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Development of a Pedestrian Capacity Using a Movement Simulation Model in Malioboro, Yogyakarta, Indonesia

M.Z Muttaqin*, A Munawar and M.Z Irawan

Civil Engineering Department and Environmental Engineering Department, Engineering Faculty, Gadjah Mada University, 55281, Yogyakarta, Indonesian

The pedestrian lane has various constraints emphasising the accommodation of daily traffic, especially in the sidewalk area. This leads to the consideration of capacity, which is a measure of the highest volume being accommodated while maintaining pleasant pedestrian conditions. Regarding this consideration, almost all previous reports have reportedly used global capacity criteria, including HCM (2010), although variable pedestrian area conditions often caused varying standard capacities. This shows that local pedestrian movement features commonly cause more capacity than the global size. Therefore, this study aims to develop basic local-characteristic pedestrian capacity, using simulation models. This employed social force theory with model simulation and PTV Viswalk as a supporting system. In Viswalk, the pedestrian behaviour coefficient described the patterns by which walkers reacted to people and their surroundings. The sidewalk in Malioboro Tourism Area was also highly and comprehensively emphasised, due to being a business and attraction district in Yogyakarta, Indonesia. Based on the results, pedestrian behaviour needs to be supplied depending on the site activity. This was obtained from the walking behaviour variable on Viswalk, which had been changed from its default value. According to Indonesian regulations, PBC (pedestrian basic capacity) was achieved using conventional sidewalks, with 65 pedestrians/min/m observed for the infrastructure in Malioboro Tourism Area. Additionally, the formulation for the connection between density, flow, and speed was appropriately defined. These modified results are expected to consider and contribute to the calibration method, as well as its existence and field appropriateness.

Keywords: Pedestrian; Simulation Model; Social Force; Viswalk; Indonesia

I. INTRODUCTION

A. Background

A sidewalk is a designated special lane for pedestrian activities in the surrounding region. This is often located near car lanes, for pedestrians to transport themselves using their feet or other non-mechanical devices, such as sticks or wheelchairs for disabled individuals. It also does not have a separate lane and is freely passed by regional pedestrians. However, sidewalk activities are presently more complicated and multipurpose than in previous years. This is based on its use for trade and social interactions among people (Kim *et al.,* 2006). Although the sidewalk has been adequately used by all pedestrians, it still experiences frequent vehicular accidents, due to its proximity to the road line. This indicates that architects and engineers need to carry out their construction with safety and comfort considerations. Sidewalk capacity is one of the measures used to describe the characteristics of this lane. It is also the highest pedestrian traffic to be attained during walking activities. Subsequently, the capacity often provides greater opportunities for authorised pedestrian qualities on the site, such as traffic speed and density. According to the American Highway Capacity Manual (TRB, 2010), pedestrian capacity was derived from BC (basic capacity), which was developed from PSD (pedestrian standard design). Sidewalk capacity is also classified into

