

Estimation of Pedestrian Flows in Urban Context: A Comparison Between the Pre and Post Pandemic Period

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Abstract. The Covid-19 pandemic, within a few months, radically changed the organization of daily life on a global scale; this has affected all aspects related to everyday life such as home-to-work or not home-to the work trips, accessibility of destination, recreational activities and so on.

The need to reduce coronavirus transmission, especially indoors, has imposed the "social or physical distancing" that has required administrations to reorganize roads and sidewalks for public use both to tackle this crisis and to prepare for the future pandemic challenges. Following a previous extensive study devoted to the analysis and prediction of pedestrian flows in urban area in the city of Cassino, a new experimental campaign has been recently designed and carried out in order to validate the previous methodology and/or to highlight new trends in urban pedestrian activities.

Comparison between pre-pandemic and post-pandemic data and calibrated models provided an interesting insight on the pedestrian behavioral impacts of emergency measures undertaken during pandemic. It is believed that obtained results may provide a useful knowledge for urban planners and designers to retrofit urban spaces taking into account the new pedestrian attitudes to mobility induced by the pandemic.

Keywords: Pedestrian flows prediction · Space Syntax · Hybrid model · Pre- and post-pandemic scenarios

1 Introduction

The Covid-19 pandemic can be regarded as the result of an *environmental imbalance*, generated by a disproportionate anthropogenic pressure on natural ecosystems, which has produced a virus that uses humans as a vector to spread. The strong interconnectedness of individuals, who travel from one part of the planet to another by plane, in a few hours has allowed the virus to spread rapidly on a global scale.

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O. Gervasi et al. (Eds.): ICCSA 2022 Workshops, LNCS 13380, pp. 484–495, 2022.
https://doi.org/10.1007/978-3-031-10542-5_33

This has generated an upheaval in people's lives by interrupting and changing their habits and passions [1].

In fact, to contain the spread of the virus, governments have been forced to impose restrictions with the consequent reduction of people's mobility (such as the blocking of flights, the temporary prohibition of intercity travel, up to total isolation in homes) and corresponding traffic volumes and public transport services. After the lockdown phase, a gradual restart has begun which required adapting the work environments and public spaces to the safety conditions required by this new risk.

Very recent observations about the impacts of the pandemic phase on habits and behaviors (conscious and unconscious) regarding the mobility, both private and public, are restituting a complex scenario: purpose, time, distance of trips and social distancing are the main affecting aspects [2, 3].

This has given rise to the problem of also modifying transport systems to ensure safe mobility for people, without losing their efficiency, since the traditional definition of such parameter for a transport system (i.e. the ability to use few vehicles to transport many people, increasing the load factor) seems to clash with the imperatives of physical distancing. In fact, it is well known that a significant amount of all trips is made during peak hours, when public transport operates near or sometimes beyond its capacity whereas it often reaches a half-empty condition during off-peak hours.

Therefore, the spatial-temporal concentration of mobility must be reduced (also exploiting technologies to mitigate queues, congestion and gatherings [4]) to avoid a sudden return to the use of the individual car (with all the consequences of congestion, climate change, degradation of urban quality of life, occupation of public spaces, road accidents, etc.).

Basing on these premises, in order to reduce the risks of contagion from Covid-19, as suggested by the World Health Organization [5], many cities are aiming at redesigning their urban spaces by promoting first and foremost pedestrian and cycling mobility (thus also yielding noticeable results in terms of mortality reduction, health, economy and society).

To this purpose the revision of mobility paradigm falls within the major issues of climate change and sustainable development, leading to a clear compliance with the Sustainability Development Goals (SDGs) defined by Agenda 2030 [6, 7], focusing above all on issues such as de-carbonization, energy independence, air quality as a measure of health resilience, promotion of local production and urban electricity logistics, integration of sustainable mobility development with the redevelopment of social spaces of urban life.

Following the urban policies undergoing in most of European countries, also in Italy, greater attention was paid to sustainable mobility in the post lockdown, leading to an increase in citizens' travel on foot and by bike (thanks also to the eco-bonus incentive policies).

The increase of dedicated spaces for pedestrians and bicycles has also led to the spread of micro-mobility. This term refers to individual transport devices (scooters, segways, monowheels and hoverboards), of small dimensions, usually with electric traction, the most representative example of which is the electric scooter.

In this particular historical period, citizens have had the opportunity to experience the benefits of walking or cycling, such as reducing the risk of many diseases and increasing psychophysical well-being.

