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The conundrum of the motorcycle in the mix of sustainable urban transport

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Abstract

Compared to cars motorcycles are potentially the more sustainable means of transport. Motorcycles need less space, consume fewer resources, and pollute less than cars with typically low occupancy. Thus, can the promotion of motorcycles potentially improve the sustainability of urban transport systems within an Asian context? The objective of this study is to investigate how pursuing this idea might impact urban transport systems beyond its apparent and immediate benefits by considering the wider consequences over an extended period of time. Chiang Mai, a medium-sized regional city in Thailand was chosen for the case study.

The analysis carried out highlights the unique features of trips made by motorcycle and quantifies the effects of policies that promote motorcycle ownership and use. The result of the study is that despite its apparent benefits, promotion of motorcycle even can worsen the sustainability of a transport system. However, implementation of certain mitigations, such as parking organisation, can improve the outcomes. The findings emphasize the need to consider a systemic perspective in implementing urban transport measures. The urban transport system is complex and can react to certain intervention in an unexpected manner that may conflict with intended goals.

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Keywords: Motorised-two wheeler; System Dynamics; System approach; Land use and Transport model

1. Introduction

Motorcycles have become a popular and dominant mode of transport in many parts of the world, especially in Asia (Hsu, Sadullah, & Dao, 2003; Pfaffenbichler & Circella, 2009). Since the turn of the century, the number of electrical

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two-wheelers has increased from near zero to 150 million within China alone (Cherry, 2013). This trend reinforces the need to study the impacts of such developments.

Haworth (2012) made a strong case to deepen our understanding of the motorcycle's usage pattern to enhance its mobility potential. It provides an affordable form of personal transport that utilises fewer resources (fuel, materials and space) for many people in developing countries. Olubomehin, (2012) provided an account on the tangible benefits the motorcycle offered to commercial sectors in Nigeria. However, there are also negative aspects that need to be dealt with, such as motorcyclists' lack of adherence to the Highway Code and increased CO_2 emission from the bikes they ride. Rose et al. (2012) suggested that Powered Two Wheelers (PTW) may have a role in contributing towards a sustainable urban transport system. However, she stated that a deeper understanding of the topic is necessary. A literature search on motorcycle and sustainability, however, currently yields limited returns.

Pfaffenbichler & Circella (2009)'s case studies of Hanoi (Vietnam), Bari (Italy), and Ho Chi Minh City (Vietnam) examined the role that the motorcycle has in maintaining the efficiency of the transport system. The motorcycle utilises only 15-20% of the space per person required by a car. It also consumes less energy in production and operation, as well as emitting less CO_2. Hsu et al. (2003) and Rose, Thompson, Amani, & McClure (2012) also reported similar benefits. The reduced space required for parking, and slowing the demand for additional roads, can reduce urban sprawling. Moreover, the motorcycle has a lower purchase cost with a car costing around 10 times more than a motorcycle. Another study by SafetyNet (2009), suggests that a motorcycle is a more economical mean of transportation. The same study found motorcycle trips to take 16% to 46% less time for the same trip as a car in an urban environment. The common disadvantages of this mode of transport are the motorcyclist's exposure to extremes of weather, the machines instability, limited number of passengers, limited capacity for transporting goods, limited range, lack of security from thieves, and its vulnerability during accidents (Rose et al., 2012).

A high proportion of motorcycles also has been found outside Asia in many places with warmer climates such as Greece (Yannis & Golias, 2007), and it seems certain that motorcycle use and ownership will continue to rise in many countries. A study by Broughton & Stradling (2005) reports an increase in motorcycle traffic in the UK of 49% between 1998 and 2003. Authorities in Austria have also sought to promote a similar form of mobility, which is powered by electricity (Pfaffenbichler & Circella, 2009).

Can the promotion of motorcycles potentially improve the sustainability of urban transport systems? The forgoing literature seems to support a strong case for such a proposal. However, the urban transport system is complex. It comprises of a vast range of different entities, which are interconnected. This complexity means that the system may react to change in nonlinear, delayed, and unexpected manners.

The objective of this study is to investigate how pursuing the promotion of the motorcycle might impact urban transport systems beyond its apparent and immediate benefits by considering the wider consequences over an extended period of time. Chiang Mai, a medium-sized regional city in Thailand was chosen for the case study.

The background to this paper and the motivation of the study is introduced in the first part. In the second part, the methodology employed is outlined. This section also presents a brief description on Chiang Mai city, the development of the CNX-MARS (Chiang Mai City Metropolitan Activity Relocation Simulator) model and the scenarios considered here. In the third section, the results of the analyses are presented. The outcomes from trip analyses, with a focus on motorcycle trips, and the results from the CNX-MARS model are shown. The outcomes are discussed and the paper is concluded in section 4.

2. Methodology

The primary data for this study originates from a household mobility survey undertaken in Chiang Mai. The Chiang Mai Mobility and Transport Survey (CM-MTS) took place in 2011-2012. The survey gathered the travel patterns of 6,189 persons domiciled in 2,319 households within the Chiang Mai city area with a strong emphasis on non-motorised transport trips.

The CM-MTS data was checked prior to any analysis. Calculated travel speed was used to screen out trips with anomalies in time and distance from the trip time and trip distance distribution analyses. A maximum speed allowable was set for each mode and trip, and where speed exceeded the set limit these datasets were omitted. The maximum speed values were set based on expert considerations. The data was analysed to identify unique trends and characteristics of motorcycle trips in comparison to those with other transport modes. Several secondary data from official sources, such as the number of vehicles, was also included to ensure the comprehensiveness of the analysis. The results of these analyses are presented in the mobility data analysis section of this paper.

Next, the mobility data was inputted into a land-use transport interaction model, called MARS (Metropolitan Activity Relocation Simulator). MARS is an aggregate system dynamic model, with an ability to simulate the complex relationships between entities within a transport system over a long period. It includes walking, cycling, and motorcycle trips making it a suitable tool to assess the effect of these modes within the city transport system. Further information on MARS can be found in Section 2.2. MARS was used in this study to process the mobility data together with official demographic and land use statistics and to quantify the impacts of motorcycle promotion.

2.1. Chiang Mai city and its transport system

Chiang Mai is the primary city of Chiang Mai province, which is situated in the northern region of Thailand. The city has been designated as the centre of development for the region. Its official urbanised area is called the Chiang Mai Principle City Area, which spans 7 districts and covers over 429 square kilometres.

Chiang Mai city is known to have a high number of motorcycles. A survey by OCMLT (2002) shows that 60% of all registered vehicles are motorcycles. This characteristic is also quite common among other countries in Asia, such as Malaysia, Vietnam, and Taiwan (Hsu et al., 2003). The magnitude of motorcycle presence in these countries is unimaginable in a European context. For instance, the motorcycle ownership for Taiwan in 2002 was 532 per 1000 capita, while the average EU value was about 20 per 1000 capita (Hsu et al., 2003; Kepaptsoglou & Milioti, 2011).

For a long time the city has been suffering from its transport problems. Nernhard's (2009) reviews of the city's newspapers show that traffic congestion has been a concern since 1969. A study by Nimnual, Srisakda, & Satayopas (1980) systematically recorded the increased delay in traffic travel time. Several decades later, transport problems are still an issue for the city and have increased in their severity. Rise in congestion, private motorised transport dependency, traffic accidents, worsening of air quality, and increased street noise are among the list of transport problems (Charoenmuang, 2007). The city currently suffers from a high dependency on private motorised vehicles as the city has no quality public transport system.

The only form of non-private motorised transport in the city is an informal transport service called the Song Teaw (hereafter, the shared-taxi), a form of on-demand paratransit service. Similar informal transport services have been observed in operation in various cities, mostly in developing countries, such as Indonesia, the Angkot (CDIA, 2011), and the Philippines, the Jeepney. The shared-taxi has operated in the city continuously for over 30 years. However, its informal nature of the service leads to unreliability, irregularity, and unpredictable journey time, and thus its usage is limited to the fringe. As will be demonstrated, the number of journeys made by shared taxi is remarkably low.

2.2. Metropolitan Activity Relocations Simulator (MARS)

MARS is an aggregated dynamic land-use/transport interaction model (LUTI) developed at the Research Centre of Transport Planning and Traffic Engineering, Institute of Transportation, Vienna University of Technology (TUW-IVV). The fundamental hypothesis of MARS is that settlements and the mobility activities within an urban area are self-organising systems (Pfaffenbichler, 2003). It is also assumed that the interactions between transport and land use systems are continuous and dynamic with time-lagged feedback loops between them. The time horizon of MARS is set to 30 years.

