Effect of Urban Development Patterns on Traffic-Related CO_2 Emissions in Greater Cairo Metropolitan Region

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カイロ大都市圏の都市構想が道路交通からのCO_2排出量に与える影響

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This paper aims to examine how urban development pattern influence the alteration in travel time and carbon emission. We investigate the travel time spent for multiple activities of the users of a high density mixed use development pattern in Central Business District (CBD) of Greater Cairo Metropolitan Region (GCMR). After that, we compare it with the average travel time in low density districts in GCMR. Our analysis found that users of CBD spend less total travel time than other residents by 17% ~ 21%. If every GCMR citizen could use such high density and mixed use areas, the travel time reduction would decrease fuel consuming that can reduce carbon dioxide (CO2) emission by 10974.24 tons per year in the study area.

Keywords: Energy consumption,Climate change ,Mixed Uses, Urban density, Travel Time, Egypt
エネルギー消費，気候変動，用途混合，都市密度，移動時間，エジプト

1.INTRODUCTION

One of the most important topics in the planning research field is whether carbon emission can be decreased through land use planning to hinder global warming. Carbon emission and urban land use, particularly level of mix of use and density, are thought to be related [1]. Mixed use development is observed as one of the tools for establishing an eco-friendly city [2),3)].

High density with Mixed use development pattern is thought as a good tool to accomplish sustainable development. Theoretically, mixed use development would use less space of land in comparison with the single-use low-density development and use less energy and less travel, and in hence support protect more green areas. We recognize that there are many researchers discussed the association between land use and travel patterns. Yet, most of them are still based upon basic relationship between travel patterns and land use attributes such as level of use mix, density, and ease of access to public transport, street connectivity of a neighborhood or a city.

This study particularly examine the alteration in travel behavior with individual travel data to recognize how a mixed use complex development pattern decreases travel time by which concentrating on alteration in move-activity pairs. We suppose that the total travel time would reduce by decreasing the travel time between activities including shopping, entertainment, education, and so forth while the travel time from their origin to the destination may expand.

This study is built as following. First, we study the previous papers on the association among travel patterns and land use pattern, and its environmental influences. Then, we established our study design to examine the impact of a mixed use development pattern on travel time and CO_2 emission. We examine the activities and travel pattern of visitors to a high density with mixed use development district in GCMR, Egypt. We compare it with GCMR's low density development pattern daily activities and travel pattern. Lastly, we

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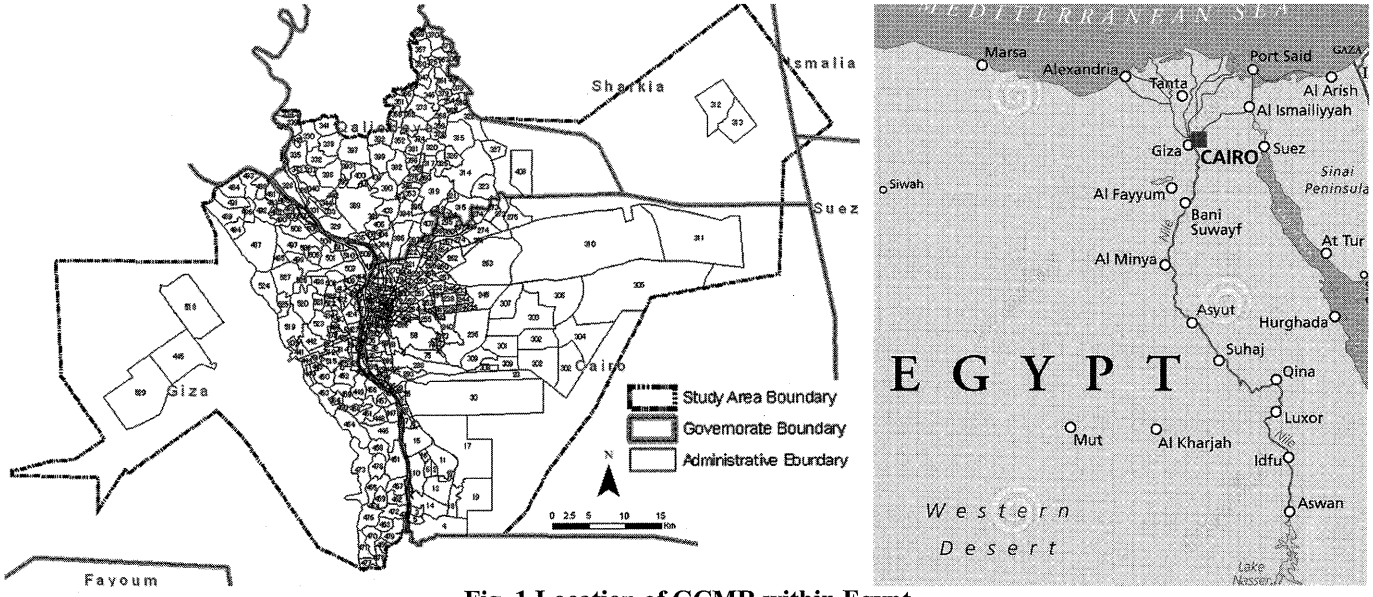

