BESt: Journal of Built Environment Studies
P-ISSN: 2746-9077 E-ISSN: 2746-9069
Journal Home Page: journal.ugm.ac.id/v3/BEST
DOI: 10.22146/best.v4i1.6887

INVESTIGATING THE PROSPECT OF AUTONOMOUS TRAM (AT) TRANSIT CONSIDERING DAILY MOBILITY PATTERNS AND EXISTING BUS SERVICES COVERAGE IN SURAKARTA

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ABSTRACT

The development of equitable and environmentally friendly public transit services is a pre-requisite if Indonesian cities were to attain sustainability objectives. Recent advances in transportation technology have introduced Autonomous Tram (AT) as an environmentally conscious option. This article investigates the prospect of implementing AT system using Surakarta as a case study. In doing so, we qualitative observe daily mobile patterns obtained through a primary survey and by considering existing Batik Solo Trans (BST) bus routes. Results indicate locations of road corridors most prominently used, overlapped with the existing bus services, indicating the geographic prospects of where to locate the AT system. The results of this study are expected to be a reference in AT research as a potential for sustainable public transportation services in Indonesia, especially in Surakarta City on corridors that have high mobility.

ARTICLE INFO

Received 6 February 2023
Accepted 5 May 2023
Available online 31 May 2023

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Keywords:
Autonomous Tram, Corridor, Surakarta City, Public Transportation, Mobility Patterns

1. Introduction

The dynamic provision of public space remains elusive in Indonesian cities. One contributing factor is the rapid growth of private vehicle and continued reliance on cars and two-wheelers, forcing competition for valuable urban space. Indeed, in recent years, sales of private vehicles have grown rapidly, as in Jakarta, where there has been an increase of around 10% per year. This increase in private vehicles raises several problems, namely vehicle congestion and environmental degradation (severe air pollution). Besides being caused by an excessive increase in the number of private vehicles, traffic congestion is also characterized by inadequate public transportation with less than optimal distribution between modes (Leung, 2016).

Apart from Jakarta, Surakarta City has also experienced an increase in private vehicles with a percentage of private vehicle ownership per household above 80% (BPS Surakarta, 2018), it is estimated that the number of private vehicles in Surakarta City will continue to increase. The increasing use of private vehicles is directly proportional to the population growth of Surakarta City. The city of Surakarta, which covers 44.04 km^2 (BPS Kota Surakarta, 2020), is the most desirable city to live in. The population reached 575,230 people in 2019 (BPS Kota Surakarta, 2020) (Table 2). The City of Surakarta has experienced an increase in population due to the establishment of the City of Surakarta as the National Activity Center (PKN) area and the problem of using public transportation that is less than optimal.

Table 1. Population Growth of Surakarta City in 2017-2021

2017	2018	2019	2020	2021
562.801	569.711	575.230	578.350	578.906

Source: Profile of Population Development in Surakarta City 2017-2020

One solution to reduce the use of private vehicles is to optimize the use of public transportation. Indonesia has considered the use of environmentally friendly transportation, especially urban public transport in order to reduce the impact of pollution and reduce the level of severe congestion in cities in Indonesia and the city of Surakarta is a good pilot ground in planning the use of environmentally friendly public transport because it has the same background as cities in other countries that is regarding population growth.

In addition, tourism in Surakarta which continues to grow allows tourists to use public transportation in Surakarta (Purnomoasri & Arbianto, 2020). The Batik Solo Trans (BST) Bus was introduced to the people of Surakarta on 1 September 2010 (Nugraha, 2015) as a solution to transportation problems in Surakarta. However, public interest in BST buses is still fluctuating. In 2017 in March-April, May-June and August-September 2017, BST bus passengers decreased (Astuti et al, 2021).

Considering the aforesaid phenomenon and the extent of existing studies on this topic, we propose the following research questions, What is the pattern of daily urban mobility in Surakarta? To what extent is the reach of public transportation services in facilitating daily urban mobility in Surakarta? in seeing the potential for environmentally friendly transportation routes in the form of the Autonomous Tram (AT).

