Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066-8570 Volume **17**, Number **1**/**2025** 61

MODELING PEDESTRIAN FLOWS BETWEEN REGIE CAMPUS AND POLITEHNICA UNIVERSITY CAMPUS IN ORDER TO DESIGN A MOVING WALKWAY TRANSFER SYSTEM – PART 1

Remus – Andrei DOBRINOIU[1],
Augustin SEMENESCU[2], Ionuț – Cosmin CHIVA[3], Florin Valentin RUSCĂ[4]

Rezumat. *Acest studiu oferă o analiză a traficului pietonal între Campusul Regie și campusul Politehnicii București, având ca scop crearea unui sistem de transfer cu trotuare rulante. Cercetarea folosește teoria cozilor pentru a prezice sosirile pietonilor și validează datele împotriva distribuțiilor teoretice, relevând că mișcarea pietonilor în diferite intervale de timp se apropie îndeaproape de o distribuție Poisson. Datele e colectate pe teren pe parcursul a patru săptămâni au fost împărțite și examinate la intervale de un minut pentru a obține frecvențe de sosire empirice precise. Compararea modelelor empirice și teoretice prin teste χ^2 a stabilit concordanța, justificând astfel aplicarea unui model Poisson pentru tiparele de sosire ale pietonilor. Aceste constatări stabilesc baza pentru îmbunătățirea vitezelor de servire și a capacității infrastructurii pentru un sistem de trotuare rulante, oferind o metodă scalabilă pentru creșterea mobilității campusurilor urbane.*

Abstract. *This study offers a comprehensive analysis of pedestrian traffic between the Regie Campus and Politehnica Bucharest campus, aiming to create a moving walkway transfer system. The research use queuing theory to predict pedestrian arrivals and validates the data against theoretical distributions, revealing that pedestrian movement across different time intervals closely adheres to a Poisson distribution. Comprehensive field data gathered over several weeks was divided and examined at minute-level intervals to get precise empirical arrival frequencies. The comparison of empirical and theoretical models via χ^2 tests established the concordance, thereby justifying the application of a Poisson model for pedestrian arrival patterns. These findings establish the basis for enhancing service velocities and infrastructure capacity for a moving walkway system, providing a scalable method for advancing urban campus mobility.*

Keywords: pedestrian flow, Poisson distribution, queuing theory, empirical modelling

DOI [10.56082/annalsarscieng.2025.1.61](https://doi.org/10.56082/annalsarscieng.2025.1.61)

[1]Ph.D. Student, Eng., National University of Science and Technology Politehnica Bucharest, Bucharest, Romania (e-mail: remus.dobrinoiu@upb.ro).
[2]Prof., Ph.D., National University of Science and Technology Politehnica Bucharest, Bucharest, Romania, Member of Academy of Romanian Scientists (augustin.semenescu@upb.ro).
[3]Ph.D., National University of Science and Technology Politehnica Bucharest, Bucharest, Romania (ionut_cosmin.chiva@upb.ro).
[4]Prof., Ph.D., National University of Science and Technology Politehnica Bucharest, Bucharest, Romania (florin.rusca@upb.ro).

1. Introduction

The dynamics of pedestrian circulation on university campuses are essential for effective transit and infrastructure development, particularly in high-density regions. A notable area is the corridor connecting the Regie Campus and Politehnica University of Bucharest, a commonly used 400-meter stretch by students and faculty. With the increasing needs of urban mobility, the incorporation of automated pedestrian aid systems, such as moving walkways, is a feasible alternative to alleviate congestion, improve accessibility, and optimise journey duration.

This article examines the statistical modelling of pedestrian traffic in the specified section, concentrating on quantifying arrival patterns and assessing their conformity to theoretical probability distributions. The study use queuing theory to model and evaluate flow behaviour through systematic data collecting across several weekdays and meticulous minute-level observations. This method facilitates the assessment of peak travel times and service requirements, which are crucial for developing an efficient transfer system with moving walkway technology.

Previous research highlights diverse techniques for predicting pedestrian mobility, including predictive models and hybrid frameworks that consider factors such as pedestrian comfort, safety, and spatial density. [1-4] These models underscore the imperative of adapting infrastructure to support high-density areas. Furthermore, studies indicate that utilising simplified, distance-based models can yield accurate predictions of pedestrian flow without necessitating comprehensive route feature data. [5-9] Conventional models may insufficiently predict traffic patterns in dynamic, high-traffic areas.