Fig. 1 Location of GCMR within Egypt

Source:JICA,2008[53]

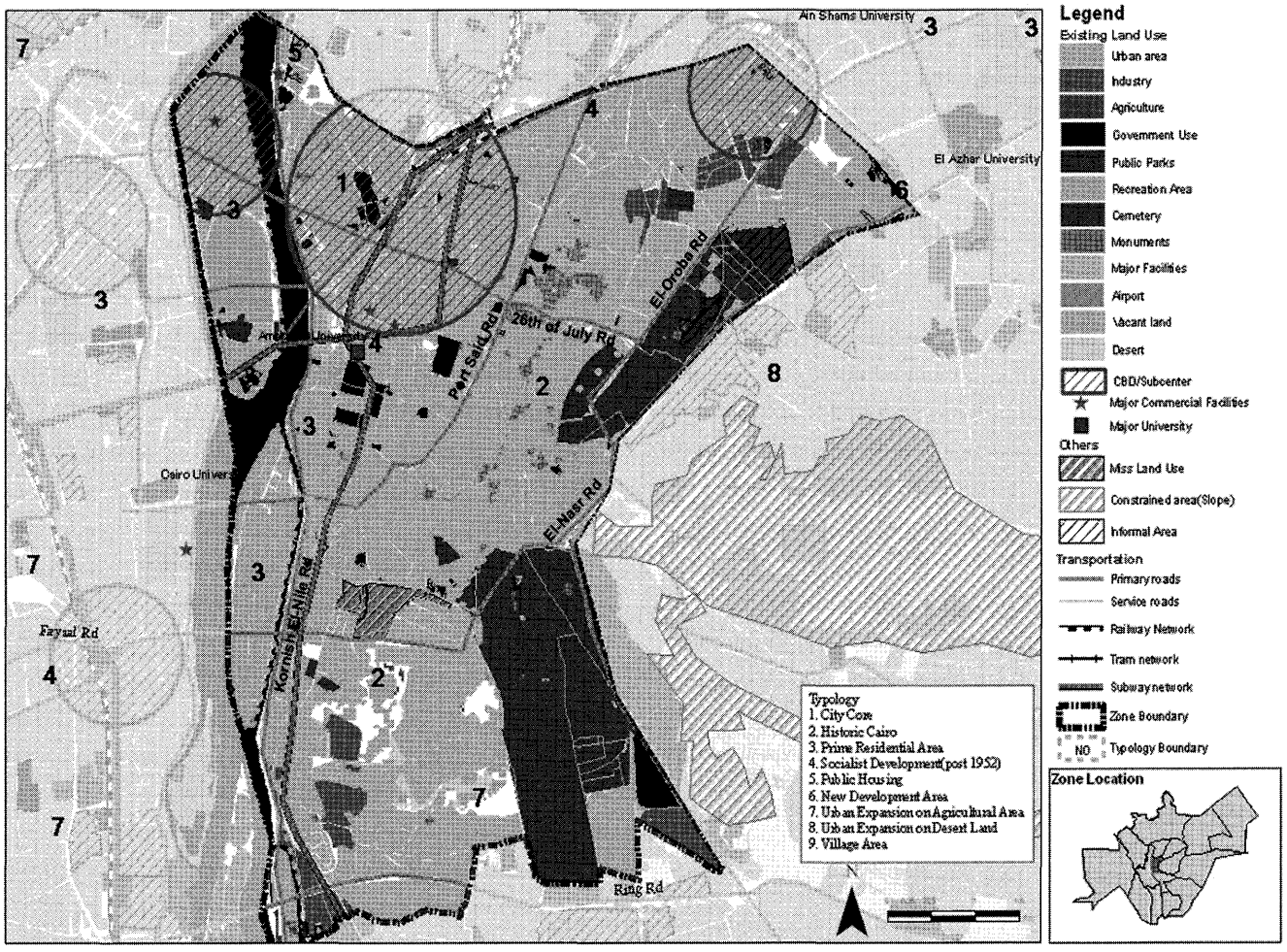

Fig. 2 Land Uses of Central Business District

Source:JICA,2008[53]

identify the influences of a mixed use development on the decrease in travel time and CO_2 emission.

There are, some researches that try to calculate the association between land use types and environment goodness including energy, and CO_2 emission. Density and housing and job proximity has important association with carbon

emission, energy consumption, air quality [4),5)] According to his empirical research of 45 metropolitan cities in the U.S., Stone(2008)[6)] recognized that cities with low land use mix, population density, road connectivity, centeredness of population distribution had high ozone emission. Schweitzer and Zhou (2010)[7)] examined 80 metropolitan areas in the United States and identified non-sprawl areas had low ozone concentrations.

Urban engineers have thought that urban land use type is intensely associated to travel patterns, so that they thought that land use and urban designs influence travel pattern [8),9),10)]. Many researchers also have identified that there are robust proofs that geographic structures in metropolitan regions influence the commuting trips [11),12),13),14),15),16)].

Cervero (1988)[17)] stated that the location of retail facilities in office parks had positive association with the usage of environment-friendly travel mode like walking and transit and decreased considerably the midday trips. Ewing et al. (1994)[18)] identified that mixed-use areas of recreation, commerce, educational services and so forth, significantly decreased vehicle trip generation and vehicle hours traveled. Frank and Pivo (1994)[19)] identified that level of the land use mix reduced the usage of single occupant vehicles and raised the transit and walking trips of work and shopping activities.

