areas with high-density areas where activities are located serving the functionality of transport or mobilisation of passengers quickly and efficiently between nodes. Trunk services are provided with large vehicles on high-speed segregated corridors and these services gain efficiency in travel time savings, especially in the trunk segment but tend to increase walking and waiting times for passengers due to interchanges. Hence, to accomplish planned levels of service, trunk–feeder systems require efficient planning and operation to guarantee ease of connectivity at interchanges and reliability of overall travel time. Direct services use the same vehicle to perform collect and transport function and consequently do not impose transfers on users, but due to vehicle size and route length they might be less cost-efficient. The flexibility of bus-based systems combined with availability of accurate demand data allows creating different levels of service for the same function. For example, in cities like Bogota or Curitiba, where there are overpassing lanes at stations, trunk services can stop at all stations or just at selected stops to provide faster services between specific origins and destinations. Curitiba's functional model is of an integrated transport network (RIT – *red integrado de transporte*) that combines more than eight different types of services, including some that are trunk–feeder, and others that are direct to achieve full coverage of the city's travel demand. Table 2 presents the different types of services of Curitiba's integrated transport network.

Havana will require a citywide transport system using a combination of different types of services, especially as portions of the transport system currently operate as different modes of transport (e.g. trunk services being equivalent to high-capacity transport services such as metro and feeder, and direct services resembling the functionality of low- or medium-capacity modes such as regular buses or trams). Other key ingredients for success include the degree of integration with other modes and the role of land use planning in maximising connected mobility (Nakamura, 2014). The multimodality and integration with the city's activities is a key factor for achieving full coverage of the travel demand in the city. Initial considerations regarding multimodal integration must be related with the integration of 'walking' mode and public transport modes, such as BRT. Good walking environments guarantee the quality of door-to-door trips and the overall accessibility of the system. Walking environments can be enhanced through design factors such as directedness and connectivity, aesthetics, ease of movement, legibility, safety and security (Wright and Hook, 2007). Moreover, integration with other modes such as bicycles, taxis, 'bicitaxis' (a type of three-wheeled bicycle-based taxi for one to two passengers) and various sorts of paratransit need to be considered because they can provide safe and convenient access to the system serving the function of feeder services and increasing the catchment area of specific corridors. In the case of Havana, operational arrangements to integrate other modes and reduce operational conflicts in the use of road space such as formal parking facilities for taxis or 'bicitaxis' or 'cocotaxis' (a type of three-wheeled two-stroke motorised taxi with a fibreglass body) need to be considered. Other measures to facilitate integration can be considered such as allowing bicycles on buses in off-peak hours if and when possible. Finally, for services and intermodality there are basically three types of integration: (*a*) physical, providing infrastructure facilities and terminals; (*b*) operational, coordinating services, layouts and frequencies to reduce walking and waiting times; and (*c*) fares, to provide free or reduced cost for transfers, usually through electronic payment. The integration with land-use planning is closely related with the overall success of BRT systems and as such the various master plan objectives must also be considered in any major transport scheme.

BRT corridors can achieve high patronage levels when guaranteed exclusive demand (no competition with other modes in the same corridor) leading towards potential transformations in urban form and urban development with growth and hubs following placement of transport corridors. Conversely, Deng and Nelson (2011) highlighted issues in India where friction between private automobile space was seen to be threatened by corridors for BRT systems showing proof of private automobile against public bus tension. However, when mixed activities are conveniently accessible by BRT or public transport, it is more likely that the population will perceive the benefits of using the service, hence creating incentives to use public transport, even when having the option of using a car. In the case of Curitiba, 45% of population has been travelling on public transport despite having one of the highest motorisation rates in Brazil of 560 vehicles per 1000 inhabitants (sibrtonline.org, 2015). Moreover, at the micro level the integrated design of public transport systems and the built environment can encourage compact, pedestrian and public transport friendly environments at human scale. For Curitiba this results in another 25% of all trips being made by non-motorised means. The potential benefits that BRT systems have on urban form and modal preferences for travel are very important for Havana especially considering the interest to deregulate the car market and the pressure that might exert on planning towards a car-led development (Warren *et al.*, 2015). Planning and developing a city for people, not cars, accessible through good-quality integrated public transport can have impacts on how and when the car is used. Moreover, with high-quality public transport in place alternative measures to charge for car use societal costs (e.g. high parking charges, surcharges on fuel or potentially congestion charges) can be implemented to control demand and to create alternative financing sources for the public transport system. In the case of Havana, because private automobile ownership is much lower (~50 cars per 1000 citizens) than other Latin American cities, there is a possibility that BRT could cater for a large modal share of motorised trips and potentially help curb the desire for automobile ownership if planned holistically. The next section outlines some of the design principles for Havana in particular and gives a short introduction to the model to calculate emissions and passenger (places or seats) supply.