The land use sub-model can be further divided into a residential and work place location sub-model (Figure 1). The two sub-models compete for a limited availability of land, which consequentially determines the land price. The land price is subsequently fed back into the sub-models for the next time period. The outputs of the land use sub-models, namely the spatial distribution residents and workplaces are fed into the transport sub-model. The mobility pattern of the population is calculated, together with the levels of accessibility of workplaces, consumers, and workforce. Levels of accessibility, a function of time taken to access work place or services, are the outputs from the transport sub-model into the land use sub-models and used to calculate land use distributions for the next time period.

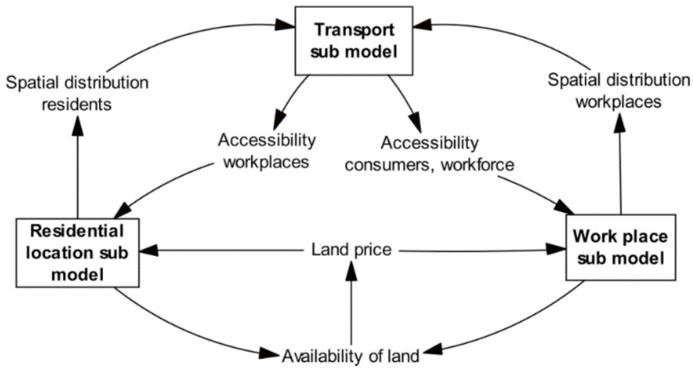


Fig. 1 MARS transport sub-model and two land use sub-models

Source: (Mayerthaler, 2009)

Since its inception, MARS has been applied successfully to a number of cities across Europe, Asia, North America, and South America. It was used in various projects to simulate the development of land use and transport systems under various development policy frameworks, including policies to develop a sustainable transport system.

MARS has the ability to simulate possible development paths of the study area under different policy instruments. Its strengths lie in its relative lower resource requirement in setting up, its ability to assess sustainable transport policy, such as walking and cycling promotion, and its high transferability. The model inputs, such as the demographic transition and the vehicle ownership model, can be adjusted to replicate different background conditions of the study area. The policy instruments are other model inputs that can be altered to simulate desired land use and transport policies. The model outputs, such as generalised costs (in terms of monetary factors and time), kilometres travelled by different modes, and vehicular emissions, enables the policies to be evaluated quantitatively.

2.3. Development of the CNX-MARS model

The development of CNX-MARS model was done prior to the planning of the CM-MTS. It began with a transferability appraisal, to ensure the model was suitable for Chiang Mai city. The appraisal showed that while the MARS model was suitable for Chiang Mai city a number of improvements would yield better results. Three modifications were selected from the list and implemented; namely, addition of the shared-taxi mode, adjustments of the quality of life indicator, and update of fuel consumption and emission.

The development of the model also contributed toward shaping the range of data collected by the survey. The survey collected mobility data that is often excluded, such as trips made by non-motorised mode, walking time to parking spaces, and parking search time. After the completion of the survey in June 2013, the final phase of the model development began.

CNX-MARS divides the urbanised area of Chiang Mai into 28 zones as shown on Figure 2. The boundary of this zone system follows the official administrative boundary. Zone 1-14 is the area within the central district, called Aumpor Muang. This area also includes the Chiang Mai municipality (Zone 1-5), which comprises of the old city area. Zone 15-28 are the outer districts of the city.

Two types of data were used to complete the model: primary data and secondary data. The primary data comes from the CM-MTS. The secondary data can be divided further into two types: statistical data and administrative data. The former was collected from the National Statistical Office Chiang Mai (CM-NSO) and the latter from the Chiang Mai municipality and the Ministry of Interior (MOI).

The model was completed in June 2014 and was calibrated using the modal share data from the CM-MTS survey. The base year of the model was 2012.

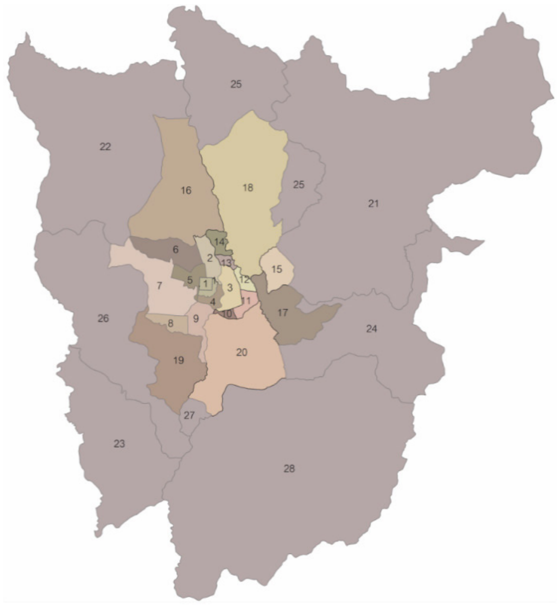


Fig. 2. CNX-MARS zone system (28 zones)

2.4. Scenario assessments

The calibrated CNX-MARS model was used to evaluate the effects of transport policies in four different scenarios. The four scenarios considered here seek to investigate the impact of transport measures related to motorcycle. They are: Scenario A - Business as Usual (BAU), Scenario B1-High motorcycle growth, Scenario B2-Promotion of motorcycle, and Scenario B3-Promotion of motorcycle with mitigations. The description of each scenario is provided under the headings below. Then the results of the model are compared with the baseline case to ascertain the impact of the measure. In all scenarios, demographic attributes, such as birth and death rates are kept constant. Only transport attributes are adjusted. The output indicators and background indicators are compared between scenarios.

A sustainable transport assessment framework was created to aid the scenario assessment. The framework is based on the city's vision on sustainability; objectives and sub-objectives are derived from the vision. A set of sustainable transport indicators was created to provide measurements for these objectives.

The main difference between conventional and sustainable transport indicators is that the latter seeks to provide measurement of transport quality beyond the private motorised transport realm (Litman & Burwell, 2006). Examples of conventional transport indicators are level of service, average traffic speed, and accident per vehicle travel distance. Sustainable transport, by contrast, aims to make visible elements that provide unbiased representative assessment of the transport system. Examples of such indicators are per capita motorised vehicle kilometre, energy or fuel consumption per trip, and percentage of the city's area dedicated to transport.

Several of the selected indicators are taken from a list suggested by May & Minken (2003) and Litman & Burwell, (2006). The selection also took into account the capacity of CNX-MARS. A set of transport statistics variables is also selected to provide a background data that will aid an understanding and explanation on the effects of the policies considered toward the behaviour of the transport system. It should be noted that the average speed values are door-to-door speed, which includes walking time to and from embarkation/disembarkation points. In other words, the average speed does not reflect only in-vehicle speed but also includes walking speeds as well.

Scenario A: Business as Usual (BAU)

In this scenario, the assumed growth rates of the transport system's supply side and the land use parameters are left unaltered. This scenario is presented as a baseline to which other scenarios are compared.

Scenario B1: High motorcycle ownership

In this scenario, the growth rate of the motorcycle is increased to simulate increasing motorcycle ownership. The percentage of cars per 1000 capita in the final year is 28% lower than the baseline. In contrast, motorcycle growth is higher, i.e. the final proportion of motorcycles per 1000 capita is 18% higher than the base line. Table 1 summarises the vehicle ownership rates of the A and B1 scenarios.

Table 1. Assumed vehicle ownership per 1,000 capita characteristic for scenario A1-3

Mode	Year 0	Year 30	
		A-Baseline	B1-High motorcycle growth
Car	322	355	255 (-28%)
Motorcycle	556	559	661 (+18%)
All	878	915	915
No. of motorcycles per 1 car	1.7	1.6	2.6

Note: value in parenthesis show the % difference in relation to the A1 baseline; changes for percentages are absolute values

Scenario B2: Promotion of motorcycle use

The effects of measures that promote motorcycle use, such as free parking space for motorcycles, motorcycle only access roads, and closer parking to destinations are tested here. The parking cost for motorcycles is reduced to zero (free parking) in all zones. The distances between destinations in zone 1-14 (area within Aumpor Muang) for the motorcycle are reduced by 20% to simulate change in road management that favour the use of the motorcycle in the city centre area. The distances between parking space and origin/destinations and parking search time for the motorcycle are also reduced by 30% to simulate provision of ample parking space close to origin and destination for the motorcycle.

