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MODELING PEDESTRIAN FLOWS BETWEEN REGIE CAMPUS AND POLITEHNICA UNIVERSITY CAMPUS IN ORDER TO DESIGN A MOVING WALKWAY TRANSFER SYSTEM – PART 2

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Rezumat. *Investigația fluxurilor pietonale între Campusul Regie și campusul Politehnici București, este continuată în această cercetare. Această a doua fază evaluează eficiența operațională a unui sistem de trotuare rulante prin teoria cozilor și simulare, bazându-se pe constatări statistice și empirice din lucrarea anterioară, care au confirmat că sosirile pietonilor respectă o distribuție Poisson. Cercetarea analizează indicatorii de servire, cum ar fi timpul mediu de așteptare, capacitatea sistemului și fluxul în diferite condiții operaționale. Configurațiile pentru trotuarele rulante monocanal și multicanal sunt evaluate utilizând date despre pietoni, în funcție de timp, colectate pe o perioadă de patru săptămâni. Cercetarea subliniază efectul substanțial al sistemelor multicanal în reducerea duratelor de așteptare în perioadele de vârf de peste 90%.*

Abstract. *The investigation of pedestrian flow between the Regie Campus and the Politehnica University of Bucharest is continued in this research. This second phase evaluates the operational efficiency of a moving walkway system through queuing theory and simulation, building on statistical and empirical findings from the previous phase, which confirmed that pedestrian arrivals adhere to a Poisson distribution. The research analyses service indicators such as average wait time, system capacity, and flow rate across different operational conditions. Configurations for both single and multichannel moving walkways are assessed utilising time-dependent pedestrian data collected over a four-week period. Research underscores the substantial effect of dual-channel systems in reducing wait durations during peak periods, achieving reductions over 90%.*

Keywords: pedestrian flow, moving walkway, queuing theory, urban mobility, simulation

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1. Introduction

When it comes to the design of modern urban and campus infrastructure, improving pedestrian mobility is an essential component, particularly in corridors that experience a high volume of foot traffic. An example of this would be the 400-meter road that connects the Regie Campus to the Politehnica University campus. This pathway is widely utilised by both students and professors throughout the university. This research investigates the difficulties associated with traffic congestion in this region by recommending and analysing the adoption of a system that utilises moving walkways.

Following the empirical modelling that was done in the first portion of the research, in which pedestrian arrival patterns were statistically validated to follow a Poisson distribution, the focus of this second phase moves to the functioning of the system under various operational configurations. The study simulates a variety of queue scenarios and pedestrian service tactics by employing mass service theory and numerical simulations. Additionally, the study analyses single channel and multichannel systems. [1-5]

By determining the ideal layout, the goal is to reduce the amount of time spent waiting while simultaneously increasing the flow efficiency. This research offers urban planners practical solutions to improve accessibility, sustainability, and the overall pedestrian experience in high-density transit zones. These strategies are derived from the incorporation of minute-level pedestrian flow data and variations in service speed.

2. Literature review

Conditional Generative Adversarial Networks (cGANs) were employed by Mokhtar, Sojka, and Cerezo Davila to create a data-driven model that represents pedestrian wind flow in close proximity to buildings. This approach delivers expedited feedback compared to traditional computational fluid dynamics (CFD) simulations and yields initial design insights on pedestrian wind comfort. The model employs several geometric encoding methods, dataset specifications, and image resolutions to enhance precision. The model exhibited mean absolute errors (MAE) as low as 0.3 m/s, indicating its efficacy in initial design stages. The study identified limitations in the generalisability of the model, particularly in metropolitan environments that are remote from the training data. Future enhancements should encompass varied urban layouts and refine model training to enhance accuracy across multiple urban scenarios.[5]

Zhang et al. have created a hybrid modelling framework, MITO/MoPeD, that accurately represents pedestrian travel demand in the Munich metropolitan region by integrating pedestrian-centric modelling with an agent-based transit model.[1]

The framework combines MITO, an agent-based transport model, with MoPeD, a pedestrian demand model, to enhance the precision of travel result predictions. Mitigating the propensity of car-centric models to overstate walking proportions in sparsely populated border regions, the MITO/MoPeD system outperforms the Munich Model in forecasting walk shares and trip length distributions. It also offers more precise predictions of physical activity volumes, crucial for health effect assessments, and can inform sustainable urban mobility strategies that prioritise pedestrian needs.

