International Journal of Sustainable Transportation Technology
Vol. 4, No. 1, April 2021, 9-21

Study of Public Transport Development in South Bali Districts: Potential Public Transport Mode

Adni Bidari Putri[1*], Muhammad Farda[1], Sigit Puji Santosa[1,2], Puspita Dirgahayani[1,3], Putu Alit Suthanaya[4], I Gusti Ayu Andani[3], Hansen Sutanto[3], Laily Rochmatul Charky[3,5], Nunuj Nurjanah[5]
[1]National Center for Sustainable Transportation Technology, Bandung, Indonesia
[2]Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Bandung, Indonesia
[3]School of Architecture, Planning, and Policy Development, Institut Teknologi Bandung, Bandung, Indonesia
[4]Faculty of Engineering, Universitas Udayana, Denpasar, Indonesia
[5]Research and Development Agency, Indonesian Ministry of Transportation, Jakarta, Indonesia
**Email:* adni.bp@itb.ac.id / adnibp@gmail.com

Abstract

Bali Province in Indonesia is one of the most attractive tourist destinations in the world. The number of tourists visiting this province keeps increasing year by year parallel with the increase of the population of local citizens. Such a phenomenon will certainly increase travel demand and put pressure on the current transport infrastructure. Hence, transport infrastructure development is essential to support the travel demand. This study explores the possibility of implementing a new public transport system in the South Bali District, a district with numerous tourist attractions and activity centres. Data collection on the current transport system and land use in the district were carried out to understand potential corridors for public transport. A stated preference survey was also conducted to discover the public transport mode preferred by the respondents, encompassing tourists and local citizens. This study then recommends the type of public transport mode to be implemented in the district based on i) space availability, ii) respondent preference, and iii) ability to accommodate demand based on calculation. The study concludes that Automated Rapid Transit (ART) is a mode that has the highest potential to be implemented in South Bali Districts.

Keywords

Mass rapid transit; Public transport; South Bali; Travel behavior

1 Introduction

Bali is one of 32 provinces in Indonesia as well as an island that is well known for its tourism sector. From time to time, people from around the world visit Bali to enjoy its attractive locations and culture. Due to its potential, approximately 80% of Bali's economy relies on the tourism business. Table 1 shows the number of tourists, both domestic and international [1, 2].

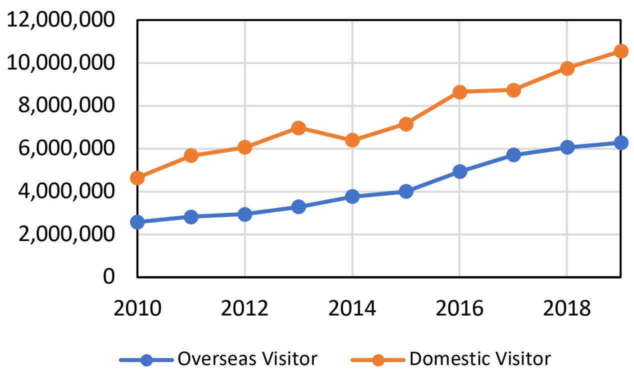


Figure 1 Number of tourists based on airport and port data.

The increasing number of tourists indicates that there is a need for transport policies to support tourist destinations within Bali Island. Moreover, it is not the tourists in Bali only whose movement need to be accommodated. According to the Bali Central Bureau of Statistic [3], the population of Bali Province has been increasing as shown in Figure 2. The population certainly needs to move from one place to another, e.g., to school, offices, shopping centers, etc. to fulfil their needs. In other words, the demand for transport or movement will increase in line with the population increase. Therefore, transport policies are needed to accommodate people's movement, not only in short term but also in the long term.

Looking at the current situation, traffic congestion has been occurring frequently in big cities in Bali Province such as Denpasar [4, 5]. Given the trend in tourist visits as well as population increase, the traffic congestion in Bali is expected to get worse unless the right measures are taken.

Received January 28, 2021, Revised February 11, 2021, Accepted for publication February 17, 2021

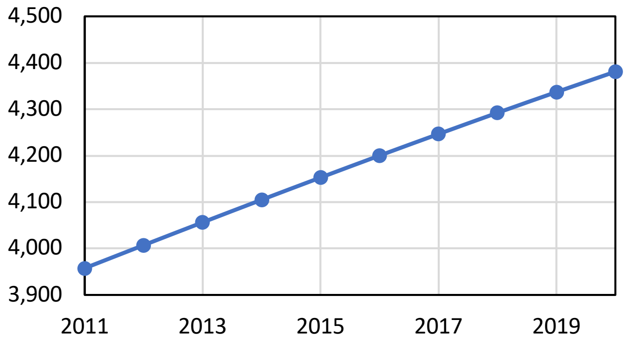


Figure 2 Population in Bali from 2011 to 2020 (in thousands) [3].

The operation of public transport is one of the measures to reduce traffic congestion as it focuses on moving people, rather than moving vehicles and encourages more efficient use of road spaces. Hence, the operation of public transport is one policy option that can be taken to address the transport challenges in Bali.

As there are many types of public transport modes, a question was arisen on what type of transport mode suits the Bali context. Therefore, this study attempts to answer this question by considering several aspects such as demand, existing road topology, local culture, etc. The result of this study is expected to be a valuable input for policymakers to choose the types of transport mode to be operated in Bali. The study focuses on the need for public transport in South Bali Area.

This article is organized as follows. Section I explains the background and motivation for this study while Section II reviews the type of public transport mode and related past studies. Section III then talks about the study area, which is South Bali District while Section IV describes the method used in this study. The analysis is then explained in Section V, while Chapter VI and VII explain the conclusion and recommendation based on this study, respectively.

2 Literature Review

2.1. Public transport definition

Public transport is a transport system that accommodates group travel and can be accessed by the public. A public transport system typically operated based on a schedule, runs in a pre-determined route, and charges an amount fee for each passenger trip. Public transport offers an advantage in which it can carry passengers more efficiently (more passengers with fewer spaces) compared to private vehicles. Such a feature is beneficial for areas with high and growing travel demand but limited spaces to develop more road networks.