Scenario B3: Promotion of motorcycle use with mitigation

This scenario tests whether promotion of the motorcycle can reduce the proportion of car trips instead of the non-motorised and public transport modes, with help of additional mitigation measures. Firstly, similar adjustments to the model as in Scenario B2 were made; i.e. the parking cost and the distance between destinations were adjusted to favour the use of the motorcycle in the city centre area.

Additionally, mitigation measures were factored into the model to demonstrate the impact of parking space organisation. It is proposed here that a form of central parking lot should be provided with the walking time between parking space and origin/destinations for motorcycle set at 3 minutes during the peak period, and 1.5 minute during the off-peak period. The measure should also implement a parking search time for the motorcycle of 1.75 minutes during the peak period, and 1 minute during the off-peak period.

All values for cars are set 1.5 times higher than for motorcycles. These differences take into account that motorcycles have a significant ‘privilege’ in terms of required parking space; i.e. motorcycle parking spaces are located closer to origin and destination, and are more numerous than for cars.

3. Results

3.1. Mobility data analysis

Vehicle ownership and number of motorized vehicles

The number of vehicles obtained from the CM-MTS Survey is considered here. Vehicle ownership of other cities is also included to provide the context of these values, in Table 2.

Table 2. Comparison of vehicle ownership per 1000 capita for Chiang Mai city and Chiang Mai province

		Vehicle ownership per 1000 capita		
City	**Population (year)**	**Car**	**Motorcycle**	**Car and motorcycle**
Chiang Mai city++	1,249,956 (2012)	304	535	839
Hanoi*	6,500,000 (2009)	12	400	412
Ho chi minh*	7,990,000 (2013)	12	371	383
Delhi*	22,000,000 (2012)	82	174	256
Jakarta*	10,200,000 (2011)	125	165	290
Bangkok*	8,300,000 (2010)	316	316	632
Taipei*	2,700,000 (2012)	257	379	636
Vienna+	1,760,000 (2013)	390	46	436

Source: * (Khuat, 2007), + (City of Vienna, 2013; Stadtwerke, 2012) and ++ included estimated unregistered population (CM-MTS, 2012)

The comparison reveals that vehicle ownership in Chiang Mai, reported by the CM-MTS, is the highest. Its car ownership is still in the same range with other cities (i.e. Vienna and Bangkok) but its motorcycle ownership rate is much higher (33% higher than Hanoi, the second highest). There are two possible reasons for the high differences. First, the CM-MTS surveys focused on the urbanised area of Chiang Mai (the Principal city area), while other cities may include their suburban area. Second, CM-MTS consider the actual number of vehicles in the city regardless of where these vehicles are registered. Other surveys may derive their vehicle ownership values from the cumulative number of vehicles registered and the number of population in the area, and do not take into account of vehicles that are registered in other areas but brought in for use.

Mode share

The mode share values from six surveys on Chiang Mai city are compared here against seven other cities. The comparison is shown in Table 3.

Table 3. Comparison of mode share with adjusted values (in % of surveyed trips)

City (survey year)	Walking	Bicycle	Public transport	Personal car	Motorcycle	Other
Chiang Mai city (2012)	15	6	1*	27	48	3*
Hanoi (2008)	n/a	2.5	10.7	4.0	80.8	2
Ho chi minh (2012)	7	7	4	4	75	3
Delhi (2006)	20	13	43	14	4	6
Jakarta (2010)	30		17	9	41	3
Bangkok (2006)	10		30	33	27	0
Taipei (2006)	10		35	26	29	0
Vienna (2014)	26	7	39	28		0

Note: Numbers in parenthesises are adjusted mode share values using NMT trips from 2012 CM-MTS
*For CM-MTS public transport constitutes of shared-taxi (1.3%) as no trip by public bus was recorded. Other mode included school/work private van[*] (1.9%) and other mode (1%)
Source: (Jittrapirom & Emberger, 2013), (Bertaud, 2011),(Van, Boltze, & Tuan, 2013),(ITrans, 2009),(Febrina, 2013),(Tuan, 2015),(City of Vienna, 2014)

The Chiang Mai city data shows that a major proportion of trips (75%) are made by private motorised transport vehicles; 27% are car trips and 48% are motorcycle trips. Surprisingly, the non-motorised modes are combined to 21% of total trips, which is much higher than any previous report. No trips were made by public bus and only 1% by shared-taxi.

Trip characteristics

The trip data is classified by modes and the two statistical values presented here are average and standard deviation, See Table 4.

[*] School/work private van is operated by a private individual or a company which provides commuting service for students and workers living in a certain area who travel to destinations within close proximity. The fare is paid monthly. It is a mode of collective transport for covering regular long distances

Table 4. Statistical analysis of Chiang Mai city trip data by trip modes

	Trip time taken (min)		Trip distance (km)		Trip average speed (kph)	
Trip mode	Average	SD	Average	SD	Average	SD
Walking	4.6 (1.0)	7.8	0.2 (1.0)	0.4	2.1 (1.0)	1.2
Bicycle	7.7 (1.7)	8.7	0.8 (4.0)	1.1	6.4 (3.0)	3.4
Private car	23.3 (5.1)	17.4	10.0 (50.0)	12.0	26.0 (12.4)	17.5
Motorcycle	14.9 (3.2)	13.3	5.0 (25.0)	5.7	19.1 (9.1)	13.6
Shared-taxi	27.2 (5.9)	17.4	9.2 (46.0)	7.8	20.8 (9.9)	14.2
Other	29.2 (6.3)	20.4	8.5 (42.5)	7.5	17.3 (8.2)	11.9
All trips	16.5 (3.6)	15.6	5.8 (29.0)	8.4	18.7 (8.9)	15.5

Note: the number in parenthesis is ratio to walking's value in that column.

Trip time

Average trip times range between 4 and 29 minutes. Trips made by car can take up to five times longer than those made by walking. The other mode category has the highest absolute standard deviation value and the non-motorised modes have the highest standard deviation values in relation to their averages. This means walking and cycling trips can take up to 110%-170% more or less time than average. For the motorised modes, this variation is less, ranging between 50%-90% of their averages.

Trip distance

Average trip distances range between 0.2 and 10.0 kilometres. Walking trips have the lowest value; with up to 50 times shorter than car trips. Shared-taxi trips have the highest average, slightly higher than the car. The motorcycle's average is roughly between the car's and non-motorised values; it has a medium range between non-motorised and four-wheeler modes.

Private car trips have the highest absolute standard deviation, which suggests a high variation in trip distance; i.e. cars are used for shorter trips as well as longer ones. However, in relation to the average values, walking trips have the highest standard deviation; the distance can vary up to 220% from the average value. This suggests that there might be a high variation in the respondents' threshold on walking distance.

Trip Speed

Average trip speeds are calculated from the trip distance and trip time of each trip. Motorised modes' speeds range between 17.3 and 26.0 kilometres per hour. The car is the fastest mode. Motorcycle and shared-taxi speeds are comparable. The average speeds show that of motorcycles is lower than that of cars, which is contradictory to the common believe that the motorcycle is faster than a car in the city. However, several points may prevent this observation from being conclusive. Firstly, the motorcycle has an advantage over a car in a saturated network, as it can weave between vehicles. The road network of the city, although congested, is observed to be far from fully saturated. Secondly, the area covered by CM-MTS contains a large proportion of non-built up areas with long stretches of highways passing through them. It is believed that cars can travel at higher speed than motorcycles in such near free-flow conditions. Lastly, the trip time and distance of the survey are estimated values, thus, several human factors, such as subjectivity and forgetfulness can affect their accuracy.

Car trips have the highest absolute standard deviation; however, walking trips have the highest relative value to its average. A particular walking trip can have up to 200% higher or lower speed from the average value, which may be caused by a range or reasons, such as a lower accuracy in estimating the time taken for walking trips by the respondents, or a higher sensitivity of walking data to change, because of its relative lower values.

Next, the mobility data of motorcycle trips in Chiang Mai is compared with data from other sources. The number of sources included here is small due to the limited number of motorcycle mobility surveys. Additionally, several data are also missing. The scale of data is also different; while Shanghai, Athens, and Chiang Mai are city-scale data, Taiwan and France are national data. Data for France is classified by the propulsion power with motorcycles of more 50cc and mopeds with an engine size less than 50 cc. The comparison is shown in Table 5.