3. Methodology

The mathematical models associated with serving traffic entities differ in relation to the aforementioned characteristics of input flows and service stations. Synthetic classification Kendall – Lee provides, for the purpose of identifying patterns, a coding of the form A/B/n: (m/D) where:

A – characteristic of the input flow (the probability density function of the intervals between entities in the input flow),
B – characteristic of the service (the probability density function of the service durations of the entities),
n – the number of identical service stations working in parallel,
m – the maximum number of places in the system (for requests-entities, in waiting and during service),
D – the service discipline.

If the average arrival rate, λ, is less than the average service rate, $n\mu$, ($\lambda << n\mu$), then the waiting time for requests before service begins is virtually nonexistent. Conversely, if $\lambda > n\mu$, it means that the waiting times before service begins are particularly significant, and if the inequality persists over time, the "queues" before service will continuously grow. For the case $\lambda < n\mu$, the most frequently encountered in traffic flow service, quantitative determinations are necessary for the significant parameters of the aforementioned service. The mathematical models we present serve these purposes. [4-11]

3.1. Determination of the system's service capacity the M/M/n:(∞/FIFO) system

Figure 1 illustrates a mass service system (queue system) featuring a single queue of waiting individuals and n parallel service stations, a model utilised for managing the servicing of pedestrians on the moving sidewalk. [12-15]

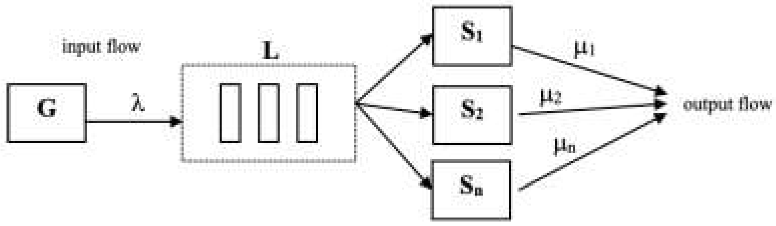

Fig. 1. Mass service system including a singular queue and multiple concurrent service stations

G - request generator, L – waiting line, S_i - service station, λ - the intensity of arrivals, μ - serving intensity.

In the initial segment of the inquiry, we asserted that the arrival flow adheres to a Poisson distribution with a mean intensity of λ. This was articulated in the conclusions. The service times follow a negative exponential distribution with a mean of μ; thus, the number of passengers served per unit time conforms to a Poisson distribution with an average rate of $\mu=1/\bar{t}_{sv}$, where $\bar{t}_{sv} = d/v_{sv}$, with d representing the distance and v_{sv} denoting the speed of a pedestrian. [4][16–23]

To address ethical concerns, the service protocol adheres to a methodology termed FIFO, which signifies "First In, First Out." The waiting list is indicated to include an unlimited number of positions, represented by the notation m, m=∞. Thus, the mass service system model appropriate for the travel agency is organised as follows, based on the Kendal-Lee classification. FIFO: M/M/n: (M/M/n).[6–9]

The stationary regime is not a property of the system's behaviour that can be easily characterised, despite its name suggesting otherwise. In waiting systems, the key parameters include the average waiting time for a unit to traverse the system and queue, represented as $\bar{t}_a$. The average duration for a request (entity) to traverse the system is represented as $\bar{t}_{sv}$. The average number of requests in the queue is represented as $\bar{n}_a$, whereas the average number of requests in the system is represented as $\bar{n}_s$. Little's connections pertain to the stationary regime for a single service station (n=1). [20–30]

$$\rho = \frac{\lambda}{\mu} < 1, \tag{1}$$

ρ – system request,

$$\bar{n}_a = \lambda \bar{t}_a, \tag{2}$$

$$\bar{n}_s = \lambda \bar{t}_{sv}, \tag{3}$$

$$\bar{t}_{sv} = \bar{t}_a + \frac{1}{\mu}, \tag{4}$$

$$\bar{n}_s = \bar{n} + \rho, \tag{5}$$

For the system with exponential "arrivals" and "departures," described in the Kendall-Lee classification as M/M/1:(∞/FIFO),[6-9] we can determine:

- the average waiting time of a unit in line[4][16][18][24-28]

$$\bar{t}_a = \frac{\rho}{1-\rho}\bar{t}_{sv} = \frac{\lambda}{\mu(\mu-\lambda)}, \tag{6}$$

- the average service time[4][16][18][24-28]

$$\bar{t}_{sv} = \frac{1}{\mu}, \tag{7}$$

- the probability of being n units in the system[4][16][18][24-28]

$$P(n) = \varphi^n(1-\varphi), \tag{8}$$

- the probability of not having any unit in the system[4][16][18][24-28]

$$P(0) = 1 - \varphi, \tag{9}$$

Analytical models for calculating service parameters are developed exclusively for a restricted number of simpler systems, influenced by factors such as the distribution of incoming flows, the number of service stations, the characteristics of service duration distribution, the service discipline, and the cooperation among service stations. For a Poisson input flow characterised by a negative exponential distribution of service times at n identical parallel service stations, we can ascertain:

the average waiting time of a unit in line[4][16][18][25-30]

$$\bar{t}_a = \frac{P(n)\cdot n\mu}{(n\mu-\lambda)^2} \tag{10}$$

the average service time[4][16][18][25-30]

$$\bar{t}_{sv} = \frac{1}{\mu} \tag{11}$$

the probability of being n units in the system[4][16][18][25-30]

$$P(n) = \frac{\rho^n}{n!}P(0) \tag{12}$$

the probability of not having any unit in the system[4][16][18][25-30]

To address ethical concerns, the service protocol adheres to a methodology termed FIFO, which signifies "First In, First Out." The waiting list is indicated to include an unlimited number of positions, represented by the notation m, m=∞. Thus, the mass service system model appropriate for the travel agency is organised as follows, based on the Kendal-Lee classification. FIFO: M/M/n: (M/M/n).[6–9]

4. Data collection

As stated in the first paper, for four weeks, data was collected on Monday, Tuesday, Wednesday, Thursday, and Friday. Tuesday's pedestrian flows were similar, so Tuesday's data will be used for following computations. The Regie Campus exit and Politehnica Campus entrance coridor saw foot traffic. This 400 m segment has two one-way traffic sessions, direction 1-2 (from Regie Campus to Politehnica Campus) and 2-1 (from Politehnica Campus to Regie Campus).

After using the for stages of resolving the problem in the first paper, we can move on to the next stage in order to determine the average waiting times in the queue.

Determining the average waiting time of a unit in queue, $\bar{t}_a$, for two scenarios: one walking sidewalk (n = 1) and two walking sidewalks (n = 2).

Each instance is subdivided into three categories:

- At serving intensity, μ_1 is 12.8 pedestrians per minute, for v_{sv} = 0.64 m/s (when all pedestrians are stationary and move at the speed of the conveyor belt of 0.64 m/s),[31,32]
- At serving intensity, μ_2 is 33.4 pedestrians per minute, for v_{sv} = 1.67 m/s (when all pedestrians travel at their average walking speed of 1.03 m/s[31,32] in addition to the conveyor belt speed of 0.64 m/s),
- At an intensity of service, μ_3 is 18.26 ped/min, with v_{sv} equal to 1.03 m/s (assuming 30% of pedestrians are stationary, moving at the speed of the conveyor belt, while 70% are travelling at their average walking speed in addition to the conveyor belt's speed), where v_{sv} denotes the speed of a pedestrian traversing the system.