2.2. Potential alternatives of public transport mode

Electric bus

Electric bus is one of the alternatives to achieve sustainability since the engines use battery energy hence more environmentally friendly compared to conventional buses or other fossil-fueled transport modes. Some countries already implemented Electric Bus as mass public transport in the city, such as China, Netherland, and UK [6]. The purpose of the use of the electric bus is to reduce carbon emission, hence this can be a greener option for travelers in South Bali, in addition to complementing the existing public transport in South Bali such as Trans Sarbagita Bus and Komotra.

Trolley bus

Trolley bus operates on the road with electric power drawn from two overhead cables with a trolley pole (pantograph). It differs from trams, which runs on rails rather than on tires. The trolley bus has the advantage of being able to operate in a hilly rail, because the electric motor works better than a diesel engine on an incline, does not cause exhaust emissions, and is not as noisy as a diesel engine hence it is a greener transport mode than the fossil-fueled ones.

However, the downside is that the operational routes have been defined, thus it is not as flexible as a bus that can change routes easily. Trolley bus must remain on the pantograph line with the overhead electric cable, which sometimes can disrupt the surrounding infrastructures or buildings and gives vision obstruction.

Light rapid transit

Light Rapid Transit (LRT) is a light train-based mass transport, which operates on a dedicated railway and uses electricity as energy. LRT is usually built to accommodate trips in urban areas, to provide a distinctive transport mode that differs from other modes, creating a more heterogenetic public transport system in the society. The construction of LRT is built in a way that adapts to the geographical condition of the area. LRT infrastructures can be underground, at grade, or elevated to avoid urban traffic. In general, LRT consists of three main systems: rolling stock, infrastructure (track and station), and supply substation.

LRT system has been used in many countries in the world. Currently, the Indonesian Government has established LRT in Palembang, South Sumatera Province and has another one in ongoing construction which connects Jakarta, Bogor, Depok and Bekasi. Bali is one of the provinces in Indonesia that have high economic growth, hence providing mass rapid transport such as LRT in the South Bali district can boost the development in the area and increase social welfare.

Autonomous-rail rapid transit

Autonomous-Rail Rapid Transit is a multi-unit vehicle, two directions, and a low deck. Each of the wheels has its control system, running on a virtual track with a train-like movement. ART consists of several subsystems, such as car body, running system, vehicle control, network control, traction, auxiliary power system (APS), onboard PIS, braking dan power saving system.

2.3. Past studies on public transport planning

Previous studies have carried out research related to public transport planning and analysis. For instance, Ayuningtyas et. al. [7] analyzed the opportunities to improve public transport in Bandung City by developing three main bus terminals. The study result shows that the addition of an intercity bus terminal will spread the load at the current intercity terminal, which will contribute to improving road performance.

A study [8] utilized the stated preference method to estimate the passenger demand of a high-speed railway connecting Jakarta and Surabaya City. The estimate was based on three scenarios, namely pessimist, moderate and optimistic scenario. By estimating the passenger demand in the future, one can also use it to estimate the required public transport fleet.

Interesting to note that Khan et. al. [9] carried out a study on how to increase public transport passengers based on the case in Sweden. By using a comparative analysis of 6 regions in Sweden, the study found that regions with the high passenger increase concentrate the resources in the corridor with the highest demand. The study also stated that the increasing public transport increase should be enabled by governance conditions.

Regarding public transport planning for tourists, research [10] explored the public transport mode choice preference of international tourists in Ghana. The study was conducted by collecting 479 international tourist data in Kotoka International Airport and analyzed the data by using multinomial logistic regression. The results show that factors that influence mode choice are affordability, accessibility, availability, safety, and comfort. A similar study was conducted to understand the influencing factor of public transport planning in car-dependent cities [11]. The study discovered that the important factors are walking distance, number of transfers and family privacy.

3 South Bali's Public Transportation System: Characteristics and Conditions

3.1. The master plan of Bali public transportation

In 2019, the Department of Transportation of Bali designed a Master Plan of Bali Public Transportation. In the document, there are several priorities of infrastructure development in the transport sector (see Figure 3) [12]:

1. Urban rail development to connect Ngurah Rai Airport – KSPN Kuta – Sanur – Nusa Dua – Mengwi Bus Terminal – North Bali Airport.
2. Urban rail development to connect Ngurah Rai Airport – Kerobokan – Mengwi Bus Terminal.
3. The establishment of short cut access between West Bali to South Bali area and North Bali to South Bali area (Singaraja – Mengwi).
4. The construction of Beringkit – Batuan – Purnama access.
5. The development of Nusa Penida Ring Road.
6. The development of Trans Sarbagita public mass transport.
7. The development of the electric vehicle.

The center of trip distribution/attraction (TOD)
Road network
Rail network
Road & rail network
Port network

Figure 3 Integrated master plan of Bali public transport system [12].

According to the master plan, the South Bali transport corridor is crucial as it covers several of the priorities (number 1, number 2, and number 3). This research will address the suitability of transport modes that can facilitate the need of the corridor.

3.2. South Bali districts

The planning of public transportation in South Bali will cover three administrative cities, i.e. Denpasar City, Tabanan Regency, and Badung Regency. As Figure 4 shows that the planned corridors will connect I Gusti Ngurah Rai Airport (DPS) with Mengwi Terminal Bus and Benoa Port through Jineng, Kuta Central Park, and Canggu area. The districts that affected directly by the corridors is illustrated in Table 1.

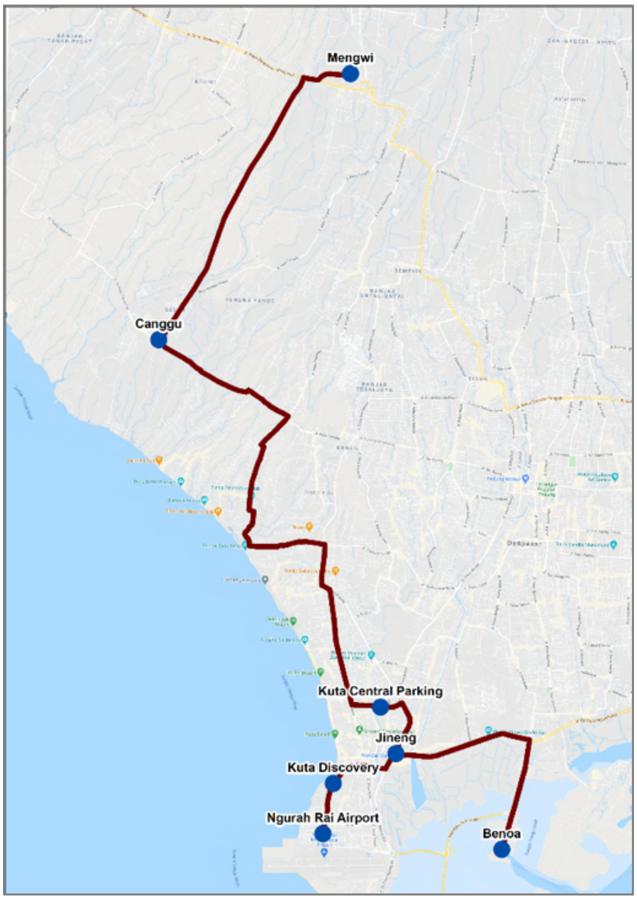


Figure 4 Planned transport corridors.

