Bicycle lanes to improve road user safety and urban air quality

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Abstract. The government should provide paths for pedestrians and cyclists base on Indonesia Government Regulation No. 22 of 2009. Kampung Inggris located in Pare District is a destination for local tourists to learn English. Tourists and residents in Pare sub-district use bicycles for their daily mobility. Currently, there is a mix of traffic in the Pare Central Business Districts (CBD), this is due to the unavailability of bicycle lanes in that area. The purpose of this research is to determine a bicycle lane to improve cyclist safety and improve air quality in the Pare CBD. The analytical method used in this research is stochastic traffic assignment to assign the bicycle route by using the Origin-Destination of the cyclist. The results showed the origin-destination movement for bicycle users in Pare District is mostly directed to Tulungrejo, Pare, Tretek. There are three alternative routes based on the results of the analysis which will serve as a typical bicycle route in the Pare CBD. There are several facilities to support typical bicycle lanes such as markers, traffic signs, and bicycle parking which must be prepared and equipped to support typical bicycle lane planning facilities in the Pare CBD.

1. Introduction
Cycling is one of the environmentally friendly modes of transportation that can improve urban air quality. Some of the advantages of cycling are healthy, cheap, flexible, and low-carbon. Base on Indonesia Government Regulation No. 22 of 2009, it is clear that road users include pedestrians and cyclists. And therefore, the government should provide paths for pedestrians and cyclists. The problem of increasing air pollution, which is mostly contributed by motorized vehicles, has encouraged the government to focus on providing non-motorized transportation facilities. Bicycle lane planning is part of the road space. It is very important, especially cyclists who are vulnerable road users other than pedestrians being a priority in road space. Therefore, special bicycle lanes must be a priority in development for the cyclists’ safety.

Kampung Inggris, which is located in Pare District, is a destination for local tourists to learn English. This is one of the Central Business Districts (CBD). Tourists and residents in Pare sub-district use bicycles for their daily mobility. Based on transportation mode use analysis found that bicycle users in the Pare CBD area are reaching 18% of the population. The use of bicycles in the Kediri Regency continues to increase until it reaches 12% of the population. Currently, there is a mix of traffic in the Pare CBD, this is due to the unavailability of bicycle lanes in that area. The goal of this study is to determine a special bicycle lane to improve cyclist safety and improve air quality in the Pare CBD.

Pare CBD is an area business and commercial center in Pare district. This district is characterized by a concentration of business land use with commercial, trade, and services offices. This district is characterized by a concentration of business land use with an excessive variety of commercial offices, retail shops, and services.
The Pare CBD is also the transportation center, due to the lack of public transport services, so based on data on the proportion of vehicles used in this area, private cars, and motorbikes dominate 77% of traffic. This causes private cars and motorbikes to contribute the largest in vehicle exhaust emissions, on the other side the use of bicycles continues to increase, and specifically for Pare CBD 18% of the population. Mix traffic, there are no bicycle lanes, signs and markers make cyclists in this area unsafe. The object of the study is bicycle users who are local people and tourists in the Pare CBD. The research scope is limited by routes, main facilities, and supporting facilities for special bicycle lanes.

2. Literature review

2.1. Bicycle planning

Bicycle planning needs to be adapted to the special conditions of the society which it serves. Bicycle planning for urban, suburban, states, and district are significantly different, depending on many factors that consist of roads or corridors, policy, funding, and stage of social engagement. Bike planning exists for each type of society. In the society growing rapidly, bicycle planning might also pay attention to policies, standards, and code language to information future development, whereas plans for a more developed society could also be extra involved with the retrofitting of bicycle enhancement sat current places and evaluation of attainable off-street corridors. To improve bicycle safety, city planners and policymakers have to motivate mixed land use, promote dense road networks, location new bike lanes in settlements and green spaces, and offices area, while keeping off steep slopes. To encourage bicycling an evaluation process of the hazard of bicyclists involving severe accidents in the local neighborhood has to be applied earlier prior to promoting bicycle activities [1,2].