Given the increase of vulnerable users, in order to design or to retrofit public areas such as squares or roads to accommodate the new mobility, ad hoc engineered tools are needed that allow obtaining cycle networks and sidewalks capable of guaranteeing the required physical spacing and that should be safe, usable and accessible to all [8–10].

However, since there are few and poor guidelines in Italy that can help technicians in the careful planning of these interventions, there is the need to develop engineering-based models to evaluate the impact on pedestrian or cyclist activities of new re-designed urban areas.

According to several studies pedestrian activity is indeed linked to network connectivity but at the same time is influenced by other variables such as population, land use, purpose of travel, transport supply [11–13]. Therefore, a new hybrid approach to pedestrian modelling has been proposed and experimentally calibrated in order to predict pedestrian activity on road network that is based on a combination of land use data and configurational analysis [14, 15].

However, because of the radical change in road users' behavior following the pandemic period, it has been recognized that the proposed approach needs to be compared against the new pedestrian scenarios, and therefore an additional experimental campaign has been carried out to verify the reliability of the proposed approach in capturing pedestrian flows in the post-pandemic age.

Then the obtained data have been analyzed by using the same modelling approach and a comparison between evaluation provided in the pre-Covid and post-Covid conditions has been derived in order to highlight how the propensity of vulnerable users to pedestrian mobility has changed.

The novelties of this study are first of all the comparison of pedestrian flows in pre- and post-pandemic phase, observing a reduction of pedestrians, which can be due to the general reduction of performed trips. Secondly, the proposed hybrid approach for the estimation of the pedestrian flows has been calibrated and validated also for post-pandemic scenarios, obtaining satisfactory results. Results of this study is detailed in the followings.

2 Method

In recent years numerous network analysis models have been developed to evaluate the number of users and their propensity to walk [16–18] which showed how the shape of a city affects them. In order to estimate the distribution of users on the road network, if the counting data is not available, models have been developed. These have different complexities as well as varying input requirements, making some more usable than others. Among these are the configurational models [19, 20] that show how the road and the built environment can influence the dynamics of movement of pedestrians.

This category includes the Space Syntax based approach which, through a graphic "proximity" algorithm, allows to estimate the pedestrian crowding. It is worth to be noticed that this approach is not linked to the emission, matrix or modal choice (it does not reflect a structure based on supply and demand) but addresses only to the network configuration that, in turn, may be regarded as the result of the history of urban evolution in which city centers are made up of densely meshed road networks and therefore are very connected.

Among the various indicators that allow to describe the configurational consistency of the elements, the one that according to the literature [21–27] is better related to the pedestrian activity is integration (Int). This parameter represents the minimum number of sections of a network graph necessary to reach one point from another.

Starting the simulations with the Space Syntax it was noticed that the configurational approach provided a poor estimate of the pedestrian activity since the data on population and land use that characterize an urban network are not considered. Therefore, a hybrid approach was developed and presented that considered both the population combined with specific land use parameter related to commercial activities present in the examined area.

A preliminary reconstruction of the entire road and pedestrian network within a GIS approach was undertaken and the spatial relationship of contiguity between the census sections (taken from ISTAT [28]) and the road sections composing the road network was obtained.

To each census section, represented by a centroid, the average value of the resident population was evaluated with the proximity approach by making use of a sequence of buffers with increasing radius (J^{th}), varying between 100 and 1600 m, chosen on the basis of an impedance function (blue line in Fig. 1 [29]) in order to represents the propensity to walk as a function of the distance to be traveled. This function has been developed on the regional household travel survey in the US context.

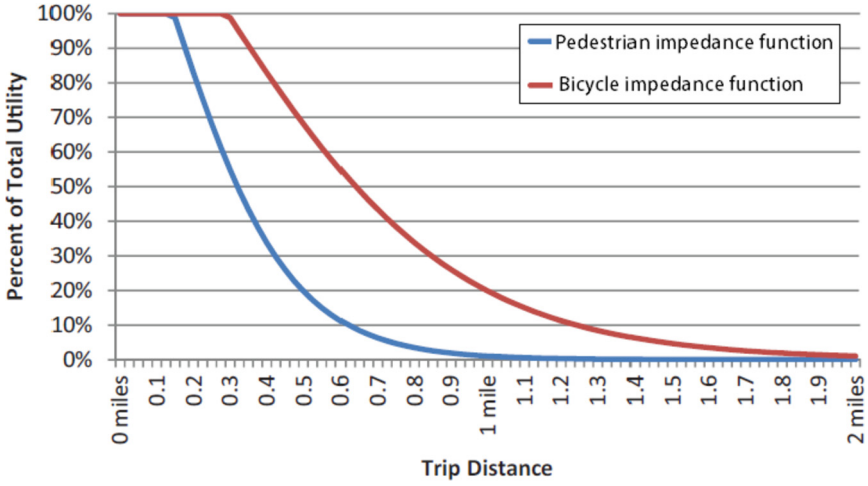


Fig. 1. Pedestrian and bicycle impedance functions (adapted from [29]).