4. Havana: BRT design principles

BRT systems can be defined as bus-based public transport systems that allow the transformation of the transport service

Terminology	Function	Lines	Bus type	Fleet size
Express	■ High-speed and high-capacity routes ■ Exclusive lanes in the main axes of the road network ■ At-level boarding and alighting and off-board payment before entering stations that are enclosed waiting zones	8	Biarticulated (230/250 pax) Articulated (170 pax)	173 12
Trunk	■ Medium-high speed and capacity routes ■ Connect integration terminals located in neighbourhoods and the city centre without exclusive lanes	21	Articulated (140 pax) Comun' (85 pax) Especial micro (70 pax)	23 120 4
Feeders	■ Medium-capacity routes ■ Connect nearby municipalities and neighbourhoods with integration terminals	221	Articulated (140 pax) Comun' (85 pax) Especial micro (70 pax)	119 635 31
Inter-neighbourhood	■ Medium-capacity, perimeter routes ■ Connect main axes passing through neighbourhoods (without going to the centre) ■ Operate in mixed traffic	7	Articulated (140 pax) Padron' (100 pax)	105 17
Direct	■ High-speed and high-capacity routes with stops every 3 km ■ Operate on exclusive lanes on main axes ■ Complement express and inter-neighbourhood routes ■ Off-board payment and at-level boarding and alighting at stations	18	Articulated (140 pax) Padron' (100 pax)	51 344
Conventional	■ Medium-low capacity routes ■ Connect neighbourhoods with the centre	78	Comun' (85 pax) Especial micro (70 pax) Micro (40 pax)	136 108 23
Centre circular	Low-capacity route around the centre Provides an alternative to walking for moving around the centre 50% of full fare	1	Micro (40 pax)	9
Tourism	Connects main tourist attractions and parks Differential fares for four stops	1	Double decker	5

Source: authors analysis based on sibrtonline.org (2015)

Table 2. Curitiba's integrated transport network services

provision through technology, infrastructure and operational innovation but most importantly through 'soft' innovations in policy, institutional regulation and business models for the transport sector. 'Soft' aspects require special attention because their transferability is limited as they are highly context dependent. Therefore, at least in developing countries where institutional capabilities for the transport sector are limited, putting the 'soft' transformations in place should be some of the key objectives of the BRT systems as they give viability and long-term sustainability to the system. Transformation can only occur after the city vision is developed and agreed among a wide network of stakeholders.

BRT planning processes should start with a project preparation stage which in many cities has been catalysed by strong political leadership, as in the case of Curitiba and Bogota

(Wright and Hook, 2007). Generally, what the political leadership brings to the process is the vision for the city and the vision for the transport system that can contribute to achieve it. The city vision can be defined within government policies and stated in planning document to give continuity to the process, and it needs to last beyond temporal political cycles. The planning documents usually provide conceptual guidelines, and can even commit funding to develop specific projects. For the case of Colombia, many of the transport systems for cities with medium and large populations were or are being planned, inclusive of BRT systems/corridors, because national financing for those systems was secured through economic and social development planning documents. Having a clear vision, which is specific for the city, protects users' interest from those of other agents that might come later in the process (e.g. private investors interested in taking part through public–private partnerships). Every city vision will need a strong capable human labour for the BRT system to be achieved. Hence, the need to form the project's planning team combining technical experts with experts in other relevant areas such as legal, financing, management, communications, design, among others and combining consultants with public officials is required (Wright and Hook, 2007).

