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Sidewalk and Pedestrian Crossing Design on Urban Mixed Land Use Area

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Abstract— Pedestrian pathways are physical infrastructure that support the smooth movement of people from one place to another. The sidewalk on Sultan Alauddin Street in Kota Makassar is damaged and has been repurposed as a parking space for motorcycles and street vendors. Pedestrians in this area are forced to use the road shoulder to walk, despite the significant safety risks for pedestrians and other road users. The purpose of this study is to determine the characteristics of pedestrians, sidewalk and pedestrian crossing planning. The references used as guidelines are Pedestrian Facility Planning, 2017. Research methods for sidewalks and pedestrian crossings generally involve several stages to measure and analyze the geometric conditions of sidewalks, pedestrian behavior, and the volume of pedestrian movement crossing the road. The sidewalk width meeting the needs of pedestrians in this section is 1.698 meters, and a pelican crossing with a duration of 94 seconds for crossing the road. Findings of the research is the average speed of pedestrian space has a positive effect on the space, but a negative effect on density. As the average speed of pedestrian space increases, the density will decrease and the space will increase.

Keywords: Pedestrian, Sidewalk, Urban Road.

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1. Introduction

Rapid population growth, accompanied by the increase in vehicles without proper urban planning, can be detrimental to society, particularly pedestrians. Walking plays a crucial role in urban transportation, thus improving the quality of pedestrian facilities in an area (walkability) can encourage people to walk [1], [2]. Walking in urban areas has various benefits such as reducing air and noise pollution, fuel savings, and cost savings. Moreover, the social benefits of walking include restoring the city's role as a meeting place, creating a more relaxed and healthy city image. Therefore, it is important to provide pedestrian facilities/walkways in urban areas. Pedestrian walkways are physical infrastructure facilities that support the smooth flow of movement from one place to another or serve as spaces between the roadside and property lines, crucial in providing safe and efficient pedestrian movement for all abilities and disabilities [3]. Pedestrian zones offer nine qualitative parameters concerning closing pedestrian walkways with buildings and the surrounding environment, building articulation considering the flow of buildings in relation to each other, space complexity and transparency related to pedestrians' ability to move from public to private public space, varied overhangs/awnings/roof lines, shade trees, supports, road network complexity, and physical component/condition [4]. Most sidewalks, especially in developing countries, serve as public areas with various social activities alongside their primary function of serving pedestrians' movement.

Most sidewalks, especially in developing countries, serve as public areas with many social activities besides their main function of serving pedestrians. Therefore, sidewalks may require various facilities to support user activities, such as benches, plantations, including street vendors' stalls [5], [6]. High traffic density on road junctions can also lead to conflicts between vehicle drivers and

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pedestrians [7]. There are 6 aspects to assess the suitability of pedestrian facilities: safety, comfort, accessibility, aesthetics, connectivity, and supporting facilities [8]. Generally, there are two levels of environmental features that affect pedestrians' abilities on sidewalks: environmental level features and sidewalk level features. The former describes the general environment of an area, such as road connectivity, residential density, and land use mix related to facility distribution. Sidewalk level features refer to sidewalk width, street furniture, shading, ground surface quality, and so on, which actually determine how pedestrian-friendly an urban road is and affect pedestrians' walking experiences [9]. Improvements to sidewalk facilities should consider several essential elements to support community interests, including 1) distributing pedestrian circulation with street vendors, 2) distributing vehicle parking spaces, and 3) placing flower pots and trash cans in appropriate locations to not obstruct pedestrians [10]. The most influential factor is lighting conditions, especially insufficient lighting in the dark, which is related to a 14.9% increase in fatal accidents. The biggest impact on the increase in fatal accidents is due to road infrastructure conditions. The most significant impact on the increase in fatal accidents due to road infrastructure conditions is related to the lack of road barriers (4.7%). Road barriers are necessary to ensure that pedestrians stay in their lane and do not disrupt traffic flow. One of the activities carried out by pedestrians while walking is using a smartphone, where this condition will reduce situational awareness and can pose a risk of accidents, both between pedestsrians, pedestrians and vehicle users and pedestrians against other objects [11], [12]. Integration between transportation systems and accessibility, safety, comfort and security aspects, are general principles for planning pedestrian facilities. Meanwhile, technical planning for pedestrian facilities needs to pay attention to pedestrian capacity, accessibility for pedestrians with special needs, construction and materials that meet safety requirements and are easy to maintain. [13], [14].

Reducing road capacity occurs with the added time pedestrians take to cross the road; to avoid this situation, the timing of pedestrian crossings needs to be planned effectively and efficiently [15]. Pedestrians must use the crosswalk facilities and are not allowed to jaywalking to ensure smooth traffic flow [16]. Pedestrian road crossing suitability needs to consider the number of lanes, height of stairs, and median barriers [17].

