Liberalisation, urban governance and gridlock: Diagnosing Yangon's mobility crisis

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Abstract:

The city of Yangon is home to over 5 million people, hosts Myanmar's largest port and produces a disproportionate share of national output. But a mobility crisis is undermining the city's economic potential and contributing to a deteriorating quality of life for its residents. The most obvious symptom of this crisis is acute traffic congestion. The proximate causes are clear: growing demand for journeys, a surge in vehicle numbers, a modal shift away from buses, and myriad 'flow disruptions'. However, solving this mobility crisis requires recognizing the underlying causes, including a 'congestion incentive spiral' fuelled by rapid liberalisation of vehicle imports in a context where there are few viable alternatives to buses and private automobiles. This situation is a direct consequence of systematic failures in urban planning, investment and regulation linked to active neglect from successive military regimes and dysfunctional institutional arrangements. To preserve its rich urban heritage, Yangon will need to embrace 21st century integrated planning practices that seek to maximise accessibility and mobility for all people rather than minimise traffic congestion for those who use cars.

Keywords: congestion, mobility, Myanmar, Yangon, urban transport

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1. Introduction

The city of Yangon is experiencing a renaissance after decades of relative international isolation and political neglect under military rule (Morley 2013). Today the city is home to over 5 million people, hosts Myanmar's largest port and is the commercial heart of the nation. In this new era characterised by political and economic liberalisation, Yangon has the potential to serve as an engine of economic growth. But the city's potential to play this role is being undermined by a mobility crisis: as the economy speeds up, the city slows down. It has been estimated that average travel speeds at peak times plummeted from 38 km/h in 2007 to perhaps 10-12 km/h in mid-2015 (ADB 2016). Yangon has been something of an outlier compared to other Southeast Asian cities, with relatively high usage of urban bus services and comparatively few private cars on the city's roads. For example, as recently as 2013 it was estimated that there were only 25 passenger cars per 1,000 population on Yangon's roads (JICA 2013). This number pales in comparison to other cities in the region, with an estimated 222 cars per 1000 in Jakarta and 363 per 1000 in Bangkok (Kutani 2013). However, rapid liberalisation is fuelling a dramatic shift away from buses as cars flood the city's roads.

Growing congestion is a significant constraint on both growth and poverty alleviation. Empirical research at the city and city-region level in other countries has shown that productivity suffers from congestion by raising the costs of doing business and generating friction in local labour markets (Cevero 2001; Weisbrod, Vary and Treyz 2003; Venables 2007). At the household level, congestion raises the costs of mobility thereby inhibiting access to livelihoods opportunities, diverting resources away from asset accumulation, and increasing exposure to harmful levels of pollutants that negatively impact upon health (World Bank 2002; Hein Ko Soe 2016). Sustainable, pro-poor urban development therefore depends upon the smooth functioning of a transport system that maximises mobility while minimising costs, particularly for the poorest and most vulnerable.

In this paper we draw on a range of sources to analyse both the proximate and underlying causes of Yangon's current congestion crisis. Our sources include key informant interviews, newspaper articles, international reports, government data, and original analysis of geospatial population data and satellite imagery.

We argue that the current situation is better understood as a mobility crisis rather than a crisis of congestion per se. The proximate causes include growing demand for journeys, a surge in the

number of vehicles on the city's roads in recent years, and a concomitant modal shift among commuters away from buses and towards private automobiles. But the underlying causes are more complex. The city has become stuck in a 'congestion incentive spiral' that ultimately stems from a governance crisis: the absence of metropolitan-scale governance institutions with the authority and capacity to deliver integrated transport solutions for the city. This is a consequence of partial institutional reforms under successive military regimes seeking to tame the city, ambiguities concerning the distribution of authority over city affairs introduced in the 2008 constitution, and political interventions in city government operations. Although the current crisis has stimulated recent efforts to improve and coordinate transport management at the Region Government level, an historical dearth of coordinated land use planning and infrastructure investment will not be overcome quickly. Nevertheless, we argue that there are some relatively simple and cost-effective options for improving mobility in the city.

The paper is organized as follows: section two provides a systematic analysis of the proximate causes of Yangon's mobility crisis; section three considers the underlying causes linked to the broader political-institutional context and the incentives facing commuters; section four discusses various policy measures and reforms that might be considered to improve mobility; section five concludes.

2. The proximate causes of Yangon's mobility crisis

2.1 Understanding mobility and congestion

Yangon's current mobility crisis is a direct result of traffic congestion, but it is important to recognize the difference between mobility and free-flowing streets. Mobility refers to the ease with which people and goods move through the urban landscape. While much of this movement happens on roads, in most cities walking, cycling and fixed-line transportation networks (e.g. trains, trams and BRTs) provide equally important means of getting around. It is therefore possible to significantly increase urban mobility without necessarily reducing traffic congestion by providing citizens and businesses with viable alternative modes of transport (UN-Habitat 2013).

However, although mobility and congestion are not intrinsically linked, Yangon's residents rely heavily on motorised transport (i.e. buses, taxis and private automobiles). Worsening traffic congestion is therefore the most immediately apparent cause of the city's current mobility crisis. To understand why traffic congestion has increased so dramatically it is useful to outline a theoretical framework for understanding the problem.

Traffic congestion is essentially a function of three factors: demand for road space, the supply of road space and 'flow dynamics'. Demand is jointly determined by the number of journeys required to satisfy the mobility needs of a population and by modal choice. An increase in the number of people traveling by road due to population growth can create a situation whereby demand for road space exceeds supply at peak times, thereby causing gridlock. Similarly, a switch from public transport to individual automobile usage (i.e. modal shift) can also lead to excessive demand given that individualised automotive transport is less spatially efficient than public transit options such as busses: more road space is required to transport the same number of people by car than by bus. Recent research has highlighted the significance of modal choice by examining the effects of public transit strikes on congestion. The results indicate that the positive effect of public transport on reducing urban congestion has likely been underestimated in the past (see Anderson 2014).

The most common response to growing demand for road space (and hence rising levels of congestion) is to increase the supply of road space. While intuitive, extensive research has shown that there is a 'fundamental law of road congestion' whereby expanding road supply generates more demand and hence further congestion (Duranton and Turner 2011; see also Arnott and Small 1994; Gakenheimer 1999; Gwilliam 2003). This is not to say that some expansion of capacity is not in order in rapidly growing cities such as Yangon, but simply generating more road space is unlikely to lead to significant increases in mobility. Indeed, there is now a consensus that improving mobility by encouraging and supporting alternative modes of transport is preferable to increasing the supply of road space (Buchanan & Gunn 2015; Mogridge 1997).

The third factor that influences the degree of congestion is the way traffic flows. Even minor 'flow disruptions' can result in gridlock. For example, 'irregularities in driver behaviour' can trigger traffic jams as the erratic action of a single vehicle produces a ripple effect that brings a whole mass of automobiles to a temporary halt (see Orosz, Wilson & Stépán 2010). Bottlenecks—i.e. where road capacity is reduced through, for example, the merging of three lanes into one—generate a similar effect (ibid). In such cases flow dynamics alone (rather than the balance between supply and demand) can be a source of congestion.

2.2 Population growth and economic growth contribute to rising demand

Although there is a dearth of reliable, time-series demographic and economic data for Yangon, we can infer substantial growth in raw demand for journeys in the city from a variety of sources.

According to official census data, the population of Yangon Region (including both rural and urban areas) grew from 3.97 million in 1983 to 7.36 million in 2014 (Ministry of Immigration and

Population 2014). This represents a compound average annual growth rate of roughly 2%. Although this is not particularly rapid, it is substantially faster than the growth rate of the national population, which was roughly 1.2% over the same period. As a result, the Yangon Region's share of the national population increased over this period from 11.2 percent in 1983 to 14.3 percent in 2014 (ibid).

The 31-year gap in census data collection hinders analysis of recent trends, which are important given the notably abrupt increase in congestion in recent years. However, there are three other data sources that can be used to infer recent demographic and economic trends. The first is a population data set produced by the WorldPop.org project, which combines census data with other ancillary data (e.g. satellite imagery) to model population distribution for countries around the world. For Myanmar, gridded population data are available for 2010 and 2015. As Figure 1 shows, analysis of these estimates indicates substantial population increase in all of Yangon's Townships over this five-year period, with central Townships experiencing the most rapid demographic change (see Appendix A for details).

Figure 1 | Population growth in Yangon, 2010-2015

The second source of data that can be used to evaluate demographic and economic trends comes Landsat 7 ETM+ satellite imagery. High resolution images from 2003, 2013 and 2016 were processed to assess the extent, direction and rate of spatial expansion in the Yangon region over these years (see Appendix A). The results show that the built-up area of the city increased from roughly 24,000 km^2 in 2003 to 64,500 km^2 in 2016—an increase of 169 percent. Between 2013 and 2016 alone the built-up area increased by 6.7 percent (see Figure 2).

Figure 2 | Expansion of built-up areas in Yangon, 2003-2016

The third data source also comes from satellite imagery; in this case nightlights data from the USA Defence Meteorological Satellite Program. Recent research has demonstrated that the amount of light radiating from a geographical region at night can be used to get a rough indication of economic activity in that region (Chen and Nordhaus 2011; Henderson, Storeygard and Weil 2011; Henderson, Storeygard and Weil 2012). Figures 3 and 4 provide a graphic illustration of the change in the intensity and geography of luminosity (and hence economic activity) in Yangon Region between 2003 and 2013. Over this 10 year period the level of luminosity in greater Yangon nearly tripled. A rough estimate based upon the calculated elasticity of GDP with respect to luminosity indicates that this translates into an average annual growth rate in GDP of 8.5 percent.

Between 2008 (when the constitutional referendum was held) and 2013 the estimated annual growth rate is 11.2 percent (see Appendix B).

Figure 3 | Luminosity in Yangon Region, 2003

Figure 4 | Luminosity in Yangon Region, 2013

Evidence of population growth, expansion of built-up areas and very substantial growth in nightlights collectively provide indirect evidence of increases in the raw demand for journeys in Greater Yangon. More people are spread over a wider area resulting in more commuters; and more economic activity can increase the demand for both passenger journeys and commercial vehicle activity (i.e. non-passenger journeys). However, demographic and economic changes alone cannot account for the speed with which congestion transformed from a minor nuisance to a matter of national concern.