1.1 Advances in Transportation Technologies

Advances in transportation technologies have enabled the development of a more environmentally friendly transportation option. Such advancement has been adopted in public transportation, one of which is the Autonomous-Rail Rapid Transit service system (ART) or known as Autonomous Tram (AT). This form of transportation mode promises advancements from previous and existing forms of public transportation. Table 1 shows the advantages of Autonomous Rail Rapid Transit (ART) or Autonomous Trams (AT) compared to public transportation services such as Bus Rapid Transit (BRT) and Light Rapid Transit (LRT) in terms of speed and passenger capacity. Autonomous Trams can accommodate more passengers than BRT, then in terms of the quality of the technological vehicles it is comparable to LRT, in addition to that the potential areas for development can be outside of LRT, in terms of ticket costs comparable to BRT, the travel time required is also comparable to BRT. So that in public transportation, this Autonomous Tram has advantages like LRT in terms of passenger capacity, speed and potential for development areas but is as affordable as BRT in terms of ticket costs and travel time.

Table 2. Comparing BRT, LRT and ART on Trackless Trams

Characteristic	BRT	LRT	ART OR TT
Speed and capacity	√	√√	√√
Ride quality	X	√√	√√
Land developers potential	X	√√	√√
Cost	√	X	√
Disruption in construction	√	X	√√
Implementation time	√	X	√
OVERALL	√	√√	√√√

Source: Newman (2018)

1.2 Indonesia's Public Transportation Landscape in the Advent of AT

The application of AT holds promises for Indonesian cities, considering multiple factors. Firstly, there have been government-led initiatives to look into the rail as possible alternative. For example, as shown in a 2021 study on Yogyakarta by the Center for Transportation and Logistics, Universitas Gadjah Mada. Secondly, Indonesia's public transportation landscape is largely characterized by its lagging development.

The need for mass public transportation has intensified in recent decades. This relates to efforts to create green transportation in order to reduce vehicle pollution due to the widespread use of private vehicles (Gusnita, 2010). From BPS data (2020), the number of bus vehicles in Central Java in 2018 was 32 thousand. The number growth per year from 2015 to 2019 was 4.22%. In the case of Indonesia, private vehicles are increasingly dominating. This can be seen from data on private vehicle ownership, such as motorbikes and cars, which BPS (2020) in 2019 reached 87.08%.

The presence of private vehicles discourages people from using *Batik Solo Trans* (BST) Bus and other public transportation. In addition, the inflexible time when using public transportation is also the reason why BST buses are not in demand (Sujatmiko et al., 2013).

Indeed, looking into the case of Surakarta, there has been a decline in the urban public transportation fleet of buses and taxis from 2015 to 2019, while *angkot* (these transportations are like smaller vans and mini buses that go on set routes on smaller and quieter roads. They seat 9-12 people depending on the type) have a stable number of fleets from 2016 to 2019 (Table 3). Research by Sujatmiko et al. (2013) in Astuti et al (2021) shows that the existence of private vehicles makes people not interested in using BST Bus (*Batik Solo Trans* Bus is a Bus Rapid Transit-based transportation service) and other public transportation. In addition, limited service coverage and inflexible time when using public transportation are also reasons why BST buses are not in demand. BRT needs to be properly integrated with existing forms of informal and non-motorized mobility (Mobereola, 2009; Salazar Ferro et al., 2013; Venter et al., 2018 in Erick Guerra (2020)). New transit investment has the potential to cause a decrease in the number of transit passengers and a less sustainable transport system overall if *angkot* passengers switch to private modes such as cars and motorbikes as opposed to walking, cycling or other forms of transport.

Secondly, at present, the level of affordability of transit points is not evenly distributed, and the majority are still concentrated in the West and East areas in Surakarta City. In addition, the existing functions of train stations and bus terminals in Surakarta are currently not optimally used as transit points for intra-city transportation services.