While most researchers found that compact land uses areas decreases travel demand at regional level, influences of land use type on travel pattern at micro geographic level, like neighborhoods, are contradictory. Many researchers propose that mixed use development and pedestrian-friendly urban design aid to decrease vehicle miles traveled (VMT) and support people to utilize public transportation modes and bicycles and walk[19),20),21),22),23),24),25)]. On the other hand, there are also many researchers identified that no important association between mixed use developments and travel pattern.[26),27),1),14)].

Hong et al (2013)[28)] identified that the contradictory papers results about the association between the attributes of a built environment and travel patterns stem from the change in study methodology and geographical scale. Also, there have been many papers trying to identify the association between land use type and travel pattern for a few decades. Moreover, there are a number of meta-analysis researches to investigate related literatures [29),30),31),32),33)].

By using a statistical model about housing uses density, vehicle usage, and fuel consumption, Brownstone and Golob (2009)[34)] identified that higher density housing development had smaller vehicular travel distance and lower fuel consumption of residents. Stone et al. (2007)[35)] supposed that a neighborhood with 10% higher density has 3.5% lower traffic volume than others and this help to decrease the carbon emissions. Bartholomew (2007)[36)] identified a median decrease of 2.32% in VMT and 2.07% in NOx emissions with a median density raise of 11% from the analysis of 80 scenario planning schemes in U.S. Marquez and Smith (1999)[37)] recommended the incorporated models of land use, and transport to examine the association of land use type and air quality. Frank et al. (2000)[38)] examined the association between land use types, modal choice, and explosive air pollution from cars in Washington, USA. To draw the association between land use type and environmental emissions, they used the panel data of residents travel in Puget Sound region. They calculated emissions from vehicle travel behavior and land use data including work commute distance, population density, employment density, and census block density. As a result, density had negative association with the amount of emission; yet, distance to work had positively associated with emissions.