2.3 A flood of vehicles and a modal shift

Growth in demand for journeys in recent years coincided with two important and interlinked trends: an abrupt expansion in the number of vehicles on Yangon's roads and a modal shift among passengers away from buses and towards the use private cars.

As Figure 5 illustrates, there has been an extremely rapid increase in the number of registered vehicles in the Yangon Region since 2011 when vehicle import restrictions were relaxed. Between 2011 and 2014 there was a 153 percent increase in the total number of registered vehicles in Yangon, including a 93 percent increase in passenger vehicles (i.e. cars and vans) and 507 percent increase in light trucks. Perhaps most surprisingly, given that there is a strict ban on civilian use of motorcycles in Yangon, there was a 263 percent increase in registered "two wheel" vehicles over this period, from roughly 56,000 to over 200,000.

Figure 5 | Change in number of registered vehicles (bars) & bus passengers (line)

This explosive growth in the number of passenger vehicles and motorcycles on Yangon's roads has coincided with a steep decline in the number of people using the bus system, even as the population has grown (see Figure 5). These two trends reflect a dramatic modal shift: more and more people are choosing to use private automobiles rather than buses, which significantly increases demand for road space even in the absence of increases in the number of road users.

2.4 Flow disruptions

Navigating smoothly through Yangon's increasingly congested streets is further complicated by myriad obstacles and bottlenecks that exacerbate the problem. One of the most often heard complaints has been the erratic behaviour of bus drivers, who weave in and out of traffic and make abrupt and un-signalled stops that lead to temporary jams and bottlenecks (Frontier Myanmar 2017). Due to the age, generally poor maintenance and constant abuse of these busses (e.g. overcrowding) breakdowns are common, leading to further bottlenecks.

Taxis are often cited as a serious problem. Idle taxis parked illegally take up road space while active taxis drive aggressively, make abrupt stops to pick up passengers and linger while negotiating prices, which are not regulated in any way (Ei Thandar Tun 2015). Efforts to improve the situation through metering have failed in the past (Nay Linn Aung 2011).

In the central business district of Yangon, a lack of adequate parking is also perceived as major sources of bottlenecks (Noe Noe Aung 2013; Aye Nyein Win 2018). There are very few dedicated off-street parking facilities leading drivers to cruise for precious street parking, which itself can cause congestion (Shoup 2006). This is compounded in some areas by the use of potential parking spaces by street vendors, who are an integral part of the downtown economy (Myo Satt 2016). However, multiple past attempts to reduce congestion by forcibly moving street vendors have done little to improve flow throughout the central business district. Other efforts to address the perceived deficiency in parking spaces downtown include expanding roads to create new spaces (Noe Noe Aung 2013), requiring new condominium developments to offer 1.2 parking spaces per unit (Kang Wan Chern 2018; Chau 2017), and introducing a policy requiring individuals seeking to import a vehicle to prove that they have a parking space to use (Aye Nyein Win 2015c). As discussed below, all of these policies have had perverse effects and have failed to make any discernible impact on congestion.

Finally, an issue that was raised by many formal and casual informants was the problem of the daily school run. There are no official school busses in Yangon, which has a large youth population traveling to and from school every day—sometimes very long distances. In the absence of a centrally organized system a private, ad hoc system has emerged comprising a fleet of perhaps 25,000 minibus shuttles, taxis and personal cars, which are all used to ferry children around, often at peak times (May Thinzar Naing 2016). Clusters of double- and triple-parked vehicles outside schools at the beginning and end of the day create bottlenecks in some areas, while the sheer number of vehicles involved in this daily migration adds significantly to the mass of vehicles on the roads at busy times. In recognition of this issue the Yangon Region Government purchased 200 school buses with the hope of improving the situation, but fears of driver safety and poor

management had delayed the government's roll with a newly proposed launch date of June 2018 (Lu Maw Naing 2017; Ei Thandar Tun 2018)

There is one potential source of flow disruption that is largely absent, at least in central Yangon. Unlike cities such as Jakarta, where mobs of motorcycles weave in and out of traffic, contributing to total vehicle mass and the stop-start behaviour that creates ripples of congestion, there are virtually no motorcycles on the roads in Yangon due to a ban imposed in 2003 (Goldberg 2015).

2.5 A perfect storm for gridlock

The combination of a growing population, increased economic activity, a flood of vehicles and a modal shift away from public transportation options has created a perfect storm of congestion in Yangon; one that is compounded by a lack of alternative modes of transport to support urban mobility.

Until very recently little had been done to address Yangon's growing transport needs, apart from the lightly regulated network of private buses that emerged to meet demand (discussed below). The only noticeable infrastructure investment in recent years has been the construction of seven flyovers that do not correspond to broader transport plan and have had a negligible impact on congestion (Thu Zar 2016). The only alternatives to cars and busses are a limited and poorly maintained circular rail line (built during the colonial era) and walking. Bicycles and trishaws have been banned from the CBD and virtually all main roads since 2003 (Long 2013).

While identifying these proximate causes is a useful and necessary first step in the search for plausible solutions, it is necessary to dig one layer deeper to understand why these conditions exist. The growth of Yangon's population and economy are unquestionably positive developments for the city and therefore undesirable targets for public intervention. This therefore leaves us with the following questions: Why has there been a surge of vehicles and what (if anything) should be done about it? Why have citizens been abandoning busses *en masse* and what can be done to reverse the trend? Why are the city's buses and taxis so ill-behaved and why are traffic laws more rigorously enforced? And why has Yangon, an emerging megacity, failed to invest in a mass urban transit system?

3. The political economy of gridlock

3.1 Congestion as a consequence of economic liberalization

The boom in private car use on Yangon's roads is a direct function of the broader process of accelerated economic liberalization that has accompanied Myanmar's political transition. Before 2011 the importation of automobiles was controlled by the military, with all imports going through either a military or government company channel. Non-affiliated auto traders would pay a premium to import vehicles and then turn and make a profit by reselling the car at a higher cost. Each time a car was sold a member in the chain could profit between 6,000 and 10,000 USD, which could bring the cost of a Toyota Land Cruiser to nearly $500,000 USD by the end of a cycle (Kuhn 2012). The high price of imports kept the supply of automobiles highly restricted before 2011; most of the vehicles on the roads of Myanmar were built decades earlier, some dating as far back as WWII (ibid).

The slow shift away from a state-socialism towards a state-mediated capitalist model began in 1988 following the failure of the Burmese Socialist Programme Party's autarkic economic management over the previous two decades (Jones 2014). By the turn of the millennium the number of private firms had overtaken the number of state enterprises, but the state maintained a commanding role, in part by restricting trade and using foreign exchange and import licenses as tools of political patronage (ibid). The failure of the state (i.e. military) to respond effectively to the devastation wrought by Cyclone Nargis in 2008 revealed the extent to which the balance of power had shifted towards crony capitalists, who mobilized resources (including the business-financed NGO Myanmar Egress) to deliver aid and lead reconstruction efforts (ibid). The subsequent reforms to currency management and import controls—including on vehicles—can therefore be understood as part Myanmar's broader political-economic transition from state socialism to nominally democratic crony capitalism.

It hasn't been a smooth process. The first step in liberalizing auto imports was known locally as the 'cars for clunkers' program. This was intended to remove older cars from the road and replace them with more modern, but still second-hand, vehicles, mostly from Japan. Under the program, any car between 20 and 40 years old could be traded in by the owner in return for a license to import a newer vehicle built no earlier than 1995 (Aung Hla Tun 2011). The trade was not cheap and required handover of the previously owned car along with payment of the new car's sale cost, customs duty, registration fee and surcharge amounting to an additional 165 percent mark-up above the purchase price (Kuhn 2012). Nevertheless, in under a year, 60,000 cars were traded in for import licenses with a total of 70,000 cars imported by the programmes end (Smyth 2014). This approach had some perverse consequences. First, a new class of brokers emerged who would purchase old cars at inflated prices from owners who were unable to afford the costs of a newly imported car. These brokers would then trade in the newly acquired used vehicle for an

import license, import a new car, and sell it at a profit (Aye Nyein Win 2015). Second, Myanmar-based car manufacturers began piecing together vehicles from old parts to sell to individuals keen to acquire import licenses (Htoo Thant 2015). In other words, many of the vehicles that were traded in for import licenses had not in fact been operating on city roads at all. The result was substantial increase in the number of vehicles on Yangon's roads.

By 2012, anyone with a national identity card could import one car and businesses could import up to 50 vehicles per license (Aye Nyein Win 2015; Aye Nyein Win 2015b). Those who could not afford a car could (and did) sell their license to brokers who would open registered or unregistered dealerships on the streets of Yangon (Aye Nyein Win 2015b). This drove a further surge in vehicle numbers on Yangon's roads (see Figure 5). The two government companies which had previously monopolized the import market now had to compete with 172 newly licensed private dealers and 14 international manufacture dealerships which had opened by 2014 (Myanmar Times 2014). At its peak Myanmar was importing 20,000 cars a month (Aye Nyein Win 2015). Regular policy changes over the next three years led to such rapid reductions in the retail price of cars that newly imported vehicles were sometimes left at the port because the taxes owed were higher than the potential resale value of the vehicle (Aye Nyein Win 2014).

The flood of new cars on Yangon's roads was, in short, a direct consequence of plummeting prices associated with Myanmar's broader trajectory of liberalization. This process has created a constellation of new stakeholders invested in the auto import business, and a large new class of commuters on Yangon's roads.[§]

3.2 Perverse incentives in a competitive bus cartel

With automobile prices plummeting, the rapid modal shift away from buses noted above is easily understood. Due to an array of perverse incentives built into the system, buses became notorious for long waits, overcrowding, price-gouging, rude staff and reckless driving (ADB 2016; JICA 2014; Tin Htet Paing 2016; Sithu Aung Myint 2017). With growing numbers of people opting for cars, these issues were compounded by longer and longer journeys. Most of the problems associated with the buses were a natural by-product of the incentives built into the system, which operated as a 'competitive cartel' in which thousands of bus owners joined an essentially independent organization that regulated entry but permitted competition on most routes.

[§] Why import liberalization was pursued in 2011 is an interesting and unanswered question. It is worth noting that this policy came on the heels of the disputed 2010 election in which the military-backed party claimed a contentious victory and just before the 2012 parliamentary by-election, in which the opposition leader Aung San Suu Kyi was allowed to participate after her release from house arrest.

