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Containing Urban Sprawl: An Integrated Improvement of Space-tranport Strategies to Reduce Air Pollution Emission

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Abstract— Diverse effective strategies have been designed to minimize the phenomenon of urban sprawl. Previous research focused on the link between spatial and transport development strategies to achieve this goal, with the intention of increasing mobility, reducing commuting time and travel costs. However, a side effect of urban sprawl is an increase of air pollution. Higher pollution levels result in higher costs for road users. To reduce these costs, improvement in public transport linked to urban development is an essential factor in limiting air pollution emission. Current research is insufficient to demonstrate the effects of urban sprawl on air pollution emission. This paper examines the extent to which an integrated approach to space-transport development strategies is able to reduce air pollution emission. The analysis includes the effect of different improvement of public transport (PT) and spatial alternatives on the load of air pollution A pro-active approach is applied for a potential viable up to 2030. By examining the alternative strategies, the intention is to reduce travel costs together with decreasing the load of air pollution emission. This research proposes the improvement of public transport (PT) by planning a combination of Mass Rapid Transit ((MRT), Light Rapid Transit, Bus rapid Transit and feeder systems. In addition, a structure of compact zones is designed as urban spatial strategy alternatives. The conclusions indicate that firstly, the improvement of PT (a combination of Mass Rapid Transit (MRT), Light Rapid Transit, Bus rapid Transit and feeder systems) has an effect on the reduction of air pollution load compared to the current PT situation (minibuses and buses). Secondly, the spatial planning with compact zone does not show a significant decrease in determining the load of air pollution. Its substantially reduction is achieved with the design of improvement of PT systems. The best option for reducing commuting costs and air pollution, the implementation of the improvement of PT systems alternative, is then recommended.

***Keywords*—Space-transport development, Controlling urban sprawl, Air pollution emission, Ratio employment and population, Improvement of public transport, Settlement development**

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I. Introduction

Phenomenal urban development with increasing settlement growth has led to an increase in the number of trips from suburbs to central urban areas. Urban sprawl is reflected in increasing congestion, demand for mobility and air pollution. This phenomenon is occurring in all over the world. Since the beginning of 20th century, serious problems have arisen in most Indonesian cities. The excessive growth in economic and residential development has significant consequences for mobility. Sustainable transportation is a major consideration in improving mobility. This consideration is projected to change modal split from private vehicles to public transport and to reduce air pollution from motorized vehicles, since the sources of environmental pollution and traffic congestion in urban areas lie in road transport.

Numerous studies have been conducted on transport demand management with the aims of reducing air pollution from motor vehicles. The effectiveness of two demand management measures, i.e. road pricing and the vehicle quota scheme (VQS) was revealed as instrumental in controlling both congestion and automobile ownership [1].

Regarding travel behavior and pollution emissions, studies have focused on the impact of mode choice on energy consumption and pollution emission. Coefficients of energy consumption and emissions are influenced by different sizes and ages of engines [2,3]. These authors have designed an integrated model for cars and motorcycles, assessing choice behavior related to ownership, type and usage. They have proposed reductions of air pollution by manipulating variables, such as increase of ownership and usage costs, and improving transit services. [4] have developed an approach for modeling CO2 emissions related to traffic-generated emissions for major roads in Norwich, UK. They suggested urban restructuring, developing road networks, and changing traffic demands would reduce air emissions.

An integrated model to reduce air pollution by improvement of transport technology was applied to Beijing, China. An intelligent transport management system can mitigate the proportion of pollution from vehicles and improve emission performances [5].