*Corresponding author's e-mail: muchzaenalmuttaqin@eng.uir.ac.id

three categories, namely basic, possible, and design. Basic capacity is the highest traffic volume moved by each lane in a unit of time, under ideal standard conditions. The highest traffic volume periodically passed by a specific road location under present standard conditions is also known as the possible capacity. Meanwhile, design capacity (DC) emphasises the volume of a road, regarding different user requirements and service levels. In this case, DC is the volume conducting service traffic and is commonly used as the foundation for road planning and design (Wu & Du, 2013). According to this present analysis, basic capacity (BC) is established as a beginning point for achieving AC (actual capacity), where a sidewalk facility is in the same area with vehicles and great local variables, such as side impediments and obstacles. In Indonesia, a lack of understanding is still observed regarding the fundamental capacity of pedestrian routes, where the available volume is a restriction for path planning design. This design is constrained by the provisions of Government Regulation No. 2 of 2018, which establishes associated requirements for the execution of pedestrian pathways, according to the norms of the American Highway Capacity Manual (AHCM) 1995. The similarities between these standards demonstrate the usage of AHCM 1995 as one of the global approaches to PRC (pedestrian route capacity). This approach is widely used in many locations, to objectively measure the service of pedestrian routes (Kusumo, 2010; Pradipto *et al.,* 2014). Meanwhile, a local-based capacity method is yet to be implemented irrespective of its high accuracy than the global approach. This is because the capacity approach is decided by the scale of the movement characteristics and circumstances in the region (Kadali & Vedagiri, 2015). Global approaches such as the AHCM, have a history in their development (Fruin, 1971) which is tailored to existing pedestrian pathways in the United States. This shows that geographical variations between Indonesia and America need a significant modification in prediction capability. Therefore, this study aims to develop a fundamental capacity analysis on Indonesian pedestrian paths, using the simulation models in the commercial sidewalk of an urban location. Simulation is a method used in achieving capacity prediction outcomes, through the modification of pedestrian characteristics, which are in line with field data. Based on a previous report, a simulation model was used to appropriately forecast pedestrian safety, using a PJ (pedestrian junction) design (Zeng *et. al.*, 2017; Forde & Daniel, 2021). A sidewalk deeply located in the city and adjacent to a dominant mixed-traffic road often causes more obscurity for pedestrians. In sidewalk development, some influential dynamic factors are also observed, such as the pedestrians originating from intersection roads and those performing several activities beside or on the infrastructure, including shopping, chatting, relaxing and sitting, and others. The results obtained are expected to affect future pedestrian characteristics in specific areas, such as speed, density, flow, and spacing (FGSV, 2002)

This study used the Social Force Model approach to describe more pedestrian movement. It also used PTV Viswalk, a programme emphasising the development of a micro model, to perform a simulation closely similar to real facts on the sidewalk. Moreover, PSV (pedestrian speed variable) is used to determine variable control, although its application to characterise pedestrian characteristics in the formulation of behaviour is restricted. In previous reports, various density factors and currents were employed as major control parameters to understand pedestrian behaviour in macroscopic and microscopic simulations (Rashedi-ashrafi, 2013; Anvari *et. al.*, 2015; Li *et al.*, 2020). Speed parameters are also solely employed as a comparison to current and density, in the model's adjustment to the theory of simulation modelling (Moussaïd *et. al.*, 2009; Kretz, Lohmiller & Sukennik, 2018). Based on these descriptions, the results obtained are expected to be part of the factors considered in building the capacity of pedestrian routes, with speed mainly prioritised to determine the characteristics suited to the field, for subsequent analysis in the future design and assessment of sidewalks.

B. Theory

Capacity is used as the main theme for this analysis, due to being a constraint on an infrastructure's ability to serve related operational objects. According to HCM (Highway Capacity Manual, 1995), capacity was defined as the volume of walkers on a pedestrian route (Milazzo *et al.,* 1999). HCM (2000) also emphasised the implementation of capacity constraints, regarding the assessment of the service of pedestrian routes operating within the available paths.

1. Pedestrian movement characteristics

The dynamics of walking is one of the most important considerations in the design and operation of sidewalks. This indicates that pedestrian movements more complicated than vehicular mobilities provide the characteristics of an analogous crowd for the entire area, such as a room evacuation (e.g., terminal or station) and open sidewalk sections (Saberi & Mahmassani, 2014). Some developed models are also separated into two categories, namely (1) The macroscopic model, which represents crowd behaviour as a continuous stream, and (2) The microscopic model, which prioritises smaller populations or the behavioural interactions between pedestrians (Twarogowska, Goatin & Duvigneau, 2014; Taherifar, Hamedmoghadam & Sree, 2019) (Lagervall & Samuelsson, 2014; Lao & Teknomo, 2016). Besides this, the microscopic models are also classified into numerous categories, namely cellular automation (Li, Jia & Li, 2018), social force model (Helbing *et. al.*, 2001; Chen *et al.*, 2018), and gas-lattice model (Zheng, Zhong & Liu, 2009). Since the macroscopic models highly emphasise global flows, more accurate results are observed in congested settings when people become stranded or panic. Meanwhile, the microscopic designs are more accurate in manageable crowds when the effect of the surrounding environment remains dominant for pedestrian movement. When walking, pedestrian behaviours also cause a process that leads to the construction of a collective mobility pattern (Burstedde *et al.,* 2008).