Presently, some researches try to estimate the environmental influences of land use types by using scenario analysis of land use types. By hypothesizing the possible rates of market share of compact uses development, decrease in VMT per capita with compact uses development, raise of new development zones, proportion of weighted VMT within urban areas, ratio of CO_2 to VMT reduction, and proportion of transportation CO_2 from motor vehicles, Ewing et al. (2008)[39] identified that the transition from sprawl to compact development would reduce travel distance and transportation CO_2 emission by 10-14% and 7-10% by 2050. Based on Ridder et al. (2008)[40)], their incorporated computer models forecast the urban sprawl scenario would raise traffic movements and deteriorate air quality. Kahyaoğu-Koračn et al. (2009)[41)] also used scenario method in their study, linking GIS system with land use and atmospheric chemistry modeling. The scattered development scenario extremely raise VMT, and hence aggravates environmental pollution. Hixson et al. (2010)[42)] used a scenario about level of development density and investments on transportation infrastructure for their research, and identified that the compact development scenario had the least raise of fine particulates.

All in all, Many factors affect motorized travel and its environmental effects in developing countries[43),44),45)].Rapid urbanization, population growth, changes in development patterns, a massive increase in car ownership, weak traffic management and the technological performance of vehicles and fuels in terms of emissions. Consequently, various methods have been employed to mitigate the environmental

Table 1 Socio-Economy Attributes of Central Business District within GCMR

Statement	Unit	Central district	GCMR
Population in 2006	1000	937	16,10
Growth Rate in 1996-2006	% per year	-0.70	2.22
Population Density	person per ha	218	257.00
No. of Household	1000 household	246	4, 01
Household Size	person per HH	3.80	4.00
Household Income	LE/HH/month	1,01	1,07

Table 2 Land Use Attributes of Central Business District within GCMR

Category	Central Business District		GCMR	
	ha	%	ha	%
Built-up area	3,200	68.10	58,100	11.90
Agriculture	0	0.00	80,500	18.40
Industry	200	4.30	11,800	2.70
Bare land	800	17.00	5,100	1.20
Airport	0	0.00	5,900	1.40
Desert	100	2.10	272,600	62.50
Water	200	4.30	3,400	0.80
Open space	200	4.30	5,100	1.20
Total	4,700	100.00	436,500	100.00

effects of motorized travel, principally the supply of transport infrastructures and technological innovations to reduce vehicle CO2 emissions. Though, these methods are criticized for numerous reasons. For instance, although advances in technology can reduce fuel usage and emissions, the outcomes of these technological improvements might be offset by increased car ownership and use. It is true that large cities in developed and developing countries have low levels of road infrastructure per person. However, building huge and expensive road transport infrastructures can induce more motorized travel[46].Many empirical studies in developed countries have already found that patterns of urban development also have an impact on motorized travel[47),48),49)].In the large cities of developing countries, urban development pattern is believed to be a major factor inducing motorized travel[43),44),45)].

Some studies have argued that in developing countries extreme changes in urban development from high-density mixed uses pattern to low density pattern would be a key reason for increasing vehicle travel[50)]. In this sense, development patterns designed to manage the patterns of rapid urbanization, in particular low density development pattern, would have positive implications with regard to reducing total motorized travel in developing and industrializing countries.

However, empirical evidence for the implications of proper development pattern to reduce motorized travel remains scarce in developing and industrializing countries, particularly in Egypt. This paper will add fresh evidence for this by studying the effects of forms of urban development patterns on an individual's car usage for their journey to various daily activities. The results of this analysis are valuable for low-carbon city development in Egypt. Moreover, the findings of this paper will also enhance our understanding of the environmental impacts of motorization since the present literature is dominated by cases from developed countries.

This paper aims to identify empirically the impact of high density mixed-uses development pattern on travel type and CO_2 emission at the micro geographic level using individual survey data. Particularly, we focus on the alteration in the move-activity patterns and the time of moving.

2. METHODS AND DATA

To find the association between mixed-use high-density land use type, travel pattern, and CO_2 emission, we examine a mixed-use high-density development zone in GCMR CBD, and operate a survey to grasp the travel pattern of its visitors. After that, we estimate the travel patterns between the visitors to this zone and average GCMR citizens of low density development pattern zone. By evaluation, we calculate the decrease in travel demand and CO_2 emission.