This system emerged organically after 1974 with the growth of private sector bus operators who were allowed to operate under the supervision of the Motor Transport Management Committee. In 2009 this became the Yangon Region Central Supervisory Committee for Motor Vehicles and Vessels, more commonly referred to as Ma Hta Tha (JICA 2014; JICA 2013). Although nominally under the control of the Yangon Region government, Ma Hta Tha appears to have operated largely independently, overseeing a range of bus operators. These included two large private companies: the military-owned Parami Bus Line (operating as Bandoola Transport Co. Ltd) and Myanmar Golden City Link (Tin Htet Paing 2016b). However, these firms accounted for a small fraction of the thousands of buses on Yangon's roads, the remainder of which were owned by small operators who were members of sub-organizations known as Bus Supervisory Committees (BSCs) and Bus Line Committees (BLCs). The role of Ma Hta Tha and the BSCs and BLCs were to regulate entry into the system and to regulate the behaviour of operators.

The result was something resembling a cartel, with restricted entry, but limited competition on routes was permitted and most drivers and conductors were paid on commission to incentivize revenue maximization. The result was competition for passengers among small numbers of operators, which led to dangerous driving, overcrowding on buses and price-gouging by the conductors responsible for collecting fares and managing passengers on board. In this cash-based system there were incentives all the way up the chain from the conductors to the regulatory organizations to under-report passenger numbers and the fares collected to capture marginal rents (Htun et al. 2012; Gwilliam 2003). At the same time, competition kept margins low, which encouraged owners to spend little on vehicle maintenance, which in turn led to deterioration of buses and frequent breakdowns (Htun et al. 2012). Without independent enforcement of standards and traffic laws, the buses became an inescapable nuisance for riders and other road users alike. Similar consequences of deregulated urban transport systems have been seen in other cities in low and middle-income countries (see Rizzo 2002; Goodfellow 2012).

The persistence of this arrangement is likely due to the lucrative nature and dispersed interests involved. If official statistics are to be believed, the system was carrying an average of 2.5 million passengers a day at its peak in 2007. If we estimate a (minimum) average daily fare of 100 MMK (given that the cheapest one-way ride would have been 50 MMK) this represents an annual turnover worth 90 billion MMK—or roughly USD 71 million at the estimated real exchange rate in 2007 of 1296 MMK/1 USD (Kato et al. 2008; Kubo 2007). This revenue was being distributed among—and therefore supporting the livelihoods of—thousands of owners, drivers, conductors

and employees of the BSCs, BLCs, Ma Hta Tha and the traffic police who were paid to look the other way (Hein Ko Soe 2017).

With such a broad base of vested interests, improving the system has proven challenging. However, as discussed below, the depth of the mobility crisis coupled with determined leadership at the Region government level has resulted in recent reform.

3.3 The congestion incentive spiral

With the price of automobiles plummeting and the de facto costs of using the bus system rising (in terms of fares, time and comfort), the stage was set for an unusually rapid modal shift in Yangon. Moreover, this shift is self-reinforcing and creates a classic 'tragedy of the commons' scenario—or a 'congestion incentive spiral'.

As congestion worsens, bus users suffer more than car users because they must sit through periodic stops and rarely disembark at their final destination. By contrast, car users can go directly from origin to destination without stops. In other words, it is nearly always faster to use a car than a bus sharing the same road. This simple fact incentivizes those individuals who have the means to do so to abandon the buses. But in so doing they contribute to worsening congestion, which creates increasingly strong incentives to abandon the buses. This self-reinforcing cycle harms both the car users and the bus users, but it is a natural consequence of the fact that the social costs of increased car usage exceed the private costs (Gakenheimer 1999).

The situation can be made even worse in the long run by what is known as the Downs-Thomson paradox (Arnott and Small 1994). Simply put, if rising congestion is met with expanded road capacity, this could worsen congestion by undermining incentives to use public transport. The more attractive alternatives become, the less people opt for the public option. This reduces revenue, which in turn incentivizes reduced public services, which in turn makes public transport increasingly less attractive to commuters.

The seismic shift in the cost-benefit analysis of individual commuters that began with the liberalization of automobile imports now has a self-reinforcing logic that could make the situation far worse without public intervention designed to realign individual incentives with the public good.

3.4 A crisis of metropolitan governance

Coherent, coordinated intervention to tackle the current crisis is unlikely in the short to medium term due to the confused distribution of authority over planning and regulation in Yangon. The current institutional mosaic is a consequence of partial institutional reforms over successive regimes determined to tame the city rather than promote its development.

The origins of Yangon's governance arrangements can be traced back to the colonial era when the British established a partially elected municipal body with decision making authority legislated under the Municipal Act of 1898 (Furnivall 1961). The Municipal Act of 1922 went one step further by giving the Municipal Committee of Rangoon (Yangon) the power to elect one of their own members to serve as President (Act III of 1934 changed this title to Mayor), with a clear description of duties and power over four standing committees including Finance; Roads and Building; Water and Sewage; Public Health and Markets and the Education Board (Pearn 1939). Additionally, this bill gave the Committee the power to collect tax in order to fund the execution of those duties (ibid). During this period investments were made in a circular rail line, a downtown tram network and bus services.

After gaining independence in 1948, municipal institutions were reformed to ensure greater democratic representation. Elections to the municipal council were held every three years, and unlike their British predecessors who held elections using race-based constituencies, the new government determined voting by geographical ward. However, the nature of governance in the city changed dramatically under two successive military regimes.

Following a military coup in 1962, Rangoon came under the full control of what was to become the Burma Socialist Programme Party (BSPP). Under the military-led caretaker government (the predecessor to the BSPP) all members of the municipal committee were dismissed while new BSPP military leadership filled the positions. In 1974 the BSPP enshrined its legitimacy as the sole political party and administrative authority at all levels of government in a new constitution.

While the British had prioritized building infrastructure in the central business district, and the post-independence government had focused on establishing new Buddhist monuments, the military caretaker government prioritized cleaning up the city and promoting "discipline" among the residents (Seekins 2014). One of the first acts of the new government was to tear down informal settlements in the colonial core and relocate the population to new suburbs on the outside of the city (ibid). Infrastructure was to be provided in these new settlements, such as piped water, roads, electricity, bridges, schools and clinics. However, in practice these services were lacking, and without proper access to public transportation the newly relocated residents

were effectively cut off from their previous lives downtown (ibid). With the exception of the initial development of new suburbs, which exacerbated transport challenges for residents, the economically stagnant BSPP invested little in the further development of Rangoon's transport infrastructure (Seekins 2014).

The centralised system of administration and generally laissez-faire approach to urban management in Rangoon persisted until the 1988 protests and corresponding security crackdown that effectively ended the rule of the BSPP. The military-led State Law and Order Restoration Council (SLORC) that took over kept the administrative organization of the previous government but renamed the city Yangon and amended the previous Rangoon Municipal Law with the Yangon City Development Law. This law put the new Yangon City Development Committee (YCDC) under the direct control of SLORC and reduced the functions and responsibility of the committee (UNDP 2015). By instituting a new governance structure without repealing the previous 1922 municipal law, the new directive reduced the mandate but did not address how tasks were to be managed by the new centrally controlled administration (ibid).

As with the BSPP, the priority for the SLORC administration was the establishment of new towns to manage the "problem" of informal settlements and those who posed a threat to state security. The 1988 protests had revealed the extent to which Rangoon could serve as a flashpoint for resistance to military rule and so the regime sought to reduce the population in the centre, cultivate religious nationalism through investments in new Buddhist monuments, and close the university campuses that were associated with 1988 activists (Seekins 2005). Over half a million residents were relocated from downtown to Yangon's new periphery (Seekins 2014), contributing to a near doubling of the physical extent of the city by the end of the century (Morley 2013).

The new towns were geographically isolated from the central nodes of commerce and there were no significant investments in transport infrastructure to ensure efficient mobility throughout the expanded city. Additionally, a motorcycle ban in 2003 took away or criminalized an essential mode of travel for the city's residents (Board 2017). Morley (2014) argues that the economic hardships these new towns were intended to prevent simply transplanted the hardships from the downtown to the periphery. The relative neglect of Yangon during this period was accompanied by massive investment in the creation of a brand-new capital city, Naypyidaw, located 300km north of Yangon. In 2005 the seat of political and administrative power was officially transferred from Yangon to Naypyidaw.

A new constitution was ratified in 2008 that established a new structure of administration for the states and regions (no longer called divisions). In the former capital, this entailed the creation of a new Yangon Regional Government (YRG) and provided for some share of responsibility over key planning and regulatory functions between the national and sub national levels of administration (Nixon et al. 2013).

Beginning in 2012 the Yangon Region Government and YCDC collaborated with the Japan International Cooperation Agency to 'develop a strategic urban development plan' for greater Yangon. Shortly after, The Yangon Heritage Trust (YHT), a local organization founded by members of the Association of Myanmar Architects, produced the *Yangon Heritage Strategy* for integrated holistic planning around the historic colonial core. Published in 2014 and 2016 respectively, these documents provided a detailed vision for transport development in the region and in the city. However, apart from a handful of token projects, these plans have essentially been ignored.

Meanwhile, the 2013 Yangon City Municipal Law – in accordance with Schedule II of the 2008 constitution - placed both the budget and administrative oversight of the YCDC under the control of the newly established regional government (UNDP 2015). Just as the 1990 law served to supplement the 1922 municipal law, the 2013 law is effectively an amendment which provides some clarity of responsibility but does not directly address the existing legislation (Hein Ko Soe 2017), thereby adding to legal ambiguities around authority over city affairs.

The law established a nine-member committee with four members appointed by the regional government, four elected members from each of the city's four districts and a mayor who is appointed by the Chief Minister of the Regional Government. The mayor then has two positions, one as the head of the YCDC and one as the Region Minister for Development Affairs and is accountable to the Chief Minister and the Regional Parliament (UNDP 2015). A city-wide election was held in 2014 once the bi-laws were established with hundreds of candidates vying for the four central committee positions along with 12 district level and 99 township level positions (Hein Ko Soe 2017). While it was the first municipal election in decades, the process was highly contested with only 25 percent of the 400,000 eligible voters turning out to vote (ibid).

Today, the YCDC is nominally responsible for planning, infrastructure development and maintenance, water and sanitation, solid waste management, management of public spaces and associated amenities, and public health in the city. It also has legal authority to tax and spend and is financially self-sufficient (UNDP 2015). In practice, however, YCDC has become paralysed and

disempowered, often coming into conflict with the Region Government and national ministries, which also have legal authority in many areas from land use planning to housing to infrastructure and transport. While YCDC has some responsibilities for roads and bridges within its area, so too does the Region-level Ministry of Transport, as well as several national ministries including the Ministries of Construction, Home Affairs and Transport and Communications (ADB 2016).