For Havana the planning of the BRT system has the advantage of having many planning documents that have been developed during the last years to define the general development goals for the country as well as specific transport-related objectives, policies and actions for the city. Key city level planning documents that frame the development of the BRT system are: (*a*) the Land-use Plans (*Plan General 2013–2030 y Esquema de Ordenamiento Territorial y Urbano de la Habana*) and Historical Centre Revitalization Master Plan (*Plan de Revitalizacion Integral del Centro Historico de la Habana Vieja*), which define the spatial functionality and structure of the city and the policies for the integration of land-use planning with transport, accessibility and mobility, and (*b*) Havana Integrated Policy for the Management of Passengers Transport (*Política Integral para el ordenamiento del transporte de pasajeros en La Habana*), which outlines the actions required for improving transport in the city such as institutional and financial programmes and infrastructure and technology projects. At the national level, the main planning document is the 'Lineamientos,' which comprises more than 200 concerted guidelines that define a high-level social and economic development vision for the country and the city, including its transport sector. From the 'Lineamientos' (PCC, 2011) the main guidelines that could guide the development of the BRT system are as follows.

- Give priority attention to the transportation of passengers, achieving stability and quality of services, ensuring sustainability and gradually increasing demand satisfaction, in line with the country's possibilities.
- Investments will be repaid from earnings, in the case of rail and port infrastructure and equipment, or by savings in energy consumption.
- Encourage the design of new state and non-state organisational forms.
- Implement new ways of charging in urban passenger transport to minimise evasion and diversion of revenues.
- Ensure compliance with the required quality of the programme for repair and maintenance of road infrastructure.
- Pay special attention to energy efficiency in the transport sector.
- Strengthen health promotion and prevention activities to improve lifestyle, contributing to improved population health, with cross-sectoral and community participation.
- Importers of machinery and equipment to work systematically to identify national manufacturing capacities.

Decisions regarding the different elements of the BRT system should be the result of understanding the goals stated in the planning documents and the travel behaviour in the city and passengers' needs. Moreover, city-specific aspects such as climate, topology and cultural preferences must also be considered as main determinants of the design.

Specific details for the physical design are covered in the 'BRT Planning Guide (3rd ed.)' (Wright and Hook, 2007) and 'The BRT Standard' (ITDP, 2014), which include detailed description on how to design stations with multiple platforms to serve different routes and services (express and stopping) to increase corridor capacity of buses and passengers per hour (Hidalgo *et al*., 2013). Tables 3–14 present a comprehensive list of 12 key 'soft' frameworks and physical design criteria of the functional model (shown in left column) along with the factors considered for the design of a Havana BRT system (right column). The 'factors with respect to Havana' are the authors' reflections on existing documents and presentations done by different mobility sector stakeholders on a two-day workshop held in Havana in February 2014 'Sustainable mobility for the Havana that we want' (Warren *et al*., 2015). The source for these tables are based on the authors' interpretations of EWRI (2010), Hidalgo *et al*. (2013), ITDP (2014), Wright (2011), Wright and Hook (2007), utilising the background factors relevant for Havana.

On the basis of the application of the functional model to Havana, a model for a single BRT route was constructed and modelled for emissions and capacity. Understanding in more detail the potential environmental impacts of a BRT line in Havana is of particular importance for two reasons. First, poor air quality is an issue in Havana, despite overall low motorisation rates, vehicle emissions are a key design factor in the functional model along with meeting basic levels of

Key planning and design criteria to be considered	Factors with respect to Havana's legal systems
■ Development of sustainable transport or mobility laws, plan, strategies ■ Development of complementary sustainable mobility strategies and/or policy packages	■ Continue to use the existing land-use plan and master plan to protect the historical city centre and guide the planning of any BRT system ■ Ensure the lead provincial transport authority controls the integration of land-use and transport planning, design of complementary infrastructure such as stops, stations and integration terminals and non-motorised modes (including any cycle hire schemes) ■ The planning of the BRT system requires a good articulation of existing planning documents. Explicit analysis of tensions overlapping and synergies of the different planning documents need to be done at the initial stages of the planning process ■ Consider making policy packages legally binding through national legislation

Table 3. Factors for consideration in Havana with respect to the legal framework

Key planning and design criteria to be considered	Factors with respect to Havana's institutions
■ Creation of multi-disciplinary planning team at the early stages of the process ■ Creation of managing authority for the integrated transport system and/or department within authority responsible of BRT mode planning, monitoring and controlling ■ Definition of agents and functions, roles and remits required for managing the system	■ Dirección Provincial de Transporte de La Habana exists and the role it plays for a BRT system needs to be defined ■ The passenger transport policy also defines the need to create a new enterprise of metropolitan buses; it will need a new organisation model and the consideration of experimental cooperatives ■ The design of the BRT and the integrated transport system will require the definition of further detailed specifications and requirements for the management of the system and the provision of the service. A detailed design of the institutional model is required

Table 4. Factors for consideration in Havana with respect to the institutional framework

demand. Second, financing restrictions need to be addressed to implement the new system or at least improve the quality of the existing buses (currently around 50% of the articulated bus fleet is out of operation on any given working day due to lack of resources for maintenance) and climate change mitigation funding are available and require a detailed analysis of environmental performance.