2.1 Operational Definition of Travel Time for Activities

People travel from one place to another place for their activities like shopping, extra-curricular education, entertainment, personal facilities, and so forth. In a neighborhood with a single-use land use type, a person has to travel places where offer what the person needs to do. While, if one place holds several purposes, people would use less than single-use land use type. Consequently, mixed use areas are theoretically anticipated to travel time.

2.2 Study Area of Cairo CBD

Central district is located in the central part of main agglomeration of GCMR. It is bounded by Sabtiyah road and Ramsis road in the north, Al-Nasr road in the east, Ring

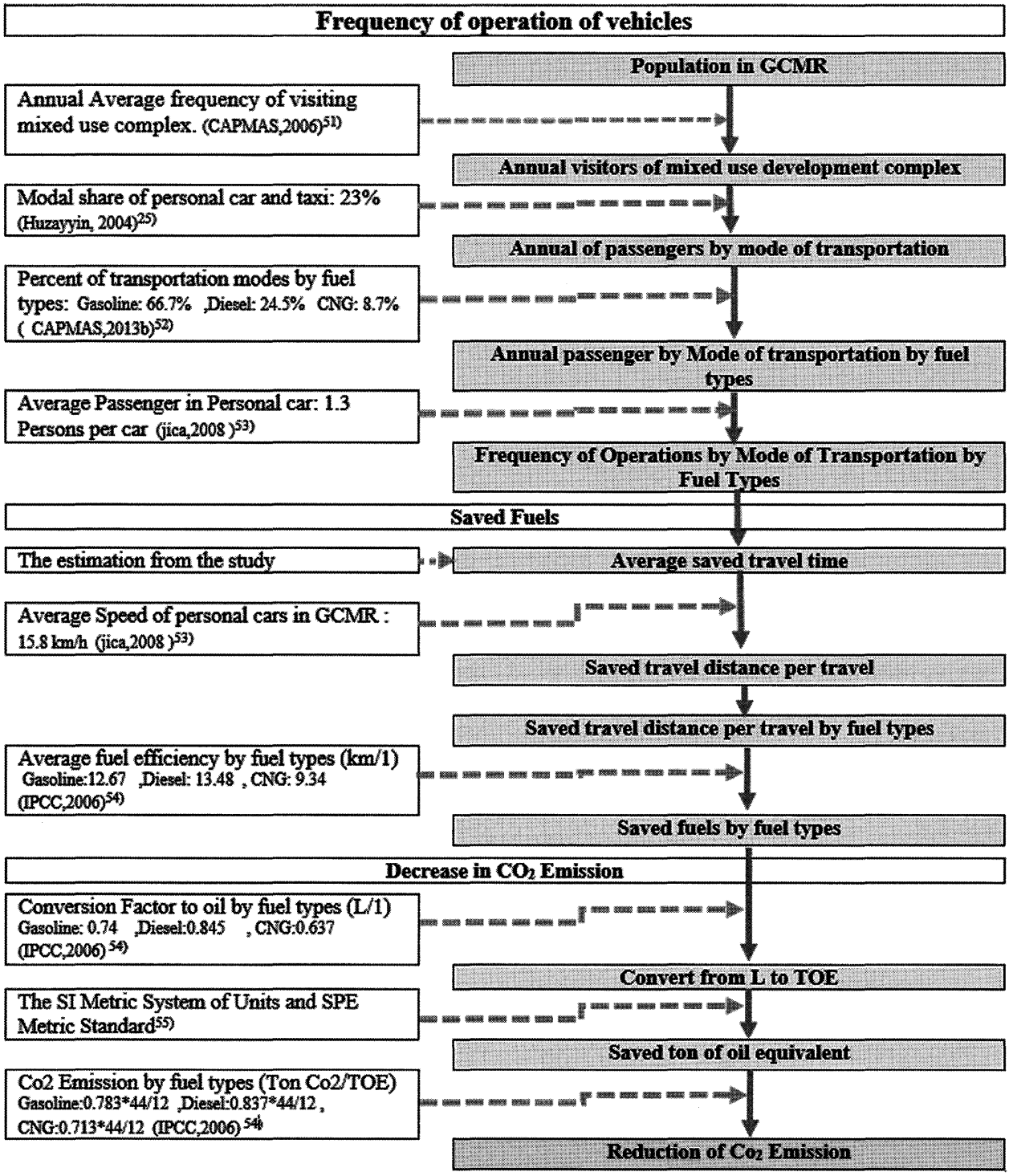

Fig. 3 CO_2 Emission Estimation Methodology

Road in the south, and Nile River in the west. In the north, a city terminal of Ramsis station is located, and connected with multi modes of railways, trams, Metro, and buses. Metro Line 1 and Line 2 run across this planning zone. Even though public transportation is provided, further efforts related to transportation are required to provide car parking areas and convenient walkways (Fig. 3). It includes Zamalek and Al-Manyal islands.

City Core area of GCMR CBD is located in the central part of Central district along the Nile river. Buildings of governments, commerce, and a national museum are located in the CBD. In the outskirts of the CBD in the south and southeast, there are Historical GCMR areas, which are major tourism areas named Old GCMR and Islamic Cairo. The Central district contains many heritage buildings and tourism spots. High-class residential and commercial areas included. 5 stars hotels are formed in the southwest and north west of the CBD. Those areas are called Garden City and Zamalek.

Table 3 Activity and Travel Time by Activity Type of the Central Business District Users

Activities	Total Number of Activities	The Spent Time per Activity (minutes)*	Total Spent Time in the Activities (minutes)	The Travel Time per Activity (minutes)	Number of Activities per Person**
Shopping	484	55.40	26,814	54.00	1.19
Education/Art	74	173.60	12,846	42.00	0.18
Socialization	273	33.88	9,249	36.00	0.67
Food	217	63.00	13,671	32.00	0.74
Work	18	30.00	540	48.00	0.04
Total	1066	355.88	63,120	212.00	2.82
Average		71.18		42.20	
Others	39	29.54	1,152	38.00	0.10

* These numbers were collected by the questionnaire survey

** One person could make the same activity twice in one travel

Table 4 Activity and Travel Time by Activity Type of average GCMR Citizen