2.2. Traffic principles for bicyclists

Based on The American Association of State Highway and Transportation Officials (ASSTHO) guidelines, the bicycle has distinct physical dimensions and performance characteristics than a motor vehicle. A cyclist is also more susceptible to a collision than a motorcyclist. The principal concepts of bicycle operation in traffic consist of the following:

- a. Cyclist on a Two-Way Road Ordinarily Ride on the Right Side of the Roadway
- b. Cyclist Obey Stop and Yield Signs, and Observe Yielding Rules
- c. Cyclist Yield When Changing Lanes
- d. Cyclist Overtake Other Vehicles on the Left
- e. Cyclist Lateral Position on the Roadway Is Determined by Speed and Usable Width
- f. Cyclist Approach Intersections in the Rightmost Lane That Provides for Their Movement
- g. Cyclist Have Several Options for Turning Left at an Intersection.

The empirical results indicate that time period (for commuters) and motorized traffic volume are the foremost necessary attributes in bicycle route choice. Different route attributes with a high effect include the number of stop signs, traffic lights, intersections, speed limits, on-street parking characteristics, and whether there are sustainable cycling facilities on the route [3].

3. Research methodology

3.1 Data collection

Primary data collected by traffic survey, roadside interview, and field observation. This data consists of traffic volume, traffic flow, road density, road inventory, and Origin-Destination bicyclist. The supporting data consist of road classification, land use maps, and Indonesian government regulation.

3.2 Method of analysis

The analysis methods using stochastic traffic assignment to determine the selection of alternative routes for bicycle lanes with Origin and Destination data of the bicycle user/hour. The Slovin method is used to determine the number of samples of bicycle users in the Pare CBD, Level of Service analysis of road performance to determine the performance of roads after implementation bicycle lane.
4. Result and discussion

Based on the movement of bicycle user in Kediri Regency, to analyze bicyclist route, Pare sub-district is divided into eight zones that are Tulungrezo, Pare, Tretek, Gudang sewu, Sumberbendo and Siderejo, Darungan and Sambirejo, Bendo, and the last Glue (figure 1).

As shown in figure 1, the movement of the bicyclist passes through collector roads. It is known that bicycle users in Pare District reach 18% of the 102,185 population, which is 18,393 residents. From 18,393 bicycle users in Pare District, samples were taken to analyze the movement of bicycle users using the Slovin method with an error value of 5%. It’s obtained a sample of 391 bicycle users.

4.1. Bicyclist characteristics

From 391 samples of bicycle users, they can be grouped based on several characteristics based on age, gender, profession, and activity. Based on gender there is a sample of 228 male and 162 females, and based on age, profession and activity is shown in table 1, table 2 and table 3.

| Table 1. Characteristic by age. |
|---------------------------------|
| <15 | 15 - 30 | 30 - 55 | > 55 |
| 195 | 106     | 77      | 13   |

| Table 2. Characteristic by profession. |
|----------------------------------------|
| Housewife | Student | Farmers | Entrepreneur | Private Employees |
| 21         | 286     | 41      | 31           | 13               |

| Table 3. Characteristic by activity. |
|-------------------------------------|
| School | Work | Social | Shopping | Other |
| 230    | 76   | 44     | 24       | 17    |

As shown in table 1, based on age the largest proportion of bicycle users are under 15 years. This shows that most of the cyclists in Pare are students.
4.2. Bicyclist origin and destination

In the Pare CBD, the Origin-Destination (OD) of bicycle users is shown in the table 4.

| Zone | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | Total |
|------|----|----|----|----|----|----|----|----|-------|
| 1    | 6  | 24 | 18 | 0  | 5  | 0  | 0  | 0  | 53    |
| 2    | 17 | 3  | 18 | 0  | 0  | 0  | 0  | 0  | 38    |
| 3    | 8  | 15 | 1  | 0  | 1  | 0  | 0  | 0  | 25    |
| 4    | 16 | 38 | 14 | 5  | 2  | 0  | 0  | 0  | 75    |
| 5    | 11 | 20 | 3  | 5  | 3  | 0  | 0  | 0  | 56    |
| 6    | 15 | 27 | 10 | 0  | 3  | 4  | 0  | 0  | 59    |
| 7    | 22 | 15 | 8  | 0  | 0  | 0  | 2  | 0  | 47    |
| 8    | 14 | 13 | 8  | 0  | 0  | 0  | 3  | 38   | 391   |
| Total| 109| 155| 91 | 8  | 16 | 7  | 2  | 3  | 391   |