In this study, two situations (or scenarios) are modelled using a single bus route as shown in Figure 2, where the dotted line ends with open circle symbols. These scenarios are described in detail in the following section and then in more detail in the modelling results. The final conclusion section brings together the modelling results and the functional model in order to summarise some of the main challenges facing the city if BRT is to be realised.

5. Methodology for capacity and emissions modelling

This study assumes that the following key values for modelling the various bus systems in Havana are constant over time: speed, population, dwell time and operational days. The BRT scenario uses lower vehicle emissions to represent more efficient buses while allowing passenger places (seat km/d) supplied to rise and letting the overall demand increase (trips/d) as it is known that daily demand is not fully met under current conditions. In the first scenario of implementing a single BRT

Key planning and design criteria to be considered	Factors for consideration in Havana
■ Interaction 'flows' between agents identified and control mechanisms assigned ■ Definition of agents and functions, roles and remits identified required for operating the system ■ Definition of conditions for the delegation of services ■ Definition of conditions for competitive bidding to choose service providers ■ Contract should include key performance indicators ■ Contracts should include bonuses or penalties to reflect impact on overall quality of service ■ Definitions of strategies to include previous operators ■ Definition of strategies to remove (scrap) old vehicles	■ Consider the use of quality contracts for service provision; these are proven to be a key tool for controlling the quality of service and the overall performance of the system ■ Decide how contracts and incentives will be set to correct any perverse incentives created by the existing models and work to achieve operational and financial self-sustainability ■ Havana must consider a strategy that addresses small private operators of taxis (*almendrones)* ■ Implement information and communication technologies (electronic payments) as a key platform in providing the monitoring performance and service quality information needed for regulation and enforcement

Table 5. Factors for consideration with respect to regulation, enforcement and business models

Key planning and design criteria to be considered	Factors with respect to financial frameworks
■ Secure funds through plans/policies for capital investment ■ Define financing 'portfolio' combining financing sources of different types (international, national and local) for infrastructure maintenance and operation ■ Build system in phases to distribute capital investments in time but structure phases to have enough demand to give a relative sound financial condition, perhaps one or two major corridors (15–60 km) and feeder routes (40–120 km) ■ Careful considerations of impacts on service quality of financial sustainability during operation ■ Structures for providing financial support to guarantee high-quality services ■ Subsidies for special groups (students, senior etc.) and alternatives for financing them (other than fare revenues)	■ Secure loans/grants for initial capital investment for building infrastructure (segregated lanes, stations, terminals and garages) from national government or multilateral agencies ■ Consider private financing through public private partnerships for system development capital (e.g. rolling stock) ■ Plan for subsidies to meet operation and maintenance expenses if fare revenue is not sufficient; accept the inherent challenge due to the very low level of existing fares ■ Prepared for a future unified currency system where there is a single currency ■ Calculate an ideal technical fare that estimates the operating cost per passenger, and deploy as the base for setting the user fare and as a tool to inform decision-making and fare policy ■ Design the system with a clear environmental focus including financial sustainability through climate mitigation financing mechanisms ■ Build transport-oriented developments along the entire BRT corridor to integrate land-use planning to create positive impacts on the system's patronage and operational revenue, especially in touristic areas

Table 6. Factors for consideration in Havana with respect to financial framing

Key planning and design criteria to be considered	Factors with respect to Havana
■ Number of lanes. Depending on the designed capacity one or two lanes to allow overpassing at stations (3·5 m of width each) ■ Busway alignment. For efficiency and to increase capacity, completely segregated central busways reduce conflict with other traffic flows and improve speeds ■ Type of right of way and level of segregation from the rest of the traffic. Higher segregation increases capacity	■ Vary the physical design of busways according to the specifications of the functional design of the system and the different corridors and/or routes required ■ Consider exclusive lanes for the 'main network' and mixed traffic for 'feeder network' operation but plan for preferential or segregated lanes on higher density routes ■ Use articulated buses with 'dual' doors that can operate in both segregated central busways in some segments of the route and in mixed traffic or preferential lanes elsewhere. This may resolve congestion on radial routes where narrowing of approach roads occurs