Activities	Total Number of Activities	The Spent Time per Activity (minutes)	Total Spent Time in the Activities (minutes)	The Travel Time per Activity (minutes)	Number of Activities per Person*
Shopping	2,925	59.50	174,038	64.00	0.42
Education/Art	1,544	167.70	258,929	57.00	0.22
Socialization	3,655	70.70	258,409	48.00	0.53
Food	4,963	51.20	254,106	41.00	0.60
Work	24	64.30	1,543	51.00	0.01
Total	13,111	413.40	947,025	261.00	2.04
Average		82.62		52.20	
Others	7,022	91.14	639,985	47.00	1.02

* One person could make the same activity twice in one travel

5 stars hotels and high-rise housings are located along Nile River. 98% of the total land area excluding Nile River has been developed for urban areas. Urban development projects are scheduled to relocate a tannery, and ministries' buildings. Future urban development will be focused on enhancing the existing potentials, such as monuments and cultural assets other than business activities in order to promote further high land use mixed uses on this zone.

2.3 Field Survey

The survey is operated at CBD of GCMR. We inquired visitors about comprehensive travel pattern details including travel time, staying time total, service buildings they used, and staying time at each amenity. This survey concentrated on usages of certain service buildings and their activities.

By using questionnaire sheet, we inquired visitors what they essentially did in service buildings they went. To consider visitors' full activity-time pattern at Central District, we utilized the responses from the visitors who completed their activities and were about to leave CBD. For the sake of our paper, we utilized the responses from visitors who dwell in districts within GCMR. We use 571 survey responses; 530 visitors lived in Main GCMR agglomeration, and 41 visitors dwelled in new urban communities within GCMR (fig. 1).

2.4 Control Group

To measure whether mixed use developments effect people's travel pattern, we calculated the travel pattern of Central District visitors and that of average citizens in GCMR. This paper compares the travel patterns of CBD visitors with that of the average of citizens in GCMR (Low density development fringes). Time use Survey of Central Agency for Public Mobilization and Statistics was utilized to find the activity-time pattern of average citizens in GCMR in low density fringes. Particularly, the travel pattern of 6415 GCMR citizens in 2004 was utilized (CAPAMS, 2006)[55].