Table 2. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 07:00-08:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,58333333	0,74869792	0,25130208	0,18814935	0,23275583	13,9653497
33,4		0,28692615	0,71307385	0,20459953	0,01204728	0,72283704
18,26		0,52482658	0,47517342	0,24938364	0,06048712	3,62922721

Table 2. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 08:00-09:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,33333333	0,72916667	0,27083333	0,19748264	0,21033654	12,6201923
33,4		0,27944112	0,72055888	0,20135378	0,01161113	0,69666761
18,26		0,51113545	0,48886455	0,249876	0,05725939	3,43556315

Table 3. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 09:00-10:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	8,68333333	0,67838542	0,32161458	0,21817864	0,16478998	9,88739879
33,4		0,25998004	0,74001996	0,19239042	0,01051841	0,63110461
18,26		0,47553852	0,52446148	0,24940164	0,04965595	2,97935723

Table 4. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 10:00-11:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,26666667	0,33333333	0,66666667	0,22222222	0,0390625	2,34375
33,4		0,12774451	0,87225549	0,11142585	0,00438482	0,26308938
18,26		0,23366192	0,76633808	0,17906403	0,01669809	1,00188532

Table 5. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 11:00-12:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	10,6333333	0,83072917	0,16927083	0,14061822	0,38341346	23,0048077
33,4		0,31836327	0,68163673	0,2170081	0,01398375	0,83902473
18,26		0,58232932	0,41767068	0,24322188	0,07635437	4,58126211

Table 6. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 12:00-13:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,18333333	0,40494792	0,59505208	0,2409651	0,05316603	3,18996171
33,4		0,15518962	0,84481038	0,1311058	0,00549993	0,32999565
18,26		0,28386272	0,71613728	0,20328468	0,02170758	1,30245451

Table 7. $\bar{t}_a$, for one walking sidewalk, n=1, direction 1-2, time interval 13:00-14:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,33333333	0,41666667	0,58333333	0,24305556	0,05580357	3,34821429
33,4		0,15968064	0,84031936	0,13418273	0,00568933	0,34136004
18,26		0,2920774	0,7079226	0,20676819	0,02259495	1,35569706

Table 8. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 07:00-08:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,58333333	0,45523449	0,12759052	0,01273251	0,76395073	0,45523449
33,4		0,55655868	0,0229098	0,00046747	0,02804812	0,55655868
18,26		0,51668453	0,07115855	0,00358154	0,21489258	0,51668453

Table 9. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 08:00-09:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,33333333	0,46145208	0,12267335	0,01186842	0,71210545	0,46145208
33,4		0,55738788	0,02176247	0,0004402	0,02641216	0,55738788
18,26		0,51970364	0,06788874	0,00335441	0,20126482	0,51970364

Table 10. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 09:00-10:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	8,68333333	0,4768914	0,10973433	0,00981641	0,58898486	0,4768914
33,4		0,55942739	0,01890574	0,00037391	0,02243469	0,55942739
18,26		0,52713791	0,05960266	0,00280907	0,16854397	0,52713791

Table 11. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 10:00-11:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,26666667	0,55085354	0,03060297	0,00172142	0,10328504	0,55085354
33,4		0,5690179	0,0046428	7,9311E-05	0,00475866	0,5690179
18,26		0,56192146	0,01533986	0,00053852	0,03231129	0,56192146

Table 12. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 11:00-12:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	10,6333333	0,42755065	0,14752869	0,01686034	1,01162031	0,42755065
33,4		0,55280087	0,02801461	0,0005932	0,03559222	0,55280087
18,26		0,50304383	0,08529295	0,00464827	0,27889639	0,50304383

Table 13. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 12:00-13:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,18333333	0,54010113	0,04428365	0,00271965	0,16317926	0,54010113
33,4		0,56761652	0,00683519	0,00012026	0,00721575	0,56761652
18,26		0,55690107	0,022437	0,00083443	0,05006581	0,55690107

Table 14. $\bar{t}_a$, for two walking sidewalks, n=2, direction 1-2, time interval 13:00-14:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,33333333	0,53811262	0,04671117	0,00291136	0,17468164	0,53811262
33,4		0,5673588	0,00723323	0,00012789	0,00767327	0,5673588
18,26		0,55597346	0,02371483	0,00089046	0,0534274	0,55597346