2. Literature review

Ernazarov's research on regulated intersections in high-traffic zones seeks to mitigate congestion by examining traffic delays and variables such as pedestrians impeding turning vehicles. He employs a traffic flow model to simulate an intersection in Jizzakh, Uzbekistan, discovering that the duration of congestion is markedly affected by the intensity of pedestrian and vehicular traffic. A three-phase traffic light system, which facilitates pedestrian movement while prohibiting vehicular access during one phase, reduced congestion by an average of 45.3%, providing "conflict-free" pedestrian transit. Ernazarov posits that this method may be crucial for traffic management, especially in congested urban settings, as it reconciles the requirements of both pedestrians and automobiles. [1]

Five predictive models are assessed in Sevtsuk and Kalvo's study on pedestrian flow forecasting in San Francisco: shortest path, equal probability, distance-weighted, utility-weighted, and highest utility. The utility-weighted model, which integrates route quality characteristics, exhibits the highest projected accuracy. Nevertheless, the distance-weighted model exhibits comparable accuracy, indicating its promise as a viable alternative in situations where route features are scarce.[3]

3. Methodology

The management of traffic entities from incoming flows can be analysed using mathematical models of queueing theory or by numerical simulation via a computer. In both scenarios, the input flow is defined by the distinct sizes of the traffic flows entering the network nodes, regarded as service stations, for which the average service intensity and the maximum number of entities present in the system at any moment (both waiting and in service) are established. Based on the attributes of the input flow, key service parameters can be ascertained either analytically or via simulation: the mean duration of an entity's transit through the system, the average waiting time prior to service initiation, the average queue length, the mean number of entities within the system at any given time, or the likelihood of refusal when the single-channel service station lacks waiting capacity and demand persists, or when the number of requests in the system reaches the maximum capacity for both waiting and servicing at the station.

3.1. Initial elements

The empirical frequencies of pedestrians arriving at the moving walkway, determined for a sample of N unit time intervals (1 minute), are presented in Table 1.[10] [11-17]

Table 1. Empirical frequencies of pedestrians arrivals (ped./min)

x_i	0	1	2	3	4	5	6	7	≥8
n_i									

3.2. Analysis of the arrival flow of pedestrians

The discrete random variable associated with the arrival of travelers at the agency is of the form: [10][11-24]

$$x\begin{pmatrix} x_i \\ p_i \end{pmatrix}, i = 0,1,2 \ldots, \tag{1}$$

x_i - the number of pedestrians arriving at the moving walkway per unit of time;

p_i - the probability of x_i pedestrians arriving at the moving walkway in a unit of time.

The probability p_i (the probability density) is calculated using the relation: [10] [11-24]

$$p_i = \frac{n_i}{\sum_k n_k}, \tag{2}$$

where ni are the empirical frequencies of pedestrians arrivals at the moving walkway per unit time (Tabel 1).

The distribution function of the random variable is: [10][11-24]

$$\Phi(x) = P(X \leq x) = \sum_{x_i \leq x} p_i \tag{3}$$

The average value of the distribution corresponding to the flow of arrivals is: [10][11-24]

$$\bar{x} = M(X) = \sum_{x_i \leq x} p_i \tag{4}$$

The selection dispersion of the arrival distribution of travelers is: [10][11-24]

$$s^2 = \frac{N}{N-1}\left[\sum_i (x_i - \bar{x})^2 p_i\right], \tag{5}$$

3.3. Determination of the theoretical distribution corresponding to the empirical distribution of pedestrian arrivals

If from the previous calculations it is observed that $\bar{x} \cong s^2$, it follows that the empirical distribution can be assimilated with a theoretical Poisson distribution with a mean of the form $\lambda=\bar{x}$.[10][11-24]

In the case of the Poisson distribution, the probability density is given by the relation:

$$P(k) = \frac{\lambda^k}{k!} e^{-\lambda}, k = 0,1,2, ..., \tag{6}$$

where P(k) represents the probability of k pedestrians arriving at the moving walkway in a unit of time. [10] [11-24] The corresponding distribution function is:[10] [11-24]

$$F(x) = P(X \leq x) = \sum_{k \leq X} P(k) \tag{7}$$

Theoretical frequencies of pedestrian arrivals at the moving walkway are determined by the relationship: [10] [11-24]

$$n'_k = N \cdot P(k), k = 0,1,2, \ldots \tag{8}$$

The verification of the concordance between the empirical distribution and the theoretical distribution of the arrival of travelers at the agency is carried out using χ^2 test. The parameter estimated in the concordance test is the mean of the distribution $\lambda=\bar{x}$. The function has a distribution characterized by the number of degrees of freedom f:[10] [11-24]

$$f = n - k - 1 \tag{9}$$

n - the number of observed empirical frequencies;

k - the number of estimated parameters of the theoretical distribution (k=1).