In front of the Muhammadiyah University Makassar campus on Sultan Alauddin Street - Bumi Permata Hijau Housing area, various issues are evident, such as the absence of pedestrian crossing facilities, inadequate maintenance resulting in physical damage to the 3-meter-wide sidewalk from Makassar to Gowa direction, and many misusing the facilities for parking. The research location serves as a connecting route between the capital of Gowa Regency and Makassar City. This area is densely populated and features businesses, schools/universities, residential areas, places of worship, inter-city and inter-provincial bus terminals (inter city inter province), offices, other public facilities, and numerous small intersections (side accesses). Sultan Alauddin Road is a route for urban public transportation, namely the Minasa Upa - Central Market and Sungguminasa - Central Market routes, contributing to the high pedestrian traffic, especially during school commute hours, lunchtime, shopping, and office hours. The gap in this research is that the relationship between pedestrian speed, travel time, space, and density on 4/2D road types with mixed land use conditions. There is still limited research discussing this, therefore this research is important so that it can contribute to policymaking in realizing walkable city designs. The urgency of this research is to determine the characteristics of pedestrians (volume, density, space, speed) and the number of pedestrians to be able to design appropriate and safe pedestrian needs. Several studies approaching this issue indicate that age, gender, travel purpose, and walking group size significantly influence pedestrian speed [18] There is no correlation between sidewalk width and pedestrian density [19]. The objectives of this research are to determine the characteristics of pedestrians (volume, speed, density, and space), the influence of pedestrian speed and travel time on density and space, and to determine the effective width of sidewalks and the type of pedestrian crossings that are suitable for the needs on 4/2D road types with mixed land use conditions.

2. Method

2.1 Study Location

The research location is on Sultan Alauddin Street, Makassar City on the segment: Universitas Muhammadiyah Makassar - Permata Hijau Housing with a segment length of 100 meters. The observation days were chosen based on a preliminary survey conducted previously, which found that Mondays, Fridays, and Sundays saw high pedestrian volumes. Furthermore, Mondays and Fridays saw higher vehicle volumes than other days. The survey was conducted in 3 days, namely Monday, Friday, and Sunday, with survey times at 6.30 – 7.30 AM (morning peak hour), 11 AM – 1 PM, and 4 – 6 PM. Study location is presented in Figure 1.

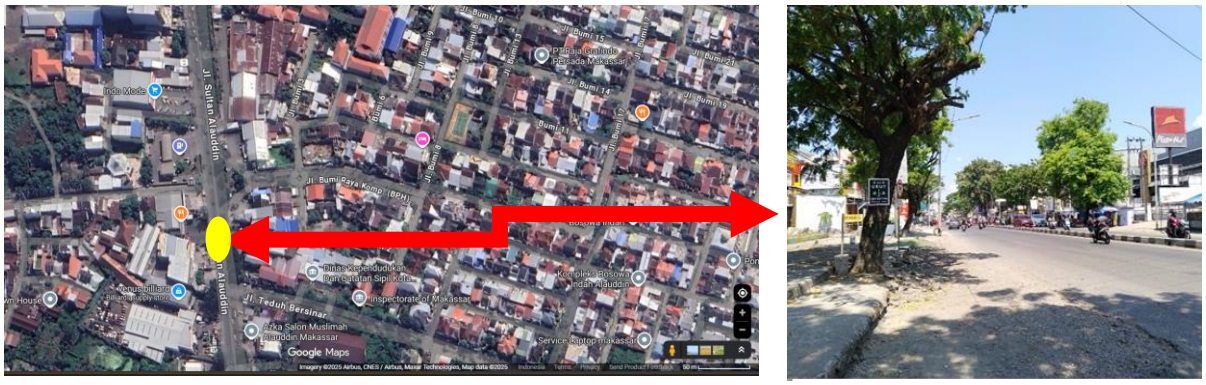


Figure 1. Study Location

2.2 Data Collection

Data collection is divided into two types: secondary data and primary data. Secondary data is obtained from previous sources such as location maps, while primary data is collected directly from the research location, including sidewalk width, pedestrian volume, volume of pedestrian crossing road, traffic volume (vehicles), and pedestrian travel time.

The methodology used in this study is based on Pedestrian Facility Planning, 2017 [20]. The parameters include the number of pedestrians per minute per meter and the environmental conditions. Pedestrian crossing facilities use variables such as the average number of pedestrian crossing road and the volume of vehicles.

2.3 Data Analysis

Some of the equations used in this study are

1. *Space mean speed* of pedestrian

$$Vs = \frac{1}{1/n} \sum 1/Vi \quad (1)$$

Vs = *space mean speed*, n = pedestrian volume, Vi = pedestrian walking speed

2. Density

$$D = \frac{Q}{Vs} \quad (2)$$

D = density, *Q* = pedestrian volume, *Vs* = *space mean speed*

3. Space

$$\mathbf{S} = \frac{1}{D} \quad (3)$$

S = space, *Vs* = space mean speed, *D* = density

4. Effective width of sidewalk

$$W = \frac{V}{35} + N \quad (4)$$

W = width of sidewalk, V = pedestrian volume, dan N = additional width adjusted to environmental conditions.