2.5 Estimation of Travel Time and CO_2 Emission

According to the comparison between CBD users and average GCMR citizens, we can calculate the fuel consumption decrease and its impact on CO_2 emission. After that, we calculated the CO_2 emission from the travel behavior alteration. We identified the frequency of vehicle operations by fuel type, using the data about modal shares, share of vehicles by registration year, and average persons in a vehicle. We then calculated the amount of saved fuels from frequency of operations of vehicles by fuel types. We utilized average vehicle speed, fuel efficacy, and saved travel time by fuel types. We transformed the saved fuels into the total amount of CO_2 emission alteration. We adopted Tier 1 estimation method to calculate CO_2 emission, which is proposed by Inter Governmental Panel on Climate Change (IPCC)[54]. According to Tier 1, the CO_2 emission is calculated as following in Fig. 3.

3. RESULTS

3.1 Activity and Travel Time of Central District Users

The number of activities per person was 2.82 and the average activity time was 71.18 minutes per activity. Longest activities are arts and educational activities and they spend 173.60 minutes per activity on average. They spend the second lengthiest time, 63.00 minutes, for eating in restaurants. Average Travel time was 42.20 minutes. The travel time for

shopping activity is 54.00 minutes per activity, the longest among all type of activities, while the travel time for food activities was the shortest by 32.00 minutes .Moreover, travel time for art was 42.00 minutes, social activities was 36.00 minutes and for work was 48.00 minutes.

3.2 GCMR Citizens' Average Activity and Travel Time

We examined 6,415 answers. The total number of activities and total spent time in the activities are 13,111 activities and 947,025 minutes. The number of activities per person is calculated to be 2.04 and the activity time per person is calculated to be 147.60 minutes. The spent time per activity is 82.62 minutes. Respondents move most frequently for food and restaurant and least frequently for arts and educational activity. Arts and educational activities have the lengthiest spent time per activity, 167.70 minutes per activity. Food had the second longest spent time per activity, 51.20 minutes per activity. The travel time for shopping activity is the longest among all types of activities by 64.00 minutes. The travel time for work activity was 51.00 minutes, and Arts and educational activity had 57.00 minutes. Food activity was the shortest, 41.00 minutes per activity, since food activity had relative long activity time per activity, compared to other activities.

3.3 Reduction in Travel Time

CBD, a mixed use district, decreased travel time and saved the average travel time per activity time for all kinds of activities. The average travel time per activity of CBD visitors is 42.20 minutes per activity, which is 19.15 % lower than that of average GCMR citizens. The average travel time for arts and educational activity and social activities in CBD are less by 26.31% and 25.00%. The average travel time per activity for food and shopping of CBD visitors is less than that of average GCMR citizens by 21.95 % and 15.60 %.

3.4 Reduction in Fuel Consumption and CO_2 Emission

By assuming that all residents of GCMR will use mixed use zones like CBD once a month. With the saved travel time, the predicted fuel savings of gasoline, diesel, and CPG will be 3,351,273 liters, 1,156,367 liters, and 1,053,656 liters. Fuel consumption decrease yields CO_2 emission reduction. By using the conversion factor to oil and CO_2 emission factor by fuel types[55], CO_2 emission would decline by 10,974.24 ton.

4. ANALYSIS AND DISCUSSION

The increasing energy consumption The growing energy consumption and related CO2 emissions because of increasing motorized travel is a significant issue regarding low-carbon developments in Egypt. In the existing fast development process, low density urban development pattern is a major factor that is affecting motorized travel. This means recognizing the proper development pattern to manage urban development can contribute to the reduction of the negative environmental influences of urbanization and traffic emissions. Though, the current policies for manging the environmental influences of traffic emissions are concentrated on the improvement of traffic and vehicle technology and the delivery of expensive transport infrastructures.