Table 3. Development of Public Transportation in Surakarta City

No	Transportation Public Mode	2015	2016	2017	2018	2019
1	Taxi	828	772	790	681	654
2	*Angkot*	380	247	247	247	247
3	Bus	159	119	114	61	61
	Total	**1367**	**1138**	**1151**	**989**	**962**

Source**:** Profile of Population Development in Surakarta City (2020)

According to a survey conducted by Erick Guerra (2020) regarding "Bus rapid transit in Surakarta, Indonesia: Lessons from a low ridership system" Although *angkot*s continue to work with and alongside the BST, there is a threat that some operators may go out of business, as commonly occurs after the introduction of new and publicly subsidized services (Gomez-Ibanez and Meyer, 1993, chap. 2; Meyer and GomezIbanez, 1991 in Erick Guerra 2020) from a survey of *angkot* passengers, less than a third of respondents indicated that the next best choice after using *angkot* was to use other modes of transportation (Table 4). Most stated that they would use private vehicles, while only 32 respondents (3.6% of the total) stated that the next best option was BST. These twenty-two respondents were among the 219 passengers

interviewed on *angkot* lines 01a and 08. These are the lines that overlap the most with the existing BST lines. Even on this trail, only 10% of riders surveyed listed BST as the primary alternative. Buses are the second most popular alternative after motorbikes. Half of the respondents reported that their next best travel option was to use a motorcycle, with another 3.8% listing a private car or motorcycle taxi. Twelve percent of respondents put walking as the next best alternative, with another 4% indicating *becak* (Table 4).

Table 4. Summary of Next Best Alternative Modes Reported by *Angkot* Passengers

Mode	User	Percentage	Mode	User	Percentage
Transit	267	30.40%	Batik Solo Trans Bus (BST)	32	3.60%
			Bus	235	26.80%
Private vehicle	469	53.40%	Motorcycle	436	49.70%
			Ojek	18	2.10%
			Car	15	1.70%
Non-motorized	142	16.20%	Walk	107	12.20%
			Becak	35	4.00%
Total	**878**	**100%**	**Total**	**878**	**100%**

Source: Erick Guerra (2019)

The urgency of the need for the main urban public transportation in the form of an autonomous tram in Surakarta will be able to complement and be integrated with urban public transportation services that are already running, namely BST and other public transportation, so that they can reach areas that are currently not yet reached by public transportation services. Thus, it is hoped that residents will begin to be interested in using public transportation because the accessibility in daily movements (proximity to the starting and ending points of the movement) is getting better.

2. Literature Review

In investigating the prospect of implementing autonomous tram (AT), we look into two broad literatures: Transportation planning modelling methods and the built environment and transit interaction. The method of transportation planning is seen based on the literature on trip generation and trip attractiveness, so that later in order to map daily mobility patterns based on this theory. In order to see the built environment and transit interactions taken from the corridor literature as a consideration in implementing AT and its relationship with the Transit Hub.

2.1 Corridor

Road corridors are urban spaces that are recognized as one of the identities in an area, because for road users, road corridors are part of an urban element that is very visible and easy to recognize. The character and visual quality of an area is related to the form or implementation of its spatial path. The appearance quality of an area is manifested by how good the quality of the elements is so that they can form the visual character of the area. "The Concise Townscape" (Cullen (1961) in Hertanto 2017).

In addition, a corridor is a road or path that is formed by a series of buildings, vegetation or guardrails and connects two areas or regions or places (Zahnd, 1999 in Aulia 2020). In another sense, a corridor is an area of open space that connects one area to another where there are boundaries on the sides of the passageway (Krier, 1979 in Aulia 2020).

2.2 Transit Hub (Intermodal Connectivity)

Transit allows riders from certain modes of transportation to move and ride the same or different modes to reach their desired destination. This integration of transportation at various nodes along with various other developments, is called Multimodal Transit Hub (Chhipa, 2018).

In Together North Jersey (TNJ) Guidebook for Transit Hub Planning, a Transit Hub is an area around a transit station—bus, train, LRT or ferry—that has diverse land uses, has a variety of activities, and is connected to fully integrated multimodal transportation with the station. The Transit Hub is a place that is walkable, has an active and vibrant atmosphere, and is culturally interesting, with lively and active public spaces and a variety of amenities. There are many (and often interrelated) benefits to be derived from a successfully planned and implemented transit hub. Even though it is built in a transportation and mobility service area, transit hubs generate benefits that extend to all aspects of life, are enjoyed by all members of society and are sustainable in the long term.