As shown in the table 4, the movement of the origin of the bicycle users in Pare sub-district to zone 1 Tulungrejo, zone 2 Pare, zone 3 Tretek which is a zone of attraction with a total trip of 90%. The other five zones are the generation zone. From the OD Matrix of the sample of user trips, the OD of the bicycle user population is obtained by multiplying the OD of the sample of bicycle users by the expansion factor obtained from the population of bicycle users divided by the sample of bicycle users as shown in table 5.

| Zone | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | Total |
|------|----|----|----|----|----|----|----|----|-------|
| 1    | 282| 1129| 847| 0  | 235| 0  | 0  | 0  | 2493  |
| 2    | 800| 141 | 847| 0  | 0  | 0  | 0  | 0  | 1788  |
| 3    | 376| 706 | 47 | 0  | 47 | 0  | 0  | 0  | 1176  |
| 4    | 753| 1788| 659| 235| 94 | 0  | 0  | 0  | 3528  |
| 5    | 517| 941 | 659| 141| 235| 141| 0  | 0  | 2634  |
| 6    | 706| 1270| 470| 0  | 141| 188| 0  | 0  | 2775  |
| 7    | 1035| 706 | 376| 0  | 0  | 0  | 94 | 0  | 2211  |
| 8    | 659| 612 | 376| 0  | 0  | 0  | 141| 1788| 18393 |
| Total| 5127| 7291| 4281| 376| 753| 329| 94 | 141| 18393 |

4.3. Bicycle network

In this research, bicycle paths are divided into several types, including the following:

a. Bike Path

Bike Path is a special bicycle path where the bicycle lane is physically separated from the motorized vehicle traffic lane. Road separation usually uses fences or additional road medians. This path can be combined with pedestrian facilities. The bike path in Pare CBD is shown in figure 2.

Figure 2. Typical bike path with separator.
b. Bike Lane
Bike Lane is a bicycle lane as part of a traffic lane that is only separated by road markings or different road colors. This path is mixed up with other traffic users. Based on the Indonesian Ministry of Transportation, road marking for a bike lane is shown in figure 3.

![Figure 3. Typical shared-lane marking cross section for bike lane [4].](image)

Figure 3. Typical shared-lane marking cross section for bike lane [4].

c. Bike Route
Bike Route is a bicycle path as part of a traffic lane that is not separated from the main highway. There are no barriers such as markers or fences for the bike route because it is used together with motorized vehicle traffic. The bike route in The Pare CBD is shown in figure 4.

![Figure 4. Typical shared-lane marking at junction layout.](image)

Figure 4. Typical shared-lane marking at junction layout.
d. Bicycle Guide Signs
Bicycle guide signs could guide bicycle users to navigate within and between various destinations in Pare CBD. Based on Indonesia Ministry of Transportation Regulation No13 of 2014 about Traffic Sign, the typical bicycle Guide Signs is shown in table 6.

**Table 6. Typical bicycle guide signs.**

| No. | Sign | Information |
|-----|------|-------------|
| 1   | ![Bicycle sign](image1) | The command uses a special bicycle lane or lane of traffic |
| 2   | ![Bicycle sign](image2) | Bike route directions |

*Figure 5. Layout of bike route in Pare CBD.*
| No. | Sign | Information |
|-----|------|-------------|
| 3   | ![Sign](image1.png) | Prohibition of running a vehicle at a speed of more than 40 km/hour |
| 4   | ![Sign](image2.png) | The deadline for the maximum speed prohibition is 40 Km/hour |
| 5   | ![Sign](image3.png) | The prohibition continues because it is obliged to give priority to bicycles from the priority given direction |
| 6   | ![Sign](image4.png) | Alert lots of bicycle traffic |
| 7   | ![Sign](image5.png) | Introductory bike path or lane instructions |

Source: Ministry of Transportation Regulation No13 of 2014 about Traffic Sign [5].