Table 5. Average trip distant, travel time, and speed for motorcycle users in different cities

Area	Type of motorised 2-wheeler	Av. trip length (km)	Av. trip Time (min)	Av. trip speed (km/hr.)
Chiang Mai (2012)	All Motorised 2-wheeler	5.0	14.9	19.1
Shanghai (2006)	Electric Bike	4.8	25.6	13.0
	LPG Scooter	6.6	28.8	14.6
Kunming (2006)	Electric bike	3.6	20.3	11.9
12 French urbanised	Moped	4.7	n/a	n/a
areas (2010)	Motorcycle	6.3	n/a	n/a
Melbourne (2012)	Scooter	15.5	n/a	n/a
Athens (2011)	Scooter	4.3	16.0	16.3
Taiwan (2001)	Motorcycle	10.8	n/a	n/a

Source: Solere (2010) – France, Cherry (2007) – China, Hsu, Sadullah, & Dao, (2003) – Taiwan, Kepaptsoglou & Milioti (2011) – Greece, and Rose, Thompson, Amani, & McClure (2012) – Australia.

The comparison shows that Chiang Mai data is comparable to most cases. Its average trip length is similar to other sets of data, such as Shanghai (electric bike), 12 French urbanised areas (moped), and Athens. The values for Melbourne and Taiwan stand out; they are nearly twice as high as other areas' values. Chiang Mai's average trip time is comparable to Athens but less than half of Shanghai. Among areas with available average trip speed, Chiang Mai has the highest values.

Travel time and distance distribution

Next, the correlations between respondents' trip mode and trip distance and time distributions are examined. The trip distance and time taken distributions classified by trip mode are shown in Figures 3 and 4.

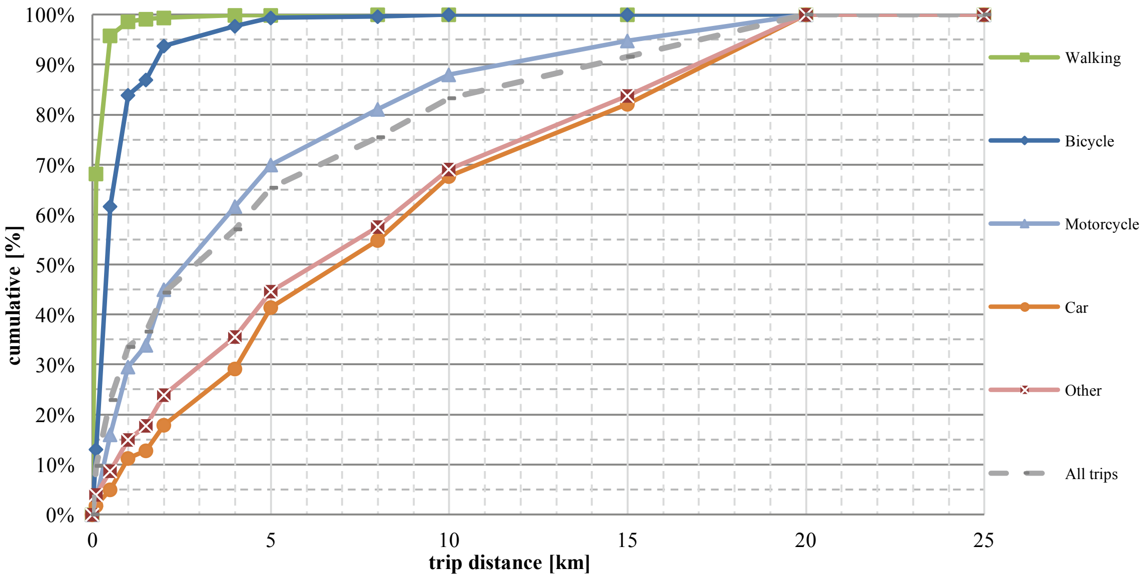


Fig. 3. Chiang Mai city's Trip distance distribution, classified by trip modes

The trip distance distributions by mode reveal an interesting pattern with three distinct distributions observed. The non-motorised modes are clustered on the top left corner; these are trips with shorter distance (90% of them are within 2km). Trips made by car, shared-taxi, and other modes, which are all motorised four-wheelers, are clustered together, making a diagonal line across the chart area; these are trips with longer distances (90% of them are within 17km). Motorcycle trips' distribution lies roughly in the middle between the two (90% of them are within 11km). The distinguishable patterns depicted here suggest that there is a strong correlation between trip mode and trip time. The distribution also emphasises the difference between motorcycle and car trips. Moreover, it purports that motorcyclists made trips that are shorter than car trips but longer then walking. In the other words, the motorcycle is used by the respondents for intermediate distance trips. The all-trips average is almost identical to the motorcycle because of the high proportion of motorcycle trips (48% of all trips).

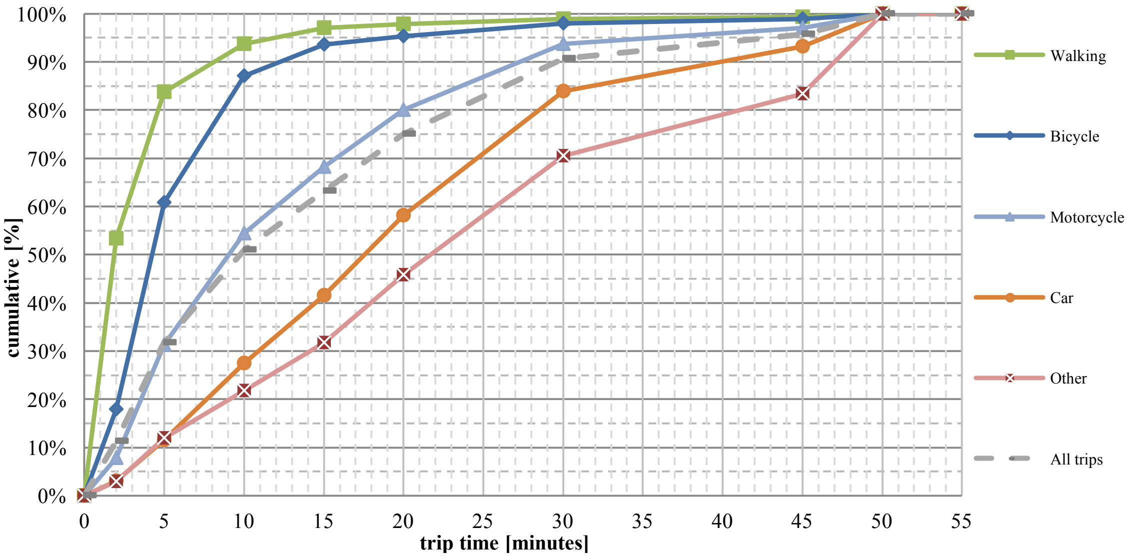


Fig. 4. Trip time distribution, classified by trip modes

The trip time distribution demonstrates similar trends to the trip distance distribution, although the clustering of the non-motorised modes and the motorised four-wheelers is looser. The pattern of the motorcycle trips' distribution also sits in between non-motorised mode and motorised four-wheelers. The distinguishable patterns depicted here suggest that trip mode also has a strong influence on trip time. It also adds to purport the differences between car and motorcycle trips, previously proposed.

Another interesting feature is that the shared-taxi and the other mode's travel times are, in general, higher than car trips even though the previous chart shows that the distribution of their trip distances are roughly the same. This suggests car trips have higher speeds than the other two modes and take a more direct route toward their destinations.

Walking time to/from embarkation points

Knoflacher (2006) presented a theorem that walking distance to or from parking space can influence mode choice selection. He argued that the way parking spaces are organised today tends to promote private vehicle use. Private vehicles are often allowed to park close to buildings, enabling drivers to minimise their body energy spent on making these trips. Whereas, public transport stops are located at a distance, normally further away than these parking spaces. Thus, public transport users will require a higher body energy to access to and from these stops. Knoflacher purported that the different in energy required to access embarkation/disembarkation influences how people make their mode choice, thus a new way to organise parking space will be required to ensure that public transport can compete with private vehicle. He proposed a parking concept, called Equi-distance parking, which put private vehicle parking space at a distance equal to or further away than the closest public transport stop.

It was found that walking time to and from embarkation points was never collected for Chiang Mai city. Efforts were made to ensure the CM-MTS survey made collection for such data. An analysis on walking time to and from embarking point of different modes is made here. The results are shown in Table 6.