2.3 Trip Generation and Trip Attraction

2.3.1 Trip Generation

A large number of trips or movements or traffic flow events generated by a zone (area) per unit of time can be interpreted as trip generation, according to Miro (2005). There are two important elements that make up the occurrence of trip generation, namely activity or trip production and trip attraction. Travel events that are generated from residential zones/areas are called trip production, while trip attraction is generated from the destination zone that the trip wants.

Trip generation can be calculated using the classic trip generation model, which is a model that predicts the number of trips produced by each zone/region based on the socio economic status of the traveller. Trip generation of a person or group of people divided into two types, namely trips originating from home (home-based) and trips not originating from home (non-home-based). Then the overall trip generation events can be classified as follows.

A. Based on the Purpose of the Trip

There are five categories of travel destinations in home-based travel process, namely:

i. Travel to work.
ii. Travel to educational facilities.
iii. Travel to a social place.
iv. Travel to recreation/tourism areas.
v. Travel to the shopping area (traditional market or modern market).

Movement or travel for work and education (school/campus). This movement is the main movement of the five movements because two of these movements must be done by everyone every day, while the others are only

optional trips and are not done every day.

B. Based on the Travel Time

This movement is distinguished at busy times and not busy times. Travel during busy times (peak hours) is generally dominated by travel activities for work and travel for education and the person's movement time is very dependent on when the person travels.

C. By Type of Person Traveling

The travel behavior of a person/individual is influenced by socioeconomic factors which include the amount of income, the number of motor vehicle owners, the size and structure of the household.

2.3.2 Trip Attraction

Trip Attraction is the number of trip movements that occur towards a certain location per unit time. Trip attraction is a modelling step that estimates the number of moves attracted to a land use or zone. The traffic pull depends on two aspects of land use, namely the type and amount of activity/intensity on the land use.

This trip attraction relates to determining the total number of trips generated by an area. Trip generation is divided into two parts, namely trip attraction and trip production. Production is a trip that ends at home on a trip that originates from home (home-base-trip) or ends at the place of origin (origin) on a trip that does not originate from home (non-home-base-trip).

The factors that influence the movement of a trip (trip) are a function of the three major factors, namely:

a) Patterns of land use and development in the study area.
b) Socio-economic characteristics and activities of the population traveling from the region.
c) The nature, reach and capability of the transportation system in the region/region, because trip generation is a vital part of the transportation planning process.

3. Research Method

In this study, the method used was to identify the physical conditions at the location by means of field observations to determine the condition of the settings in the corridor (vehicle lane distribution and road width), giving questionnaires to respondents. Then process the data obtained and analyze it based on related theories. Then summarize the results of the analysis and find the conclusions of the research.

This research is focused on things that can be used to see the potential of the Autonomous Tram (AT) public transportation service line in Surakarta City as the main public transportation in Surakarta City. This research aspect was generated based on the Daily Mobility Pattern taken from a total of 33 respondents who met the requirements. The criteria or requirements of respondents that can be used as data are those that clearly describe the path they take in their daily mobility from their place of domicile to their destination. After the questionnaire was distributed through several social media, only 33 respondents filled out the questionnaire and only 29 respondents filled out the questionnaire correctly according to the instructions and could be used as research data. In addition to the questionnaire data, it is necessary to look at the affordability of the Trans Solo Batik Bus (BST) seen from the route map and BST Bus routes. So that it can be known which routes have routes that are frequently passed and more than one route, this analysis will later become the basis for seeing the density or tendency of the roads that are traversed in the Surakarta City corridor so that this potential can be seen for the development of AT transportation facilities. Data collection and existing theoretical studies are adjusted to the observed aspects, so that they are in line with the research objectives.

In the observation method using questionnaire data, there are still deficiencies from the lack of respondents, so it is hoped that in future research that has the same concern, it can be observed further with even more respondents so that it is stronger in taking samples and can be added with other data that supports research this is next.