2. Social force model

The social force model is a pedestrian behaviour theory employed in the process of walking, using a microscopic model. This was developed by Helbing and Molnár in 1995 and caused various human behaviours (Chen *et al.,* 2018). It was also part of the self-driven particle model (PTV AG, 2020). Social force model was part of the self-driven particle model (Vicsek, 1995) which shows that each particle is independent, moves at a constant speed, and is connected to other characteristics. This explains that the movement of pedestrians is equivalent to Newtonian mechanics in the social force theory paradigm. The social force model also combines a person's public, psychological, and physical strength, to produce a PPA (pedestrian physical acceleration) parameter. In this case, the pedestrian's goal motivation leads to the development of strength. Subsequently, these walkers are influenced by other lane users and various barriers. The model's general equation is represented as the sum of several attractions and rejection forces, as shown in Equation (1):

$$\overrightarrow{f_1}(t) = m_i \frac{\overrightarrow{dv_i}}{dt} \quad (1)$$

Where f = the resultant impact of pedestrian attraction and rejection. In this process, the pedestrian mass (m) and the change in speed (dv) at any specific time impacted the force (dt). The movement simulation procedure is also separated into two types, namely macro and micro. Based on the macro computation, pedestrian movements are analysed as fluid currents while the micro-simulations highly emphasised the interactions between pedestrians when walking (Huang *et al.,* 2018). Furthermore, the Social Force Model is one of the most widely used simulation ideas in the world, indicating that pedestrians are often impacted by the public circumstances of their surroundings when walking. The tools for shortening the simulation process are also commonly used in pedestrian simulations. These tools are likely to generate visual movement circumstances, to compare the outcomes of the walking and applied analyses in the field, such as PTV Viswalk aids.

3. PTV Viswalk

A pedestrian simulation is used to demonstrate the use of social force theory through PTV Viswalk, which was developed by Germany's Planung Transport Verkehr AG (PTV group) and adopted for a tiny walking model. The model's features focus on discrete time and pedestrian behaviour with regular factors, such as time, speed, and flow (PTV AG, 2020). Irrespective of these features, the application is still being gradually developed with the global evolution of walking dynamics. This programme is frequently used with other products, such as PTV Vissim for vehicle simulation and public transit operations, including pedestrians. Moreover, PTV Viswalk is used in various settings, ranging from traffic planning to pedestrian evacuation models. It is also used with multiple standard systems, such as site characteristics, functions, and community planners. In this application, the social force model equation is subsequently produced by the internal motivation affecting pedestrians' mobilities. This style is influenced by four influences, namely $F_{driving}$, F_{social}, F_{wall}, and F_{noise}. $F_{driving}$ was an internal force pushing pedestrians to the line, with F_{social}, F_{wall}, and F_{noise} strengthening or weakening people. These unstable activities are often observed when walking within the routes produced by other pedestrians (F_{social}), objects adjacent to footfall (F_{wall}), and existing crowds within the path (F_{noise}). Figure 1 shows the example of the simulation produced by PTV Viswalk. Regarding the advantage of this tool, pedestrian movement is visually observed with quantifiable factors, such as lane area circumstances containing width and lane resistance, as well as mobility conditions.