Table 6. Average walking time between origin/destination and embarkation points

Mode	a) Origin to Embarkation point (min.)	b) Disembarkation point to destination (min.)	c) Difference (a-b)	d) % Relative difference (c/a)
Bicycle	0.93	0.80	0.13	14%
Car	2.12	1.52	0.6	28%
Motorcycle	1.28	1.11	0.17	13%
Shared-taxi	3.30	2.55	0.75	23%

School/work private van	1.65	1.36	0.29	18%
Other	1.51	1.18	0.33	22%

In Table 6 the average walking time from origin to embarkation point and from disembarkation point for different modes are shown. It shows that the bicycle has the lowest access time at both origin and destinations. The motorcycle has less access time than the car, and the shared-taxi has the highest access time among all modes. The values for car are higher, perhaps because it requires a larger parking space than the motorcycle and the bicycle, thus it may be harder to find car parking space close to destinations. Share-taxi, on the other hands, operates mostly on the main roads. Respondents who live away from the main road must walk to hail the shared-taxi along the main roads, which can be quite a journey, especially outside the city centre area.

Additionally, the data also shows that the walking times from disembarkation to destination are lower than the walking time from origin to embarkation point for all modes. The differences are higher in the car and the shared-taxi trips than other modes. These differences are interesting, since the two values should roughly be the same, as most trips surveyed are closed-loop trips. They suggest the respondents may have a higher subjective to walking time from origin to embarkation point than from disembarkation point to destination.

Figure 5 further shows the distributions of walking time between origin and embarking points / disembarking points and destination for each mode. The results confirm the trends observed previously. It shows a higher proportion of motorcycle trips parked close to their origins and destinations; 82-83% of motorcycle trips were parked within 1 minute walking time of the starting/finishing point of the journey. By contrast, 71%-75% of car trips were parked within 1 minute walking time.

Interestingly, the bicycle has the highest penetration (88% and 91% within 1 minute walking and shared-taxi has the lowest penetration rate (48% and 53% within 1 minute walking) among all modes. This means bicycle users actually utilise the least energy to access their 'vehicle'. This finding revealed the potential to promote bicycle use; it has the shortest access time, thus requiring the least body energy to gain access. It also shows the challenge to promote the shared-taxi service, which has the longest access time at both ends of the trips.

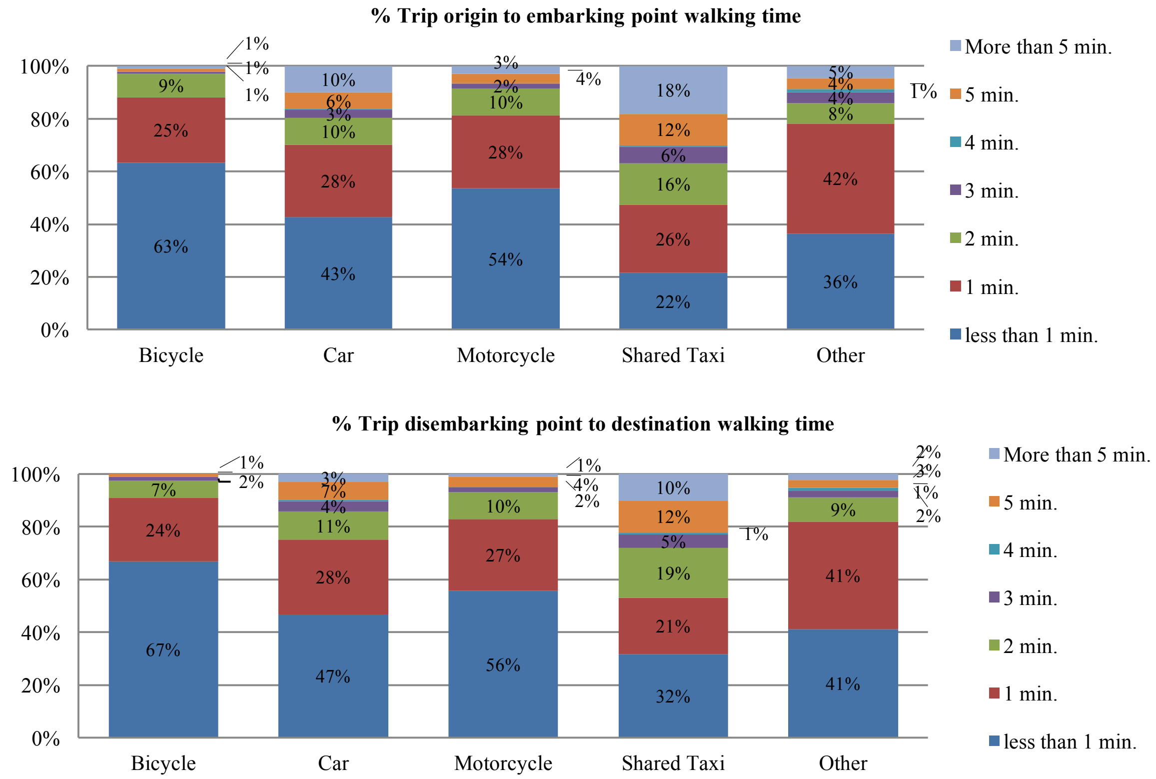


Fig. 5. Walking time to/from embarking point of different modes

In accordance to Knoflacher (2006)'s theorem, the combination of the two results above suggest that the motorcycle has a potentially higher penetration (or ease of access) than the car, as the shorter walking distance makes this mode of transport more convenient. According to Knoflacher's research, the result also suggests that the motorcycle may have a stronger 'lock in' or captive effect on drivers than the car as they save more body energy in accessing their vehicle. The findings also indicate the potential of bicycle in becoming a mode of transport that 'captures' users, as it has the lowest average walking distance and time to access.

3.2. Scenario assessments results

The performance indicators of the four scenarios from CNX-MARS model are shown in Table 7 with their background indicators presents in Table 8.

Table 7. Results of scenario assessment

Objective	Sub-objective	Indicators	Unit	Year 30 A:	B1:	B2:	B3:
1.Environmental protection	1.1 Efficient in the use of resources	1.1a Use of fuel per trip	(litre/trip)	0.29	0.27 (-7%)	0.23 (-21%)	0.43 (+48%)
		1.1b Cumulative fuel consumption	Billion litre	11.44	11.03 (-4%)	11.80 (+3%)	10.29 (-10%)
	1.2 Reduce greenhouse gas (GHG) to a reasonable level	1.2a Emission per trip	(CO_2 equivalent kg/trip)	698.55	627.50 (-10%)	561.99 (-20%)	1,038 (+49%)
		1.2b Cumulative GHG emission	Trillion kg	27.13	25.77 (-5%)	27.87 (+3%)	24.39 (-10%)
2. Accessibility	2.1 Provide reasonable accessibility	2.1 Change in accessibility	(ratio to base year)	1.35	1.32 (-2%)	1.40 (+4%)	1.21 (-10%)
	2.2 Reduce automobile dependency	2.2 % of trips made by NMT	(%)	33.1%	32.8% (-0.2)	28.2% (-4.9)	42.5% (+9.4)
	2.4 Control urban sprawl	2.4a Av. trip distance (peak)	(kilometre/trip)	4.97	4.94 (-1%)	4.31 (-13%)	6.61 (+33%)
		2.4a Av. trip distance (opeak)	(kilometre/trip)	4.63	4.66 (+1%)	4.04 (-13%)	5.61 (+21%)
3. Safety	3.1 Reduce transport accidents, including non-vehicular	3.1a No. of traffic injuries	(injured)	23,173	23,298 (+1%)	24,100 (+4%)	20,804 (-10%)
		3.1b No. of traffic deaths	(death)	2,988	3,004 (+1%)	3,107 (+4%)	2,682 (-10%)
4. Quality of living	4.1 Enhance the social, cultural, and recreation activities	4.1 % of trips make by NMT	(%)	33.1%	32.8% (-0.2)	28.2% (-4.9)	42.5% (+9.4)
5. Equity and fairness	5.1 Accessibility for non-vehicular users	5.1 % of trips make by NMT	(%)	33.1%	32.8% (-0.2)	28.2% (-4.9)	42.5% (+9.4)

Note: value in parenthesis is in relation to Scenario 1

Scenario B1 High motorcycle ownership result

In the high motorcycle growth case (B1), the cumulative fuel consumption value is lower (4% less) than the baseline. A similar trend can be observed on the greenhouse gas values (-5%). These trends suggest an increase in the proportion of the number of motorcycle on the roads will decrease cumulative fuel consumption and emission of greenhouse gasses. It is also interesting to note that the correlations between these factors are non-linear. For instance, the cumulative fuel consumption in Scenario B1 is only 4% lower than the baseline case, while the consumption of fuel per trip is 7% lower. This suggests there are factors that dampen the effects of decreased fuel consumption per trip on lowering cumulative fuel consumption, such as an increase to the average trip distance of the motorcycle and shared-taxi.