Table 7. Factors for consideration concerning the physical design of the busway

Key planning and design criteria to be considered	Factors with respect to Havana
■ Size of vehicles. Depending on the function of the route (collection/distribution or transport) and required capacity ■ Type of propulsion. Depending on environmental objectives	■ Continue use of single articulated and biarticulated buses but deploy larger buses operating in high-capacity corridors and single buses operating in medium- or low-capacity corridors ■ Upgrade fleet hybrid articulated buses with 'dual' to increase the flexibility of services; consider pure electric only if viable ■ Vary vehicle size based on demand and ensure feeder routes connect neighbourhoods to integration terminals and interchange stations but also provide 'perimeter' services for connecting neighbourhoods and municipalities, without going to the main central area

Table 8. Factors for consideration in Havana with respect to vehicles

system, the model does not reduce loading times although the BRT vehicles are expected to have multiple points of exit and entry with an automated fare collection system eventually put into place. Thus for BRT systems, the overall passenger load is expected to be increased when compared with the current situation in Havana; demand is also expected to rise due to the high levels of suppressed demand (Arias, 2014). It is assumed that demand for bus trips is currently two to three times higher than what is currently supplied for all routes in the network and that as supply increases demand will continue to rise. The scenarios are described in Table 15.

Results are derived from the key scenarios which can achieve increasing levels of daily passenger trips per citizen; these are defined from a mobility index set equal to 0·4 passenger trip/population, for a single bus route corridor. This route currently has an estimated daily trip demand of some 51 600 trips/d, or about 6% of all trips in Havana. The results illustrate how modelling a BRT system can match and subsequently raise the overall capacity with higher frequencies. For this route it is assumed that the maximum number of 86 buses on this route could be accommodated without using a dedicated lane, although in some parts of the route especially before and after stations there would be exclusive bus-only sections in order to allow for traffic signal prioritisation for buses at specific intersections. At a frequency of 60 buses every hour, an estimated peak demand hour of 10 320 pax/h would not be met for this route, unless the passenger capacity of each bus were to be raised to ~175. The model used is based on that of Hidalgo *et al.* (2013, see p. 141, Table 3, C), which yields a maximum hourly throughput of some 14 300 pax/h for BRT systems with single platforms; in Havana this throughput is much lower currently due to longer loading times due to cash fare collection methods, lack of signalisation and a decreased number of doors for both loading

Key planning and design criteria to be considered	Factors with respect to Havana
■ Required station space. Depending on location (from 2·3–5 m wide) on the central verge to serve both directions or on the curb ■ Multiple, staggered platforms and overpassing lane increase capacity by allowing multiple routes and services ■ Payment collection. Off-board fare collection using electronic payment requires a closed 'paid-zone' or 'proof of payment' ticket ■ Information technology systems. Operational data used or made available to give real-time information through electronic panels or mobile phone applications ■ Platform level aligned with bus level to reduce vertical and horizontal gap, improve security and efficiency ■ User information. Signalling system consistent and comprehensive throughout the system. Staff presence to provide help and information ■ Distance between stations of 300 up to 800 m balancing the trade-off between walking distances for passengers and operational speeds ■ Secure parking for bicycles and bays for taxis, bicitaxis, motorcycles taxis to facilitate inter-modality and integration ■ Architectural design, cleanliness and maintenance to improve system's image and design for safety and security (see-through material, lighting, CCTV when appropriate etc.)	■ Match geometrical design for stations depending on the expected capacity and speed for the corridor ■ Consider the implementation of express and super-express services with central verge stations with off-board fare collection ■ Model total system dynamics using single platforms as above with a capacity of up to 10 000 passenger per hour per direction operating with frequencies of around 67 veh/h ■ Explore other geometrical station designs for the route near the centre of the city ■ Provide real-time service information and maps, timetables and route layouts at all stations and terminals ■ Provide supplementary information regarding places of interest and integration with other modes, including non-motorised modes