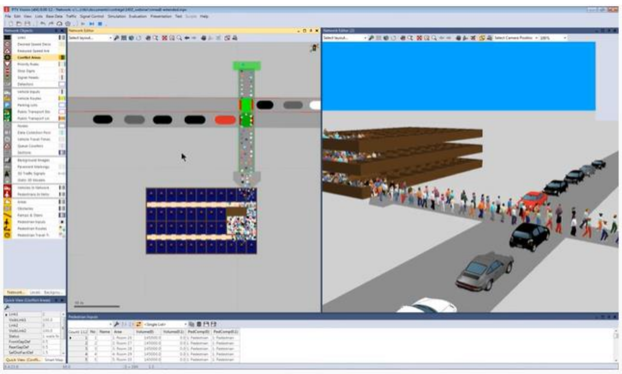

Figure 1. Viswalk Simulation

The motive of people to proceed on the sidewalk is assumed in the Viswalk simulation settings. This incentive is a personal desire mixed with supportive facilities, to expedite objectives while being secure and comfortable. The urge to quickly and comfortably perform tasks is also feasible. Furthermore, a pull effect caused by external stimuli is observed, such as window displays, which cause pedestrians to slow down, halt, or take a detour. In this case, PB (pedestrian behaviour) is responsible for the description of attitude. Table 1 explains the metrics linked to PB on PTV Viswalk, which are then connected to Social Force Models (Lopez-rodriguez, 2020). In this case, Viswalk's parameters are all connected to the social force hypothesis. Based on Table 1, the parameter, tau, represented $F_{driving}$, which was an internal force for the pedestrians walking on the sidewalk. Parameters, n, $A_{soc\ iso}$, $A_{soc\ mean}$, $B_{soc\ iso}$, $B_{soc\ mean}$, and VD also reflected and reacted to the external force of F_{social}, indicating the irritation caused by some walkers to others while travelling in line. In addition, grid and obstacle distances emphasised Fwall, which was the external force originating from the objects surrounding the sidewalk. The force from these objects was then represented by a unit of distance, regarding the length between the pedestrians and the surrounding elements.

II. MATERIALS AND METHODS

The pedestrian traffic characteristics in the Malioboro Tourism Area, Yogyakarta, Indonesia, were measured using a field survey, through a manually-operated video footage camera. This neighbourhood is deeply located in Yogyakarta and is often visited by many domestic and foreign tourists. It also acts as a special attraction for visitors, especially the shopping areas, and becomes a major icon in the global tourism sector (Galura, 2019). Figure 2 depicts the present lane condition, where the data of uninterrupted traffic movements were obtained by positioning the camera in an uninterruptible location. The quantity and duration of pedestrians walking through this location were also recorded. Subsequently, extra data were obtained regarding the sidewalk characteristics. Malioboro's sidewalk contains various pieces of furniture, such as chairs and trees, to improve pedestrian comfort. As a commercial area, it also reintroduced people to the shopping or walking experience.

Table 1. Parameter behaviour coefficient in Viswalk

Parameter	Description	Default Value
tau	The desired speed achievement time of the current speed	0,4
React to n	The maximum number of people nearby that affects the movement of pedestrians.	8
Asoc_iso	The power of interaction between pedestrians indicates the style of pedestrian repellent.	2,72
Bsoc_iso	The range between pedestrian repellent styles that determines the distance of researching influence between pedestrians.	0,2
Lambda	Regulate the power of anisotropy forces to model psychological and social reactions of pedestrians based on the pedestrian's existing position	0,176
Asoc_mean	The power of interaction between pedestrians indicates the style of pedestrian repellent. (Johansson *et al.,* 2008)	0,4
Bsoc_mean	The range between pedestrian repellent styles that determines the distance of researching influence between pedestrians.	2,8
VD	Variables that affect the distance between 2 pedestrians when they have to move to avoid incidents or collisions.	3
Noise	A random force is added specifically in case many pedestrians move below the desired speed.	1,2
Grid distance	A global parameter that aims to determine the maximum distance between pedestrians that affects pedestrian behaviour during simulated time	5
Obstacle distance	Parameter to calculate static potential related to closeness to a wall.	0,5