5. Pedestrian crossing type

$$PV^2 \quad (5)$$

P =The number of road users crossing the road during 1 hour with a segment length of 100 meters, and V = number of vehicles in the observation segment during one hour.

6. Duration of pelican crossing

$$Pt = \frac{L}{1,2} + 1,7\ \frac{N}{W-1} \quad (6)$$

L = The length of the crossing field, W = the minimum width of the crossing field, N = number of pedestrian crossing road

3. Result and Discussion

The characteristics of pedestrians in mixed-use urban land involve several aspects related to pedestrian movement and activities in environments with various land functions. Mixed land use creates a diversity of functions such as offices, commerce, residential areas, and recreation within one area, which causes pedestrian movement to become more complex and dynamic. The sidewalk on study location has experienced physical damage, leading some pedestrians to walk on the road shoulder instead of using the sidewalk. This may result in conflicts between pedestrians and other road users.

3.1 Pedestrian Characteristics

3.1.1 Volume

Figure 2 shows the fluctuation in the number of pedestrians, which will be used as a reference for designing sidewalk needs and the appropriate type of pedestrian crossing at the observation location. The pedestrian flow/volume using the sidewalk in the observation segment on Monday, Friday, and Sunday. The pedestrian volume on observation days is 589 pedestrians/6 hours on Monday, 577 pedestrians/6 hours on Friday, and 521 pedestrian/6 hours on Saturday. On Monday, the highest pedestrian flow is at 4.30 – 5.30 PM (end of office hours) and in the morning when people go to work at 7.30 – 8.30 AM. On Friday afternoon at 11.30 AM – 12.30 PM, the highest pedestrian traffic per hour is observed. On Friday, pedestrians were seen heading to and from worship places and in the evening from 4 – 5 PM when returning from work. Whereas on Sunday, the highest number of pedestrians were seen at 11.15 AM – 12.15 PM.

Observation obtained in 15-minute intervals, the maximum number of pedestrians were 36, and the minimum were 13. The average pedestrian count were 24, with a standard deviation of 5.55. On Monday, the total pedestrian count during the observation period were 589 pedestrians, while on Sunday, the total pedestrians were 521. Throughout the observation period, Sunday was the day with the lowest pedestrian count, as on Sunday, there were no office or school/university activities, with

pedestrians mainly heading to dining and shopping locations at the observation site.

The pedestrian count in this research segment is influenced by activities going to school or office and vice versa during return hours. As Monday marks the beginning of the routine for the week, pedestrian numbers are higher on Mondays compared to other observation days. Prayer times also influence pedestrian numbers, evident on Fridays at 11.30 AM – 12.30 PM, the peak time for pedestrians heading to and from places of worship. Pedestrians were seen for shopping and culinary tourism on sunday. Figure 2 shows pedestrian volume.