Another strategy, based on the compactness was expected to produce lower levels of pollutant emissions, particularly CO_2 emissions, fuel usage, travel distance and travel time [6]. They explained the influence of city structure on air quality by taking into account the relationship between various components such as the GIS database, the land use-transport-environment module and the airshed model. [7] revealed that large metropolitan regions rank more highly on a quantitative index of sprawl than spatially compact metropolitan regions. This research has promoted land use strategies concentrating on more compact urban, intended to solve problems related to the urban air quality with technological emission controls. [8] explained that there was a significant level of environmental inequality in Leeds, UK. Briefly, environmental inequality was reduced by analysis of transport strategies with natural fleet renewal and road-user charges. The changing modal split from private vehicles to public transport and decreasing travel demand are advantage in promoting emission control technology and clean fuel. [9] also explained a sustainable urban structure related to air quality. The impact of various urban growth patterns on air quality of the Porto urban region in Portugal has been assessed by applying the MM5-CAMx modeling system with a year data simulation. The results concluded that an urban structure with sprawl has a high pollutant level. On the other hand, a compact structure has a dense population who are polluted due to living at the highest concentration level.

Insufficient studies consider integration of urban planning and transport systems as an opportunity to reduce air pollution. Furthermore, these primarily focus on development of integrated space-transport development strategies related to the impact assessment, such as on air emission. This research will present a strategic option based on spatial transport development and consequences of air pollution emitted from each transport mode, particularly the most prevalent transport mode, the motorcycle and car. Choice behavior of residents and the load of air emission components are compared with alternatives proposed for design of space-transport development strategies. This research has been based on a large survey to estimate the parameter in a four-step transport model and the weighted emission parameters. In the face of rapid growth in the use of cars and motorcycles, it is vital to consider the strategy of space-transport development in order to reduce the number of private vehicles and the high level of air pollution they emit. In general, the motorcycle is a relatively fuel efficient but high polluting mode.

The results of this research are expected to assist in determining a policy for minimizing the phenomenon of urban sprawl, considering the best option for an urban structure linked to improvement of public transport and assessing the load of air pollution. Housing development in the suburbs is based on an integrated approach with emphasis on reducing air pollution from motor vehicle traffic. An integrated approach consists of transport and spatial development and impact assessment.

The organization of the paper is described as follows: data collection and explanation of methodology are explained in the second section. Background information on the public transport and urban spatial development of Surabaya City is described in the third section. The fourth section explains estimation of emission parameters. The fifth section discusses the effect of settlement development in the suburbs according to three scenarios: current trend in 2030, improvement of public transport, and balance of employment and population density on the load of air pollution. The final section presents conclusions and recommendations for further analysis.

II. DATA and METHOD

This section describes the data collection in the study case area, the process for conducting this research by employing a combination of the JSM and OmniTRANS model. This comprises data needed to estimate parameters of the weight emission, and to present overview of alternatives of transport and space development strategies

A. *Data*

In this paper, three scenarios have been applied for Surabaya City to identify the effects of various alternatives on minimizing the load of air pollution. The scenarios comprise 2030 in current trend, secondly, 2030 with spatial development strategies and 2030 with improvement of public transportation (PT) such as Bus Rapid Transit (BRT), a combination of Mass Rapid Transit (MRT) and Light Rapid Transit (LRT), and thirdly, an integrated PT-system consisting of MRT, LRT, BRT, and feeder systems.

To apply the models, data was collected for each village (called "*desa*") within the urbanized area of Surabaya City. Surabaya City, the capital city of East Java Province, comprises 31districts and 163 villages with a total area of 327 km², and is located at an altitude of 3-6 m above mean sea level. The city has a population of approximately 2.8 million, with a high density of more than 10,000 persons per km^2, which can be indicated as a highly urbanized area as seen in Fig. 1 [10].

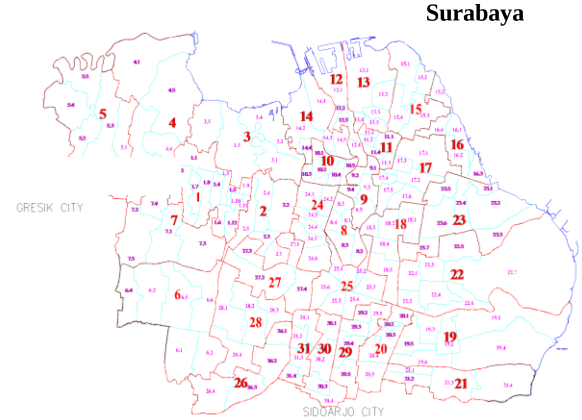

Fig. 1.Location of study area (Surabaya City) in East Java Province, Indonesia

The data was collected by 2010 Census data, secondary data from the Department of the Environment, and by distributing questionnaires to 163 villages (approximately 554 respondents). The questions consisted of three parts: socio-economic background, trip characteristic, transport mode choice.