To obtain a single Pprox weight (proximity weight) (Eq. 1) for each centroid, it is necessary to add the products of the mean population M of each annulus for the impedance function.

$$P_{prox,i} = \sum_{j=100m}^{1600m} k_{Mj} M_{ij} \tag{1}$$

By inserting these weights prior to the Space Syntax simulation, it has been highlighted that not even the population alone is able to represent the pedestrian activity of the area which indeed appears to be much more affected by purposes related to commuting. Then a correct hybrid approach was developed with an additional factor K that also took into account the impact of retail activities and other structures and attractors [15].

Once the results from the hybrid configurational analysis performed by means of Space Syntax has been obtained, it is necessary to compare these data with the on-site pedestrian counts to evaluate effectiveness of the model. Therefore, surveys were carried out on the network to estimate pedestrian crowding. The literature shows that numerous techniques have been developed over the years for the direct measurement of vulnerable users.

These are sometimes different from those consolidated for the survey of motorized traffic; this because it must be taken into account that non-motorized traffic is characterized by a greater sensitivity to environmental conditions (precipitation, temperature, darkness, etc.) and does not follow regular patterns that are not being confined to fixed lanes (vulnerable users can travel off designated footbridges and cycle paths, take unsigned shortcuts or stop unexpectedly).

According to the Federal Highway Administration [18] the most used techniques for identifying pedestrian flows can be grouped into two macro-types: manual and automatic detection. The first consists of the acquisition of data based on the direct survey of an operator for a short period of time; for this reason, the automatic survey has been developed which allows to collect data with continuity, high precision and for long periods of time. However, when there is a significant time constraint together with reduced economic resources, one can think of adopting the technique of the *mobile observer*.

According to this technique, the survey is carried out by a monitoring vehicle, equipped with video recording devices, which moves along the route to be examined. This technique has the advantage of being able to acquire data over an entire network, albeit for a shorter period of time. This makes the data unstable at a statistical level therefore it is necessary to repeat the survey several times in order to stabilize it.



Fig. 2. Location of Cassino in Italy.

3 Case Study

The experimental calibration of the model was carried out in the city of Cassino (Fig. 2). An average Italian city falling within Southern Lazio characterized by easy accessibility, by the presence of transport infrastructures (railway station, bus services, bike sharing service, etc.) and by the pedestrian-friendly peculiar features (mainly flat territory, etc.) other than by the presence of several relevant attractors such as schools, universities, restaurants, shops and public activities.

To obtain the pedestrian counts, video recordings were made after defining the position of the devices on the car and the routes to be follow, considering both the weekday and pre-holiday scenarios (Fig. 3 and Fig. 4).



Fig. 3. Post-covid weekday path. (Source plugin base-map: Open Street Map, [30]).

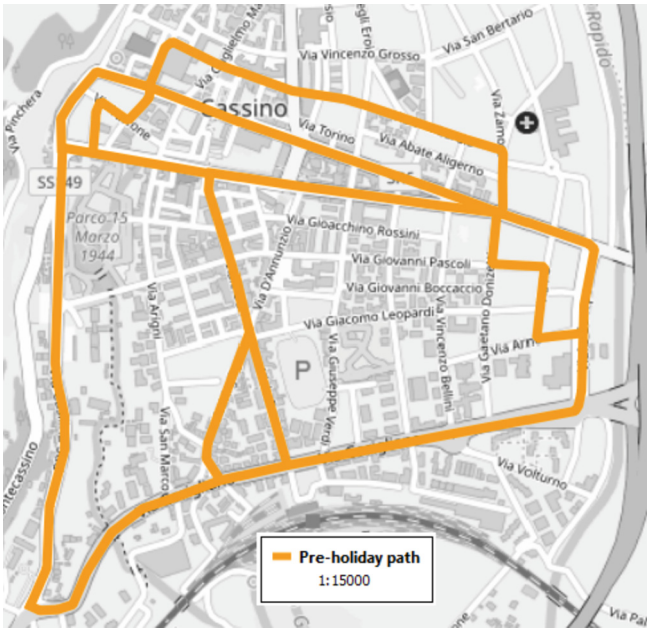


Fig. 4. Post-covid pre-holiday path. (Source plugin base-map: Open Street Map, [30]).

Following the post-processing of the acquired video footages (Fig. 5), the geo-referenced pedestrian counting data useful for the final comparison were obtained.