Figure 2. Sidewalk condition

Survey activity was quantified regarding the geometric side of the pedestrian lane, such as the sidewalk. Field measurements were also obtained by determining the total dimensions of the infrastructure, including the location and size of barriers, as well as the pedestrian entrance and departure lanes. As a starting point, an observation area is a walkway erected at a distinct position from the vehicle's path. This indicated that the pedestrian survey consumed much time, which was subsequently separated into three types. In this process, each type had a 2.5-h observation period, which was from 10:00 AM to 12:30 PM (morning), 01:00 PM to 03:30 PM (afternoon), and 04:00 PM to 06:30 PM (evening). Regarding the pedestrian traffic simulation model, the busiest time with the highest-hour volume emphasised the reference period for each duration type. Calibration and validation techniques were also performed to guarantee the consistency of the modelling outcomes with field circumstances. In this process, the GEH and RMSE statistical statistics were employed as test parameters. GEH is a statistical formula combining the difference between relative and absolute T-Test outcomes. This procedure is used to validate traffic simulation modelling, with the model outputs often considered satisfactory when the GEH value is more than 5 (Zhang & Rakha, 2008).

MAPE prioritises the percentage of error in estimating or forecasting results against the actual outputs over a specific period. This provides information on the percentage of very high or low errors. It is also the average of absolute errors over a specific period, which is then multiplied by 100% to obtain the final results (%). Furthermore, MAPE is a relative provision metric used to calculate the proportion of deviations from estimation outputs. This method is effective when the size or magnitude of the forecast variable is essential in determining prediction accuracy. It also measures the amount of inaccuracy in guessing when compared to real values. This method is subsequently a parameter displaying prediction accuracy (%), where very low values led to better forecasting model capabilities with a maximum limit of 50% (Sun *et al.,* 2013).

III. RESULTS AND DISCUSSION

The analysis was carried out on the Malioboro sidewalk in Yogyakarta, Indonesia, where the observed features satisfied the standard Indonesian policy No. 3 of 2014, concerning the minimum width size for the pedestrian route being greater than 2 m. Data were also generated on the overall traffic volume, with about 4,984 persons found with the balanced characteristics of male and female pedestrians with 49% and 51%, respectively. Furthermore, the samples in Malioboro's business sector were dominated by group pedestrians, marking up 80%. When strolling in the business district section, pedestrians considerably felt more comfortable and safe (Amprasi *et al.,* 2020). They also carry more objects through body integration with 49%, compared to being reinforced or pushed at 20%. Table 2 comprehensively shows the pedestrian characteristics.

Table 2. Parameter behaviour coefficient in Viswalk

Pedestrian characteristics		**Morning time**	**Afternoon Time**	**Evening time**
Walking Nature	Individual	20,26%	42,58%	32,56%
	Group	79,74%	57,42%	67,44%
Sex	Man	48,82%	53,41%	48,36%
	Woman	51,18%	46,59%	51,64%
Bring Luggage	No carrying	31,14%	27,79%	26,37%
	Holding bag	48,64%	49,12%	43,56%
	Carrying bag	20,22%	23,09%	30,07%
Total Volume (pedestrian)			4984	

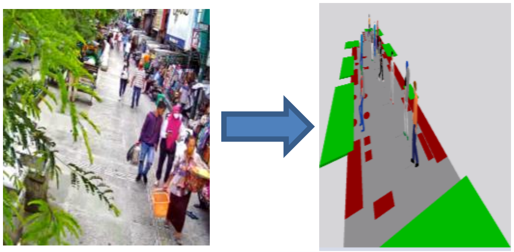

Figure 3. Pedestrian data vs Model Simulation

The next experimental phase emphasised the analysis of simulations, to determine the performance of the pedestrian path, including the speed of the walking area. In this process, PTV Viswalk version 2020 was used for the development of models, such as volume, speed, and geometry design, which included the measurements of pedestrian characteristics. The key parameter inputs also included the pedestrian kinds, routes, classes, behaviour, and desired speed. Moreover, the model's walking composition was determined by the walker's direction and type. This confirmed that pedestrians were only permitted to walk along pre-planned routes and zones, which were subsequently characterised manually based on ground conditions. Figure 1 illustrated a snapshot of the simulation model and field circumstances. In this case, the simulation process was carried out in the same condition as the observation field. A pedestrian also joined the queue with its kind, such as a man or woman, or while holding a bag. This indicated the mobility of objects along a straight path, from start to finish.