Table 15. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 10:00-11:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9	0,703125	0,296875	0,20874023	0,18503289	11,1019737
33,4		0,26946108	0,73053892	0,19685181	0,01104349	0,66260921
18,26		0,49288061	0,50711939	0,24994931	0,05322685	3,19361089

Table 16. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 11:00-12:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,63333333	0,36197917	0,63802083	0,23095025	0,04432398	2,65943878
33,4		0,13872255	0,86127745	0,11947861	0,00482234	0,28934021
18,26		0,25374224	0,74625776	0,18935712	0,01862101	1,11726036

Table 17. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 12:00-13:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,66666667	0,75520833	0,24479167	0,18486871	0,24102394	14,4614362
33,4		0,28942116	0,71057884	0,20565655	0,01219471	0,7316827
18,26		0,52939029	0,47060971	0,24913621	0,06160477	3,69628595

Table 18. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 13:00-14:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	7,81666667	0,61067708	0,38932292	0,23775058	0,1225439	7,35263378
33,4		0,23403194	0,76596806	0,17926099	0,00914783	0,54886969
18,26		0,42807594	0,57192406	0,24482693	0,04099035	2,4594213

Table 19. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 14:00-15:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	8,98333333	0,70182292	0,29817708	0,20926751	0,18388373	11,033024
33,4		0,26896208	0,73103792	0,19662148	0,01101551	0,6609307
18,26		0,49196787	0,50803213	0,24993548	0,05303283	3,1819697

Table 20. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 15:00-16:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,83333333	0,37760417	0,62239583	0,23501926	0,04739801	2,84388075
33,4		0,14471058	0,85528942	0,12376943	0,00506571	0,30394287
18,26		0,26469514	0,73530486	0,19463162	0,01971414	1,18284821

Table 21. $\bar{t}_a$, for one walking sidewalk, n=1, direction 2-1, time interval 16:00-17:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,78333333	0,45182292	0,54817708	0,24767897	0,06439281	3,86356888
33,4		0,17315369	0,82684631	0,14317149	0,0062699	0,3761939
18,26		0,31672143	0,68327857	0,21640897	0,0253851	1,523106

Table 22. $\bar{t}_a$, for two walking sidewalks, n=2, direction 2-1, time interval 10:00-11:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9	0,46950335	0,11605765	0,01078196	0,64691738	0,46950335
33,4		0,5584547	0,02027449	0,00040539	0,02432328	0,5584547
18,26		0,52359117	0,06359834	0,00306676	0,18400556	0,52359117

Table 23. $\bar{t}_a$, for two walking sidewalks, n=2, direction 2-1, time interval 11:00-12:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,63333333	0,5468395	0,03582589	0,00208631	0,12517842	0,5468395
33,4		0,56849287	0,00547002	9,4548E-05	0,00567286	0,56849287
18,26		0,5600458	0,01802931	0,00064758	0,03885464	0,5600458

Table 24. $\bar{t}_a$, for two walking sidewalks, n=2, direction 2-1, time interval 12:00-13:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	9,66666667	0,45312866	0,12921862	0,01303022	0,78181324	0,45312866
33,4		0,55627671	0,02329815	0,00047678	0,02860685	0,55627671
18,26		0,51565851	0,0722577	0,00365947	0,21956835	0,51565851

Table 25. $\bar{t}_a$, for two walking sidewalks, n=2, direction 2-1, time interval 13:00-14:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	7,81666667	0,49575605	0,09244028	0,00748299	0,44897913	0,49575605
33,4		0,56188847	0,01538758	0,00029545	0,01772717	0,56188847
18,26		0,53611422	0,0491212	0,00217738	0,13064305	0,53611422