This institutional mosaic has proven dysfunctional and has undermined efficient and sustainable management of urban development in Yangon (ADB 2016; JICA 2014). For example, the regional parliament initiated a USD $24 million project to build two flyovers that was not related to any structural plan and was ultimately halted despite being approved by the previous government (Eleven Myanmar 2016). In the construction sector, multiple governing bodies have authority to grant building permits, which has contributed to uncoordinated land development and often project delays. Indeed, construction companies have expressed frustration with the current mosaic of six different authorities that may need to grant permission to build, resulting in a process that can take between two and three years (Htun Kaing 2016). Companies essentially find themselves essentially shopping for permission: if the YCDC declines approval for a project the Region Government may overrule the YCDC (ibid). This lack of coherent authority structures in Yangon is ultimately a consequence of the way responsibility over key urban management functions evolved through successive regimes and were articulated in the Constitution (Section 96 and Schedule 2), as well as the various overlapping legal structures that empower the YCDC (see UNDP 2015).

To complicate matters further, political contestation and allegations of rampant corruption have resulted in a crisis of legitimacy at the city government level. Following the victory of the National League for Democracy in 2015, the 115 elected members of the YCDC were dismissed from their positions on the pretence that a fresh election should be held under the new political dispensation. To date this municipal election has still not occurred, with the city run by four committee leaders and the mayor, all appointed by the Region government (UNDP 2015). A new law set to replace the 1922 law is currently under review, but postponements and a lack of transparency have driven some MPs to voice concerns that the government is effectively operating illegally (Hein Koe Soe 2017).

In sum, Yangon was seen as a political liability under successive military regimes in the independence era. As a result, both the BSPP and SLORC sought to disempower the city government, assert direct control and disperse populations away from the core of the city. The resulting sprawl combined with a dearth of investment in new transport infrastructure and

services has contributed significantly to the current crises. Moreover, the institutional legacy of efforts to tame Yangon is a mosaic of overlapping authority structures vulnerable to political manipulation and devoid of popular accountability. As a result, Yangon does not have a robust institutional foundation for coordinating land use planning and transport development. This is a classic example of the 'fundamental paradox of urban transport'—a situation in which demand for mobility is not met with concomitant supply due to coordination failures across those responsible for transport infrastructure, service delivery and financing (Gwilliam 2003).

4. Improving mobility and taming congestion

4.1 Prioritising mobility over congestion relief

Barring an unforeseen crisis, Yangon will continue to grow over the next decade and journey demand will continue to rise and exert further pressure on the urban transport system. While some of this demand might be met through an improved and expanded bus service, the congestion-incentive spiral that is driving growth in private automobile use will not be broken without more radical interventions.

When considering solutions, it is helpful to frame the problem as one of mobility rather than traffic. Prioritising mobility encourages a shift away from focusing on congestion relief towards increasing the average speed that people move through the city. This in turn highlights the importance of enhancing alternatives to cars, including walking, cycling, motorcycles, buses and fixed-line networks insulated from traffic such as rail and bus rapid transit.

4.2 Supporting alternative modes: walking, cycling and motorcycles

There has been very little discussion—at least publicly—of promoting alternative modes of transport, including walking, cycling and motorcycles. Yet these could play an important complimentary role in boosting urban mobility. According to a survey conducted in 2012 over 40 percent of all journeys in Yangon are on foot (JICA 2013). Provision for pedestrians varies widely across the city and could be substantially improved in many areas with modest investment. This could be particularly helpful in the city centre and around key transport hubs in greater Yangon.

Promoting bicycle usage could have an even more wide-ranging positive impact on mobility in the city. Bicycles are a highly efficient, sustainable and healthy mode of transport (UN Habitat 2013), and Yangon's relatively flat topography is very cycle-friendly. Reducing or eliminating restrictions on the use of bicycles in the city centre, as well as along some arterial routes, could

rapidly increase individual mobility without exacerbating air pollution. It would also be a comparatively affordable option for many of Yangon's lower-income residents and an attractive one—particularly if investments were made in developing some cycling infrastructure such as dedicated lanes on the busiest roads. Embracing a city-wide cycling plan would place Yangon among the world's leading cities in terms of promoting sustainable urban mobility. However, while permitting bicycles would boost urban mobility, it is unlikely to reduce congestion.

The same is likely true of permitting motorcycles in the city. Lifting current restrictions would almost certainly increase mobility without reducing traffic. In the short to medium run motorization rates would increase as new people who can afford a motorcycle but not a car take up this option. But it is highly unlikely that existing car owners would choose to invest in a new vehicle and switch having already invested in a car. Indeed, the evidence suggests that motorcycle usage is an intermediate step in motorization, with users eventually upgrading to automobiles (Gwilliam 2003). Moreover, allowing motorcycles might encourage some people to abandon the bus system, thereby stimulating the Downs-Thomson Paradox noted above and potentially undermining the financial viability of the bus system (ibid). Finally, motorcycles would likely lead to higher injury and fatality rates on the roads and could significantly increase flow disruptions (ibid). In sum, there is simply not enough research to make an informed cost-benefit analysis of the current motorcycle policy or the potential impacts of reform.

4.3 Reforming the bus system and reviving Bus Rapid Transit plans

In January 2017, the Yangon Region government pushed through a dramatic reform of the bus system by taking over Ma Hta Ta, forcing a consolidation of ownership in the sector and introducing a new route structure. Compensation has also been reformed: all drivers and conductors now receive fixed salaries rather than commissions to eliminate incentives for overcrowding and reckless driving. Although the change was abrupt and perhaps premature, resulting in a shortage of buses on the roads and frustrating both bus owners and passengers, it was not an unmitigated disaster. Moreover, the new hybrid system of public control combined with private operators in the Yangon Bus Service (YBS) resolves many of the market failures inherent in the previous competitive-cartel system and is more aligned with best practice in the sector (Estache and Gomez-Lobo 2005). It also represents a bold test of the government's ability to tackle intense vested interests established in the previous era of military rule, with the outcome likely to be interpreted as an indicator of the extent of substantive political change in Myanmar (Frontier Myanmar 2017).

While initial reactions were mixed at best with many referring to the bus line as *pyithu seit pyet* YBS, or the "people's disappointment" in many respects the rollout of the YBS has already been a partial success. One year after the roll out the Yangon Regional Transport Authority (YRTA) secretary Dr. Maung Aung told a local newspaper that the YBS project had been "70 percent successful" (Hein Ko Soe 2018). Against the odds the Region government has forced a restructuring of ownership and management of the sector despite the many vested interests involved. This may have been facilitated by securing buy-in from some key stakeholders, including Bandoola Transportation Co, Ltd (owned by the military); Golden City Transportation Company (with 500 buses purchased by crony-owned Ayeyarwaday Bank); Omni Focus Co, Ltd (run by the grandson of former military leader Ne Win); and the Yangon Bus Public Co, Ltd, which is a public-private partnership originally established to run the Bus Rapid Transit system. Several other companies—including several recently created by conglomerates of small scale bus owners—have bought in to the system, including Yangon Urban Public Transportation Co, Ltd; Power Eleven Public Co, Ltd; Sanwalela and San Raung Ni Co, Ltd; City Linter Bus Public Co, Ltd; Golden Southern District Co, Ltd.

Some bus owners have resisted the reform and refused to put their buses on the road under the direction and regulation of the new YBS authority (Hein Ko Soe 2017). During the initial rollout this meant that there was a short-run capacity deficit, and even after two contentious deals brought 2,000 new buses to the roads, the deficit has been reduced but the system has nearly 1000 fewer vehicles than it did in the previous system (Slodowski, Wa Lone and Lee 2017; Hein Ko Soe 2018). Expansion of capacity among those who have joined the scheme should make up for current deficits and yield a system with more transparent fares, safer driving and improved behaviour on the part of conductors. However, this reform is unlikely to significantly reduce congestion in the medium to long term given rising demand for journeys and the precipitous modal shift in recent years.

A very promising alternative was announced in 2015 in the form of a Bus Rapid Transit plan, with new buses set to ply key arterial routes. Although new buses did indeed hit Yangon's roads early in 2016 with BRT logos they did not benefit from dedicated lanes, which is the defining characteristic of a BRT system. Consequently, they were subject to the same traffic conditions as all other vehicles and made no obvious impact on commuter behaviour. The BRT plans appear to have been quietly shelved, with the buses now incorporated into the new YBS. This warrants reconsideration.

One of the only things that might arrest the 'uncontrolled haemorrhage' (ADB 2016, pg. 7) of passengers from the bus system will be an alternative to driving that is faster, reasonably priced and relatively comfortable. This in turn requires a fixed line network that is fully insulated from city traffic—particularly at peak times—and a BRT system would be the most rational option under the circumstances.

The economic argument for such a system is strong: estimates suggest that constructing a BRT network would be far cheaper than the currently proposed alternatives. A BRT plan proposed by the Japan International Cooperation Agency (JICA) has an estimated price tag of 5 million USD per km. By contrast, the cost per km for modernizing the existing circular rail line is estimated at $20 million per km (ADB 2016). Other proposed options are similarly expensive, with per km prices of $10-25 million for a tram, $15-40 million for light rail system, $35-40 million for a monorail, $50-100 million for an above ground mass rapid transit system and between $130 million and $162 million for an underground MRT system (JICA 2014).

The sooner such a system is implemented the better given the strong 'path dependency' in commuter habits. In other words, once people shift towards using automobiles to get around the harder it will be to lure them back into using public transport options such as the bus system.

4.4 Restructuring incentives and raising revenue

Rather than lure people out of cars with a faster alternative (such as a BRT), policymakers could try to incentivise commuters to consider alternatives by influencing the personal costs of each option. Three mechanisms that have proven effective in reducing private automobile use in other contexts are petrol taxes, parking policies and congestion pricing. Each have the collateral benefit of generating revenues that can be re-invested in upgrading and maintaining transport infrastructure.