The value of χ_c^2 is calculated using the formula: [10] [11-24]

$$\chi_c^2 = \sum_i \frac{(n_i - n'_i)^2}{n'_i} \tag{10}$$

The empirical distribution is in accordance with the theoretical Poisson distribution if $\chi_c^2 < \chi_{0,f,\alpha}^2$, where $\chi_{0,f,\alpha}^2$, represents the distribution value for a number of degrees of freedom f and a significance level α (α=0,05). [10] [11-24]

4. Data assessment

Data collection occurred throughout five days (Monday, Tuesday, Wednesday, Thursday and Friday) for four weeks; hence, the data gathered on Tuesday will be utilised for subsequent computations, as pedestrian flows on Tuesday were observed to be approximately equivalent. The pedestrian movement was observed in the segment between the Regie Campus exit and the entrance coridor of the Politehnica Campus. This 400 m section delineates two traffic periods, each corresponding to a single direction of travel. The data were gathered from 07:00 to 17:00, with the peak pedestrian flows for phase I occurring between 07:00 and 14:00 (directions 1-2, from Regie Campus to Politehnica Campus) and for phase II between 10:00 and 17:00 (directions 2-1 from Politehnica Campus to Regie Campus).

Stages of solving the problems:

1. Dividing the pedestrian flows, for each direction, into hourly intervals (1 h), which in turn will be divided into subintervals (1 min);

2. Analysis of the arrival and service flows of the pedestrians

3. Determining the numerical characteristics associated with the input distributions

4. Establishing the theoretical distribution that approximates the empirical distribution of pedestrian arrivals

4.1. Pedestrian flow for directions 1-2

Table 2. Empirical frequencies of pedestrians arrivals for interval 07:00-08:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
n_i	0	0	1	1	1	1	1	5	10	13	10	9	1	1	1	1	1	1	1	1

$\bar{x} = 9{,}58333333$; $s^2 = 9{,}67090395$

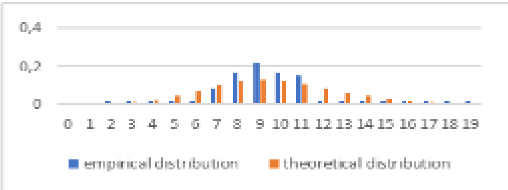

Fig. 1. The probability density of the arrival stream for interval 07:00-08:00

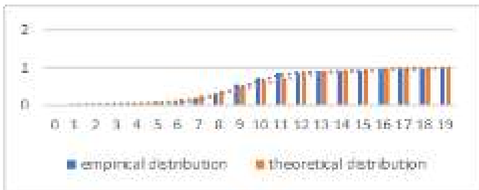

Fig. 2. The distribution function of the arrival flow for interval 07:00-08:00

$\chi_c^2 = 27{,}747959$ and $\chi_{0,f,\alpha}^2 = 28{,}87$ for $f = 18$, $\alpha = 0{,}05$

Table 3. Empirical frequencies of pedestrians arrivals for interval 08:00-09:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
n_i	0	0	1	1	2	2	3	5	10	10	6	6	4	4	3	2	1	1	1	1

$\bar{x} = 9{,}33333333$; $s^2 = 9{,}20903955$

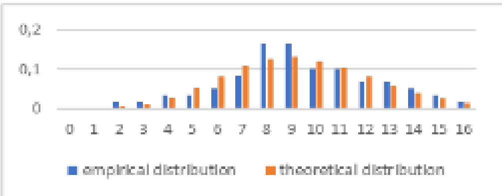

Fig. 3. The probability density of the arrival stream for interval 08:00-09:00

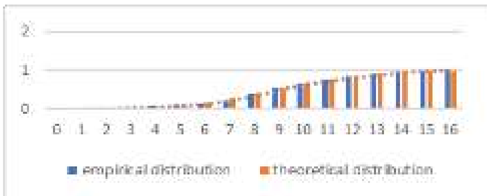

Fig. 4. The distribution function of the arrival flow for interval 08:00-09:00

$\chi_c^2 = 6{,}53926257$ and $\chi_{0,f,\alpha}^2 = 25$ for $f = 15$, $\alpha = 0{,}05$

Table 4. Empirical frequencies of pedestrians arrivals for interval 09:00-10:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
n_i	0	1	1	2	2	2	3	6	8	12	9	7	2	2	1	1	1