Table 1 District coverage of South Bali transport corridors.

No	City	Districts
1	Badung Regency	Kuta
2	Badung Regency	North Kuta
3	Denpasar City	West Denpasar
4	Denpasar City	South Denpasar
5	Tabanan Regency	Kediri

The analysis of the public transport plan will refer to the travel demand of affected districts, as well as the physical framework of the route for deciding the most feasible and favorable transport mode.

3.3. Land use and socio-economic condition of South Bali

The type of land use along South Bali transport corridors are dominated by a residential area, in addition to business and tourism destination in the central area, and port and industrial area in the southern (see Figure 5). The corridors are planned to accommodate residents and tourists hence it is important to highlight local attractions vis-à-vis business districts and residential areas. However, the planned route will still need feeders for some tourism destinations in the northern area, especially for Tanah Lot Beach, since the location is far from the main road.

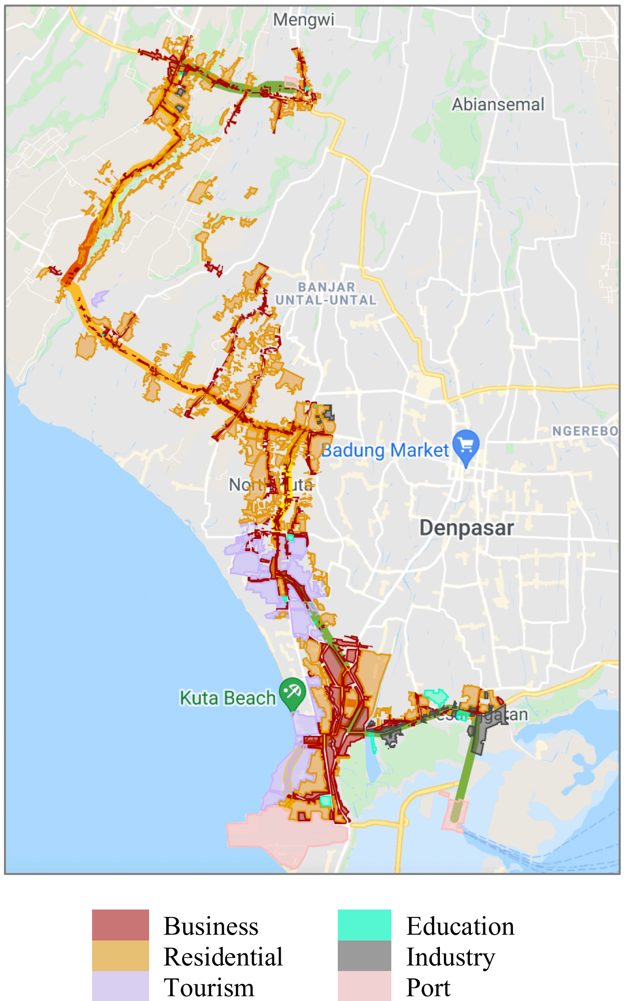


Figure 5 Type of land use on South Bali transport corridors.

3.4. Existing public transport modes

The South Bali District is currently served by two bus systems, namely i) Trans Sarbagita Bus and ii) Trans Metro Dewata Bus. The Trans Sarbagita serves the route from I Gusti Ngurah Rai Airport to three end destinations, namely Nusa Dua, Batubulan and Tabanan.

The other bus system, namely Trans Metro Dewata is an expansion of the Trans Sarbagita. The system serves the agglomeration area which includes Denpasar, Badung, Gianyar, and Tabanan. This system currently serves three routes, namely i) Persiapan Terminal – Kuta Central Park, ii) Ubung Terminal – Monkey Forest Central Park, and iii) Matahari Terbit Beach – Dalung.

4 Methodology

To understand the public transport mode that fits the South Bali District context, several aspects are considered. These aspects include, i) demand for different types of transport modes, ii) spaces on the road to accommodate public transport operation, iii) fleet requirement and maximum capacity. In addition, local culture, which would not allow a transport infrastructure to be built above the worship place, is also considered.

To understand the demand for different types of transport modes, a stated preference survey was conducted. The survey form was spread through an online form and aimed at two types of respondents, namely tourists and local citizens. The survey form itself consists of 6 alternatives, namely i) Light Rapid Transit, ii) Trolley Bus, iii) Automated Rapid Transit, iv) Hybrid Bus, v) Car, vi) Motorcycle. The attributes for the survey are i) travel time, ii) headway, iii) cost and iv) type of track (elevated, at grade, or underground). In addition, the survey form also asked the respondent about their origin and destination, data that will be useful for analysing the fleet requirement and maximum capacity. The attribute and attribute level of the stated preference survey can be seen in Table 2.

Based on the alternative, attribute, and its level in Table 2, the choice sets are then generated by using the fractional factorial design approach. Based on the survey result, the demand for public transport is then generated based on a multinomial logit approach.

The next approach that is used to understand spaces on the road to accommodate public transport operation in South Bali District is by a drone survey as well as secondary data collection from google maps – street view. Based on these data, the road width and number of lanes of roads in the study area are then identified. Such information is used to understand whether the existing road can be used for new public transport operations and determine whether the construction of elevated or underground public transport infrastructure is necessary.

Table 2 Attribute and attribute level of the stated preference survey.