Myanmar has the second lowest petrol prices of any Southeast Asian country after Malaysia (Globalpetrolprices.com). Low prices reduce incentives to use public transport and represent a forgone revenue opportunity: many countries use petrol tax as a means of financing transport related infrastructure investments. However, increasing taxes on fuel is politically challenging everywhere, and particularly in Myanmar. The 2007 'Saffron Revolution' began following an overnight doubling of petrol prices and five-fold increase in natural gas prices (BBC 2007). More recently there have been complaints that prices are in fact too high given that oil prices have fallen but prices at the pumps haven't changed (Pyae Thet Phyo 2016), with some pointing out that station owners are profiting from the widened margin between global wholesale prices and local

retail prices (Chan Mya Htwe 2016). Despite the political challenges, introducing a marginal tax on some types of fuel within the Yangon Region may be a useful strategy for incentivising the use of public transport while raising revenue for transport-related investment and maintenance.

An alternative (or complement) to petrol taxes could be modernise parking policies to increase the price of parking, restrict the number of available spaces and ensure new parking facilities are focused around transport hubs outside of the city centre to encourage public transport use (UN-Habitat 2013; Yangon Heritage Trust 2016). Current policy is almost a mirror opposite of this approach. Parking charges in downtown were eliminated in 2013, thereby reducing costs for drivers (Noe Noe Aung 2013), although there is some indication that fees will be collected in a planned new multi-storey facility downtown (Aye Nyein Win 2018). The requirement that importers prove access to a parking space has only had the effect of stimulating a market for the official letters from township officials required as proof (Aye Nyein Win 2015c). And the requirement that developers offer 1.2 parking spaces per new condominium unit has had the perverse effect of encouraging developers to build fewer small units that would have wide market appeal and instead focus on building larger, less affordable units (Chau 2017; Kang Wan Chern 2018). This, in turn, will result in lower habitation densities in the urban core, which will increase demand for journeys from those forced to live further from the centre. In short, the current policy mix reflects mid-20th century planning practices that minimise the costs and maximise the availability of urban parking, rather than the 21st century planning consensus that making parking scarce and expensive is a useful way to optimise the use of urban space, raise revenue and encourage use of public transport options (UN-Habitat 2013; Yangon Heritage Trust 2016).

In some ways, this approach to parking is a form of indirect congestion charging, which is an increasingly popular idea among planners. This could provide a complementary policy in Yangon. There are numerous examples from around the world that confirm the efficacy of this approach including Stockholm (Eliasson et al. 2006;); London (Prud'homme et al. 2005); and Singapore (Goh 2002). Moreover, Yangon is already in the process of introducing a camera mesh in the city centre that could potentially be used to implement such a plan (Shine Lin Aung 2017). However, this is also a politically challenging policy strategy and one that requires a high level of institutional capacity to implement and manage successfully. Given the tenuous state of urban governance arrangements in the city this may not be a viable option in the short to medium run.

4.5 Governance reform

Current efforts to reform the bus system, introduce a CCTV equipped traffic control system and improve traffic enforcement are all positive developments, and it is sensible to consider longer-

term plans for large-scale infrastructure development, such as a proposed metro system. However, such projects and initiatives will not yield sustainable improvements without governance reform.

As an emerging megacity Yangon desperately needs an independent transport agency with a mandate to maximise urban mobility and accessibility. Such an authority would need to have oversight of all modes of transport in the city and coordinate with other authorities involved in land use planning. This is complicated by the current fragmented nature of governance in Yangon. Creating a transport agency therefore may require deeper institutional reforms to establish a coherent foundation for integrated transport planning and delivery.

Sustainable development and maintenance of Yangon's transport system will require the clarification and rationalisation of roles between different tiers and agencies currently involved in transport delivery, the creation of a dedicated authority to manage urban transport, and a reconsideration of the appropriate boundaries of this authority with reference to the functional area of Greater Yangon. This should be considered an urgent priority. Establishing the appropriate institutional architecture now could help Yangon avoid the fate of cities such as Jakarta, which are today suffering the consequences of coordination failures stemming from decades of fragmented urban governance arrangements.

5. Conclusion

Yangon is thriving, but it is facing a mobility crisis fuelled by rapid economic liberalisation in a city that suffers from a legacy of underinvestment and fragmented governance arrangements. This crisis has recently stimulated reforms in the bus system, efforts at Region Government level to accelerate the delivery of new services (e.g. water taxis) and improve regulation and enforcement on city streets. While these are welcome initiatives for city residents, they will not provide much relief in the longer run.

As an emerging megacity Yangon will always have traffic. While efforts should be made to reduce the social and economic costs of road congestion, eliminating it entirely is simply unrealistic. The overarching goal of planners and policy makers should therefore be to maximise mobility and accessibility through a holistic approach to urban transportation delivery. Reducing road congestion should be a secondary objective and collateral benefit of improving mobility. Focusing on improving the experience of drivers by building more roads and parking facilities will not ultimately yield the most efficient and equitable outcome.

In the short run improvements to urban mobility could be achieved with relatively modest expenditure by consolidating ongoing reforms to the bus system, strengthening traffic enforcement to reduce flow disruptions, relaxing restrictions on the use of bicycles in central Yangon, and investing in cycle and pedestrian infrastructure. In the medium term, developing a proper BRT system—with dedicated lanes on key arteries—could be the most cost-effective option for creating an attractive mass transit alternative to private transport. A BRT system would likely benefit from a parallel strategy of dis-incentivising car use through some combination parking restrictions, implementing a tax on petrol consumption in Yangon Region, or congestion charging.

To preserve its rich urban heritage, Yangon will need to embrace 21st century integrated planning practices that seek to maximise accessibility and mobility for all people rather than minimise traffic congestion for those who use cars. This will ultimately require addressing deficiencies in the institutional foundations for sustainable urban transport delivery through a comprehensive review and reform of metropolitan governance institutions in Greater Yangon.

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Figure 1 | Population growth in Yangon, 2010-2015