$\bar{x} = 8{,}68333333$; $s^2 = 8{,}76242938$

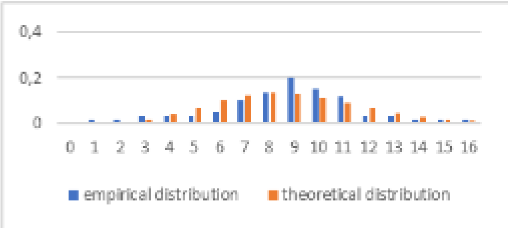

Fig. 5. The probability density of the arrival stream for interval 09:00-10:00

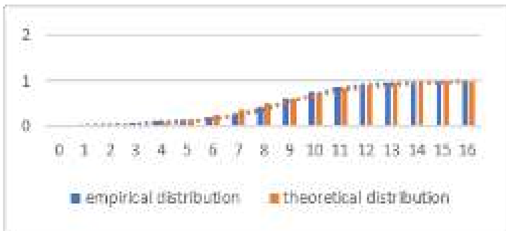

Fig. 6. The distribution function of the arrival flow for interval 09:00-10:00

$\chi_c^2 = 19{,}3255686$ and $\chi_{0,f,\alpha}^2 = 25$ for $f = 15$, $\alpha = 0{,}05$

Table 5. Empirical frequencies of pedestrians arrivals for interval 10:00-11:00

x_i	0	1	2	3	4	5	6	7	8
n_i	3	3	5	10	10	11	10	6	2

$\bar{x} = 4{,}26666667$; $s^2 = 4{,}02937853$

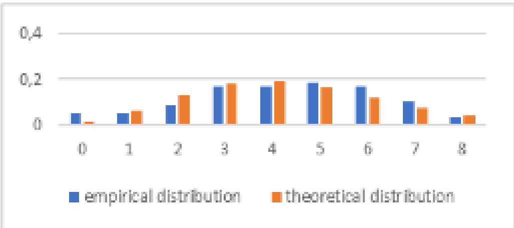

Fig. 7. The probability density of the arrival stream for interval 10:00-11:00

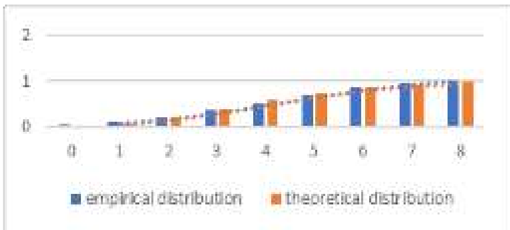

Fig. 8. The distribution function of the arrival flow for interval 10:00-11:00

$\chi_c^2 = 8{,}91655052$ and $\chi_{0,f,\alpha}^2 = 14{,}07$ for $f = 7$, $\alpha = 0{,}05$

Table 6. Empirical frequencies of pedestrians arrivals for interval 11:00-12:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
n_i	0	0	1	1	1	1	2	3	4	4	6	9	8	8	7	1	1	1	1

$\bar{x} = 10{,}6333333$; $s^2 = 10{,}4214501$

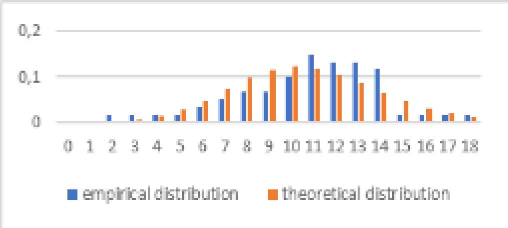

Fig. 9. The probability density of the arrival stream for interval 11:00-12:00

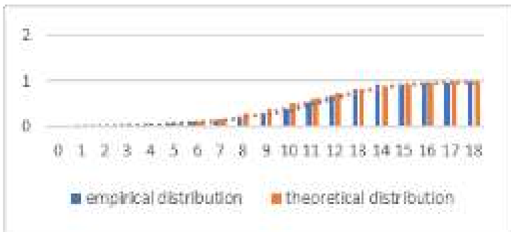

Fig. 10. The distribution function of the arrival flow for interval 11:00-12:00

$\chi_c^2 = 21{,}834135$ and $\chi_{0,f,\alpha}^2 = 27{,}58$ for $f = 17$, $\alpha = 0{,}05$