Table 9. Factors for consideration with respect to the physical design of stations and terminals

Key planning and design criteria to be considered	Factors with respect to Havana
■ For direct and feeder routes outside the main BRT network, shelters are required ■ Payment collection is usually done on-board through electronic payment but requires certain arrangements to facilitate integration, improve efficiency in operation and prevent evasion (e.g. conductor located inside the bus located to allow queueing space) ■ User information similar to the one provided in trunk stations ■ Buses and curbs design and drivers training to minimise vertical and horizontal gaps ■ Architectural design, cleanliness and maintenance to improve system's image and deliver safety and security ■ Consider measures to mitigate traffic impacts during operation	■ Provide shelters for hot/warm conditions with shade and cooling ■ Design features that improve comfort under different weather conditions (direct sun, torrential rain etc.) for pedestrian access paths to the system ■ Regard bus stops as entrance points for the city's transport system; all need standardised information including timetables, schedule and layout of services available ■ Provide real-time information in stops with many services

Table 10. Factors for consideration of the physical design of bus stops

and unloading. Technically, there is no platform as such but most of the current systems are relatively low floor and queuing in the capital is highly ordered; however, the use of multiple entrances coupled with prepayment cards or tokens would decrease boarding times significantly. If such a route was trialled then it would be appropriate to engage further routes throughout the city so that a single BRT route did not begin to distort the overall travel patterns by attracting travellers due to faster travel times and hopefully a better overall trip experience.

Daily emissions are modelled based on the average fuel consumption multiplied by total bus numbers, an average speed (20 kph) and typical working day (17 h). Minimum and maximum fuel consumptions used in the current scenario are 2 and 1·46 km driven per litre fuel combusted, and correspond to 1325 and 1825 g/km carbon dioxide (CO_2) emission levels. The BRT buses have much lower emission levels than current buses and are based on Euro II units in use in Mexico (OMU, 2015, 2009).

Key planning and design criteria to be considered	Factors with respect to Havana's depots
■ Sufficient space available to perform different functions (vehicle maintenance and cleaning, drivers resting areas, operators control centre and other offices) ■ Strategic location for efficiency (i.e. impact on dead mileage)	■ Coordinate depot location with that of interchange terminals and main stations ■ Verify the viability of existing depots and proposed depots utilising the detailed design of the BRT corridors

Table 11. Factors for consideration with respect to the depots

The scenarios modelled in this study for Havana's first BRT line are within a conservative approach, which suggest that the corridor could operate with 'light' interventions such as exclusive lanes on the curb side with two platforms per station and electronic on-board payment (with physical adjustment on buses to formalise conductors and queuing space inside the vehicle to reduce dwelling time). Focusing on an adequate design of 'soft' frameworks for Havana, the city could explore the 'light' BRT possibility as a low-cost, quick-development demonstrator, which could act as an interim measure. Plans for potentially three BRT corridors have been considered in Havana covering much of the current 'Metrobus' network using various feeder systems and situated appropriately to cater for other modes.

The trajectory of the powertrain technologies can be considered as a linear process starting with the current diesel engine buses, followed by newer diesel units and then moving to a next-generation diesel hybrid (using ultra-low sulfur fuel). The next-generation hybrid is expected to have increased fuel efficiency due to further advances in regenerative braking and other features. Finally, some consideration is given to pure electric vehicles (Miles and Potter, 2014) that could be charged inductively within the road. However, these systems can be quite costly and the complexity involved may not be appropriate for every city situation. The next section outlines the results for the modelling in terms of emissions and passenger capacities.

6. Modelling results

A single BRT system is demonstrated along a single lane corridor heading south–north into the city from the airport zone

Key planning and design criteria to be considered	Factors for improved Havanian intersections
■ Traffic lights network planning to improve system's performance ■ When limited by traffic system's technology forbid turns at intersections to increase green time for BRT corridors	■ Control and coordinate traffic lights to enhance system performance at the corridor and network level ■ Plan for pedestrian bridges to allow user crossing and access to the system, especially for central busways ■ Measure pedestrian accessibility in order to determine overall access and impact on patronage levels ■ Give priority to pedestrians at level crossings and facilitate access for disabled people and women travelling with children, or those with carrying objects ■ Pedestrian areas should be a single continuous level or height if/when possible