Table 26. $\bar{t}_a$, for two walking sidewalks, n=2, direction 2-1, time interval 14:00-15:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	8,98333333	0,46989859	0,11572555	0,01072955	0,64377282	0,46989859
33,4		0,55850689	0,02020136	0,00040369	0,02422157	0,55850689
18,26		0,5237814	0,06338603	0,00305282	0,18316937	0,5237814

Table 27. $\bar{t}_a$, two walking sidewalks, n=2, direction 2-1, time interval 15:00-16:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	4,83333333	0,54448932	0,03881798	0,0023043	0,13825809	0,54448932
33,4		0,5681866	0,00594924	0,0001035	0,00620973	0,5681866
18,26		0,55894861	0,01958095	0,00071222	0,04273294	0,55894861

Table 28. $\bar{t}_a$, two walking sidewalks, n=2, direction 2-1, time interval 16:00-17:00

μ [ped/min]	λ [ped/min]	ρ	P(0)	P(n)	$\bar{t}_a$ [min]	$\bar{t}_a$ [s]
12,8	5,78333333	0,53175685	0,05427747	0,00353833	0,21229981	0,53175685
33,4		0,56653696	0,00849301	0,00015238	0,00914308	0,56653696
18,26		0,55300821	0,02773681	0,00107219	0,06433169	0,55300821

5. Design of a moving walkway system

The system comprises a total of three moving walkways, utilised in both directions. This infrastructure configuration offers both capacity for peak demand and operational redundancy for maintenance or technical difficulties.

During peak pedestrian periods (07:00–10:00 for direction 1-2 and 11:00–13:00 for direction 2-1), arrival rates reach roughly 9–10 pedestrians per minute, rendering a single moving walkway inadequate and leading to average waiting times of up to 23 seconds.

Conversely, activating two pathways in a single direction during peak periods reduces the average waiting time to less than 1 second, even amidst tremendous demand.

Off-peak hours (post-14:00) exhibit reduced arrival rates (4–6 pedestrians per minute), necessitating only one moving walkway per direction, with negligible queue forming.

Simultaneous use of all three walkways is seldom required; the system should prioritise intelligent distribution based on temporal factors and directional flow.

Tabel 29. Operating Strategy of the three moving walkways

Time Interval	Direction 1-2	Direction 2-1	Walkway Allocation
07:00–10:00 (Peak)	High pedestrian flow	Low–moderate flow	2 for 1-2, 1 for 2-1
10:00–11:00	Moderate flow	Increasing flow	1 for 1-2, 2 for 2-1
11:00–13:00 (Peak)	Moderate flow	High pedestrian flow	1 for 1-2, 2 for 2-1
13:00–15:00	Low flow	Moderate flow	1 for each, 1 standby
15:00–17:00	Low flow in both directions		1 for each, 1 standby

6. Conclusions

The second phase of this study expands upon the statistical underpinning that was developed in the first phase of research. It does this by translating empirical pedestrian flow data into architectural ideas that can be implemented for urban mobility. The performance of single and multichannel moving walkway systems was thoroughly examined across a variety of pedestrian speed situations and traffic intensities. This was accomplished through the application of queuing theory and modelling based on simulation.

The findings indicate that multichannel systems work much better than single-channel designs, particularly during peak hours, when the average waiting times were decreased by more than 90 percent. In order to achieve a balance between capacity, energy efficiency, and user pleasure, the dynamic allocation approach, which involves altering the usage of walkways depending on time intervals and directional flow, proven to be beneficial. Scalability and resilience are both supported by this approach when it comes to the planning of pedestrian infrastructure plans.

Additionally, the customisable character of the system that is being proposed is in line with the goals of contemporary urban planning, which place an emphasis on accessibility, sustainability, and the integration of intelligent transportation. This study presents a comprehensive framework for decision-makers who are looking to improve transit corridors within university campuses or other high-density locations. This framework is achieved by modelling the behaviour of pedestrians in the actual world and simulating numerous service scenarios.

This model should be expanded in the future to incorporate real-time adaptive technology, cost-benefit analysis, and environmental effect assessment. This will pave the way for intelligent pedestrian mobility systems that are efficient in terms of energy consumption in smart cities.

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