B. *Planning Methodology*

The purpose of this research is to evaluate the potential impacts of different improvement of PT and spatial development strategies on urban air quality. The three scenarios are designed taking proposals from local government into consideration, i.e. current trend 2030, 2030 with compact zone in western regions of the city, and 2030 with improvement of PT. To simulate the scenarios, the models employed in this research are OmniTRANS, to set up a transport model, and Java Spatial Model (JSM) to determine a spatial settlement model. These models are applied to analyze the projection of settlement and transport networks as pro-active planning for Surabaya City. The main point of this research is to achieve optimization of the transport network by proposing alternatives for the improvement of public transport combined with settlement development strategies aimed at reducing air emission.

The conceptual framework of this research is intended to develop an integrated plan to minimize the urban sprawl phenomenon and is described in five steps, as explained in Fig. 2.

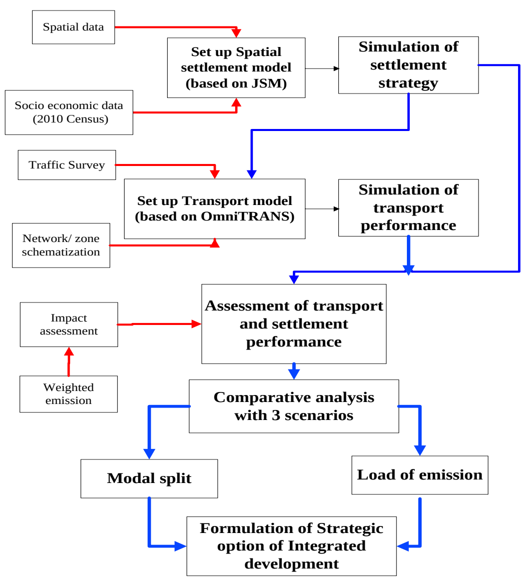

Fig. 2. The conceptual framework of space-transport development.

JSM (Java Spatial Model) as the *first* step; a spatial settlement model is analyzed with the input of the statistics for population and employment in 2010 census, socio-economic scenarios and spatial planning interventions. Simulation of settlement strategies is the current trend 2030, and 2030 with a balance employment and population. The output of JSM (projection of population, employment, and housing area) will be used to generate traffic demand by employing OmniTRANS model.

The *second* step, OmniTRANS model is constructed to set up a transport model. The transport model uses the four-step model for modelling trips between zones (*desa* level). In general, the input of OmniTRANS consists of zonal data, transport networks and user behavior. The zonal data was added from JSM and the network was based on the GIS application program. The user behavior consists of: trip production and attraction parameters, distribution functions, BPR-functions, and VOT (value of time). The parameters of the different functions had been estimated in previous research [11].

The *third step* was undertaken to assess and evaluate the impact assessment module, particularly the load of emission parameters such as CO, CO_2, NO_x, pm10, and HC.

The *fourth* step was to assess the technical performance of the different alternatives of transport and spatial development. In this paper, alternatives were explored to achieve the goal of being a strategic option for transport and spatial development regarding air quality.

The fifth step was undertaken by comparative analysis in order to evaluate the technical performance of the different alternatives. There are 6 alternatives within 3 scenarios proposed in this assessment, consisting of a scenario for 2030 with current trend, three alternatives for 2030 scenario with improvement of PT (design of grid-structure BRT system, combination of MRT and LRT systems, and design of all PT systems consisting of MTR, LRT.BRT systems), and two alternatives for the 2030 scenario with space-transport development by designing compact zones in western regions, and a combination of the improvement of all PT-systems and compact zones. Then, we formulate the strategic option based on simulation of all alternatives by assessing the performance of the integrated plan. The integrated plan includes a simulation of transport performance, settlement development integrated with public transport systems, and space-transport development strategies with regard to assessment module. The optimal design should provide the best possible future alternatives.