Attribute/Alternative	Level-1	Level-2	Level-3
Travel Time (minutes)			
Light Rapid Transit	20	40	60
Trolley Bus	35	55	110
Automated Rapid Transit	30	45	70
Hybrid Bus	35	55	110
Car	45	55	70
Motorcycle	35	45	55
Headway (minutes)	5	15	30
Cost (in IDR)			
Public Transport	5,000	10,000	15,000
Car	15,000	20,000	25,000
Motorcycle	10,000	12,000	14,000
Type of right-of-way			
Light Rapid Transit	Underground	At-Grade	Elevated
Automated Rapid Transit	At-Grade	Elevated	
Car/Motorcycle	At-Grade		

Finally, to determine the number of fleet requirements and maximum capacity, the number of fleets is determined based on public transport demand as well as public transport mode's carrying capacity. The demand for public transport is then assumed to increase every year at 6% (for 30 years) hence the public transport fleet addition requirement is calculated accordingly. Note that the demand for public transport in this phase is in form of origin-destination (OD) matrices that are derived from the stated preference survey. From such calculation, the study then sees which public transport mode that can accommodate passenger demand increase for 30 years, and which will not be able to accommodate demand increase. This then will become major consideration to choose which transport mode fits with the South Bali District context.

5 Data and Analysis

5.1. Overview of survey respondents

The total number of survey respondents is 1082, with 86% of them is Bali's resident. The proportion of male and female respondents is relatively balanced with 50.16% of males, which is quite representative of the gender proportion of the population in Bali Province [13]. The majority of the age group of the residential respondents is 21-30 years old with 66%, while tourists' sample is more age distributed from 21-50 years old. The domination of young age in the sample delivers positive impacts, as the plan of transport development will be executed in the coming years hence the most people who will be affected is the people in their productive ages in the future. The age distribution and occupation of respondents are presented in Table 3 and Table 4.

Table 3 Sample of respondents.

Age group	Resident		Tourist	
	N	Percentage	N	Percentage
<17	10	1%	0	0%
17-20	102	11%	3	2%
21-30	619	66%	39	27%
31-40	110	12%	44	30%
41-50	42	4%	31	21%
51-60	46	5%	27	19%
>60	8	1%	1	1%
Total	937	100%	145	100%

Table 4 Respondents' occupation

Occupation	Resident		Tourist	
	N	Percentage	N	Percentage
Civil servant	185	20%	88	61%
Teachers & Lecturers	44	5%	7	5%
Private sector staff	438	47%	41	28%
Retired	1	0%	1	1%
Student	217	23%	4	3%
Housewives	7	1%	3	2%
Others	43	5%	1	1%
Total	937	100%	145	100%

5.2. Travel behaviour analysis

OD matrix

The distribution of OD trips per district was generated from the revealed preference (RP) survey. The data was originally for all districts, but for this research, we only analyzed trips from and to the affected districts by South Bali corridors. In addition, the movement was estimated from the trip rate per person for residents only, as tourists' movement was minor compared to local trips [14]. Because the survey represented a portion of the population, the number of trips for the OD matrix was calculated using the approximation method to estimate the trip distribution model that will be used to determine the fleet required for the demand.

Table 5 illustrated the estimated number of trips from the origin (Oi) to the destination (Dj) of each district in year 0 when the survey was taken, with the exception of interzonal trips in West Denpasar district and South Denpasar district since it is irrelevant with the planned corridor. The data shows that the highest number of trips were generated between Denpasar Barat district to other districts especially North Kuta, and its interzonal trips as well. On the other hand, the total number of OD pairs from and to Kediri districts has the least number of trips. It concluded that the movement within South Bali was mostly concentrated on the middle and southern area of the route, rather than the northern area. It determines the magnitude of supply for the transport mode needed in those areas.

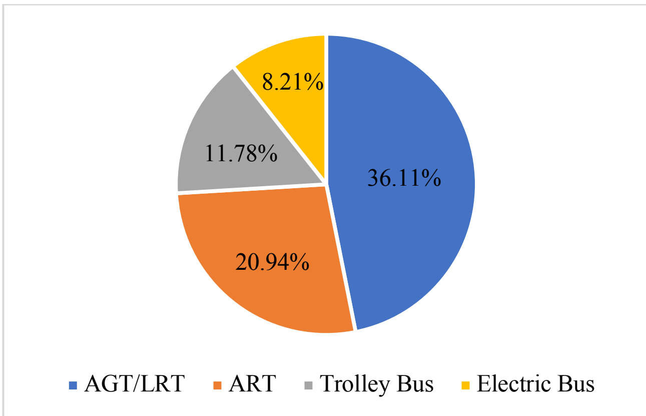
Table 5 Estimation of the number of trips according to demand distribution in OD matrix for South Bali corridors on year 0

O/D	South Denpasar	West Denpasar	Kuta	North Kuta	Kediri	Oi
South Denpasar	-	9,202	4,323	2,532	550	22,142
West Denpasar	11,458	-	6,940	9,867	3,342	37,310
Kuta	3,925	5,061	4,978	2,515	634	24,502
North Kuta	2,299	7,193	2,515	6,456	2,535	23,063
Kediri	757	1,131	254	1,015	1748	5,185
Dj	18,439	22,587	19,010	22,386	8,809	11,2203

Public transport mode preference

To estimate public transport preference, the respondents were asked to fill Stated Preference (SP) survey for each scenario of travel cost, starting from IDR5,000 to IDR15,000. The headway and travel time for each mode was also provided within the scenario thus the respondents can opt for the best convenience for their choice. Sensitivity analysis was conducted to find the average result for public transport mode choice. The result reveals that the average travel cost the respondents were willing to pay is IDR10,000, with the proportion of public transport as presented in Table 6.

Table 6 Probability of public transport preference based on travel cost of IDR10,000



From the result, this study projected the demand using the moderate scheme, due to financial consideration. The tariff used in this scheme was IDR10,000 based on the SP survey. Then the demand was projected until year 30, the expected optimal operational age of typical public transport, using demand growth of 6% as it is the average of the growth of DPS airport visitors per year [15].

5.3. The geometrical framework of the route

In general, South Bali roads were dominated by narrow roads and some wider ones in a limited part of the route. As Figure 6 illustrates, the middle section of the route is mostly 2/2 UD (2 lanes, 2 directions, undivided) type with the width is in the range 5-6 m. The wider roads were found at the southern part (Sunset Road, 6/2 D) and the northern part (Raya Denpasar-Gilimanuk Road, 4/2 UD) of the study area with its width is in the range of 11-15 m.