4. Results and Discussions

4.1 Daily Urban Mobility Patterns in Surakarta City

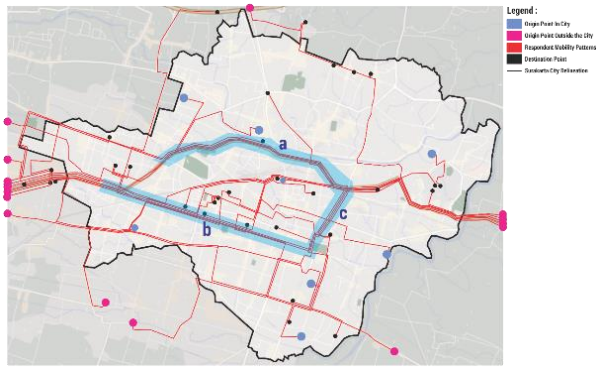

Figure 1. Daily Mobility Patterns
Source: Author's Questionnaire Data

Efforts to look at the potential of routes and transit hubs in the development of the AT service system in Surakarta City first to see how the propensity of mobility patterns in urban areas, after that, look at the current distribution of the main public transportation, namely Bus Batik Solo Trans (BST) and then look at the transit hub points and their connectivity with areas outside Surakarta City. Afterwards, you can find out the potential for TO services in Surakarta City. In terms of the daily mobility patterns of residents taken from the questionnaire data, it can be seen that in the daily mobility patterns of 29 respondents, the pink dot is the starting point of the daily movement of residents who carry out activities in Surakarta City but are domiciled outside Surakarta City and the blue dot is the starting point of the daily movement residents who live and carry out activities in the city of Surakarta, then the black dot is the end point of their daily movements. From the data analysis, it is found that in the daily mobility pattern of Surakarta City, there are 70% live outside Surakarta City but have activities in Surakarta City and 30% live in Surakarta City. The majority of trip generation is based on the purpose of the trip travel to work and travel to educational facilities.

From the mapping it can be identified that they tend to pass Slamet Riyadi Street (b), Ahmad Yani Street (a) and

Jend. Urip Sumoharjo Street (c) because the majority of the end points of their daily movements are in that area (Figure 1). Residents who use public transportation from the questionnaire data do not exist. Of the 29 respondents all use private vehicles in their daily mobility.

From the results of the questionnaire, it appears that there is a tendency for the intensity of daily mobility in Surakarta City to be high at several street points and a tendency to use private vehicles for activities. It can be seen from the daily mobility patterns above that connectivity is low from one place to another. People tend to pass through roads that are not all covered by public transportation services.

4.2 Stretch of Public Transportation Service in Daily Urban Mobility of Surakarta City

From the data obtained, the BST Bus data shows specifically and clearly the paths traversed by the main public transportation compared to other public transportation, so that the BST Bus route data becomes a reference in the analysis of the affordability of using public transportation in the City of Surakarta. The schematic of this BST Bus line (Figure 2) shows that the mobility of BST Bus movement tends to pass through the main roads, namely: (a) Adi Sucipto Street; (b) Slamet Riyadi Street; (c) Jend. Urip Sumoharjo Street; (d) Raya Ngawi – Solo Street; (e) to the Palur Terminal stop point, then make a loop. The blue zone corridor is a corridor with more than 1 BST bus route that passes through the road.

Regarding transportation services, Surakarta City has four train stations, namely Solo Balapan Station, Solojebres Station, Solo Kota Station, and Purwosari Station which are used as transit points. Train stations in Surakarta City currently only serve regional (inter-city) trips and have not all of them become transit points for urban (in-town) transportation. In addition, the city of Surakarta also has 1 type A bus station, namely the Tirtonadi Bus Station and BRT public transportation services, namely the Batik Solo Trans (BST) Bus, but their use is also not optimal because the majority of residents still prefer private vehicles compared to public transportation for daily mobility.