Table 12. Factors for consideration at intersections

Key planning and design criteria to be considered	Factors with respect to Havana
■ Take advantage of buses intrinsic flexibility to better adapt supply and demand through multiple routes per corridor and/or direct services operating in and outside high-capacity corridors ■ To improve system's efficiency and integration of modes and services implement technology to allow real-time fleet control and management and monitoring of key performance indicators (e.g. punctuality, reliability and route compliance) ■ Design a main control centre and control centres for operators ■ To allow virtual integration implement electronic payment method. New buses should include technology requirements and existing fleet need to be adapted ■ Include on the institutional framework fare collection agent functions and identify money flows between agents in the system ■ Define strategy for facilitating the adoption of electronic payment method to facilitate access to the system (e.g. number and location of selling points) For physical integration consider the following ■ Quality of sidewalk or pavements ■ Pedestrian facilities and access and cycle paths near BRT corridors ■ Bicycles allowed on buses at certain times ■ Operational coordination of services ■ Reduced fare for integrated services ■ Land-use planning and transport planning integration ■ Information for navigating the system on different modes, including walking (legibility) ■ Information (electronic, real-time updates on operation and contingencies) ■ Construction impacts ■ Branding and integrated transport system image	■ Implement technological systems, including the fleet control and management and electronic payments ■ Use operational information of journey patterns and vehicle performance to monitor and adapt the BRT system by the authority ■ Use operational information to improve passengers' journey by providing real time at stations or through mobile or web applications ■ Develop institutional capacity and analytical skills to process and analyse information ■ Integrate with other modes, including informal modes such as bicycle-taxis, moto-taxis (cocotaxis), or taxis (classic vehicles known as almendrones) should be considered as a way of increasing system's coverage and its overall acceptance ■ Provide physical spaces for alighting and boarding of other modes at interchange terminals and other stations. ■ Devise metric(s) for gauging seamless travel between modes ■ Facilitate integration by improving or increasing the number of good-quality walking environments

Table 13. Factors for consideration with respect to the information technologies, integration and service plans

whereby the same number of buses per hour would be employed as at present and then increased significantly. This level of working vehicles then determines the overall daily passenger load and emission outputs. The current situation and the BRT system results are shown in Table 16.

Overall emissions are increased significantly for the BRT when expressed in tonnes/day or total emissions for the route. However, since the single BRT corridor provides more passenger places the emissions per person are reduced. This study does not model exact flows in each direction along the corridor as more data is required to determine demand in each direction (to and away from the city centre) throughout the entire day; instead the model assumes that ~20% of daily demand is observed for a single peak morning 'rush hour'. The average daily emissions per passenger would drop slightly further towards 0·09 kg/pass, if buses of higher quality are adopted in the scenarios when compared with the current situation. Further reductions in carbon dioxide emissions may be possible with buses producing overall emissions of some 600 g/km when using pure electric systems (Miles and Potter, 2014), but this would require a relatively low-carbon electricity supply

Key planning and design criteria to be considered	Factors with respect to Havana
■ Formal public consultation strategies to design services to address customers' needs and include them in the different stages (planning, implementation, operation) ■ Formal consultation and socialisation strategies to involve stakeholders in all project stages ■ Other strategies to identify public views and involve them in the planning and operation (e.g. media, discussion with community leaders and other engagement tools) ■ Impacts on direct employment generation for planning, implementing, building, operating, managing and maintaining the system (Bogota's Transmilenio created 4000 jobs and its operation created other 2000 long-term jobs) ■ Potential impacts of economic growth through technology transfers due to forward and backward linkages in industries such as the bus body builders, due to their manageable economies of scale	■ Acknowledge the previous work of concerted planning that involved different state institutions in the decision-making processes ■ Deploy public engagement strategies in which planning issues are discussed openly and widely in the community ■ Share detailed planning of the BRT system for aspects that define new route layouts, location of stops, design of community amenities and public spaces ■ Strengthen stakeholder engagement by using criticisms and suggestions of the system and allow for a sense of ownership

Table 14. Factors for consideration with respect to communication, stakeholder engagement and process management

Scenario description and headway	Emissions levels	Vehicle technology	Complementary infrastructure
Current situation for the route, every 10–15 min	1325–1825 g/km (carbon dioxide)	Euro0–Euro1 diesel or older	'As is'
New buses (BRT) at current supply level and higher, every 2·5–10 min	900–1180 g/km (carbon dioxide)	Euro2 or newer (diesel)	Improved signage and stations/stops; further improvements at stations and consider capacity at interchange platforms

Table 15. Description of scenarios modelled in this study

system. Their work showed that 600 g/km can be achieved in the UK when buses consume about 1 kWh/km.