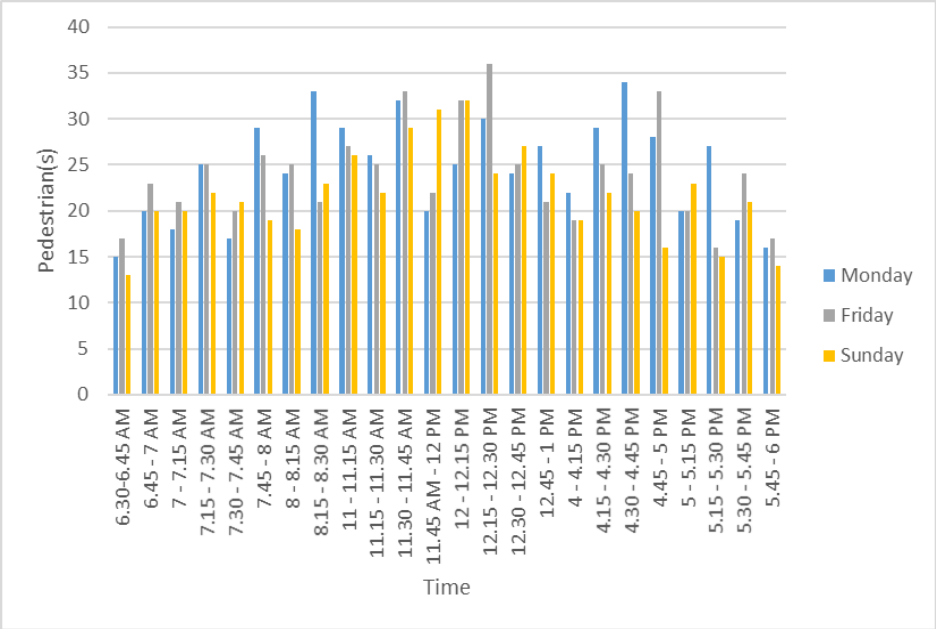


Figure 2. Pedestrian Volume

3.1.2 Travel Time

Travel time ranges from 0.911 to 0.982 minutes. From 6:45 AM to 7:15 AM, travel time decreases. The lowest travel time of 0.911 minutes occurs between 7:00 AM and 7:15 AM, when students are walking to school, with school starting at 7:15 AM. Pedestrians between 7:15 AM and 7:45 AM walk more leisurely compared to the previous hour; during this time, many pedestrians at the observation location are university students. Travel time decreases again from 0.944 to 0.974 minute between 7:45 AM and 8:15 AM, with the majority of pedestrians being workers. The faster travel time is due to avoiding being late for work. During office hours, from 5 PM to 6 PM, it is 0.951 to 0.963 minutes. Meanwhile, outside of school and office hours, the travel time ranges from 0.963 to 0.982 minute. Pedestrian walking time is presented in Figure 3.

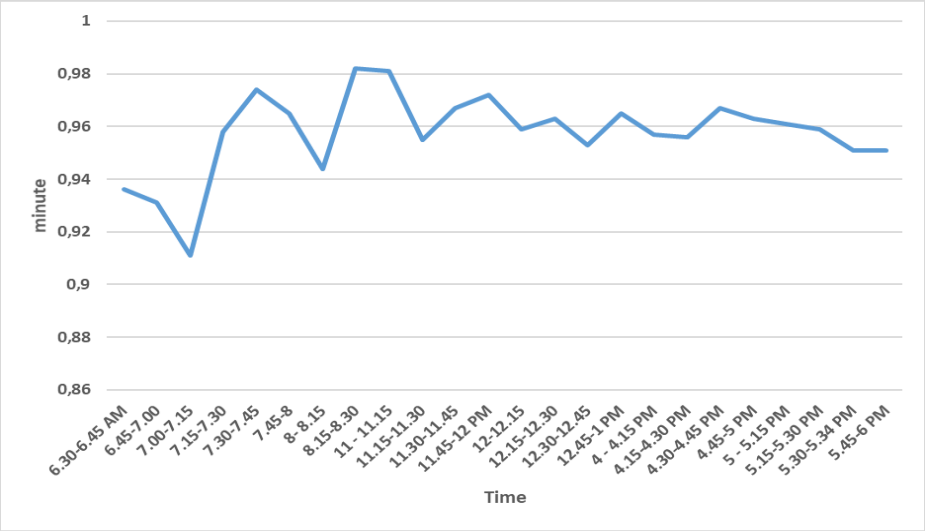


Figure 3. Pedestrian Travel Time

3.1.3 Speed

On mixed land use, pedestrian movement and speed is influenced by existing land use activities, where locations such as offices and shopping centers generate high pedestrian flows, especially during peak hours. This creates a need for pedestrian paths that are responsive to density and changing movement patterns. In mixed-use land development, pedestrian speed management should adapt to existing environmental conditions, including surrounding vehicle speeds, pedestrian density, and the function of the land being accessed. The average space speed analysed is the highest on Mondays in terms of pedestrian traffic compared to other observation days. Speed is determined by comparing the distance (segment length) and pedestrian travel time. The highest speed was 109.769 m/minute and the lowest was 101.832 m/minute. The average speed was 104.6495 meters/minute. The highest speed of pedestrian was 109.769 m/minute and the lowest was 101.8329 meters/minute. At 6.30 – 7.15 AM, students dominate pedestrian traffic, while from 7.30 to 8.15 AM, workers did, and from 11 to 12 AM, many pedestrians enter and exit the shopping centre. From 4.30 to 6 PM, the pedestrian traffic was mainly workers returning from the office. Pedestrian speed is presented in Figure 4.

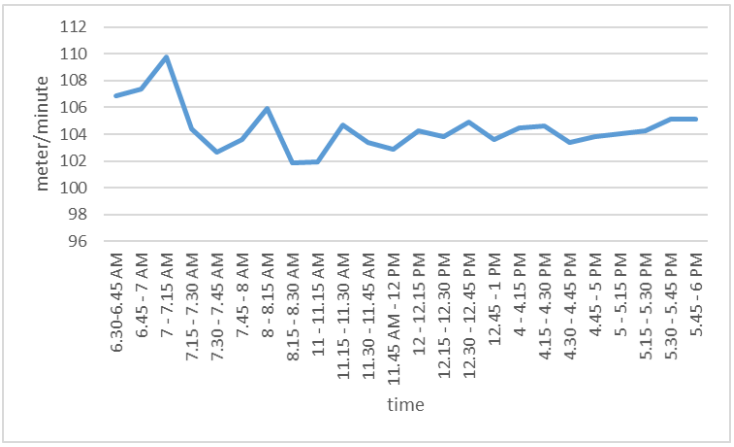


Figure 4. Pedestrian's Speed

3.1.4 Density

On Monday, the pedestrian density is calculated based on the day with the highest pedestrian volume observed. The higher the density value, the more people there are in that area per unit area, which describes the level of pedestrian path density or saturation and requires design adjustments or pedestrian traffic management. Density of pedestrian is presented in Figure 5.