The geometric condition of the route is important to determine the feasibility and suitability of public transport mode. For instance, the operating bus will fit in most of any range of road width, but a typical mass transport such as LRT will require significant space for the station and the railway. Therefore, applying mass transport in the narrow section will need a larger investment as it will be either elevated or underground infrastructure.

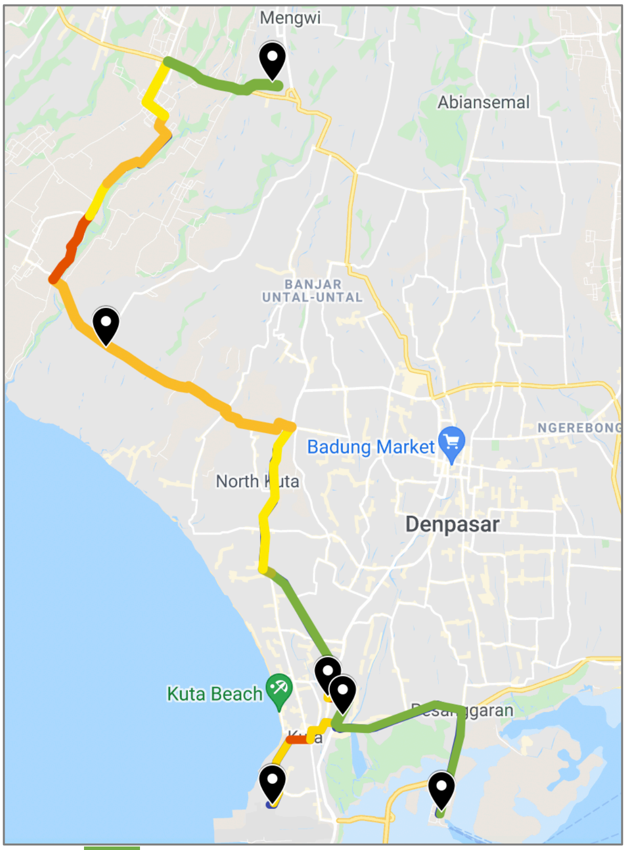


Figure 6 Road type classification on South Bali public transport route

5.4. Operational design of public transport alternatives

Based on the result of the Stated Preference (SP) survey, the most preferred public transports according to their popularity among the respondents were as follow:

1. AGT/LRT
2. ART
3. Trolley bus
4. Hybrid/electric bus

The socio-culture analysis revealed that there was a potential resistance from the society for elevated infrastructure across certain buildings or residential areas due to religious concerns. Therefore, establishing the trolley bus will be problematic since it requires cable installation above the route. Public transport alternatives considered in this study are limited to Electric Bus, Light Rapid Transit (LRT), and Automated Rapid Transit (ART). In general, the characteristic of those modes is presented in Table 7.

The design of stops, stations, and routes

According to the characteristics of transport mode in Table 7, the number of stops and stations will differ for each mode. The placement of stops considered the available space along the route, such as a wide sidewalk, gas station, or unoccupied land/park nearby. The number of routes or lines depends on the capacity of the transport mode with the current demand.

A. Electric Bus

The stops for electric buses are plotted on the existing road along the corridor, with a total number of 6 main stations and 23 small stops. The distance between stops approximately is 1-1.5 km depending on the land use and population density of the area. The illustration is shown in Figure 7.

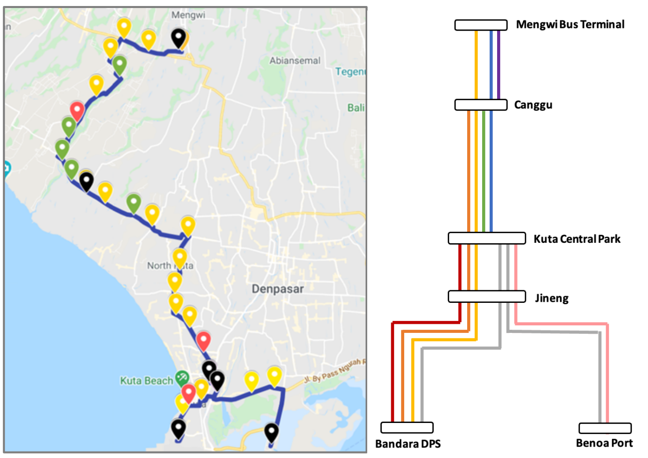


Figure 7 Potential bus stops and planned bus routes

Due to the limited number of bus capacity, there were 8 routes planned for the electric bus in South Bali. Since the demand within the southern-middle area of the route was relatively greater than the northern area, the number of fleets for the former trips should be higher to accommodate the needs.

B. LRT

Most of the LRT infrastructure was designed underground, thus it will not disrupt the buildings on the surface and will be more socially accepted. The underground route was plotted under and nearby the existing road to minimize conflict with utilities. It also had relatively wide angles in the curves since LRT needs an adequate turning radius. The LRT track is shown in Figure 8.

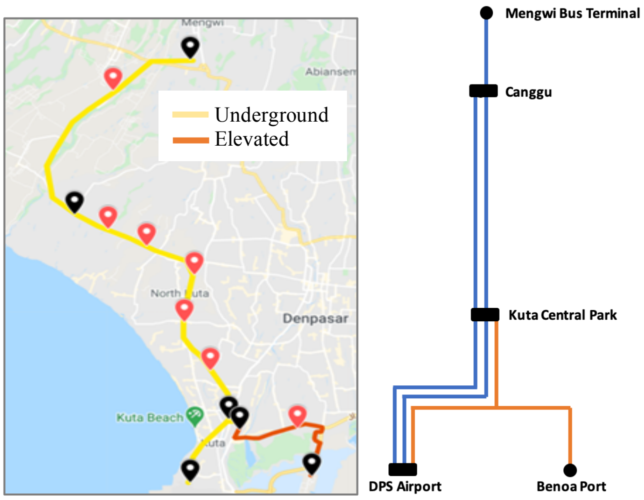


Figure 8 Potential LRT stations and planned line

Table 7 General specification of Electric Bus, LRT, and ART

Element	Electric Bus	Light Rapid Transit (LRT)	Automated Rapid Transit (ART)
Capacity (passenger/set)	30	270-540	300-500
Number of carriages per set	1	2-4 carriages	3-5 carriages
Running way	Road	Rail	Rail
Type of right-of-way	Usually at-grade, or in some cases elevated or underground	At-grade, elevated, or underground	Usually at-grade, or in some cases elevated or underground
Dimension (length x width) [m]	7 x 2.14	51 x 2.65	31 x 2.65
Distance between stations [km]	1-1.5	1.5-2.5	1.5-2.5
Average operational speed [km/h]	20-40	40-50	40-50
Maximum speed [km/h]	65	80	70
Min. turning radius [m]	15	40-60	15
Max. grade/ramp slope	13%	6%-10%	13%
Min. required space for station/depot [Hectare]	<1	2.5-3.7	<1
Minimum width of space required for the track			
At-grade [m]	2-3	6-7	2-3
Elevated (pier) [m]	-	1.5	1.5