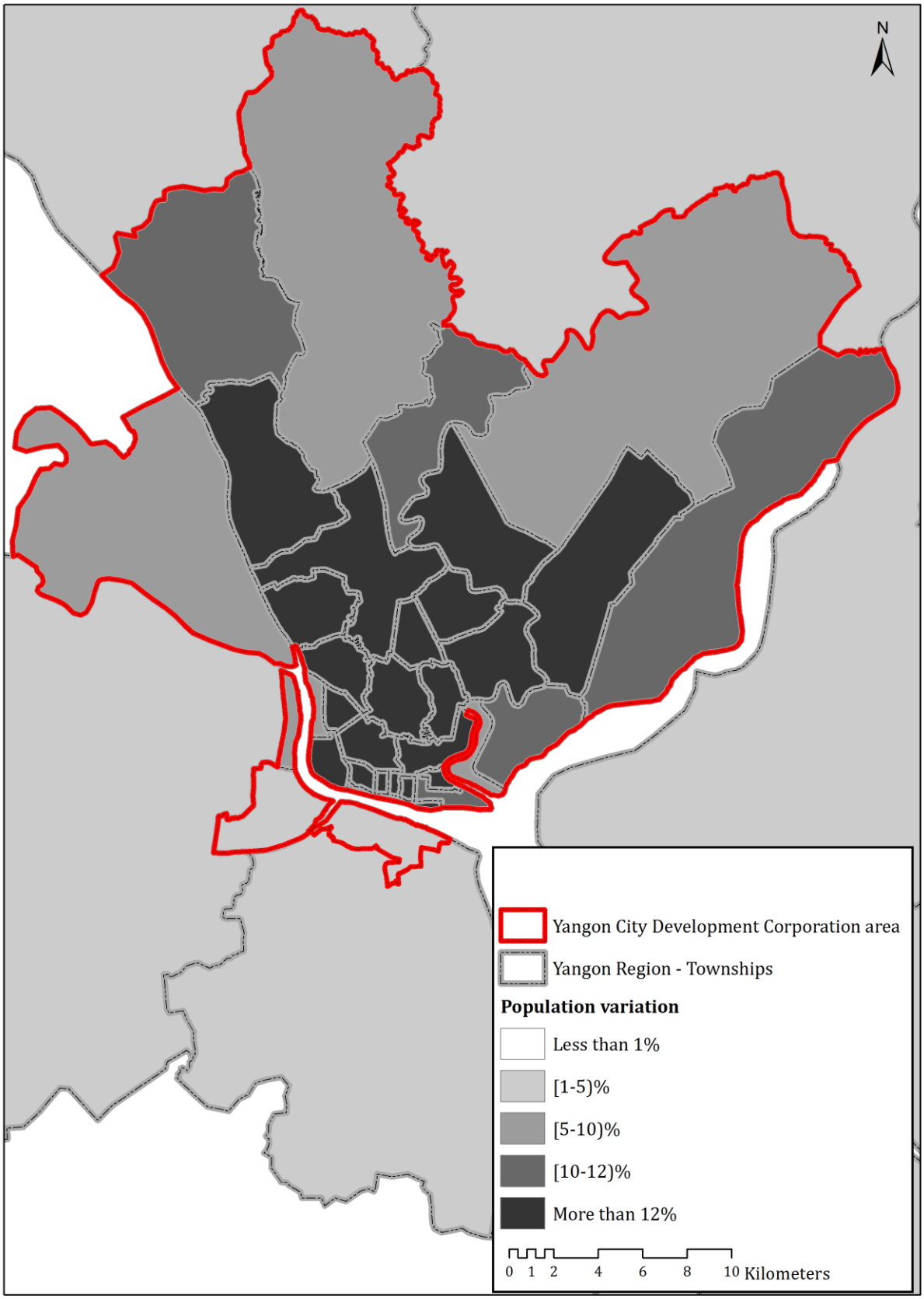


Figure 2 | Expansion of built-up areas in Yangon, 2003-2016

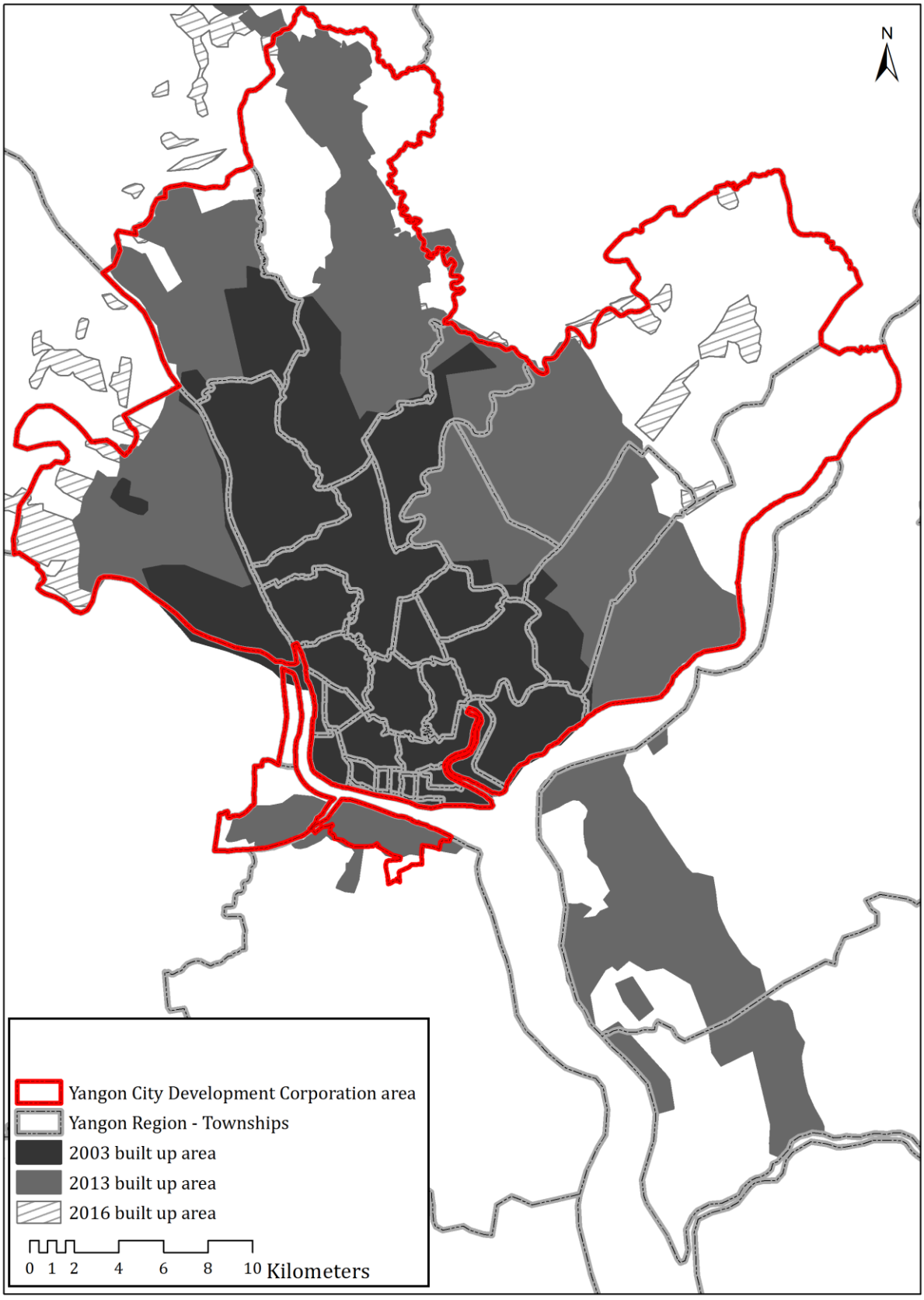


Figure 3 | Luminosity in Yangon Region, 2003

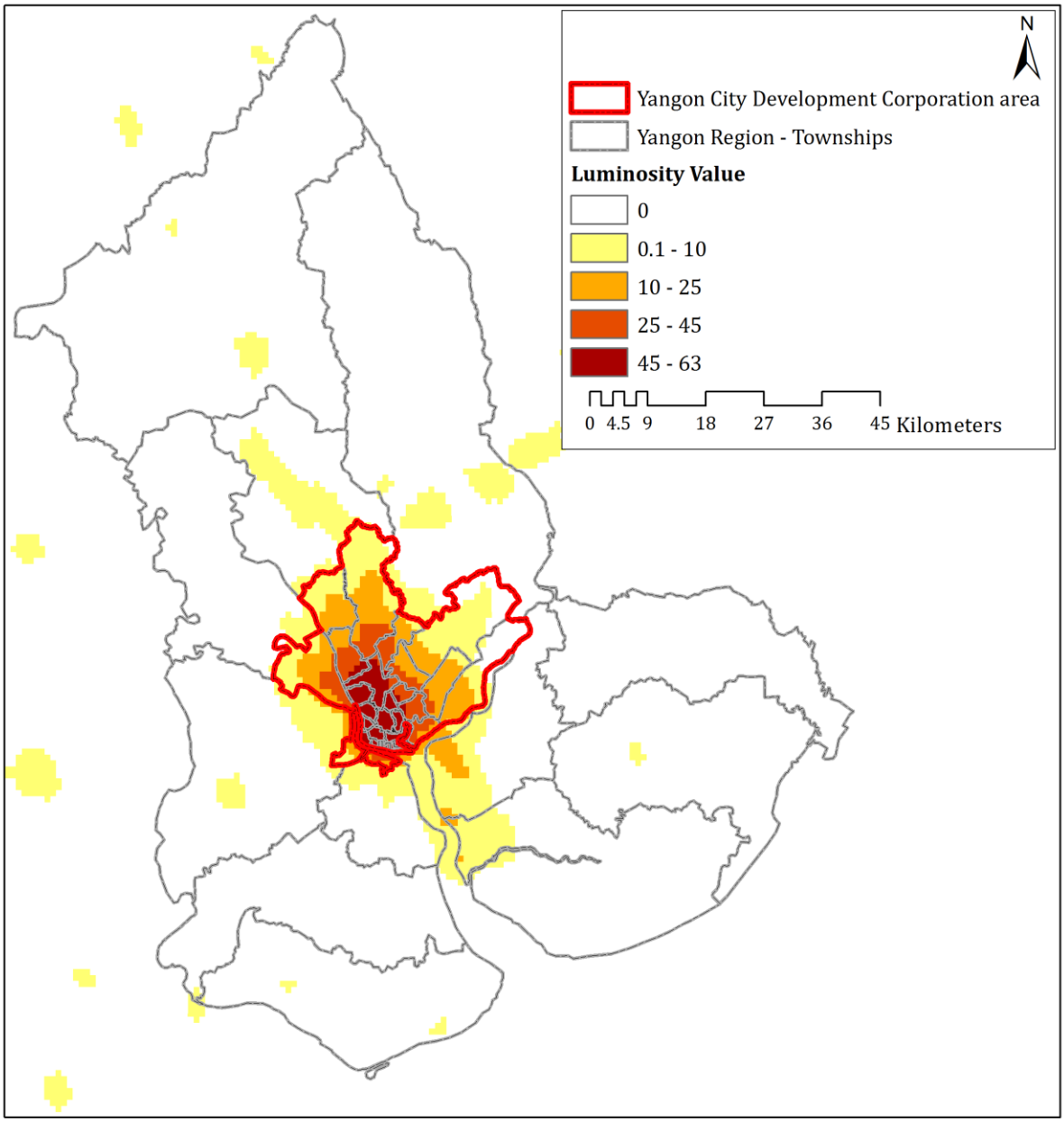


Figure 4 | Luminosity in Yangon Region, 2013

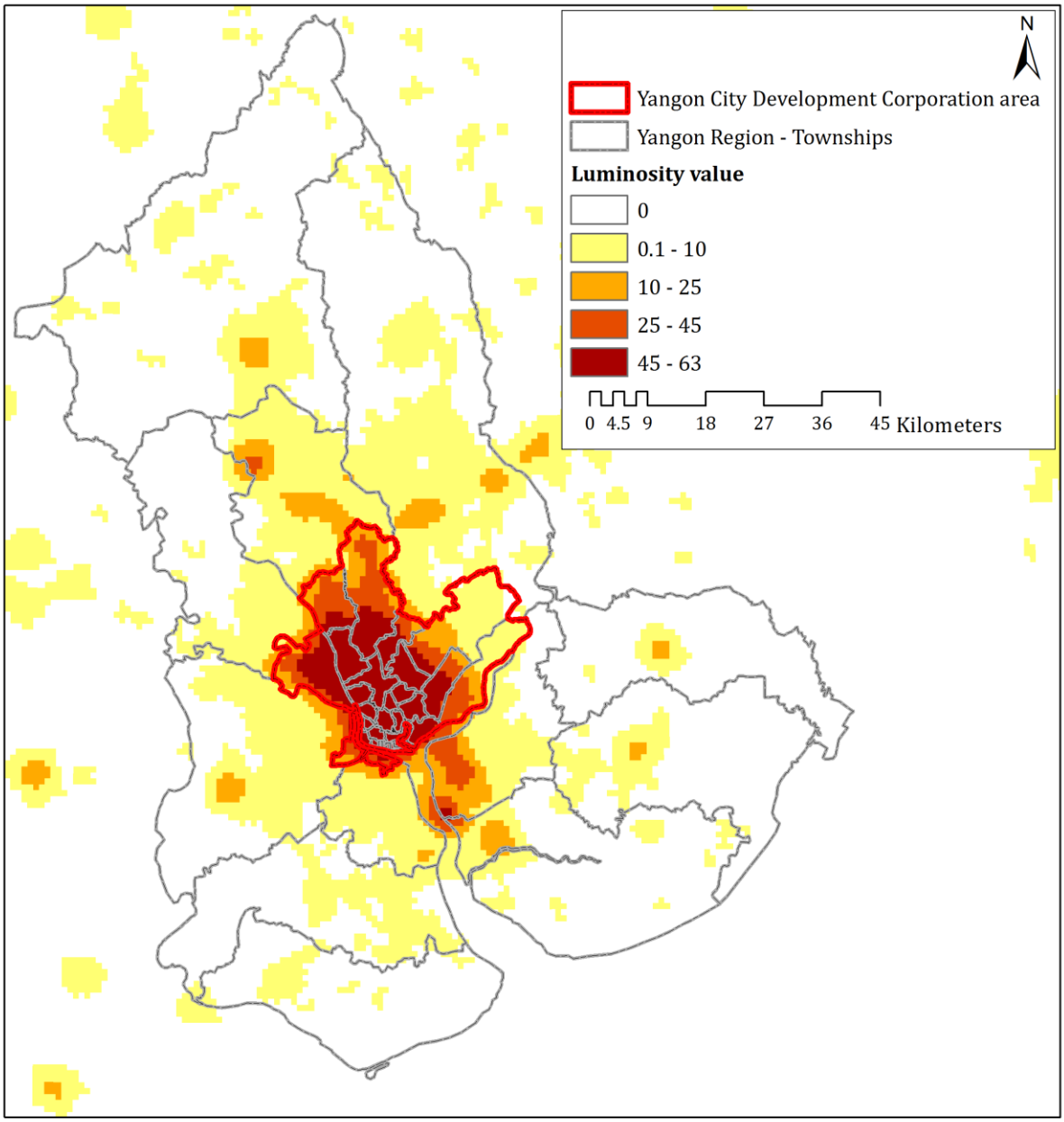
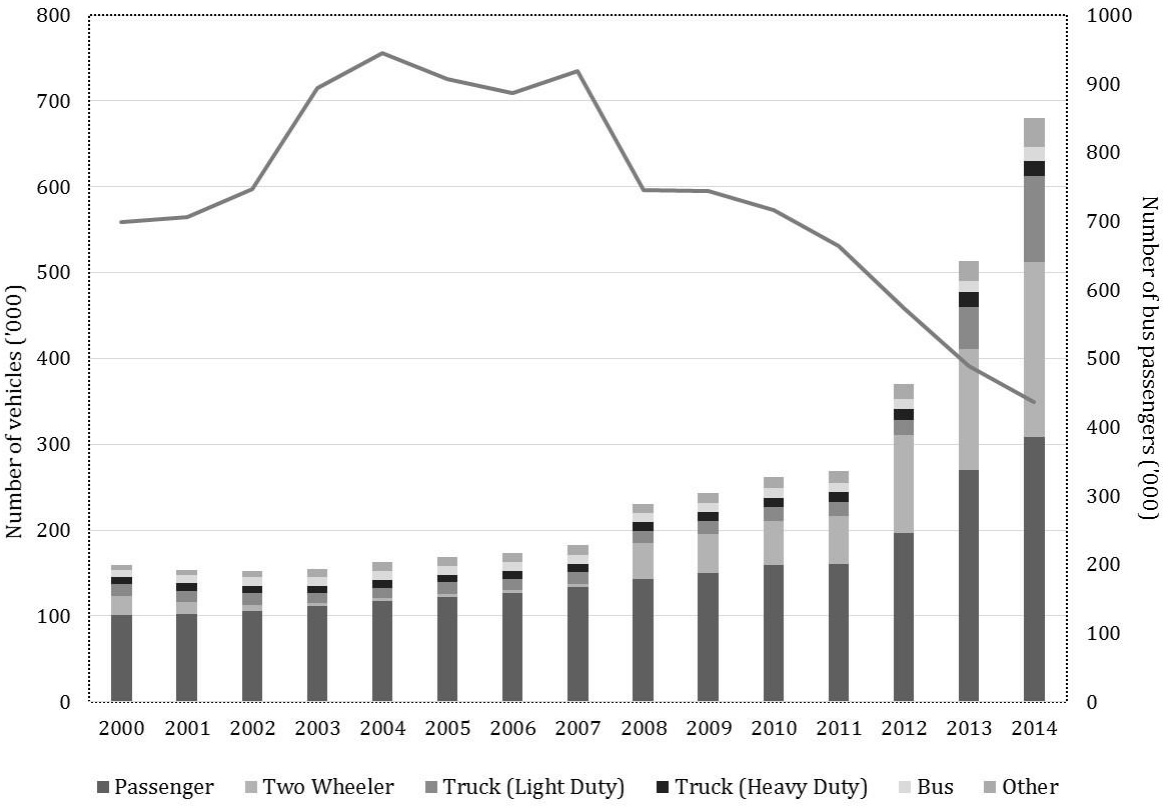