For equalisation, the actual results were compared to the pedestrian simulation model. This explained that the walking model was replicated during all observation hours, including morning, afternoon, and evening conditions. As an ideal kind of simulation, the usage with diverse study circumstances was assumed to develop no difference with field conditions. The calibration for walking behaviour parameters was also conducted using a trial-and-error procedure for each data. This was reinforced by testing the outcomes of the speed as the key parameter, to optimise the walking behaviour data. To determine the test parameters, the GEH and MAPE analyses were subsequently performed. Table 3 displays the simulation validation outputs, which showed that the adjusted value of the walking behaviour parameter was superior to the default. At the modification value, the resultant speed parameter was closer to the field output than the standard value.

Based on the MAPE values, similar results were specifically exhibited regarding the test parameters for pedestrian flow, where the default and modification conditions were in identical ranges of less than 10. This was accompanied by a comparison between the default and the modification conditions. In this process, the MAPE test value on the pedestrian flow parameter was greater in the default condition than in the modification. However, the contrast originated with the MAPE value in the pedestrian speed parameter, where a higher than 10 estimation value was identified in the default circumstance. This proved that the simulation outputs were less accurate in portraying the speed estimation in the actual condition, using the walking value. Under the modified circumstance of 7.238 or > 10, the MAPE test outputs were inversely observed. This indicated that the velocity value produced was closer to the field circumstances, by combining modifying behaviour settings.

Table 3. Validation parameter

Parameter	Speed	
	Default value	**Modified Value**
GEH Coefficient	1,204	1,059
MAPE Coefficient	10,538	7,238

Based on Table 3, the modified value outperformed that of the default. Table 4 compares the adjusted walking behaviour parameter value to the standard estimation. This explained that the variation from the default value exhibited the characteristics of Yogyakarta pedestrians. For example, the increase of the Asoc mean from its default value theoretically demonstrated that pedestrians preferred to travel inconsistently in a direction within their paths. This was because they were more careful about the people in front of them. These results were subsequently observed in the higher VD values, where pedestrians altered their movement position early to prevent accidents. In this process, they also travelled quicker and avoidantly when learning about the movement patterns of other people walking oppositely. On similar movement routes, pedestrians also move faster and avoidantly with a magnitude of the obstacle nearing the grid size. This proved that the speed appeared even when it was applied on a minor level (Lagervall & Samuelsson, 2014). Additionally, the validity of the walking behaviour value adjustments was evaluated to guarantee that the pedestrian flow simulations were used to reflect the field settings connected to the PC (pedestrian characteristics) in Yogyakarta.

Table 4. Walking behaviour values

Parameter	Default value	Simulated Value
Tau	0,4	0,05
React to n	8	3
Asoc_iso	2,72	1
Bsoc_iso	0,2	0,1
Laybda	0,176	1
Asoc_mean	0,4	0,7
Bsoc_mean	2,8	1
VD	3	6
Noise	1,2	2,4
Obstacle distance	0,5	0,5
Grid Size	0,5	2

According to the selection of models, the value of pedestrian behaviour combination parameters that should be used for the optimisation of walking systems was equivalent to the estimation of the PB (pedestrian behaviour) producing the smallest difference between simulation and field speed. The verification was then performed using a graph depicting the link between actual and simulation speed. Figure 4 shows the relationship between real and simulation speed from the default and adjusted values. An equation point around the 45° slope line was also found as the optimal solution (Pinna & Murrau, 2017). Based on the results, the real and simulation speed were more closely related to ideal circumstances. For the entire analytical duration, minor discrepancies and output comparability were also demonstrated between actual and simulated speed. Moreover, the results theoretically emphasised a study's normal distribution, whose data were adequately assessed for subsequent in-depth analysis (Raharjo, 2017). Since this present study aimed to obtain a standard design for pedestrian lines, sidewalks were provided throughout Indonesia and implemented as a local region in Yogyakarta. The T-statistic test also reinforced the final simulation outputs, where the p-value for the T-test was 0.103. This demonstrated that the selected parameter did not discernably affect the actual speed ($p>0.05$).