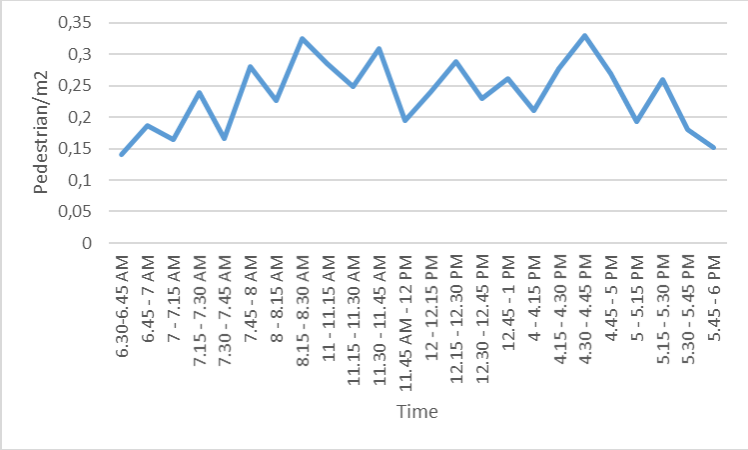


Figure 5. Density of Pedestrian

3.1.5 Space

The average pedestrian space is 4.495 m^2/pedestrian with the largest and smallest space for pedestrians being 7.1225 m^2/pedestrian and 3.0415 m^2/pedestrian respectively. The more crowded the pedestrian walkway, the less space available per person. This measurement of pedestrian space is very useful for assessing the comfort and capacity of pedestrian walkways in an urban area. Pedestrian space is presented in Figure 6.

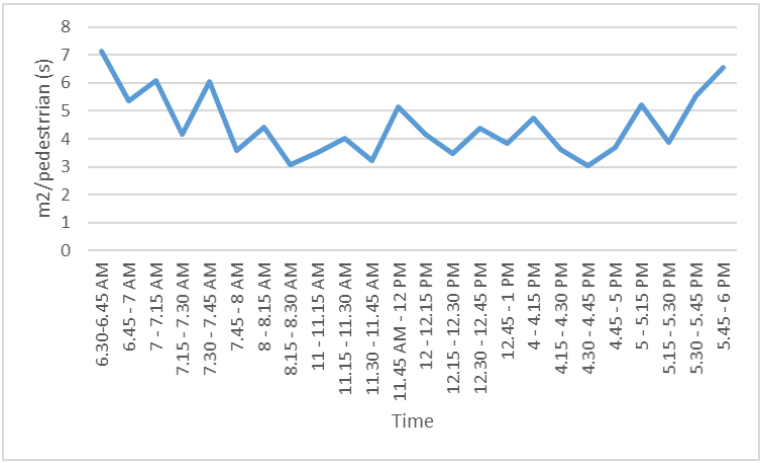


Figure 6. Pedestrian's Space

3.1.6 Relationship Between Pedestrian Walking Speed, Travel Time and Density, Space

The average speed of pedestrian space has a positive effect on the space itself, but a negative effect on density. As the average speed of pedestrian space increases, the density will decrease and the space will increase. This reinforces the findings of previous research [21] [22],[23]. If the volume of pedestrians decreases, pedestrians can walk more freely according to their speed, without any obstacles that can reduce their freedom of movement. In addition, the lower the density, the fewer conflicts between pedestrians. Pedestrian movement is influenced by walking speed, which in turn is affected by the adequacy of space for movement, both for leg movement and arm swing while walking, as well as the adequacy of space when pedestrians are walking while carrying goods in one or both hands. An R-squared value of less than 0.5 implies that the influence of pedestrian speed on density and space accounts for less than 50%. The remainder is due to the influence of other factors not discussed in this study. Relationship between pedestrian space mean speed and density, space is presented in Figure 7.