Table 7. Empirical frequencies of pedestrians arrivals for interval 12:00-13:00

x_i	0	1	2	3	4	5	6	7	8	9	10
n_i	1	3	4	6	8	10	10	8	7	2	1

$\bar{x} = 5{,}18333333$; $s^2 = 5{,}10141243$

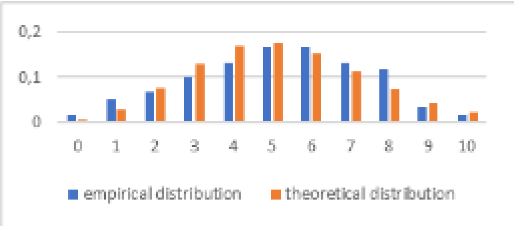

Fig. 11. The probability density of the arrival stream for interval 12:00-13:00

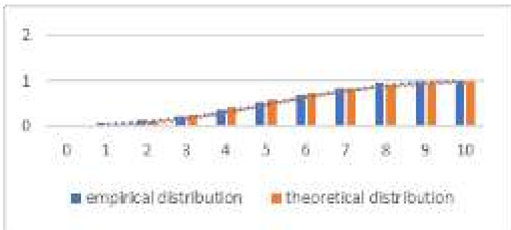

Fig. 12. The distribution function of the arrival flow for interval 12:00-13:00

$\chi_c^2 = 5{,}28900385$ and $\chi_{0,f,\alpha}^2 = 16{,}92$ for $f = 9$, $\alpha = 0{,}05$

Table 8. Empirical frequencies of pedestrians arrivals for interval 13:00-14:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
n_i	2	2	2	6	10	9	9	8	7	5	8	7	6	4	3

$\bar{x} = 5{,}33333333$; $s^2 = 5{,}27683616$

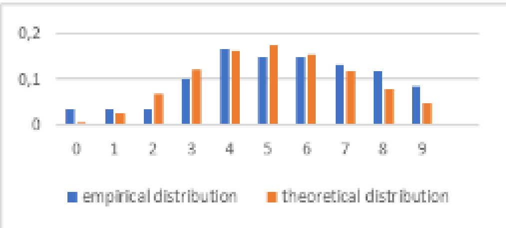

Fig. 13. The probability density of the arrival stream for interval 13:00-14:00

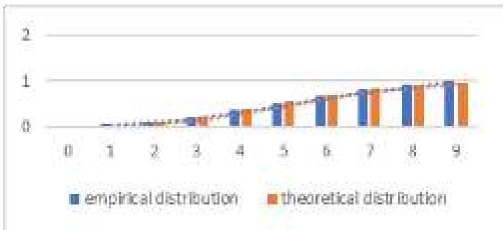

Fig. 14. The distribution function of the arrival flow for interval 13:00-14:00

$\chi_c^2 = 14{,}7735355$and $\chi_{0,f,\alpha}^2 = 15{,}51$ for $f = 8$, $\alpha = 0{,}05$

4.2. Pedestrian flow for directions 1-2

Table 9. Empirical frequencies of pedestrians arrivals for interval 07:00-08:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
n_i	0	0	1	2	3	3	3	4	8	8	8	7	6	4	3

$\bar{x} = 9$; $s^2 = 8{,}881355932$

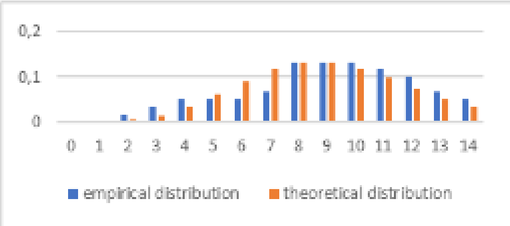

Fig. 15. The probability density of the arrival stream for interval 10:00-11:00

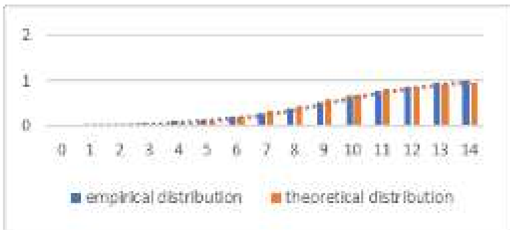

Fig. 16. The distribution function of the arrival flow for interval 10:00-11:00

$\chi_c^2 = 7{,}90817038$ and $\chi_{0,f,\alpha}^2 = 22{,}36$ for $f = 13$, $\alpha = 0{,}05$

Table 10. Empirical frequencies of pedestrians arrivals for interval 11:00-12:00

x_i	0	1	2	3	4	5	6	7	8
n_i	1	3	7	8	10	9	8	8	6

$\bar{x} = 4{,}63333333$; $s^2 = 4{,}473446328$

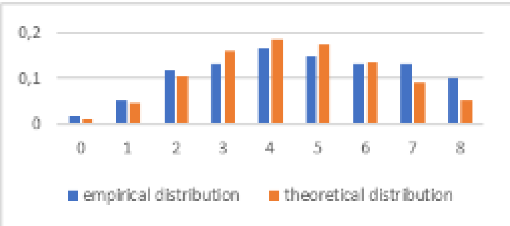

Fig. 17. The probability density of the arrival stream for interval 11:00-12:00

Fig. 18. The distribution function of the arrival flow for interval 11:00-12:00

$\chi_c^2 = 5{,}17482994$ and $\chi_{0,f,\alpha}^2 = 14{,}07$ for $f = 7$, $\alpha = 0{,}05$