The LRT track is divided into 2 sections: elevated and underground. The underground part is designed for Corridor 1 DPS Airport-Mengwi Bus Station. The elevated section is designed to accommodate half of Corridor 2, particularly from Benoa Port-Kuta Central Park. According to the Bali Public Transportation Master Plan, there will be another underground LRT providing mass transit from the southern to the northern part of Bali, planned by Nindya Karya and the Bali Province Government. This makes the current track design intersect with Nindya Karya's LRT track from DPS Airport to Kuta Central Park, hence both can be integrated to cut the cost and distribute the demand more evenly.

There are 3 designed lines for LRT (DPS Airport-Canggu, DPS Airport-Mengwi Bus Terminal, and DPS Airport-Benoa Port). The LRT design has 6 main stations and 7 small stations with the average distance between stations is around 1.5-2.5 km (see Figure 8). Even though most of the track will be underground, land acquisition still will be required in some places due to the density of the building in the business district and tourism area.

C. ART

ART for South Bali is designed in at-grade, elevated, and underground infrastructure depends on the geometrical condition of the road. The elevated section is from DPS Airport to entering Sunset Road segment, where the road is quite wide and there are not many restrictions of elevated infrastructure. After that, it requires some underground infrastructure before entering Sunset Road due to the density of the building there. On Sunset Road, the ART is expected to use the mixed traffic lane with other vehicles, as well as the segment from Benoa Port to the end of Sunset Road. After the end of Sunset Road, ART should use an underground section until it reaches Mengwi Bus Terminal due to narrow roads and social resistance for elevated infrastructure. The potential track for the ART is shown in Figure 9.

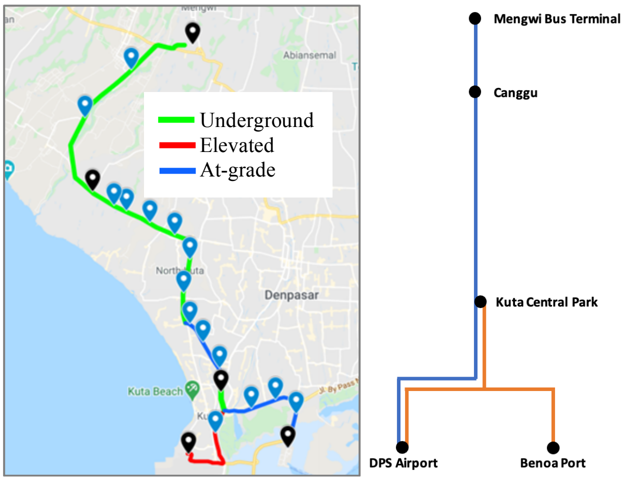


Figure 9 Potential ART stations and planned lines

According to Bali Public Transportation Master Plan, there will be another ART from the southern to the eastern part of Bali, planned by PT KAI and the Bali Province Government. This makes the current track design intersect with PT KAI's track from DPS Airport to Kuta Central Park, hence both can be integrated to cut the cost and distribute the demand more evenly.

ART design has 6 main stations and 15 small stations with the distance between stations around 1-2.5 km (see Figure 9). The placement of stations depends on the density of movement around tourism and residential area.

Fleet calculation

The number of fleets is determined based on forecasted demand calculated from mode share and population data. Headway in-between departure of the fleet is computed iteratively, with a minimum length of 10 minutes. To achieve the optimum number of fleets for daily demand, the vehicle will be reused after it finishes one cycle time of the trip. Each mode has a different cycle time, depending on travel time, layover time and contingency. The cycle time can be calculated by using the following formula:

$$CT = TT + LT + C \tag{1}$$

Where:

CT	: Cycle time (hr.)
TT	: Travel time (hr.)
LT	: Layover time (hr.)
C	: Contingency (hr.)

Cycle time is the required time for a fleet to travel the route from origin to destination and back to origin. Travel time is the time a passenger spent in the vehicle to travel from origin to destination. It depends on the vehicle's speed and length of the route. In this study, travel time is calculated for a return trip. Layover time indicates the break time for the vehicle and the driver to rest in-between trips. It is specified as 15 minutes per cycle. While Contingency is the estimated time spent to pick up and drop passengers off, and additional time to anticipate traffic uncertainty. Contingency time in this study takes up to 25% of travel time.

The number of trips in the OD-pair matrix determines the number of routes and fleets, where the significant ones will be prioritized to avoid oversupply or undersupply in the areas. Each route has a various number of fleets to suit the high demand in crowded areas. The optimum number of fleets is achieved after iteration of headway to accommodate the time-based demand.

As the baseline, the calculation of fleet number used electric bus with the capacity of 30 passengers, ART with the capacity of 300 passengers (3 carriages = 1 trainset) and could be expanded to 500 passengers (5 carriages = 1 trainset), and LRT with the capacity of 270 passengers (1 trainset) and could be expanded to 540 passengers (2 trainsets). Table 8 shows the calculation result of the number of fleets and average cycle trip for each fleet on 8 routes of South Bali corridors.

The required number of fleets was calculated each year until year 30. It was computed iteratively to suit the increasing demand each year, with the change of a reasonable amount of headway time and passenger capacity. According to Figure 10, the demand for the bus is raised each year, while ART and LRT need to upgrade the trainset on year 20 and 15 respectively (illustrated by darker color). With the arranged fleet, ART and LRT are estimated to cover all time demand without significant hassle. The detail of calculation result is presented in Table 8.