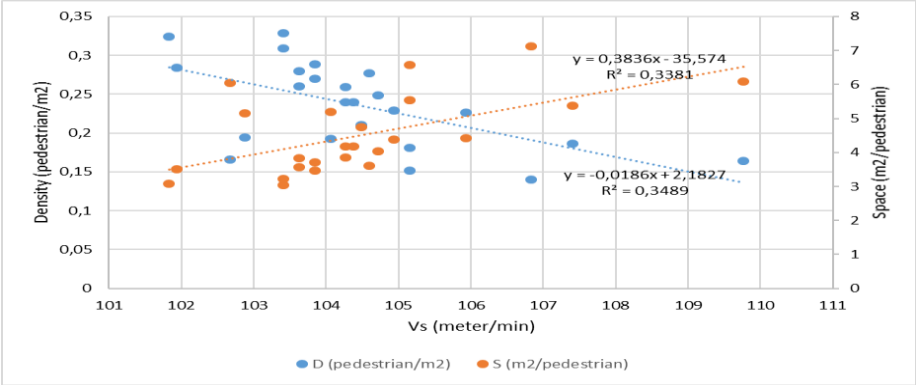


Figure 7. Relationship Between Pedestrian Space Mean Speed and Density, Space

The relationship between travel time and density is almost the same as the relationship between travel time and space. 35% shows a positive relationship between travel time and density, and 34% shows a negative relationship with space. As travel time increases, it can lead to increased density, thus reducing or limiting the space for pedestrians. In this condition, pedestrians reduce their walking speed to avoid conflicts with other pedestrians.The relationship between travel time and density, and space is presented in Figure 8.

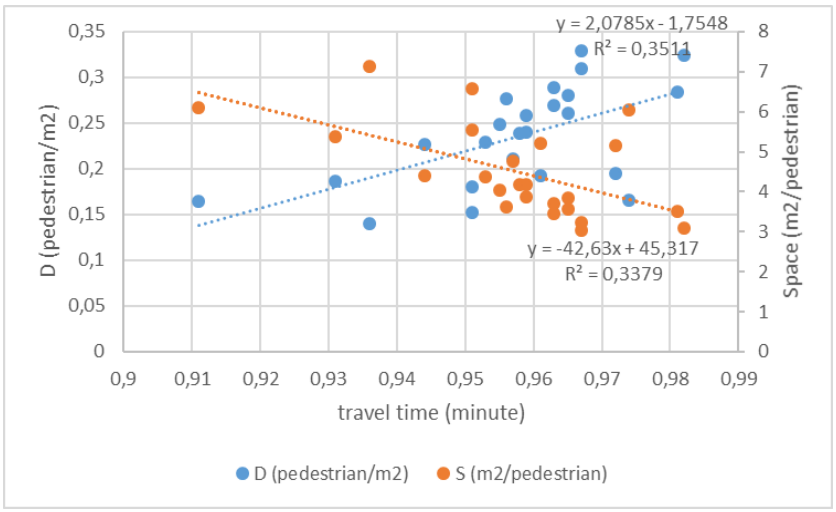


Figure 8. Relationship Between Travel Time and Density, Space

3.2 Sidewalk Needs

Pedestrian sidewalk width planning needs can be calculated based on the number of pedestrians (both ways) and additional width adjusted to the local land use conditions (Ministry of Public Works, 2018). The average daily pedestrian flow observed is 24 pedestrians on Monday, 25 pedestrians on Friday, and 22 pedestrians on Sunday. The pedestrian flow ranges from 16 to 33 individuals per minute per meter, and if the location is a shopping area rather than a market, the value of N is 1. The planned sidewalk width is a minimum of 1.689 meters, which complies with sidewalk planning guidelines where the minimum sidewalk width is 150 cm (for 2 pedestrians passing each other without carrying goods) and the maneuvering space for wheelchair users is 160 cm. Sidewalk width can be seen in Table 1. In sidewalk construction, the width should not be less than the planned 169.8 cm, considering the research location is in shopping areas, residential areas, places of worship, offices, and educational establishments where pedestrian activity is prevalent. Sidewalk design plan can been seen in Figure 9.

Table 1. Sidewalk Width Plan

Day	Average of pedestrian (V)	N	W (m)
Monday	24	1	1.686
Friday	25	1	1.698
Sunday	22	1	1.626