Table 11. Empirical frequencies of pedestrians arrivals for interval 12:00-13:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
n_i	0	0	0	0	1	2	5	6	9	9	9	8	2	2	2	1	1	1	1	1

$\bar{x} = 9{,}66666667$; $s^2 = 9{,}81920904$

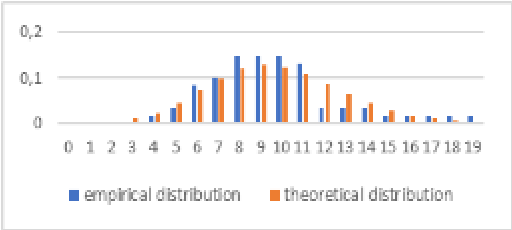

Fig. 19. The probability density of the arrival stream for interval 12:00-13:00

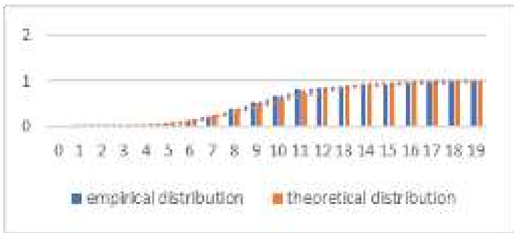

Fig. 20. The distribution function of the arrival flow for interval 12:00-13:00

$\chi_c^2 = 11{,}9230768$ and $\chi_{0,f,\alpha}^2 = 28{,}87$ for $f = 15$, $\alpha = 0{,}05$

Table 12. Empirical frequencies of pedestrians arrivals for interval 13:00-14:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13
n_i	0	1	1	2	3	3	9	10	9	5	5	5	4	3

$\bar{x} = 7{,}81666667$; $s^2 = 7{,}847175141$

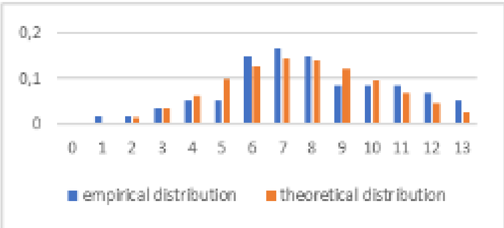

Fig. 21. The probability density of the arrival stream for interval 13:00-14:00

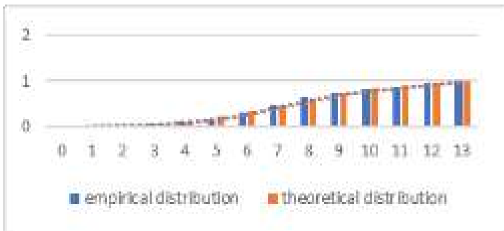

Fig. 22. The distribution function of the arrival flow for interval 13:00-14:00

$\chi_c^2 = 8{,}70503615$ and $\chi_{0,f,\alpha}^2 = 21{,}03$ for $f = 12$, $\alpha = 0{,}05$

Table 13. Empirical frequencies of pedestrians arrivals for interval 14:00-15:00

x_i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
n_i	0	0	1	1	2	4	5	5	7	8	8	6	6	4	2	1

$\bar{x} = 8{,}98333333$; $s^2 = 8{,}59293785$

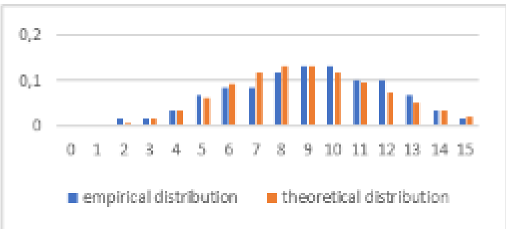

Fig. 23. The probability density of the arrival arrival stream for interval 14:00-15:00 15:00

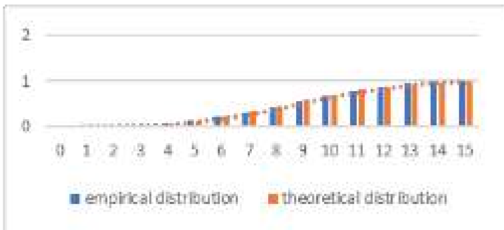

Fig. 24. The distribution function of the flow for interval 14:00-

$\chi_c^2 = 3{,}57077232$ and $\chi_{0,f,\alpha}^2 = 27{,}58$ for $f = 17$, $\alpha = 0{,}05$