Scenario B1 sees a decrease in accessibility (-2%), which indicates that the population as a whole has reduced opportunity to access work and shopping. The proportion of NMT trips is slightly lower in B1 (-0.2), which suggests an increase in the percentage of motorcycle reduces NMT trips. The average trip distance during peak period reduce slightly in B1 (-1%), while the change is relatively smaller for the off-peak.

An increase in the proportion of motorcycles results in increased numbers of casualties and deaths from transport (+1%). It should be emphasised that the numbers of casualty and death calculations are based on the average numbers of casualties and deaths per kilometre of vehicle travel of past years. In other words, they are linked directly to the number of kilometres driven and do not take into account any other effects the policies may have on road safety. This relationship is based on the accident data available at the time.

Table 8. Background indicators of the four scenarios

Mode share %

		Year 30		
Mode	**A1: Baseline**	**B1**	**B2**	**B3**
Pedestrian	21.3%	21.1% (-0.2)	18.2% (-3.1)	27.8% (+6.5)
Bicycle	11.7%	11.7% (0)	10.1% (-1.6)	14.7% (+3.0)
Pt bus	0.2%	0.2% (0)	0.1% (-0.1)	0.3% (+0.1)
Car	23.5%	20.6% (-2.9)	20.9% (-2.6)	19.8% (-3.7)
Motorcycle	41.4%	44.6% (+3.2)	49.1% (+7.7)	35.1% (-6.3)
Shared-taxi	1.8%	1.9% (+0.1)	1.6% (-0.2)	2.3% (+0.5)

Average trip distance (km)

		Year 30		
Mode	**A1: Baseline**	**B1**	**B2**	**B3**
Pedestrian	0.54	0.54 (0%)	0.54 (0%)	0.54 (0%)
Bicycle	1.02	1.02 (0%)	1.02 (0%)	1.04 (+2%)
Pt bus	8.24	8.23 (0%)	8.23 (0%)	8.48 (+3%)
Car	7.75	7.13 (-8%)	7.57 (-2%)	11.53 (+49%)
Motorcycle	5.98	6.35 (+6%)	4.39 (-27%)	9.11 (+52%)
Shared-taxi	10.90	11.45 (+5%)	10.69 (-2%)	11.28 (+3%)

Average trip time (minute)

		Year 30		
Mode	**A1: Baseline**	**B1**	**B2**	**B3**
Pedestrian	16.13	16.13 (0%)	16.11 (0%)	16.21 (0%)
Bicycle	8.70	8.69 (0%)	8.70 (0%)	8.72 (0%)
Pt bus	52.75	51.86 (-2%)	52.87 (0%)	53.05 (+1%)
Car	19.51	16.69 (-14%)	19.34 (-1%)	31.68 (+62%)
Motorcycle	13.87	14.23 (+3%)	9.98 (-28%)	21.87 (+58%)
Shared-taxi	37.91	38.10 (+1%)	37.49 (-1%)	39.28 (+4%)

Average travel speed/mode door to door (km/h)*

		Year 30		
Mode	**A1: Baseline**	**B1**	**B2**	**B3**
Pedestrian	2.00	2.00 (0%)	2.00 (0%)	2.00 (0%)
Bicycle	8.38	8.40 (0%)	8.36 (0%)	8.36 (0%)
Pt bus	9.44	9.57 (+1%)	9.45 (0%)	9.65 (+2%)
Car	24.56	26.71 (+9%)	24.22 (-1%)	21.50 (-12%)
Motorcycle	28.22	29.41 (+4%)	28.89 (+2%)	26.46 (-6%)
Shared-taxi	12.18	12.66 (+4%)	11.99 (-2%)	12.60 (+3%)

Note: numbers in parenthesis are the ratio in relation to year 30 of the A1 baseline; changes for percentages are absolute values
*include walking to embarkation point and from disembarkation point during peak period

The background variables of Scenario B1 show the increase in the proportion of motorcycle trips. It also confirms that an increase in motorcycle ownership has a slight negative impact on non-motorised transport. The decrease in

NMT of the former is likely to be linked to the closer proximity a motorcycle can park in relation to a car, to the start/end of a trip, thus offering a more attractive alternative to walking and cycling. Interestingly, the percentage of shared-taxi trip increases slightly. This is likely to be linked to a decrease in car trips as the two have similar trip distribution patterns. The change in vehicle ownership seems to have little effect on the average trip distance and trip time of non-motorised transport and public bus. In contrast, the trip time and distance by motorcycle and shared-taxi seem to have been affected and moved in the same direction as vehicle ownership (i.e. high motorcycle ownership, higher motorcycle trip distance and trip time). In contrast, the average trip distance and time by car decreased. Nevertheless, it is uncertain why the shared-taxi's values move in the same direction and proportion as the motorcycle.

Scenario B1 sees increases in all motorised vehicles' average trips speeds. The speeds of the non-motorised modes are unaffected. These trends are perhaps logical; the reduction in the number of cars increases road capacity as motorcycles occupy less road space.

The results indicate that an attempt to promote motorcycle can reduce fuel consumption and emission. However, the overall benefit may be subsumed by an increase in the number of fatalities and injuries. Nevertheless, this situation is based on the current assumption of the model that the number of fatality and injuries are linked directly with the total vehicles per kilometre of road.

Result of Scenario B2: Promotion of motorcycle use

The promotion of motorcycle usage (B2) significantly decreases the average fuel consumption (-21%) and the average CO_2 emission per trip (-20%) but increases the cumulative fuel consumption and CO_2 emission slightly (+3%). It appears that the benefits gained in forms of reduced average fuel consumption and emission per trip, are not passed on to the cumulative values. This suggests that the measure must have stimulated the system to react and change some attributes that counter the initial improvements.

The measure increases accessibility by 4% but reduces the proportion of NMT trips by 4.9. This indicates that motorcycle use can have a reducing effect on non-motorised trips. It also reduces the average trip distance (-13%). The number of casualties and deaths also increases (+4%), even though averages trip distance is lower. This suggests that other indicators, such as an increase in the total number of trips may result in an overall increase of the total vehicular distance travelled; this effect consequently impacts the number of transport casualties.

The background indicators show an increase in motorcycling trips (+7.7) at the cost of non-motorised modes (-4.7) and car (-2.6). The shared-taxi and the public bus are slightly affected (-0.2% and -0.1%). The average trip distance of the motorcycle decreased significantly (-27%), while the car and the shared taxi are mildly affected (both -2%). The average trip time values followed similar trends. Only the average speed of the car (+1%), the motorcycle (+2%), and the shared-taxi (-2%) altered.

The results indicate that promotions of motorcycle use can worsen the system. It may deliver local improvement in form of reduced average fuel consumption and emission per trips but it reduces the non-motorised transport trips. The overall effects of this measures increase the cumulative fuel consumption and emission values, as well as increasing the number of transport accidents.

Another interesting finding is the implication that an increase in motorcycle usage has the effect of reducing non-motorised trips more so than when there is an increase in car use. In other words, motorcycle use has a higher detrimental impact on non-motorised transport than car use. This finding also supports the hypothesis proposed earlier that the motorcycle has higher penetration of usage than the car.

Result of Scenario B3: Promotion of motorcycle use with mitigation

The deployment of mitigations (B3) reverses the effects of Scenario B2; the average fuel consumption and emission per trip are increased (between 48% and 49%), but there is a 10% improvement on the overall system in terms of cumulative fuel consumption and reduced emissions.

Although the implementation of mitigations (B3) reduces the accessibility (-10%), it has a positive effect on the proportion of NMT trips (+9.5). It also increases the average trip distance by +33% to +21%, which most likely results from increased difficulty in finding parking spaces.