III. Public Transport Performance and Housing Development in the Suburbs

The performance of public transport is explained based on the current public transport system of Surabaya City. The current PT is served by bus and minibus/paratransit and train. There are 68 available paratransit routes, 22 bus routes. Most bus routes use national/provincial roads and toll roads in the central area of city, other areas are served by paratransit (minibus accommodates 8-12 passengers). The paratransit routes have no fixed time schedule or frequency.

Surabaya city has a major problem with settlement development for its residents, population density being approximately 10,000 people per km^2 in 2011. The central urban areas have a high density (45% built-up area). These conditions have an influence on the increasing number of informal settlement areas. Since 1980s, settlement development has extended the outskirts of urban areas, particularly on the western and eastern sides of the city with less than 15% built-up area. There are 135,000 households living in the suburbs. Local government finds it difficult to provide a transport network because new settlement areas are far from the central business district (CBD) and employment areas. Strategies are proposed to have an effect on the distribution of population and work in the city. These strategies consist of an economic center taking into account the significantly higher growth in employment in the economic centers, good government, meaning more consistency in the land-use plan, and establishing a compact zone with a ratio of employment to inhabitant in the particular area (economic centers). An urban strategy is proposed, implementing a balance between job and population density (compact zone) and linkage with the improvement of all the PT-systems. The urban strategy with a compact zone in western regions is based on a GDP growth of 7%. The number of jobs increasing employment by 3% is result of the GDP growth.

Ratio of employment and population is projected with a balance ratio in city economic centers (compact zones), as explained in TABLE I. The increasing ratio of employment and population occurs in several zones in the economics center on the western side, where business centers such as factory locations are planned.

TABLE I. RATIO OF EMPLOYEMENT AND POPULATION IN TWO SCENARIOS

Locations	2030 current trend			2030 with compact zone scenario		
	population	employment	ratio	population	employment	ratio
Central	434,148	151,250	34.84	435,861	132,195	30.33
North	821,107	242,279	29.51	821,320	239,346	29.14
South	1,060,599	386,143	36.41	1,127,005	363.214	32.24
West	1,262,695	497,469	39.40	1,238,042	522,390	42.19
East	1,498,414	458,695	30.61	1,454,735	478,692	32.91
Total	5,076,963	1,735,836	34.15	5,076,963	1,735,837	34.15

IV. Emission Parameters and change of weighted emission parameters for each scenario

Assessment of the impact on air quality of the proposed alternatives is based on the scenarios. A change in the load of traffic flow, and modal split based on scenario proposed are assessed. The change in the load of traffic flow and mode choice influences the load of air emissions.

To determine the load of emissions, specific weighted emission parameters regarding air quality for Surabaya City roads are required. The weighted emission parameters refer to air quality data containing the weighted emission values per vehicle kilometer (gr/veh-km). The weighted parameters, such as CO, CO2, NOx, pm10, and HC are estimated. The weighted emission values for each vehicle type depend on average speed standard of each vehicle class for each road type (motorway, urban, and rural). The values were analyzed for the current base 2010 according to [12], the procedure for determining air pollutants at micro level due to traffic, as explained as follows:

$$NOx = 0.0005.\ U_v^2 - 0.0656.\ U_v + 3.6586 \quad (1)$$

which U_v is average speed standard for each vehicle class for each road type in km/hr.

A concentration of each emission is determined based on the weighted emission parameters, and traffic flow for each vehicle class. Assessment of concentration of each emission parameter is explained as follow:

Air pollutant (gr) = traffic flow of each vehicle class (vehicles) x emission value for each parameter for each type of vehicles (gr/veh-km) x road length (km). (2)

Three scenarios are proposed in this research, i.e. current trend in 2030, improvement of public transport, and balance of employment and population density as they affect the load of air pollution. With the scenarios proposed, traffic flow is reduced, decreasing air pollutant for each parameter.