Figure 5 | Change in number of registered vehicles (bars) & bus passengers (line)



Source: Government of Myanmar (2017) Myanmar Statistical Information Service. Central Office of Statistics. Available at: http://mmsis.gov.mm

Appendix A

Summary of geospatial analysis methods

Analysis of population variation between 2010-2015

WorldPop datasets for 2010 and 2015 were used for the analysis of population variation in the Greater Yangon region, both at township and ward level. The raw 2010 and 2015 raster WorldPop data were initially analysed by means of the zonal statistics algorithm using a reference grid covering the full extent of the Greater Yangon region with cells of the same spatial resolution as that of the WorldPop rasters (i.e. hectare). The zonal statistics algorithm calculates the sum of pixels value (population) for each of the cells in the grid, thus allowing us to define population densities and population counts for urban settlements.

For the mapping of the population growth rates at township and ward level, the zonal statistics algorithm was reapplied to the raw raster scenes using the administrative boundaries of each of the townships and wards of the Greater Yangon region as the spatial units of reference. For the townships, the estimated population counts have been checked against the available census data.

Analysis of urban expansion

To evaluate expansion of built-up areas in Greater Yangon over a period of 15+years, a 3 scene mosaic Landsat time-series was acquired and pre-processed to a resolution of 15 meters for the years 2003, 2013, and 2016. Urban areas were then manually digitized and validated by means of visual interpretation.

To establish the ideal years and intervals of acquisition for the scenes the following factors were taken into account:

- For the first scene, conditions of cloud cover, luminosity, and the necessity to work with Landsat 7 ETM+ (which has the same resolution of Landsat 8 OLI), determined the choice of 2003 as the baseline year;
- The second scene was acquired 10 years from the first to allow for a reasonable timeframe for the analysis of urban expansion;
- The 2016 scene was chosen to provide the most recent possible “snapshot” of the state of urban expansion.

The three urban masks resulting from the process of manual digitization were used to assess the extent, direction, and the rate of the spatial expansion of Greater from 2003 to 2016.

Appendix B

Estimating GDP growth in Yangon with nightlights data

In the absence of reliable, sub-national time-series statistics on economic activity in Greater Yangon we developed estimates of growth in output in the region by combining data from a series of satellite images of nightlights in Myanmar between 1992 and 2013 with national GDP estimates covering the same period. The use of nightlights data to estimate GDP in data-scare contexts is now well-established but controversial.
The rationale behind this approach is simple: economic activity requires energy, which can be remotely observed by sensors on satellites as light emitted by objects on the earth's surface at night (e.g. from lights in factories, homes and transport infrastructure). Assuming that light emitted from a region at night and economic output are correlated, changes in the amount of light observed in a region should reflect changes in GDP (Elvidge et al 2007).

Several studies have indeed confirmed such a correlation utilising national level luminosity and GDP data for a large cross-section of countries (Chen and Nordhaus 2011; Henderson, Storeygard and Weil 2012; Nordhaus and Chen 2015). This approach has also been used to measure spatial variation in levels of economic development across regions within individual countries (cf. Gennaioli et al 2013; Michalopoulos & Papaioannou 2013; Alesina, Michalopoulos & Papaioannou 2015). However, there are some important technical limitations when applying this approach at the sub-national level.

The most widely used nightlights data come from the US Defense Meteorological Satellite Program (DMSP). DMSP satellites are fitted with luminosity sensors that have a bounded range of measurement, from 0-63. This restricts the amount of variation in luminosity that can be observed and is particularly problematic a) in areas of high economic density, such as wealthy metropolitan areas, which can emit enough light to saturate the sensor (thereby creating an upper limit on the level of economic activity that can be inferred), and b) in low density areas that may emit such low levels of light that they are not captured by the sensor and mistakenly recorded as having no human-generated luminosity (Bickenbach et al 2016). This technical problem is likely to be attenuated in future research by the launch of new satellites with sensors that can accurately measure a wider range of frequencies, such as the Suomi National Polar-orbiting Partnership weather satellite equipped with the Visible Infrared Imaging Radiometer Suite (VIIRS). However, our analysis relies on the availability of publicly available time-series data, which only the DMSP provides at this point in time.

Other limitations relate to uncertainty with regard to measurement error in both the luminosity data and GDP data. This can obscure the 'true' relationship between luminosity and real GDP and undermine the statistical robustness of the method (see Norhaus and Chen 2015). It is also important to note that a relation of exact direct proportionality between GDP and observed luminosity cannot be established in mathematical terms. Different economic activities will emit different amounts of light, while similar activities utilising different technologies may emit exhibit different light intensities. As a result the elasticity of luminosity with respect to GDP may not be universal but rather country-specific, region-specific and variable over time.

Nevertheless, the accumulated research supports the premise that luminosity and GDP co-vary and that using changes in luminosity as a proxy for changes in GDP can be valuable in contexts where reliable sub-national economic data are missing. Moreover, for the purposes of obtaining a rough measure of change in output in metropolitan areas in low- and middle-income countries, concerns about the bounded nature of luminosity measurements are minimised. Metropolitan areas are less susceptible to lower-bound errors in measurement than rural areas due to the relatively high density of people and hence economic activity; and low- and middle-income countries are less likely to have large numbers of saturated pixels (even in urban areas) than high income countries.

Estimating GDP for Greater Yangon

In order to estimate changes in GDP in greater Yangon we acquired annual DMSP images of nightlights in Myanmar covering the years 1992-2013 and national GDP data from the Penn World Tables version 9 (PWT)(see Feentra et al 2015). As we are interested in the correlation between luminosity and output we use PWT estimates of output-side real GDP at chained PPPs in millions of 2011 US dollars. We then calculated the elasticity of luminosity with respect to GDP at the national level using the time-series data and then applied this equation to the luminosity data from Greater Yangon to derive our sub-national output estimates.

This approach builds on the findings of previous studies but it is tailored and scaled to a sub-national scale of analysis. For instance, in order to prove the correlation of luminosity data with national GDP values, Henderson et al. (2012) assumed that the same value of elasticity can be applied universally (i.e. the same everywhere and over time). Statistically this approach – which is based on the calculation of a normalised value of elasticity - is valid to establish a means of comparison across case studies. Our approach does not compare several case studies, but it does assume that elasticity is consistent within Myanmar, so as to establish a baseline of comparison between luminosity at national level and luminosity observed at sub-national level. The approach is strengthened by the use luminosity data across the longest possible time series (i.e.,1992-2013).

The nightlights datasets (stable lights series), which are available for the whole of the Earth's surface, were resized to the national boundaries of Myanmar and to the administrative boundaries of the Greater Yangon region. Using the zonal statistics algorithm, the overall luminosity value for the two boundaries was calculated on an annual basis. When two images were acquired by two different sensors in the same year, the luminosity values of the two images were used to produce a mean value image to analyse with the zonal statistic algorithm.

Figure 1 illustrates the trends in national luminosity, greater Yangon luminosity and real GDP between 1992 and 2013. The data were converted to index numbers to facilitate visual comparison of rates of change with 2003 set as the base year.