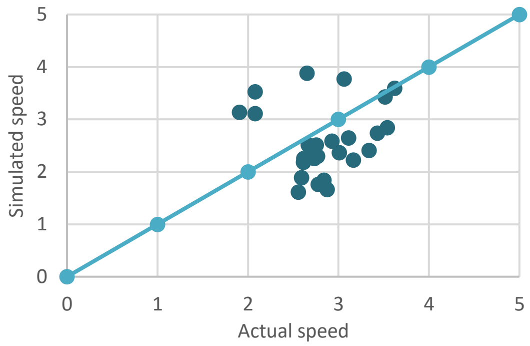

Figure 4. Simulated speed vs actual speed in modified value

Basic pedestrian capacity in Yogyakarta was analysed using a simulation model, which included a conventional sidewalk design. In this case, the standard design for the infrastructure was established by Indonesian Local Policy No. 3 of 2014. The simulation model was then developed with Viswalk using data input volume, speed, and pedestrian behaviour. Furthermore, the basic capacity was examined using three methods, namely linear, logarithmic, and exponential. Using the link between speed and density, the proper capacity was attained with the best value. Figure 5 depicts the PTV Viswalk output standard simulation. Under typical design parameters, the graph demonstrating the connection between speed and density had a negative slope. This indicated that higher density led to a slower speed. This was consistent with traffic theory, where high density reflected the number of pedestrians moving quickly on the walking lane. Speed also decreased when the movement of pedestrians was restricted by those walking together. Additionally, Viswalk simulation consisted of speed and density outcomes, where four types of function methods were observed, namely linear, logarithmic, exponential, and complex.

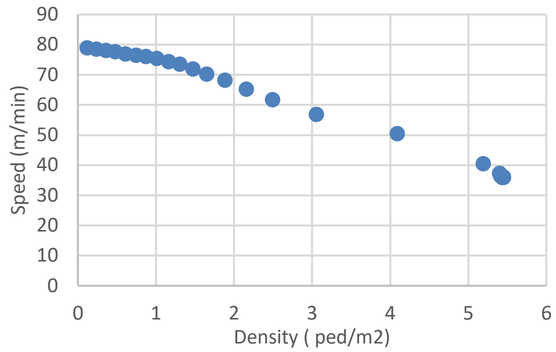

Figure 5. Output graphic simulation of standard design of sidewalk

The formulation of each linear function also emphasised Formula 2, regarding the approach's linearity assumption about the connection between velocity and density.

$$V = Vf\ x\ [1 - \left((\frac{k}{kj})^n \right)]^{((m+1)/2)} \quad (2)$$

Where V = a speed parameter (m/min) and k = a density parameter (person/m2). The formulation composition of the linear function equation was also a coefficient containing the values of V_f and K_j, which are the speed and density points intersecting the y and x axes, respectively. Subsequently, the values of m and n were observed as the coefficients of a free nature, depending on the data suitability. They also reflected the influential factors on the curvature of the final linear function. Table 5 displays some of the constructs produced from the reference and optimal functions obtained regarding the relationship between speed and density. This illustrated that the value of R^2 in the formulation of the optimum function model was the greatest, compared to other equations. Based on these results, the linear function approach in the optimum function definition model was better than that of other programs.

Table 5. Model function

Model Definition	Function	Function Parameter				R^2 Value
		Vf (m/minute)	Kj (ped/m²)	m	n	
Greenshield	$V = 82{,}90\ x\ [1 - \left((\frac{k}{9{,}69})^1 \right)]^1$	82,90	9,69	1,00	1,00	0,997
Kristex	$V = 86{,}00\ x\ [1 - \left((\frac{k}{28{,}16})^1 \right)]^4$	86,00	28,16	7,00	1,00	0,371
May and Keller	$V = 77{,}22\ x\ [1 - \left((\frac{k}{14{,}43})^{1{,}8} \right)]^5$	77,22	16,16	2,60	5	0,997
Optimal function	$V = 79{,}44\ x\ [1 - \left((\frac{k}{12{,}90})^{1{,}43} \right)]^{2{,}28}$	79,44	12,90	3,56	1,43	0,999