Table 8 Fleet calculation of potential public transport mode

Route	Origin	Destination	Bus		LRT		ART	
			No. fleet	Average trip cycle per bus	No. fleet	Average trip cycle per trainset	No. fleet	Average trip cycle per trainset
1	DPS Airport	Kuta Central Park	6	11	3	13		
2	DPS Airport	Canggu	3	5				
3	DPS Airport	Mengwi Bus Terminal	5	3	6	8	6	8
4	DPS Airport	Benoa Port	4	7	4	18	4	17
5	Kuta Central Park	Canggu	16	7				
6	Kuta Central Park	Mengwi Bus Terminal	11	4				
7	Kuta Central Park	Benoa Port	6	11				
8	Canggu	Mengwi Bus Terminal	11	7				

However, the analysis shows that even though the number of Electric Bus was expanded over the year, it will be insufficient to cover the demand starting year 20 (see Figure 11). As it could not exceed the headway limit of 10 minutes, adding another fleet would be impractical as shorter headway will cause bus-bunching and overcrowded on the road. Figure 11 demonstrates that on year 30, 17% of the demand cannot be covered by the bus fleet. Therefore, the most sustainable plan for South Bali transport mode is ART or LRT.

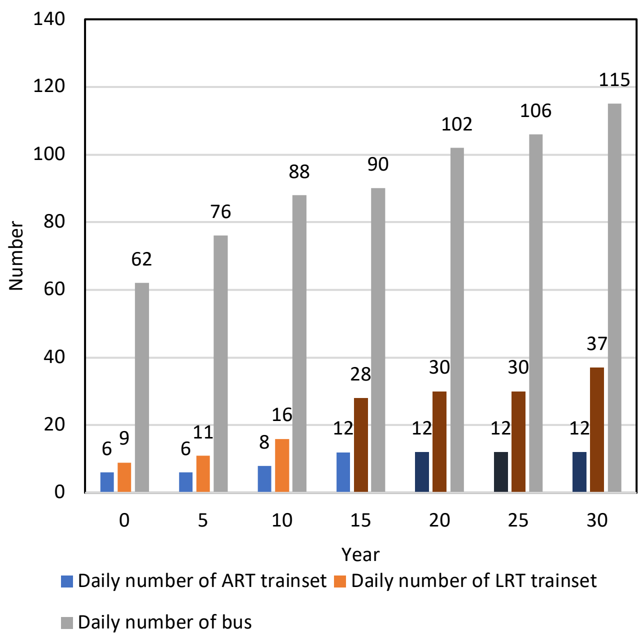


Figure 10 The required number of daily fleets for each mode

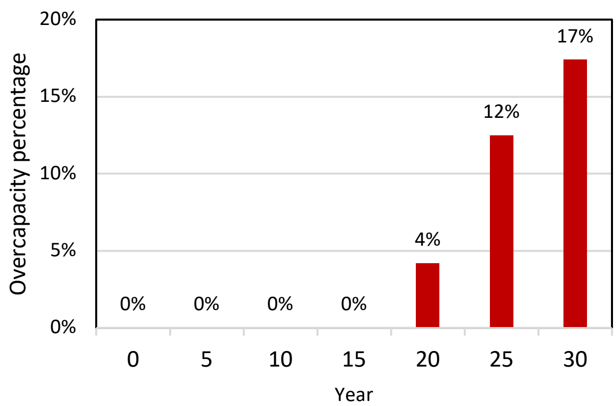


Figure 11 The percentage of overcapacity of electric bus

5.5. Comparison of public transport alternatives

Based on field survey and qualitative analysis, several aspects can be the indicator to distinguish compatibility of public transport options between electric bus, LRT, and ART for South Bali transport corridors. The aspects include the geometrical framework of the road, space availability for dedicated lanes, turning radius, and stations/stop, and land use limitation. The detail of the comparative analysis is presented in Table 9.

According to the appraisal, the electric bus is the most favorable transport mode as it has the least of conflicts with the mentioned aspects. On the other hand, LRT has the most conflict among the indicators, even though it can be changed by making more investment in the elevated or underground structure.

Table 9 Compatibility of transport modes in South Bali corridor

Aspect	Existing condition	Compatibility		
		Electric bus	LRT	ART
Geometrical aspect of the road (space availability for dedicated lane)	Almost 80% of the road along the route is type 2/2 UD with 5-6 m width. The wider section (4/2 UD and 6/2 D) only appears in the southern and northern parts of the route.	Mixed traffic is possible with limited speed, especially in peak hours. For at-grade, bus lanes can be installed on Sunset Road and Raya Denpasar Road section only.	Not possible to operate at grade, since the space required for LRT is about 6-7 m, while most of the road width is around 5-6 m.	Not possible to operate at grade, since the space required for ART is about 2-3 m, while most of the road width is around 5-6 m.
Space availability for turning radius	On the at-grade existing road along the route, there are several intersections with a low turning radius (5 m).	Still possible to run at grade since the turning radius is around 6.5-7.5 m, but some intersections will need minor reconstruction.	LRT needs a 40-60 m turning radius hence it will not fit in most of the turning sections of the at-grade route.	ART needs a 15 m turning radius hence it will not fit in many of the turning sections of the at-grade route.
Space availability for stations/stops	Large stations (e.g. intermodal changes) can only be placed in certain areas such as Sunset Road or Raya Denpasar Road. While small stops can be installed on the sidewalk or empty spaces along the route.	Adequate spaces on the sidewalks and clearance around the greenfield are suitable for simple bus stops (does not require huge space).	Insufficient space to install proper interchange stations on the existing routes.	ART stops require a relatively small space (similar to bus stops but slightly larger) hence still feasible to install on the existing routes.
Land use limitation	The land around the Ngurah Rai airport, the southern part of the route, is mostly used for residential, business, and tourism purposes. The middle section of the route (By Pass Road-Tanah Lot) is dominated by green fields (rice fields) and residential areas in some parts. The northern part of the route is the business and residential areas. Note that land acquisition nearby the existing road will be difficult, costly, and generating negative social impact.	The electric bus can operate on existing roads and without a dedicated bus lane due to space limitations and the difficulty of land acquisition.	LRT cannot operate at grade on the route due to large space requirements both for the track and the stations.	ART cannot operate at grade on the route due to large space requirements for the tracks.
Socio-culture (based on Focus Group Discussion, observation, and questionnaire)	Elevated infrastructure will embrace social resistance due to religious concern among society. Pier or elevated tracks can only be constructed at the green fields area or another route.	The electric bus can operate on the existing route thus minimising the occurrence of social resistance.	LRT requires huge spaces for both track and stations hence to minimise social resistance this option requires underground infrastructure on most of the route section. Elevated sections of LRT can be installed on the undeveloped area, spacious roads on the route, or greenfield.	As ART requires huge space for the track, to minimise social resistance it can use an underground track on most of the route section. Elevated sections of ART can be installed on the undeveloped area, spacious roads on the route, or greenfield.