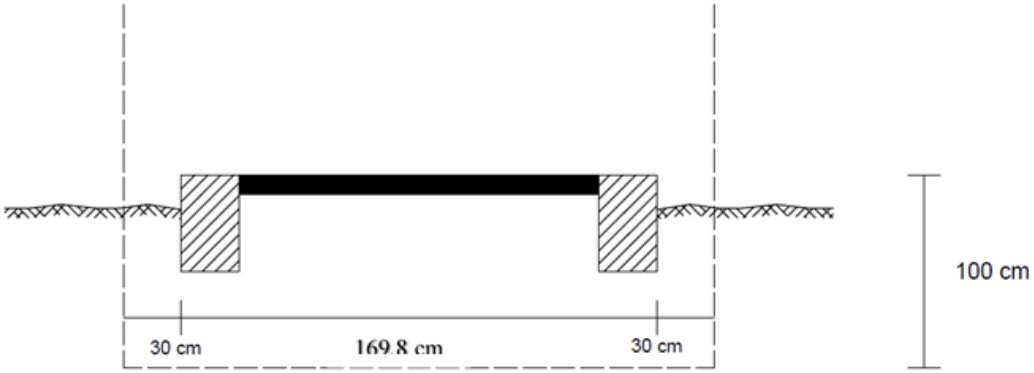


Figure 9. Sidewalk Design Plan

3.3 Pedestrian Crossing

3.3.1 Pedestrian Cross Volume

During the observation interval, the maximum number of pedestrian road crossing was 18 people while the minimum were 7 people. The average number of pedestrian road crossing were 12 people. On Monday, the peak number of pedestrian road crossing occurred between 4 PM and 5 PM, whereas on Friday and Saturday, it was between 11.30 AM and 12.30 PM. The highest and lowest number of pedestrian road crossing on Monday were 57 and 39 people, with an average of 49.657 (50 people). On Friday, the highest and lowest numbers were 62 and 39 people, with an average of 50.376 (51 people). On Sunday, the highest and lowest numbers were 58 and 37 people, with an average of 44.827 (45 people). The higher the density, pedestrian space, and speed of pedestrians in a particular area, the higher the number of pedestrians, especially at strategic crossing points such as near shopping centers, offices, or public facilities. However, in this study, these pedestrian characteristics are an indirect indicator of the number of pedestrians. Figure 10 shows volume of pedestrian road crossing.

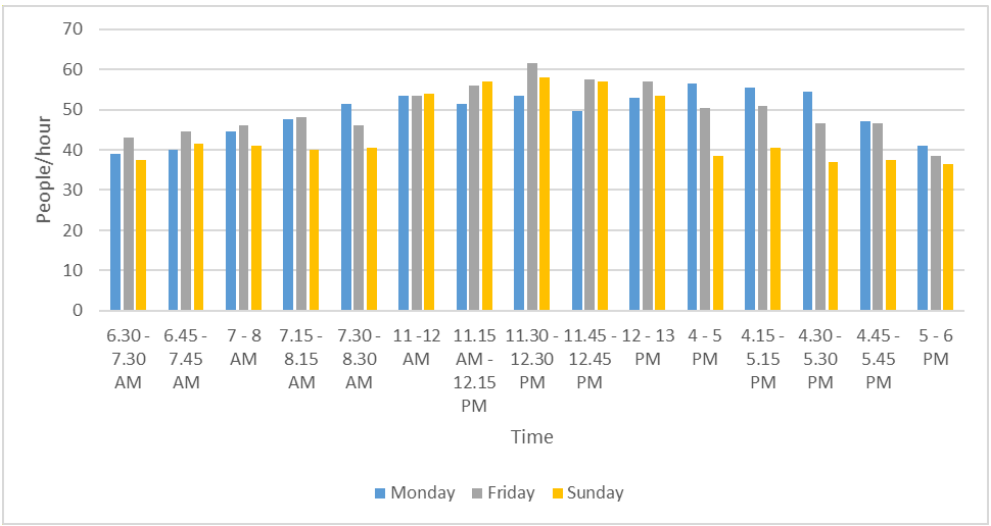


Figure 10. Volume of Pedestrian Road Crossing

3.3.2 Traffic Volume

Parameters for planning human crossing types include the average number of motor vehicle volumes and pedestrian crossing road per hour (both ways in total). The highest motor vehicle volume on Monday, Friday, and Sunday successively were 9,904 vehicles/hour (from 7-8 AM), 10,141 vehicles/hour (from 7 – 8 AM), and 8,009 (from 4.45-5,45 PM). The highest motor vehicle volume per hour on Monday was 9,904 vehicles/hour and the lowest was 6,041 vehicles/hourThe average hourly vehicle volume on Monday was 8,021.549 vehicles/hour. The highest motor vehicle volume per hour on Friday was 10,141 vehicles/hour and the lowest was 7,524 vehicles/hour. The average hourly vehicle volume on Friday was 8,723.134 vehicles/hour, with the highest frequency in the class of 7,524 - 8,060 vehicles/hour. The highest motorized vehicle volume per hour on Sunday was 8,009 vehicles/hour and the lowest was 6,375 vehicles/hour. The average hourly vehicle volume on Sunday was 7,079.597 vehicles/hour, with the highest frequency in the class of 6,375 - 6,710 vehicles/hour. In locations with high vehicle-pedestrian interaction, but without pedestrian crossing facilities, the presence of vehicles can influence pedestrian crossing behavior, which sometimes disregards crossing facilities to avoid vehicle queues or delays, potentially leading to conflict. High vehicle volumes also contribute to long vehicle queues when pedestrians cross regularly, which can hinder vehicles and affect traffic management. Volume of vehicle is presented in Figure 11.