The next stage prioritised the identification of the fundamental capacity value. As previously stated, capacity is the maximum current a pedestrian path needs to attain. This showed that PF (pedestrian flow) was connected to PC (pedestrian capacity), with capacity being the limit of flow. These observations prioritised a point where the pedestrian movement was at a minimum and maximum, such as speed and density, respectively. According to the standard design of PUPR regulation No. 2 of 2018, the required sidewalk width should be 3 m, containing 2 m and 1 m for privileged and disabled people, respectively. Moreover, the relationship between the movement of pedestrian currents was defined by three key parameters, namely speed, density, and power. As previously stated, the link between velocity and density was the best construct in this linear function optimisation. This enhanced the construction of the relationship between current and density, which was then portrayed as a form of currency. The density and current functions are shown in the following equation.

$$Q = 79{,}44k\ \ x\ [1 - \left((\frac{k}{12{,}90})^{1{,}43} \right)]^{2{,}28} \quad (3)$$

Figure 6 shows the function and current density data, and the graph illustrated that the equation pattern had more current images than the simulation data. Regarding the coefficient of determination (r2), the value of the function's conformance with the simulation data was 0.974, which was close to 1. This indicated that the current originated from the density function and the greater simulation images. These results were because the pedestrian current parameter was solely connected with density in the function graph. Theoretically, the other impact on the present value was limited by the coefficient of the equation produced from the relationship between pedestrian speed and density. According to PTV AG (2020), the magnitude of the density exceeding 4 pedestrians/m2 produced output parameters different from the previous types. This was because the pedestrian spacing factor (space) was unable to allow pedestrians to pass through the path with the previous movement surpassing 4 persons/m².

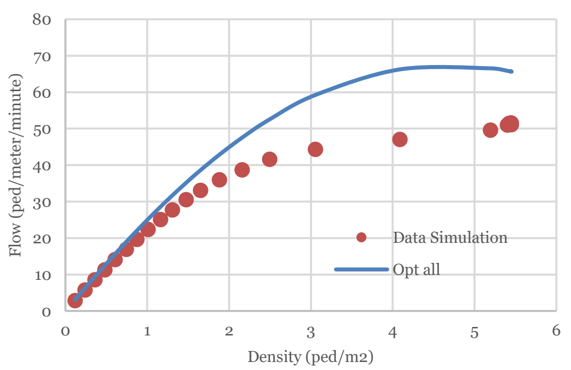

Figure 6. Density and flow on standard capacity

Based on Figure 6, the pedestrian path's capacity was 201 people/min in a standard width of 3 m or 67 persons/min/m. This emphasised the maximum flow associated with the ideal function established as the best construct. In a normal width of 3 m, the current is achieved at a saturated density of 4 people/m². When at maximum current, the pedestrian path width of 1.33 persons/m² or 0.75 m²/person was produced. This value exceeded the minimal space requirements established by previous reports, such as (Fruin, 1971) which was subsequently adopted into the HCM (2000) regulation. Based on the results, a pedestrian sidewalk route of 0.75 m²/person was produced with a minimum width of 0.5 m/person.

IV. CONCLUSION

The capacity of a pedestrian path limited the ability of the task execution area. In this process, a local approach generated a magnitude consistent with the features of the present path region. This study aimed to develop fundamental capacities for commercial areas in Indonesia, regarding the mobility of pedestrian norms. The results obtained generated an initial idea, which is included in the IRCM (Indonesian Road Capacity Manual) of the pedestrian sections used in urban areas. This idea was generated through the PTV Viswalk microscopic simulation tool and a social force model theory method. Therefore, the IRCM recommends a pedestrian path width capacity of 65 persons/min/m in commercial areas.

V. ACKNOWLEDGEMENT

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