In all cases, the switch to BRT reduces per capita externalities while meeting much higher service demand levels. In all of these BRT scenarios, as this is a single corridor, with one lane in each direction, saturation levels of buses per hour are much higher than what is modelled here. The critical factors that would be required for an expanded BRT system to be successful are discussed with respect to the functional model in the concluding section.

7. Conclusions

For Havana's case, considering the inclusive nature of the socio-economic and planning system and the need to transform the quality of the public transport and mobility system, users' needs must be placed at the centre of the planning, design and operation of the system, even before financial constraints. However, as presented in the different scenarios discussed in this paper, good-quality service requires highly capable human capital and adequate level of capital investment in infrastructure and fleet renewal to improve the environmental performance. Hence, innovative financial strategies that combine different sources of revenue need to be considered. Moreover, providing good quality of service will create a virtuous cycle in which the system will have positive impacts on the quality of life that will attract additional financial funds (such as the multilateral agencies funding for climate change mitigation projects). This study has modelled emissions and passenger trips for a single known bus corridor in Havana, and has

Parameter	Current system	With BRT on single route
Buses per route: veh/h	4–6	6–24
Maximum capacity: pax/d	12 750	51 000
Peak hour capacity: pax/h	900	3600
Carbon dioxide emissions, minimum and maximum: t/d	1·8–3·7	1·8–9·6
Carbon dioxide emission per passenger, average: kg/pass	0·22	0·12

Table 16. Emissions and passenger trips for a single route in the Havana bus network using current (actual) and modelled (calculated) BRT systems

highlighted the conceptualisation of a BRT functional model, and the authors stress that in order for this to be successful it needs to be considered as part of a citywide integrated mobility system including different modes and different types of services.

A critical set of interconnected factors focuses around the economic situation, the capability of the city and the overall planning. The city needs to create enough investment opportunities for the most minimal BRT system to be implemented, while maintaining the lowest achievable fare, since currently fares are so low; this is indeed a particularly Cuban issue as public transport is almost considered as a public good or right and mobility and accessibility is woven into the governmental guidelines. Raising fares will undoubtedly create inequalities that will need to be addressed and as such one way forward that will work is the process of 'studying, adopting and adapting' (Morris, 2014) certain systems to suit their own needs. Many of the official transport bodies are familiar with what can be achieved by BRT systems in Latin and South America and it is possible that these successful systems can transfer to their own city. With respect to the capability of various working bodies that provide transport and those that regulate transport, Havana has made significant steps towards the creation of a single body (DPT, 2014), which can help steer many types of pilot projects or demonstrators and effectively evaluate them to ensure outcomes are met. Planning and, in particular, master planning, in Havana has long been practised with good outcomes in mixed use and consensus reached through thorough public consultations. It would seem that the technical and institutional capabilities required to operate efficient transport systems are available. BRT systems when coupled with other pro-public, and 'green modes' could work in tandem to reduce the overall need and desire for private automobile ownership, if designed in user-centric manners for (and by) Havanians, but there is always potential for tension between space in the city for private car use and public transport systems.

A more comprehensive approach that considers the complete design of the corridor as a high-capacity 'full BRT' as part of the integrated transport system of Havana could support much of the urban regeneration potential outlined in the city vision and it would help reduce some tensions between automobile use and public modes. The flexibility of the bus-based technologies creates a range of options with different outcomes. Many options could be valid if the system's functionalities are clear and if the outcomes are fully understood and they contribute to the achievement of the overarching vision. These visions could include upgraded transport hubs, revitalised rail systems, emphasis on pedestrian and cycle modes along with increased automobile-related facilities.

Acknowledgements

The authors acknowledge the funding from The British Embassy, Havana, which provided seed funding through the Bilateral Partnership Fund; University College London (through the UCL Grand Challenges for Sustainable Cities) and The Open University. The paper has benefitted significantly from two anonymous reviewers.

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