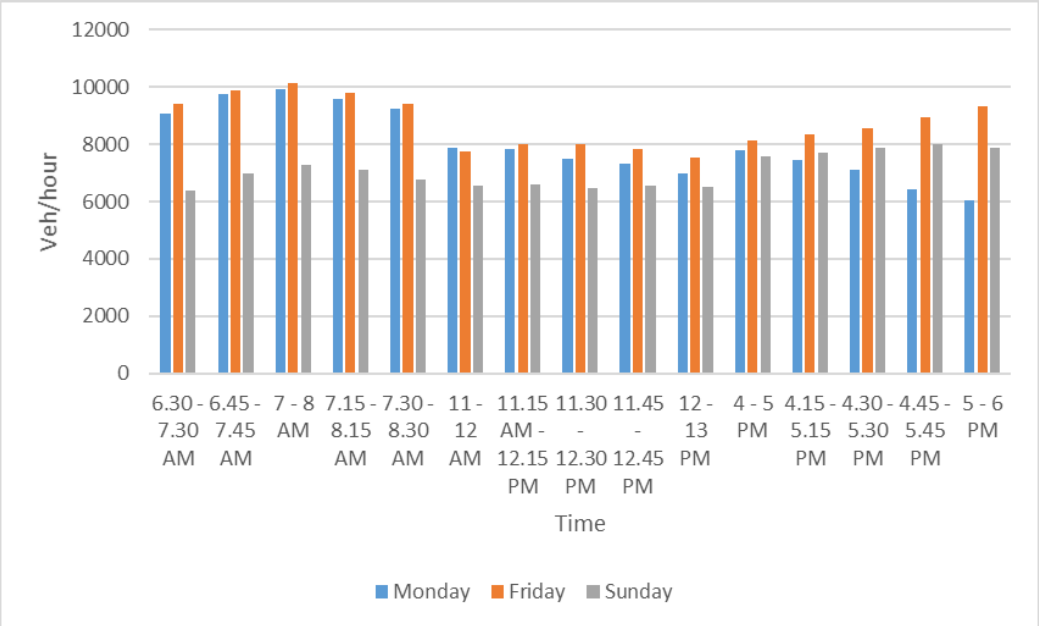


Figure 11. Volume of Vehicle

3.3.3 Pedestrian Crossing

The appropriate type of crossing obtained from the average traffic flow multiplied by the average number of pedestrian crosswalkper hour. Determining PV^2 based on the highest value, which is on Friday 3,880,746,325.02 > $2x10^6$. From the value of PV^2, the suitable type of crossing is a pelican with a waiting bay [20]. The length of the crossing field (L) is 18.15 meters, the average speed is 1.2, the maximum number of pedestrian crossing per hour on the observation day is 51 people, and the minimum width of the crossing field (W) is 2.5 meters. The minimum green time duration for a suggested pelican cross is 78 seconds. Considering pedestrian crossing with special needs, the crossing speed value (Vt) is 0.5 meters per second, hence the minimum green time for a pelican cross is 94 seconds. As seen in Table 2, the PV^2 value in the context of pedestrians versus pedestrians represents the number of conflicts or disruptions that occur between pedestrians crossing the road and passing vehicles. A higher PV^2 value indicates the number of interactions or conflicts between pedestrians and vehicles, which can impact traffic safety and smooth flow. The correlation analysis depicts that the pedestrian crossing speed has significant negative correlation with the crosswalk width, the crossing length, the width of the pedestrian island, the classification of road, average traffic flow and average

pedestrian delay, whereas the availability of separate bicycle paths at intersections is positively correlated [20].

Table 2. Average number of motorized vehicles and pedestrians crossing

Average of vehicle (veh/hour)		P	PV^2
monday	8021,549449	50	3.195.221.803,74
friday	8723,133909	51	3.880.746.325,02
sunday	7079,597109	45	2.246.797.904,62

Considering pedestrians with special needs crossing the road, the crossing speed (Vt) is 0.5 meters per second, therefore the minimum green duration for the pelican cross is 94 seconds.

4. Conclusion

Pedestrian speed decreases as pedestrian density increases. Therefore, sidewalks need to be designed with sufficient width to maintain pedestrian speed and prevent congestion or discomfort. To avoid congestion and queues, sidewalks must accommodate the maximum pedestrian volume during peak hours to prevent overcrowding that impedes movement. By considering the relationship between speed, density, and pedestrian volume in sidewalk design, pedestrian space can be optimized to prevent congestion, increase comfort, and reduce the risk of accidents in urban areas.The highest pedestrian traffic averages 25 individuals occurred on friday.The average speed was 104.6495 meters/minute. The average pedestrian space is 4.495 m2/pedestrian . The highest average number of road crossers is 50 people. The planned width of the sidewalk for this section is 1,698 meters, with a pedestrian crossing facility is a pelican crossing. It is expected that in future research, surveys will be conducted on school holidays to determine the volume of pedestrian attractions and attractions to shopping centres and culinary destinations, as well as on days with special activities at schools/universities (e.g. graduation ceremonies). The average speed of pedestrian space has a positive effect on the space, but a negative effect on density. As the average speed of pedestrian space increases, the density will decrease and the space will increase. Furthermore, there will be a prediction of pedestrian facility needs, taking into account anticipations for changes in land use or public transportation fare adjustments, increases in fuel prices for motor vehicles, or changes in local socio-economic conditions.

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