Bicycle routes have to be placed on roads and shared use pathways with favorable conditions for bicycling, as well as those with bicycle facilities, low motorized vehicle volumes, low traffic speeds, or
enough dimension for shoulders or applicable lane sharing. Bicycle route guide signs are helpful for various functions including guide bicyclists navigate; however, the location of signs doesn't essentially lower bicycle crashes, as a result of the signs don't change the geometric design or traffic volume and traffic speed. For this reason, it should be desirable to additional bicycle wayfinding signs with alternative main street enhancements to accommodate bicycle travel, depend on upon motorized vehicle speeds and traffic volumes on the route. Bicycle guide signs should be clearly visible to bicyclists and ensure that cyclists can recognize and understand these signs. Thus, the bicycle guide signs could be installed in the correct position.

![Figure 6. Placement of wayfinding/guide signs in CBD Pare layout.](image)

### 4.4 Bicycle safety effects of land use

Cycling is a healthy, low price travel option that is accessible to almost everyone. Cycling is also one of the most energy-efficient types of transportation. Cycling, while non-polluting requires no external power source, and makes use of land efficiently, it efficiently moves humans from one area to another without negative environmental influences. Based on the land use, the bicycle lane pass through residential area, commercial and service area. Road functions are collectors and local, the typical lane of the roads is 2 lanes 2 ways Undivided. Roads that are designed to have bicycle lanes and their characteristics are shown in table 7.

| No | Road Section            | Road Function | Typical Lane | Lane Width (m) | bicycle routes Type |
|----|-------------------------|---------------|--------------|-----------------|--------------------|
| 1  | Jl. Dr. Soetomo         | Collector     | 2/2 UD       | 7               | Bike lane          |
| 2  | Jl. Wahidin Sudiro Husodo | Collector   | 2/2 UD       | 7               | Bike lane          |
| 3  | Jl. Jend. Sudirman 1    | Collector     | 2/2 UD       | 7               | Bike path          |
| 4  | Jl. Jend. Sudirman 2    | Collector     | 2/2 UD       | 7               | Bike path          |
| 5  | Jl. Jend. Sudirman 3    | Collector     | 2/2 UD       | 7               | Bike path          |
| 6  | Jl. Pahlawan Kusuma Bangsa | Collector   | 2/2 UD       | 7               | Bike path          |
| 7  | Jl. Letjen Sutoyo       | Collector     | 2/2 UD       | 7               | Bike lane          |
| 8  | Jl. Brawijaya Pare 1    | Local         | 2/2 UD       | 6               | Bike route         |
| 9  | Jl. Brawijaya Pare 2    | Local         | 2/2 UD       | 6               | Bike route         |
| 10 | Jl. Yos Sudarso         | Local         | 2/2 UD       | 6               | Bike route         |
| 11 | Jl. A Yani Timur        | Local         | 2/2 UD       | 6               | Bike route         |
| 12 | Jl. WR Supratman        | Local         | 2/1 UD       | 6               | Bike route         |
| 13 | Jl. Mastrip             | Local         | 2/2 UD       | 7               | Bike route         |
Locating bike lanes in or around settlements and public areas. In addition, mixed land use can be a major zoning strategy to improve bicycle safety. The bike paths had been determined to have lower concentrations of BC and NO₂ than bike lanes in each adjusted and unadjusted model. Cyclists can minimize their exposure to traffic-related air pollution (TRAP) for the duration of their shuttle by way of the use of bike paths preferentially over bike lanes regardless of the potential for improvement of traffic along these routes. Based on these study outcomes and the connection to the safety of bicycle users, planners have to encourage the improvement of bike pathways instead of bike lanes whenever feasible and must design bike pathways with vegetation between the cyclists and another vehicle [6].

In accordance with UN Environment’s Global Report on walking and cycling, switching from a motorized vehicle to a bicycle saves 150 grams of CO₂ per kilometer. Each 7 km by cycle will save gas emissions of 1 kilogram of CO₂ as compared to the same distance covered by motorized vehicles.