First scenario, air pollution for current trend 2030, is assessed by assuming an emission growth equal to traffic flow growth for each vehicle class, i.e. 4.01% (car), 9.9% (motorcycle), 2.76% (bus), 6.7%(truck) respectively. Another assumption is described; most motorcycles emit CO, NOx and HC, while cars exhaust 30-50% CO and HC [13].

Second scenario, 2030 scenario with a compact zone in particular areas in western regions of city, is designed with reduction of air pollution equivalent to the decrease of ratio employment and population.

Third scenario, 2030 with improvement of PT, is determined by assuming a ticket price for the new PT system equal to travel cost of other modes. The reduction of travel cost is 43.9% which is similar to the decrease of the concentration of each emission parameter. Three alternatives are proposed in the second scenario, i.e. design of BRT grid structure, MRT and LRT system, combination of BRT, MRT and LRT systems, as illustrated in Fig. 3.

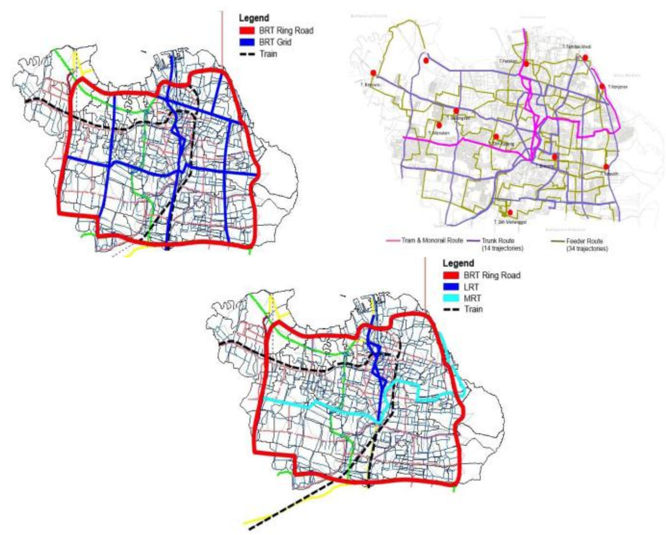

Fig. 3. BRT-system (3a), development of MRT and tram lines (3b), and all PT-systems consisting of BRT, LRT, MRT and feeder systems (3c)

For example, for the weight emission parameter, NOx values are determined for each scenario as explained in Table II.

TABLE II. THE WEIGHTES EMISSION FOR NO_X FOR EACH SCENARIO

Road type	Population				
	Speed in fee flow	Concentration of NOx			
		2013	2030 CT	2030 compact zone	2030 with improvement of PT
motorway	80	1.616	1.642	1.461	0.68
urban	70	1.674	1.708	1.52	0.709
rural	80	1.616	1.642	1.461	0.68

V. Air quality related to the scenarios

Increasing air quality is anticipated in all scenarios based on the change of modal split within each scenario. This section explains the change of load of air pollution in six alternatives.

A. *Modal Split and the load of each vehicle class*

Each scenario has an effect on change of modal split for each vehicle class. The modal split is explained in Table III. A 65% increase in the use of PT indicates that public transport passengers are more interested in a design incorporating a space-transport development strategy than in other strategies.

TABLE III. MODAL SPLIT FOR EACH CSCENARIO OF 2030 CURRENT TREND AND IMPROVEMENT OF VARIOUS PT SYSTEMS AND SPATIAL DEVELOPMENT STRATEGY (%)

Transport mode	Scenario 1	Scenario 2			Scenario 3	
	Alternatives					
	(A1) Current trend	(A2) BRT	(A3) MRT and LRT	(A4) All PT	(A5) Compact zone	(A6) All PT + compact zone
Public transport	5.62	5.69	7.72	8.51	5.66	9.23
Motorcycle	63.39	60	58.7	59.8	64.3	60.3
Car	30.23	28.86	28.7	26.58	29.2	25.39
Bicycle	0.75	5.48	5	5.04	0.82	5.09

The number of cyclists also increases six times compared to the current trend 2030. This finding means that the alternative of the design of a space-transport development strategy will influence the load of traffic flow and air quality on the road corridors.