Table 14. Empirical frequencies of pedestrians arrivals for interval 15:00-16:00

x_i	0	1	2	3	4	5	6	7	8
n_i	2	3	4	7	9	9	11	9	6

$\bar{x} = 4{,}83333333$; $s^2 = 4{,}5819209$

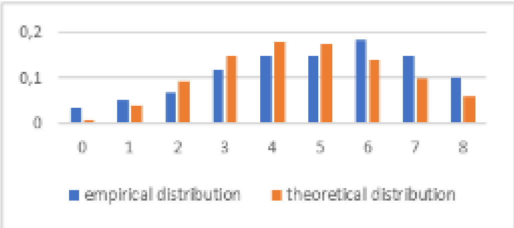

Fig. 25. The probability density of the arrival stream for interval 15:00-16:00

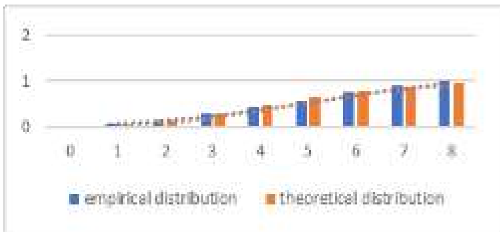

Fig. 26. The distribution function of the arrival flow for interval 15:00-16:00

$\chi_c^2 = 10{,}6867536$ and $\chi_{0,f,\alpha}^2 = 10{,}07$ for $f = 7$, $\alpha = 0{,}05$

Table 15. Empirical frequencies of pedestrians arrivals for interval 16:00-17:00

x_i	0	1	2	3	4	5	6	7	8	9	10
n_i	0	2	3	7	7	8	9	9	6	5	4

$\bar{x} = 5{,}78333333$; $s^2 = 5{,}698022599$

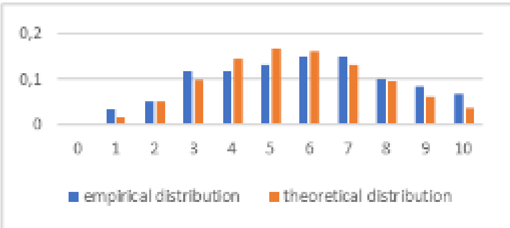

Fig. 27. The probability density of the arrival stream for interval 16:00-17:00

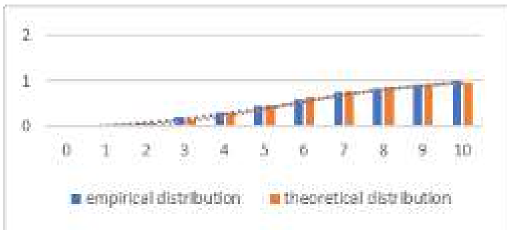

Fig. 28. The distribution function of the arrival flow for interval 16:00-17:00

$\chi_c^2 = 4{,}17392787$ and $\chi_{0,f,\alpha}^2 = 16{,}92$ for $f = 9$, $\alpha = 0{,}05$

5. Conclusions

It is observed that for all time intervals (direction 1-2 and 2-1) $\bar{x} \cong s^2$, resulting that the empirical distribution is being assimilated to a theoretical Poisson distribution with the mean $\lambda = \bar{x}$.

$\chi_c^2 < \chi_{0,f,\alpha}^2$ for all time intervals (direction 1-2 and 2-1). It results that there is concordance between the empirical distribution and the theoretical Poisson distribution.

The study indicates that the arrival flow follows a Poisson distribution with an average intensity of λ. The service times exhibit a negative exponential distribution with a mean of μ; consequently, the number of passengers serviced per unit time adheres to a Poisson distribution with an average rate of $\mu=1/\bar{t}_{sv}$. $\bar{t}_{sv}$ is the average service time, which has a different value for each v_{sv} (serving speed), that we will study in the next article.

This pattern is consistent with other studies conducted in high-traffic urban environments. This alignment indicates that the methodology employed in this study is both robust and suitable for replication in comparable settings.

The study provides actionable insights; however, there are numerous obstacles that must be resolved. The variability of real-world scenarios may not be completely captured by the assumptions regarding uniform pedestrian behaviour and consistent peak periods. For example, this analysis did not consider the potential impact of public events, transitory construction, or weather conditions on pedestrian flow dynamics.