Egyptian governments usually neglect the potential value of urban development pattern in addressing the transport issue. The results of the analyses in this paper suggest that the patterns of urban development have significant effects on Cairenes' travel modes for their journeys to daily activities. The low density sprawling development on the planned urban fringe, which is characterized by a low density and low level of land mixed use and high level of expressway system, tends to rise car usage. This means growth management designed to mitigate forms of local urbanization would have a significant role in altering the course of rising motorized travel.

Urban density is the most significant aspect of urban development in Traditional districts of GCMR, and high density with mixed uses can decrease traffic energy consumption and related CO2 emissions56).Traditional urban development in GCMR such as CBD area has a relative high density mixed uses pattern. However, since the 1970s low-density development in the planned suburban has increased swiftly owing to the growing economy. Many low-density gated communities were developed on the urban fringe. The total floor area of low-density housing reached more than 59 million m2 in 2010, which was more than 50% of the total of newly planned -developed housing in the suburban areas of GCMR57). The outputs of this analysis propose that low-density development pattern could be a major reason for the rise in motorized travel in GCMR. Consequently, the trend for low-density development needs to be controlled to decrease the negative environmental effects of traffic emissions.

Low-density development in GCMR is affected by the market demand, but is also greatly affected by alterations in the governmental policies of land development. Since the 1970s, Egypt has been undergoing a transformation from socialist to capitalist economic system. This alteration has involved two interrelated processes: decentralisation, and marketization. The process of decentralisation has led to a radical rescaling of the relationships among the state, enterprises and private developers58),59),60). With more

decentralization in the decision-making process related to local development, and local governments have become progressively powerful in the pursuit of local social and economic development. Growing local decentralization and local fiscal responsibility are major drivers affecting urban development. government control over development is often challenged by local developments, with the resulting urban development arising across the urban fringes58), 59), 60). In particular, dispersed low-density housing projects have been developed in new suburban areas.

Since the 1970s, the decentralization process has opened up multi-scale forms of governance with non-governmental organizations, community-based organizations and private developers, particularly global investors58),59),60). In this multi-stakeholder governance system, marketed development is growing and becoming a new force forming land development on GCMR urban fringes. Market-led development enhances particular development patterns such as office, retail and commercial, high class housing units. Consequently, local revenue-enhancing development might be at the expense of the degree of local mixed land use with less urban density.

5. CONCLUSION

This paper tried to identify how much mixed high-density uses zones can decrease travel time, fuel consumption and CO_2 emissions. To examine the likely influences, the paper focuses on the travel pattern alteration from multi-moves-multi-activities and alteration from single-land use type to mixed use complex. Our paper utilized individual level micro data of travel patterns to track the alterations, and calculated the time-use pattern of CBD visitors, and average of whole GCMR citizens.

The result find that CBD visitors make less travel time for shopping, socialization, arts/education, and food than citizens in GCMR. The travel time of Central District visitors is 19.15% less than that of an average citizen in GCMR. This travel pattern alteration yields CO_2 decrease of 10974.24 ton, which is equal to the fuel consumption decline by 3351273 liters of gasoline, and 1156367 liters of diesel, and 1053656 liters of CPG per year.

In addition to environmental merits, travel time decrease can yield economic value by saving travel time. If a GCMR citizen have five activities a day as common, they spends 52.20 minutes travel time a day. If they do the same activities at a mixed use zones like CBD, they will spend 42.20 minutes (19.15 % less). If every GCMR citizen use mixed use, it would save 7.04 million hours per year. If we interpret this number into a time value (average time value of 1-hour work in GCMR is approximately $10), the time cost saving is approximately 70.40 million dollars per year. If we add the impact of the decrease in fuel usage and car appreciation, the fiscal value of travel time decrease will raise.

All in all, the existing Egyptian policies designed to decrease traffic emissions by enhancing vehicle and fuel technology, and improving road system. However, the continually growing carbon emissions from private transport sectors propose that the influences of this enhancement would be counteracted by a fast rise of GCMR traffic. Consequently, choosing the proper pattern of urban development to control the future urban development can play a positive role in containing the growing of motorized travel in GCMR, thus mitigating traffic CO2 emissions. Most current developments in Egypt are affected by the new trend of market demand towards less urban density with single land uses. That means the institutional capacity of current urban growth management approaches needs to be enhanced.

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