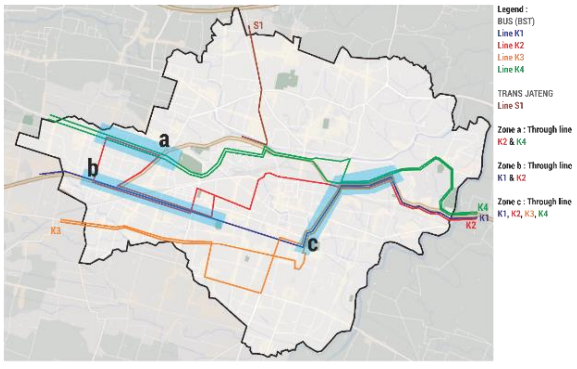

Figure 2. Map of the Trans Solo Batik Bus Route (BST) & Central Java Trans
Source: Ministry of Transportation of the Republic of Indonesia

There are transit hub points around Surakarta City so that from 4 stations and the Tirtonadi Bus Terminal in Surakarta City they can be connected to areas around Surakarta City so that people who have domiciles outside Surakarta City can facilitate their daily mobility aiming for Surakarta City. After that, it is necessary to have medium-mode facilities within Surakarta City that connect places that have attraction or nodes within Surakarta City, so that the autonomous tram service can be one of these modes of choice.

4.3 Corridor Potential and Hub Transit Points as AT Service Development

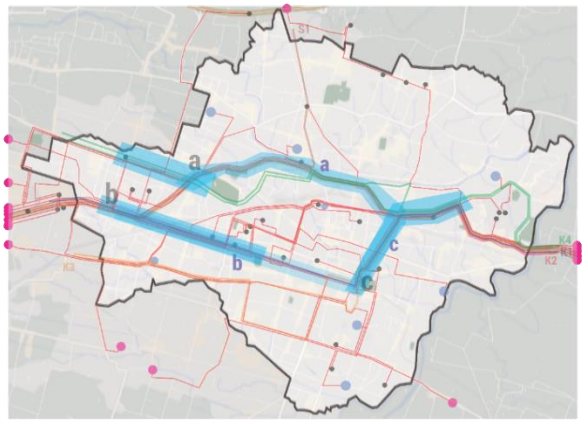

Figure 3. Propensity of Daily Mobility Lines and BST Bus Lines
Source: Author Mapping

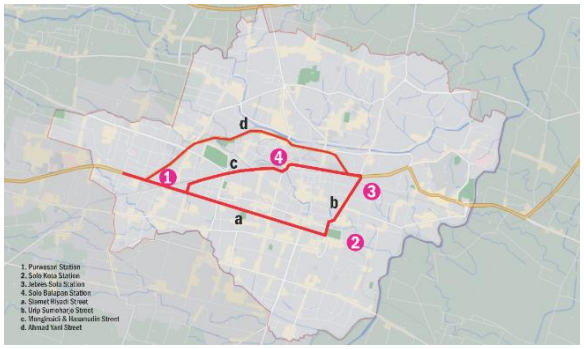

Figure 4. Object of Research
Source: Author Analysis

In determining the scope of the research area, mapping of daily mobility patterns (obtained from the results of surveys of respondents of mobility actors) and public transportation service routes were carried out. The mapping of daily mobility patterns is a component in determining the unit of observation intended for the potential coverage of AT services that can be developed, while the mapping of public transportation service routes is carried out to find out how far the current coverage of public transportation services is. From these two data we will get areas that have the potential to be developed into AT service lines. After the map of daily mobility patterns and BST bus lines is overlaid, it can be seen that the blue zone corridor is the corridor that the majority of the people of Surakarta City pass as the path used in their activities to the destination, so the selected object area is the corridor that has the highest tendency to be passed by road users in their activities, namely Corridor Slamet Riyadi Street, Urip Sumoharjo Street, Monginsidi Street, Hasanudin Street and Ahmad Yani Street (Figure 3 & 4).

This corridor is the route most used by the people of Surakarta City, and most of BST rotations pass through that road, besides that most urban activities are concentrated in

that area. The majority of the area's functions are commercial and trade.