Traffic flow decreases based on the change of modal split. The reduction can be determined by multiplying the existing traffic flow by the number of passengers using the new public transport systems, such as BRT, MRT and LRT, a combination of these systems.

The increase of passengers in the new PT system reduces the use of private motorized vehicles, resulting in declining air pollutant emission, particularly CO, and NOx.

Focusing on the effects of CO and NOx emitted from private vehicles (car and motorcycle), the loads of car and motorcycle are assessed. The number of cars and motorcycles is expected to decrease with the design of an improved PT system and a spatial strategy (compact zone) as seen in Fig. 4 and Fig. 5.

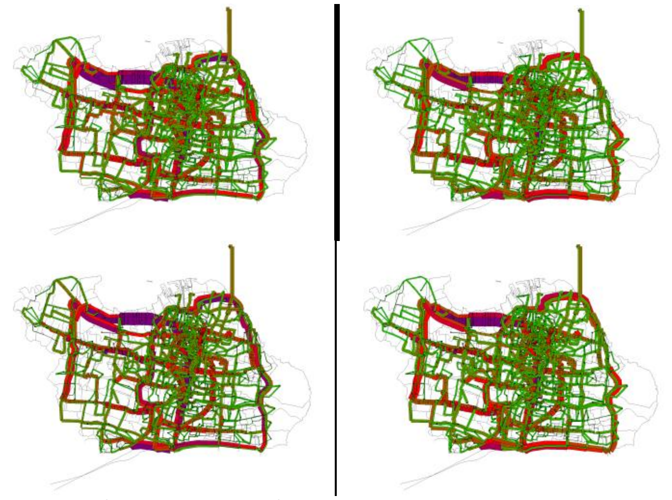

Fig. 4 Load of car in alternative of current trend 2030 (A1), (A4), (A5), and (A6).

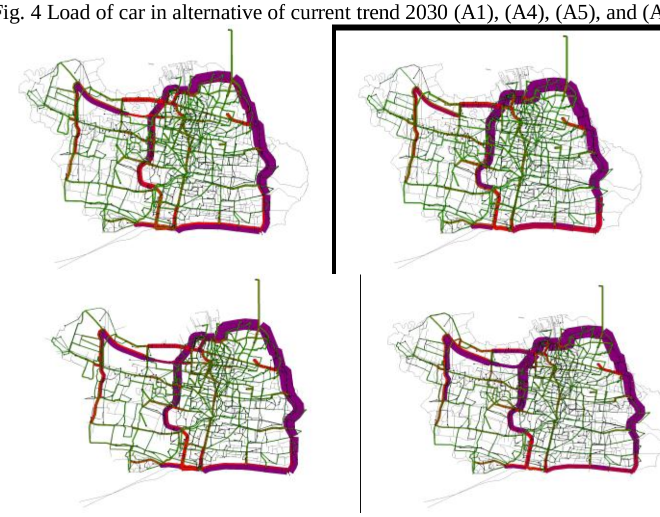

Fig. 5. Load of motorcycle (MC) in alternative of current trend 2030 (A1), (A4), (A5), and (A6)

Fig. 4 describes a significant change in decreasing the load of car with the scenario of the improvement of all PT systems (see Fig. 4b), while the scenario of compact zone does not influence the change of car loads (see in Fig. 4c). In Fig. 5, load of motorcycle does not significantly decrease with scenario of compact zone, but is reduced slightly with the improvement of PT system scenario, as seen in Fig. 5b.

B. *The change of air emission load*

The change of air emission load, particularly CO and NOx, emitted by private vehicles is expected to decline with the design of improved PT systems and development of a compact zone in the western regions of the city.

In order to evaluate the influence of the design of PT systems improvement and the development of compact zone in the western regions in the air quality, we analyze the relative CO concentrations emitted by car and NOx concentrations exhausted by motorcycles, as shown in Fig. 6 and Fig. 7.