4.5 Bicycle safety effects of road performance

Road performance is a measure that describes specific conditions that occur on a road. The performance of road sections can be defined, the extent to which the road is capable of carrying out its function [7]. According to Indonesian road manual capacity [8], used as a parameter to calculate road performance is the degree of saturation for intersections, while for roads it can be calculated based on the scope of the Volume per Capacity (V/C) ratio, speed, and density of the road sections studied.

| No. | Road Section                  | V/C before the Bicycle Path | V/C after the Bicycle Path | Value | Level of Service (LOS) |
|-----|-------------------------------|-----------------------------|---------------------------|-------|------------------------|
| 1   | Jl. Dr. Soetomo               | 0.45                        | 0.43                      | 3.00  | C                      |
| 2   | Jl. Wahidin Sudiro Husodo     | 0.38                        | 0.35                      | 2.96  | C                      |
| 3   | Jl. Jend. Sudirman 1          | 0.62                        | 0.61                      | 2.96  | C                      |
| 4   | Jl. Jend. Sudirman 2          | 0.61                        | 0.59                      | 2.99  | C                      |
| 5   | Jl. Jend. Sudirman 3          | 0.63                        | 0.61                      | 3.08  | C                      |
| 6   | Jl. Pahlawan Kusuma Bangsa    | 0.60                        | 0.57                      | 3.05  | C                      |
| 7   | Jl. Letjen Sutoyo             | 0.41                        | 0.39                      | 2.94  | C                      |
| 8   | Jl. Brawijaya Pare 1          | 0.29                        | 0.29                      | 2.64  | C                      |
| 9   | Jl. Brawijaya Pare 2          | 0.23                        | 0.23                      | 2.64  | C                      |
| 10  | Jl. Yos Sudarso               | 0.26                        | 0.26                      | 2.87  | C                      |
| 11  | Jl. A Yani Timur              | 0.22                        | 0.22                      | 2.55  | B                      |
| 12  | Jl. WR Supratman              | 0.29                        | 0.29                      | 2.05  | B                      |
| 13  | Jl. Mastrip                   | 0.22                        | 0.22                      | 2.43  | B                      |

After the implementation of bicycle lanes with several types, the volume of the roads is reduced because bicycle users have their own lanes. With the bicycle lane, it can reduce the V/C ratio of several roads depending on the type of bike path. As shown in table 8, after the bicycle lane there is a reduction in the V/C ratio, which indicates that road performance is increasing.

5. Conclusion

Based on the land use, the bicycle lane pass through residential area, commercial and service area. Road functions are collectors and local, the typical lane of the roads is 2 lanes 2 ways Undivided. The bicycle routes were categorized into three types: Bike Path, bike lane, and bike route. The bicycle route selection indicator with the safety level is assessed from the speed of the vehicle on the route. In this indicator, the higher the traffic speed on the road traversed by the bicycle route, the higher the fatality that threatens bicycle mode users on the route. Then selected roads that have traffic speeds that are not too high.
The results of the analysis, based on Origin and Destination bicycle user movement, there are three alternative routes that will serve as a typical bicycle route in the Pare CBD. For increasing the safety of bicycle users, it's should provide several facilities to support typical bicycle lanes such as markers, traffic signs, and bicycle parking which must be prepared and equipped to support typical bicycle lane planning facilities in the Pare CBD. After the implementation of bicycle lanes with several types, the volume of the roads is reduced because bicycle users have their own lanes. With the bicycle lane, it can reduce the V/C ratio of several roads depending on the type of bike path, which indicates that road performance is increasing.

The LOS assessment of cycling is according to a large amount of empirical research on the views and reactions of cyclists to a particular road environment. By designing safer bicycle routes, it could encourage an increase in bicycle users in the Pare CBD and could reduce local air pollution caused by motorized vehicles. The reduced volume of motorized vehicles could improve air quality in the environment, for this the role of local government is very important so that people prefer to use bicycles for daily activities.

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