4.4 The Prospect of the Autonomous Tram (AT) Public Transportation is Compared to the Existing Public Transportation in Surakarta City

Table 5. Advantage of AT Over BST Bus

	BST Bus	AT	Advantage of AT Over BST Bus
Operating Average Speed	20-40	20-40	AT has the same operating speed and turning radius as the BST Bus
Turning Radius	15m	15m	
Capacity	30-50	100	AT has more capacity than the BST Bus
Units per Carriage	1	1-5 (max)	AT can be arranged up to 5 carriages if the user increases
Control	Manual	Automatic	AT has an automatic system for moving it so it is more efficient than the BST Bus
Fuel	Gasoline	Battery	AT is more environmentally friendly than the BST Bus
Track	Side by side with other vehicle users	Side by side with other vehicle users	The AT and BST Bus tracks can coexist with other vehicles

Source: Kajian Regulasi Penyelenggaraan Autonomous-Rail Rapid Transit/Art di Indonesia

Previously, in the introduction section, the advantages of AT have been explained over several types of public transportation. In this sub-chapter, the prospects for AT public transportation when implemented in Surakarta City will be presented. Previously, Table 5 shows the advantages of AT over BST Bus, because BST Bus is the main public transportation in Surakarta City, so it needs to be compared in order to see AT prospects from the characteristics of the vehicle. And also prospects as a means of public transportation which can later become an alternative as the main public transportation to replace BST Buses on several corridor lines that have the potential to become AT routes.

The long-term prospects for AT public transportation if it becomes the main means of public transportation for the City of Surakarta:

1. It will bring smart city sensors into transit systems in a way that will need to be applied to all aspects of transport into the future.
2. Cities around Surakarta City will be coming to view the new system and professional jobs in the area will be created to service other cities.
3. Climate change emissions reductions.
4. Can optimize the use of intermodal public transportation because some people who are active on the AT potential route live outside the City of Surakarta because AT connects four stations so that the use of intermodal transportation is more optimal. The density targets within the central subregion cannot be realized without significant changes in urban mobility. A mode shift to a mid-tier transit system is considered imperative to enable urban regeneration where it is most needed within the inner ring of Surakarta.

5. Conclusion

There needs to be main public transportation that is able to accommodate the mobility of the population of Surakarta City efficiently and effectively. One of the potentials that can accommodate this is the Autonomous Tram public transportation. The results of the study show that the road corridors of Surakarta City can become the Autonomous Tram (AT) public transport route.

The results of the questionnaire on daily mobility patterns in Surakarta City, which have been explained previously, it can be concluded that there are road corridors that tend to be passed by more people who are active in the area because the majority of the end points of their daily movements are in that area. After the map of the daily and existing mobility patterns of the BST Bus lines is overlaid, it can be seen that corridors have the potential to become AT lanes in terms of the trend of using the corridors in daily mobility and the point of the public transportation route, namely Slamet Riyadi Street, Urip Sumoharjo Street, Monginsidi Street, Hasanudin Street and Ahmad Yani Street**.** Monginsidi and Hasanudin Streets are included as road corridors that have the potential to become AT routes because there is a transit hub point, namely Solo Balapan Station, so AT can be the main public transportation for activities in the city area which replaces BST Buses on that route.

What this research wants to show is the trend of how people's mobility in their activities is shown by looking at the tendency of the roads that are traversed and the range of existing bus services indicating the extent to which public transportation can accommodate the mobility of its people. Certain roads due to one of them being the uneven coverage of public transport and the not yet optimal use of between modes, from here what we want to achieve is knowing this so that the corridors of roads that tend to be traversed will become potential lanes of AT public transport and other public transport routes can be expanded so that people can switch from private transportation to public transportation, and people feel comfortable and happy using public transportation.

Of course, there are several things other than data or variables "daily mobility patterns" and "existing bus service coverage" that become mobility variables in a city that occur. Therefore, it is hoped that in the future other studies that have the same concern for the development of AT, especially in the city of Surakarta, can strengthen the community's tendency towards urban mobilization which can later support the development of AT public transportation.

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