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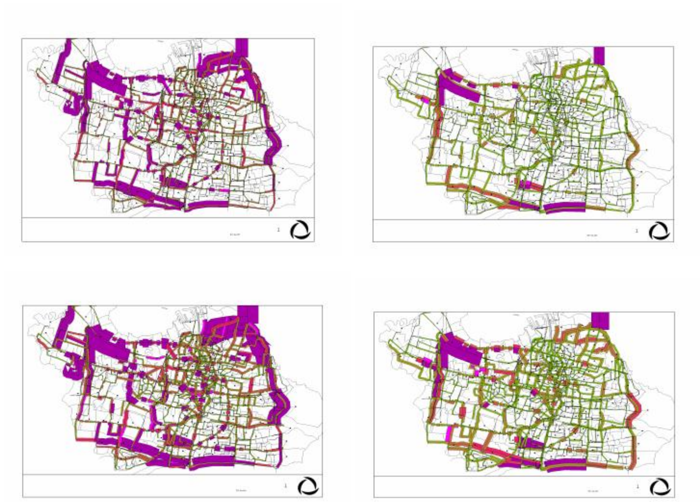

Fig. 6. Comparison among CO concentration emitted by cars for each scenario with alternative of A1, A4, A5, and A6.

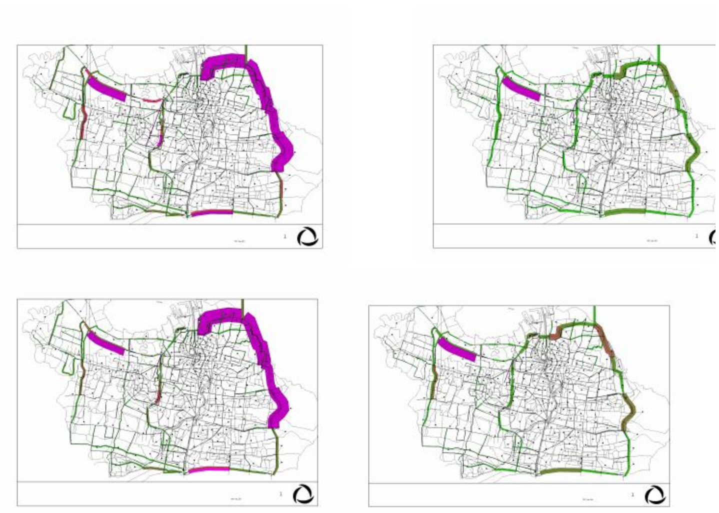

Fig. 7. Comparison of NOx concentrations emitted by motorcycles for each scenario with alternative of A1, A4, A5, and A6

Regarding the effect of CO emitted by cars, as explained in Fig. 6, there is a significantly different behavior of CO concentrations for each alternative. The improvement of PT systems leads to the highest decrease of CO concentrations, even the high CO concentrations occurring in the western and southeastern regions due to a high load of cars.

NOx concentrations emitted by motorcycles are huge, declining with the improvement of PT systems. This behavior is a similar phenomenon to the effect on CO concentration. In the western and northeastern regions, there is still a fairly high load of motorcycles which lead to high NOx concentrations. Even the improvement of PT systems combined with a compact zone designed in those regions does not reduce the level of NOx concentrations, as seen in Fig. 7.

Concerning the mode choice, the combination of improved PT systems and compact zone (A6) encourages more passengers to use public transport. On the other hand, this alternative does not decrease substantially the concentrations of CO and NOx.

Conclusions and Recommendations

This research demonstrated the influence of the design of PT system and development of urban spatial strategy with compact zone on the effects of air quality. Taking air quality into consideration on air quality is an important factor in urban transport planning. A projection of air pollution concentration (i.e. CO and NOx concentrations) was analyzed for three scenarios with six alternatives.

The alternative with improved PT systems was characterized by the smallest emissions rates, while the spatial development strategy with compact zone demonstrated an insignificant decrease of air pollution concentrations. A combination of improved PT system and compact zone results in a significant increase in the use of public transport. On the other hand, this alternative does not show a significant decrease in air quality concentrations.

The compact zone strategy does not provide better air quality. Other strategy in urban planning should be designed, such as examining closest job housing, in order to assess the effect on air quality.

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