Note:

(red)	Almost not applicable/require considerable changes
(yellow)	Relatively applicable with some notes
(green)	Applicable with no significant problem

6 Conclusion and Recommendation

This study aims to determine which type of transport mode fits with the South Bali District context. The context here includes i) the demand for different types of transport modes, ii) spaces on the road to accommodate public transport operation, iii) fleet requirement and maximum capacity. Based on the stated preference survey, the three most preferred public transport modes for tourist and South Bali District local citizens are i) light rapid transit (LRT), ii) automated rapid transit (ART), and iii) electric bus. However, rather than determining the type of transport mode based on the demand only, this study also considers the road geometry as well as the carrying capacity for 30 years ahead.

The results show that, for electric buses, the mode can be operated on the existing road. However, with respect to carrying capacity, this mode cannot accommodate all travel demand from the year 20 onwards. It should be noted that the demand here only considers the respondents who prefer electric bus as their transport mode. If the demand for other public transport mode is needed, it is highly likely that Electric Bus only will not be able to carry more passenger demand before year 20.

It is interesting to note that the light rapid transit (LRT) and autonomous rapid transit (ART) is a mode that can accommodate all its demand even until year 30. Therefore, we can conclude that a mass rapid transit system, which is provided by light rapid transit or automated rapid transit is a solution for mass transportation in South Bali District. However, due to narrow road spaces as well as the local culture that forbids building elevated tracks, the LRT can only be operated underground, while ART also must be operated underground except in several wide road segments.

Judging from the infrastructure requirement, the LRT will require massive investment as all of its track has to be built underground while ART requires less investment. Therefore, ART is a public transport mode that should be highly considered to be operated in South Bali District.

However, it should be noted that choosing the right type of public transport mode also requires aspects such as economic and financial analysis. Moreover, the construction and operation of the mass rapid transit system are usually capital intensive and infeasible, unless additional measures are taken to increase the number of the passenger as well as adding the source of income for the system operator. Therefore, future studies can consider carrying out economic and financial analysis for the light rapid transit and automated rapid transit operation in South Bali District, and also explore the potential of supporting measures such as transit-oriented development, ticket subsidies, etc. In addition, as there are many plans for public transport system development in Bali, opportunities exist to integrate the different public transport systems and see the impact of the integration on the number of passengers as well as income for system operators. Such comprehensive analysis will strengthen the government or transit authority decision on which public transport mode to be operated so that sustainable transportation in South Bali District can be achieved.

References

[1] Bali Central Bureau of Statistics, "Number of Domestic Visitor to Bali by Month, 2004-2020," 2020. [Online]. Available: https://bali.bps.go.id/statictable/2018/02/09/29/banyaknya-wisatawan-domestik-bulanan-ke-bali-2004-2020.html. [Accessed: 28-Jan-2021].

[2] Bali Central Bureau of Statistics, "Number of Monthly Foreign Tourists to Bali According to Entrance (Person)," 2020. [Online]. Available: https://bali.bps.go.id/indicator/16/106/11/banyaknya-wisatawan-mancanegara-bulanan-ke-bali-menurut-pintu-masuk.html. [Accessed: 28-Jan-2021].

[3] Bali Central Bureau of Statistics, "Projected Population of Bali Province by Gender and Age Group, 2011-2020 (thousand people)," 2020. [Online]. Available: https://bali.bps.go.id/statictable/2018/02/09/28/jumlah-wisatawan-asing-ke-bali-dan-indonesia-1969-2017.html. [Accessed: 28-Jan-2021].

[4] The ASEAN Work-Life Balance Project, "Traffic Jam in Bali and Its Impacts on Productivity, Health, and Tourism – The ASEAN Work-Life Balance Project (2015 – 2017)," 2016. [Online]. Available: https://asean-wlb.net/traffic-jam-in-bali-and-its-impacts-on-productivity-health-and-tourism/. [Accessed: 28-Jan-2021].

[5] A. Ilahi, P. F. Belgiawan, and K. W. Axhausen, "Mode choice of transit system in Denpasar greater area (Sarbagita)," *Proc. East. Asia Soc. Transp. Stud.*, vol. 11, no. 62, 2017.

[6] Sustainable Bus, "Electric bus, main fleets and projects around the world," 2020. [Online]. Available: https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world/. [Accessed: 28-Jan-2021].

[7] K. N. S. Ayuningtyas, R. B. Frazila, S. S. Wibowo, and M. Farda, "Network Analysis of Intercity Bus Terminal and Inner-City Toll Road Development – The Case of Bandung City," *Int. J. Sustain. Transp. Technol.*, vol. 2, no. 1, pp. 8–18, April. 2019.

[8] H. A.-R. Lubis, V. B. Pantas, and M. Farda, "Demand forecast of Jakarta-Surabaya high speed rail based on stated preference method," *Int. J. Technol.*, vol. 10, no. 2, 2019.

[9] J. Khan, R. Hrelja, and F. Pettersson-Löfstedt, "Increasing public transport patronage – An analysis of planning principles and public transport governance in Swedish regions with the highest growth in ridership," *Case Stud. Transp. Policy*, vol. 9, no. 1, pp. 260–270, March. 2021.

[10] R. Y. Nutsugbodo, E. K. Amenumey, and C. A. Mensah, "Public transport mode preferences of international tourists

in Ghana: Implications for transport planning," *Travel Behav. Soc.*, vol. 11, pp. 1–8, April. 2018.

[11] M. Aljoufie, "Exploring the Determinants of Public Transport System Planning in Car-dependent Cities," *Procedia - Soc. Behav. Sci.*, vol. 216, pp. 535–544, January. 2016.

[12] Bali Province Government, "Bali Transport Masterplan 2023", Denpasar, 2019.

[13] Bali Central Bureau of Statistics, "Bali Province in Figures," Denpasar, 2020.

[14] Department of Transportation, "Origin-Destination Data of National Transport", 2018.

[15] Bali Central Bureau of Statistics, "Bali Province in Figures," Denpasar, 2019.