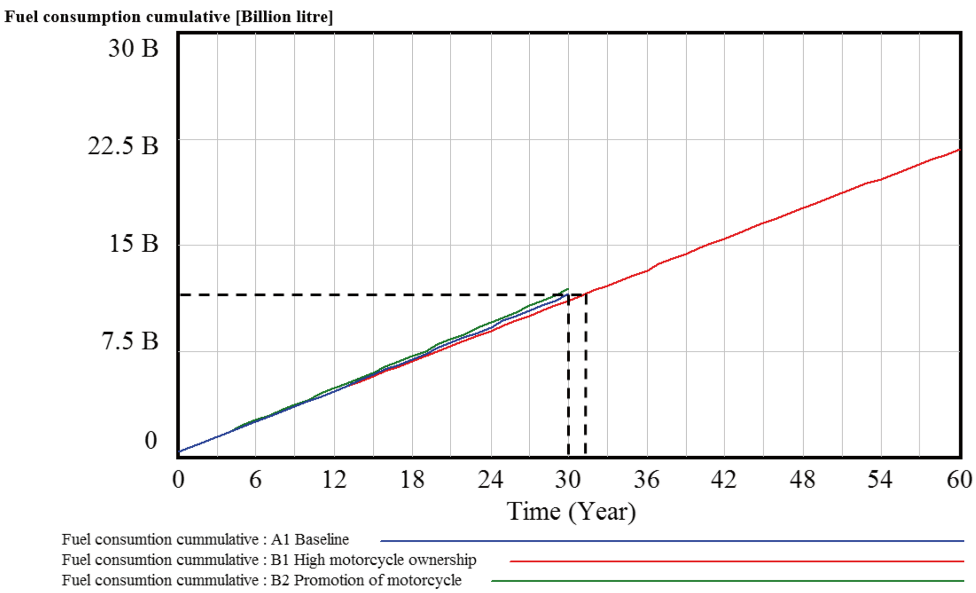
As to the total number of casualties and average trip distance, it is interesting to see a reverse trend to that observed in Scenario B2. The total number of casualties is reduced (-10%) even though the average trip distance is increased. This indicates that the measures employed here work to reduce some indicators, such as the total trip distance.

In background indicators, Scenario B3 decreases the proportion of car trips (-3.7) as well as motorcycle trips (-6.3). It slightly increases public transport (+0.1) and shared-taxi (+0.5). It decreases the average trip distance of the public bus and shared-taxi trip slightly (-3%). The average trip distance of bicycle trips are increased slightly (+2%) but it have higher impacts on motorcycle trips (+52%) and car (+49%). The average trip time for motorcycle (+58%) and car (62%) also increased by a similar magnitude. The average trip time of other modes remains largely unaffected. The average speed of private motorised modes decreases, for cars by -12% and for motorcycles by -6%. The average speed of the Public Bus and the shared-taxi are equally affected; they increased by +2 to +3%.

The result indicates that when the mitigation measures are implemented alongside the promotion of the motorcycle as the preferred mode of transport, the overall condition of the system is improved.

Effect of motorcycle as a sustainable transport measure

In order to examine the effects promotion of motorcycle ownership and usage have on delaying adverse effects of motorisation, the time horizon of the model is extended to 60 years. The fuel consumption and CO_2 emission of scenarios A1, B1, and B2 are shown on Figure 6.



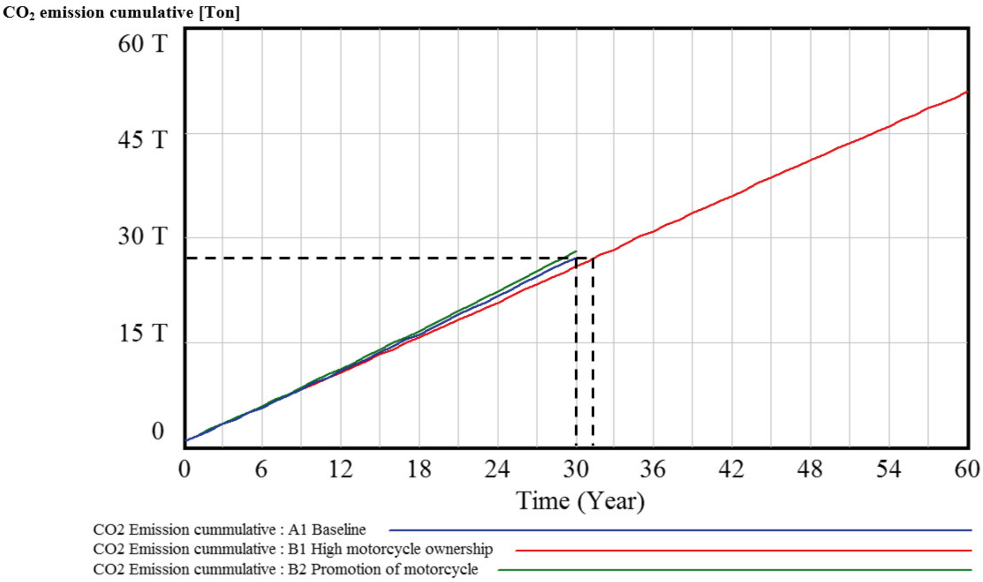


Fig. 6 Limited benefits in reducing fuel consumption and emission by promoting motorcycle ownership and usage

The extended-time horizon model shows that it takes only one additional year (i.e. in year 31) for Scenario B1 to consume the same amount of cumulative fuel as the Scenario A and 1 additional year (i.e. in year 31) to emit the same amount of CO_2 as year 30 of the base scenario. In other words, the promotion of the motorcycle ownership can only delay the environmental impact of the base line year by 1 year.

The graphs also show the fuel consumption and CO_2 emission benefits gained from motorcycle use promotion (B2) are insignificant. A closer observation on the data emphasis these findings; fuel consumption and emissions in Scenario B2 exceed the baseline from the first year. Thus, promotion of motorcycle use actually results in higher fuel consumption and emission than the base line. In other words, it aggravates the overall condition.

Parking organisation ensures motorcycle promotion benefits

In contrast, implementation of proposed mitigations (B3) ensures that the promotion of motorcycle improves the system performance; the cumulative fuel consumption and emission values of B3 remain 10% lower than the baseline at year 30. The cumulative fuel consumption and emission of scenarios A1, B2, and B3 are shown on Figure 7 below.

4. Discussion and Conclusions

Trip distributions analysis in this study reveals that motorcycle trips have an intermediate distance range in relation to non-motorised and motorised four-wheelers modes. The distributions show a well-defined pattern that separated out non-motorised modes, the motorcycle, and motorised four-wheelers. Trip time distribution also shows a similar pattern. The results also suggest that trip distance and time has a strong correlation to trip mode, i.e. non-motorised trips have lower average trip distance and trip time than car trips, while motorcycle trips lie in the middle between the two. This finding is in line with the finding from the trip data analysis, which shows the motorcycle's average trip time taken and trip distance to be approximately 50% less than the private car.

Walking time to/from embarking points for different modes of transport was also analysed. This type of data collection and analysis was the first of its kind in Chiang Mai. The results show that motorcycles are parked closer to their origins and destinations than either the car or the shared-taxi, the latter being the furthest away. Thus, the motorcycle has a higher ease of access than the car and shared-taxi as the shorter walking distance results in greater convenience and less effort expended by motorcycle riders and passengers. In accordance to the Equidistance Parking Principle proposed by Knoflacher (2006), the motorcycle has a potentially higher penetration than the car, as the shorter walking distance results in expending less (human) energy. In other words, motorcycles may have a stronger 'lock in' or 'captive' effect than cars as they are more readily accessible. Further study in this area is recommended, especially collection of walking time between embarking points and destination. Additional data and/or improvement in data collection methodology will help to overcome limitations of the walking data, such as inaccuracy estimation of walking time.

The assessment to quantify the impacts of motorcycle promotion was carried out using CNX-MARS model. The evaluation shows an increase in motorcycle ownership (Scenario B1) will help to delay the effect of negative transport externalities. It slows down the rate of increase in fuel consumption and greenhouse gas emission. However, the effects of the delay are limited. High motorcycle growth will delay the level of fuel consumption reached by the baseline scenario for only 1 year, and the level of CO_2 emission by 2 years. Moreover, motorcycle promotion will lead to increased motorcycle usage, at the cost of other modes, especially walking and cycling. It is likely the motorcycle effects walking and cycling in particular because of its ability to park closer to origin and destination.

Promotion of motorcycle usage (Scenario B2) seems to produce mixed results. It reduces fuel consumption and emissions per trip. It also lowers the average trip distance and increases accessibility rating. However, it also seems to increase indicators associated with high vehicle use; i.e. higher levels of cumulative fuel and emission consumption, higher road casualties, and lower proportionate use of non-motorised transport. This scenario thus illustrates that improvements in some specific areas may lead to an overall undesirable result.

Moreover, the fuel consumption benefit gains from the promotion of motorcycle use become insignificant after 4 years and the CO_2 emission reduction become obsolete after 9 years.

Implementation of the proposed mitigation factors (Scenario B3), namely parking organisation, helps to enhance the benefits gained and suppress the detrimental effects of motorcycle promotion. Although the fuel consumption and emission per trip increase, as well as the average trip distance, the cumulative externalities decrease and the proportion of NMT trip increases. In this sense the converse of the previous point holds true i.e. deterioration in some specific areas can lead to an overall enhancement of the system.