R E F E R E N C E S

[1] Kim, E.J., & Gong, Y., *Perceived built environments correlated to route choice for healthy leisure walking,* Journal of Asian Architecture and Building Engineering, 0:0, pages 1-12, (2024)

[2] Sevtsuk, A., *Estimating Pedestrian Flows on Street Networks*, Journal of the American Planning Association, 87:4, pages 512-526, (2021)

[3] Sevtsuk, A., Kalvo, R., *Predicting pedestrian flow along city streets: A comparison of route choice estimation approaches in downtown San Francisco*, International Journal of Sustainable Transportation, 16(3), 222–236, (2021).

[4] Ewing, R., Hajrasouliha, A., Neckerman, K.M., Purciel-Hill, M. & Greene, W., *Streetscape features related to pedestrian activity,* Journal of Planning Education and Research**,** *36*(1), 5–15, (2016)

[5] Zhang, Q., Moeckel, R., Clifton, K.J., *MoPeD meets MITO: a hybrid modeling framework for pedestrian travel demand*, Transportation, 51, 1327–1347, (2024).

[6] Antonini, G., Bierlaire, M., Weber, M., *Discrete choice models of pedestrian walking behavior,* Transp. Res. Part b Methodol**,** 40(8), 667–687, (2006).

[7] Clifton, K.J., Singleton, P.A., Muhs, C.D., Schneider, R.J., *Representing pedestrian activity in travel demand models: framework and application,* J. Transp. Geogr, 52, 111–122, (2016).

[8] Borrmann, A., Kneidl, A., Köster, G., Ruzika, S., Thiemann, M., *Bidirectional coupling of macroscopic and microscopic pedestrian evacuation models,* Saf. Sci, 50(8), 1695–1703, (2012).

[9] Cotrus, A.V., Prashker, J., Shiftan, Y., *Spatial and temporal transferability of trip generation demand models in Israel,* J. Transp. Stat, 8, 37–56, (2005).

[10] Raicu, Ș., *Sisteme de Transport*, Editura AGIR, București, România, (2007).

[11] Hernández-Suárez, C. M., Castillo-Chavez, C. López, O. M., Hernández-Cuevas, K., *An application of queuing theory to SIS and SEIS epidemic models[J],* Mathematical Biosciences and Engineering, 7(4): 809-823, (2010).

[12] Asmussen, S. & Boxma, O.J., *Editorial introduction,* Queueing Syst*,* 63, 1, (2009).
[13] Roşca, E., Ruscă, F., *Informatică și Cibernetică în Transporturi - îndrumar de laborator,* CreateSpace Independent Publishing Platform, București, Romania, (2013).
[14] Rosca, E., Ruscă, A., Popa, M., Ruscă, F.V. & Olteanu, S., *Modelling and Simulation for Intermodal Transportation in Logistics Chains, In: Sładkowski, A. (eds) Modern Trends and Research in Intermodal Transportation,* Studies in Systems, Decision and Control. Springer, Cham, 400, 1-48, (2022).
[15] Ramaswami, V., *A stable recursion for the steady state vector in markov chains of m/g/1 type,* Communications in Statistics. Stochastic Models, 4, 183–188, (1988).
[16] Szel, A., Bungău, C., *Fundamentarea optimă a deciziilor în sisteme tehnico-economice*, Editura Universităţii din Oradea, Oradea, România, (2011).
[17] Asmussen, S., Boxma, O.J., *Editorial introduction,* Queueing Syst, 63, 1, (2009).
[18] Mihoc, G., Ciucu, G., Muja, A., *Modele matematice ale așteptării,* Editura Academiei RSR, București, România, (1973).
[19] Sundarapandian, V., *Queueing Theory. Probability, Statistics and Queueing Theory*, PHI Learning, India, (2009).
[20] Whittle, P., *Applied Probability in Great Britain*, Operations Research, 50 (1): 227–239, (2002).
[21] Cox, R.T., *The Algebra of Probable Inference*, Johns Hopkins University Press, Baltimore, USA (1961).
[22] Cox, D., Little, J., O'Shea, D., *Ideals Varieties and Algorithms, An Introduction to Computational Algebraic Geometry and Commutative Algebra Undergraduate Texts in Mathematics, 3rd edition,* Springer*,* New York, USA, (2015).
[23] Cox, D. A., Little, J., O'Shea, D., *Using Algebraic Geometry, 2nd ed*, Springer-Verlag New York, USA, (2005).
[24] Harris, D. *The Distribution of Returns,* Journal of Mathematical Finance, 7, 769-804, (2017).