Overall, these three series exhibit similar trends. There are, however, two obvious outlier years: 2009 and 2010. It is likely that the dip in luminosity in 2009 reflects extensive damage to infrastructure associated with Cyclone Nargis, which hit the country in May 2008. We cannot confirm the date that the 2008 and 2009 images were taken, but we suspect the 2008 image was taken before the cyclone and hence the effect on

infrastructure only became apparent in the 2009 image. Conversely, 2010 was an historic election year and one which saw a boom in public spending and strong commodity exports (IMF 2012).

It is important to note these outliers because variance and co-variance measures - which the method is based upon - are sensitive to outliers. The influence of outliers propagates to the estimation of the correlation between national luminosity estimates and national GDP estimates, and hence to our estimates of the elasticity of luminosity with respect to GDP. Figures 2 and 3 show the linear correlation between national luminosity and GDP with and without these outlier years respectively. There is a clear linear fit in both cases, confirming the robustness of the method increases with the length of data series and the richness of the sample, but the fit is considerably stronger when the luminosity observations for 2009 and 2010 are excluded—the R-squared increases from .68 to .84. By applying these equations to the Greater Yangon luminosity scores we estimated real GDP for the city-region. In doing so we assume a) that these equations reflect a true underlying correlation between luminosity and GDP in Myanmar, and b) that the elasticity of luminosity with respect to GDP is the same at national and sub-national scales. These estimates, along with the underlying data, are presented in Table 1. Yangon Estimate A employs the equation shown in Figure 2; Yangon Estimate B employs the equation shown in Figure 3.

Comparing these figures suggests that the estimates produced from the latter model with outliers omitted is preferable. For example, Estimate A suggests that Yangon's GDP was greater than national GDP in 1992 and accounted for over 80 percent of national GDP between 1993 and 1997. This is highly unlikely given the size of Myanmar's population.

Figure B1| Changes in national luminosity, Yangon luminosity and national GDP (2003 = 100)

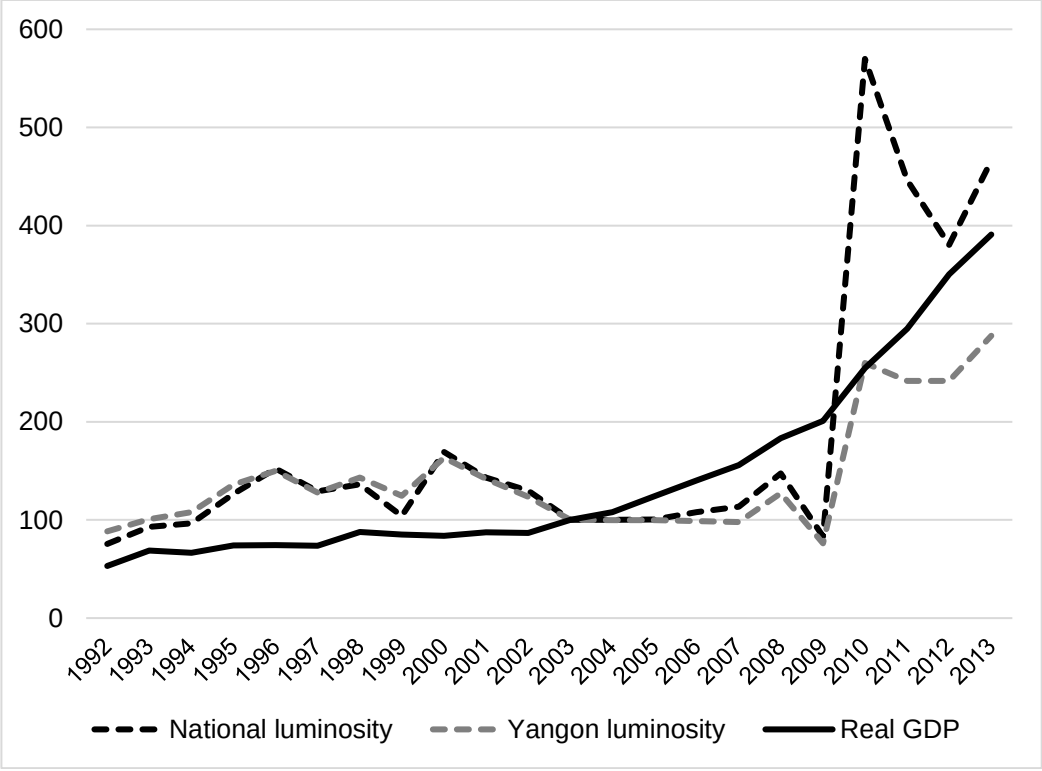


Figure B2 | Luminosity & GDP (all years)

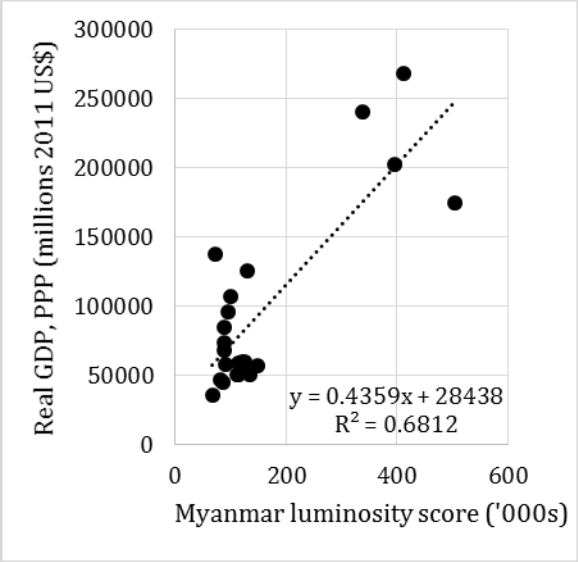


Figure B3 | Luminosity & GDP (ex. 2009 & 2010)

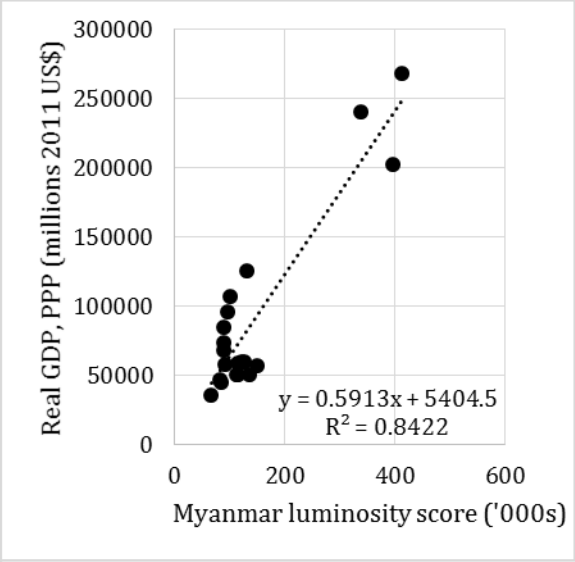


Table B1 | Myanmar Real GDP, Luminosity and Greater Yangon GDP Estimates, 1992-2013

Year	Real GDP (millions 2011 US$)	Myanmar Luminosity Score	Yangon Luminosity Score	Yangon GDP Estimate A	Yangon GDP Estimate B
1992	36467	66930	19841	37087	17136
1993	47334	82332	22610	38294	18774
1994	45600	85465	24262	39014	19751
1995	50913	112085	30529	41746	23456
1996	51099	135018	33671	43115	25314
1997	50653	114514	28712	40954	22382
1998	60200	120903	32143	42449	24411
1999	58412	92162	27941	40617	21926
2000	57632	149940	36697	44434	27103
2001	59988	126827	31867	42329	24247
2002	59475	115118	27743	40531	21809
2003	68644	88567	22448	38223	18678
2004	74172	88806	22406	38205	18653
2005	85341	89106	22401	38202	18650
2006	96302	95588	22167	38100	18512
2007	107126	100648	21966	38013	18393
2008	125765	130582	28573	40893	22300
2009	137864	73779	17108	35895	15520
2010	174954	504669	58360	53877	39913
2011	202453	395084	54265	52092	37491
2012	240380	336961	54279	52098	37500
2013	268314	412884	64583	56590	43592

Discussion

Between 1992 and 2013 the total amount of luminosity observed in Greater Yangon more than tripled, from 19841 to 64583. According to our preferred estimates, this suggests that GDP in the region increased 2.5 times from roughly 17,000 million US$ to 44,000 million US$ over the same period. This translates into an average annual growth rate of 4.45 percent. If we consider the more recent period of reform, beginning in 2008 when the constitutional referendum was held, Yangon is estimated to have grown at an average annual rate of 11.17 percent.

While these are plausible estimates of growth for the city they must be treated cautiously. The World Bank ranks Myanmar's statistical capacity below the IDA and East Asian averages, which highlights the potential for significant measurement error. There are also sensor limitations. Strong growth may lead to saturated cells, which can lead to underestimation of growth thereafter. Conversely, multi-scatter reflections (i.e. the same beam of light splitting by reflection is captured by the sensor in multiple cells) can lead to the over estimation of total light. To check this, the earliest and most recent series (F18-2013) of the nightlights data was evaluated in discrete classes and plotted in Figures 4 and 5 below. The results show that very few areas exhibited saturation in 1992, but that a large portion of the built-up area of greater Yangon reached the upper bound value of 63 by the year 2013. This limits our ability to capture further growth in these areas, although the method stillremains a potentially valid approach to retrospectively estimating growth in the region monitoring the pace of economic change in non-saturated (e.g. suburban) areas of Greater Yangon in the future.

Overall, our method yields plausible sub-national estimates of growth in Greater Yangon. Given that the DMSP data inevitably exhibit some stochastic variation in the measurement of luminosity, estimating elasticity (and hence growth) with short time series would not be statistically robust. The measurement of luminosity data depend on the sensitivity of the sensor to capture light and it is therefore a technical measure. As all the technical measurements, it is reasonable to assume that errors in the measurement will be systematic. However, random errors can occur both in the measurement (i.e., sensor malfunction) as well as in the processing of the satellite value (i.e., data rendering). A longer time series reduces the statistical significance of random errors.

Besides technical errors, long time series helps to reveal the presence of outliers—i.e. observed luminosity values that are influenced by non-routine events that affect an economy, such as natural disasters. It is also important to monitor sensor saturation over time in national and sub-national estimates to establish the limits of valid empirical inference from this data. Nevertheless, it is a method that may be suitable for monitoring economic change in metropolitan areas in low and middle- income countries where subnational GDP data are absent and sensor saturation is not widespread.

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