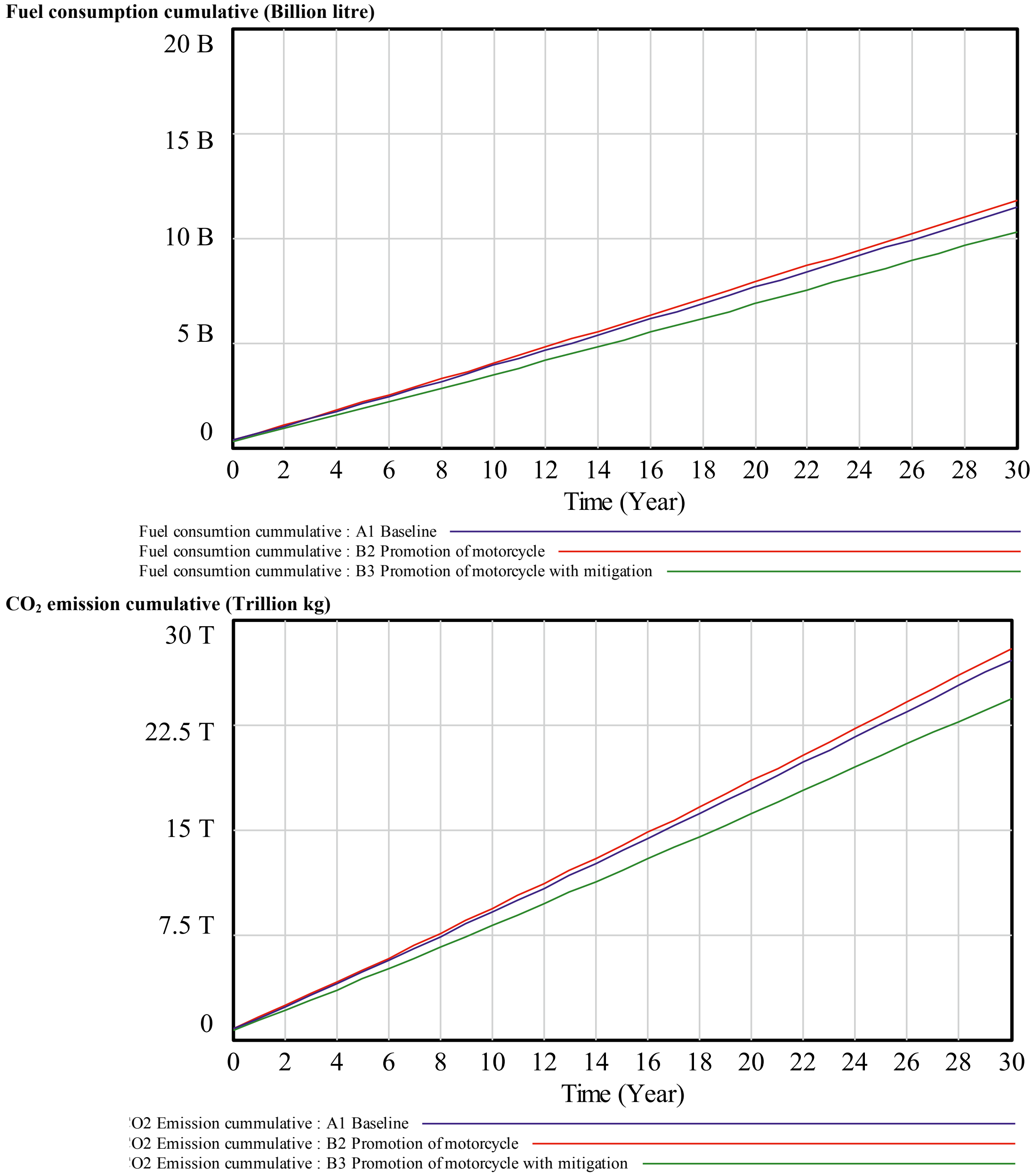


Fig. 7 Cumulative fuel consumption and CO_2 emission, showing benefits of B3 in relation to Scenario A1 and B2

The foregoing results purport that the promotion of the motorcycle alone will provide a limited benefit to the system over a short period of time. After that it will worsen the overall performance of the system. This demonstrates the limited benefit of oil-fuelled motorcycle promotion, and asserts the necessity of the proposed mitigations in parking organisation.

Motorcycles show potential as a more sustainable mode of transport than cars in that they utilise less space and fuel and emit fewer harmful emissions. This study reveals that motorcycles are used by residents for short trips as well as long trips and thus meet the need of a wide range of distance coverage. As demonstrated above, motorcycles also have higher penetration than cars as they can be easily parked closer to the origin and destination points of a journey.

From this perspective, it is tempting to promote motorcycles as a substitution for some car trips, with the aim to improve the sustainability of the system. Yet, from the system point of view, this measure will not contribute positively to the system in the long term. At best it would be a short term measure to slow down the negative impacts of the current transport system. The motorcycle still is a motorised mode of transport, which utilises external energy for transportation.

Results from CNX-MARS advocate these points. A policy to promote motorcycles shows localised benefits, such as reduced fuel consumption and emission per trip, but produces cumulative losses, such as increased overall fuel consumption and emission. The benefit gained in delayed fuel consumption and emission is also minute. It can be likened to replacing one 'deadly addictive drug' with a milder substitute. The only gain is the delay of the negative effects. Even worse, the motorcycle seems to have a reducing effect on non-motorised transport modes and may have a stronger 'lock-in' effect due to its higher potential to save body energy.

One may consider the substitution of energy source for motorcycle from fuel to electricity (i.e. e-motorcycle) to improve the vehicle's consumption/emission. This, in turn, however, raises the same challenge of how best to use finite resources.

In addition, encouraging motorcycle use may lead to increased car use in the long term. The motorcycle's lower purchasing and running costs provide a cheaper entry level to a motorised life-style. Establishment of a motorised life-style provides convenience and allows cheaper accommodation further away from the work place to be traded for increased travelling time. This promotes further sprawling of the city. The convenience of owning a motorcycle may also lead the driver to become mentally 'locked in' as a willing captive of a motorised life-style. Knoflacher (2013) explained this phenomenon succinctly and described it as 'Virus Auto'. In addition, the driver may also become physically 'locked-in' if relocation to the urban fringe takes place and vehicle ownership becomes a necessity for travel to work as opposed to the acquisition of a convenient means of transport. Finally, unless local government provides an efficient and effective public transport system, upgrading to car ownership is almost inevitable when a certain level of wealth is reached, or the perceived level of safety/comfort for family members is increased, or the air quality drops below an acceptable level for riding a motorbike.

Nevertheless, promotion of the motorcycle may still be used as a 'time buying' measure that would delay the negative effects of motorisation and allow time to implement measures that directly improve the transport system's sustainability. In addition, the implementation of parking and access control can limit the negative impacts from increased use of the motorcycle and discourage use of the motorcycle as a substitute for non-motorised modes. The aim here is to ensure that the motorcycle will reduce car growth, instead of reducing non-motorised trips. Other types of measure, such as education for rational use of motorcycle can also be considered.

These findings have implications for policies that promote petrol or alternative fuelled motorised two-wheeler vehicle as a more effective and efficient mode of transport; for example China's promotion of electrical vehicle, which has thus far received positive endorsement. China e-bike use is also rising rapidly from zero to a projected +150 million by 2015 in little over a decade (Cherry, 2013).

Cherry (2013) argues that, despite the E-bike's high accident rate and lack of safe design standards, it is a more sustainable mode than its four-wheeler counterpart; it occupies less space and consumes less fuel. He also stresses that 'they are the most energy efficient motorised commercial vehicle in existence' and encourage more people to get on a bike. He proposed that the inherent problems can be solved through the introduction of a bike-share system and adoption of a design standard that ensures the E-bike remains more of a bicycle than a motorbike.

However, the measures to promote e-bike also have complicated implications themselves. China's experience of promoting electric vehicles shows that increased electric vehicle use can improve the air quality within urban areas, but taking into account that the electricity used is produced by burning fossil fuel and coal then the benefits are limited. Even worse, the electric engine further isolates the users from the effects of pollution elsewhere from burning fossil fuels to create 'clean' energy, giving them a false impression that they contribute positively to the environment. In addition, an electric bike and car occupies a similar amount of space - also a limited resource (especially within urban areas) - as a fossil fuel motorcycle and car. Moreover, the behaviour of individual residents in response to the fuel or emission savings may limit the system gains as shown in this study.

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