Fig. 5. Screen of the software for the analysis of the routes.

Comparing only the data of the pedestrian counts of the pre-pandemic phase (collected within 2018 and 2019 years) with post-Covid ones (collected in the end of 2021 and in early 2022) a significant reduction in walking was highlighted for most of the investigated road sections (see Fig. 6).

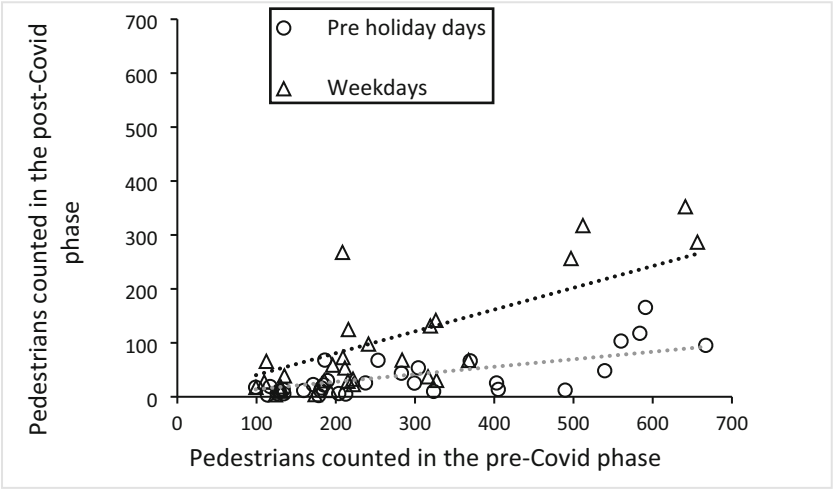
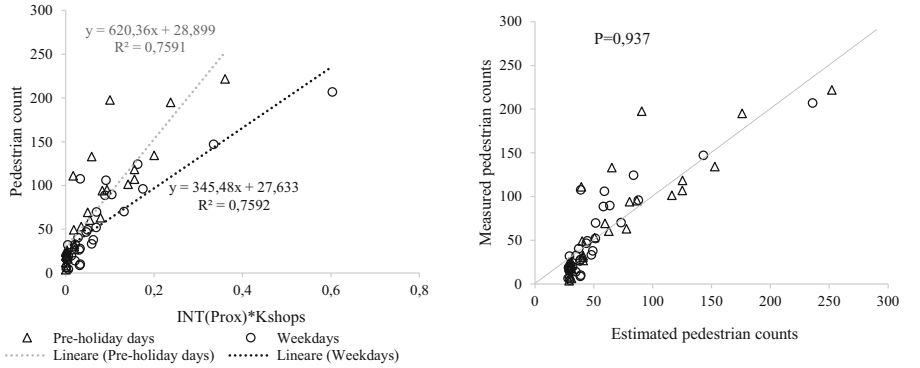


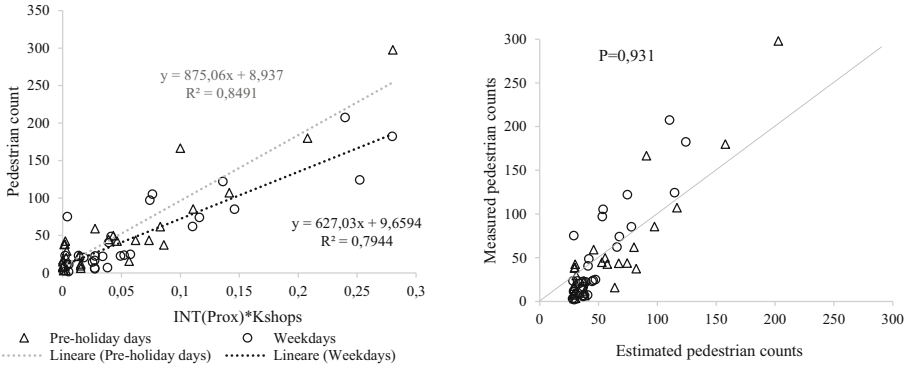
Fig. 6. Comparison of pre and post Covid pedestrian counts.

To apply the correct hybrid model, calibrated in the pre-pandemic conditions Fig. 7, the appropriate revisions were made to take into account the variations due to the restrictions that characterized the period following the lockdown or the possible closure or movement of commercial activities in the study area Fig. 8.



a) b)

Fig. 7. ***Pre Covid*** a) calibration of pedestrian count predictive model and b) corresponding Pearson statistics between measured and predicted pedestrian flows.



a) b)

Fig. 8. ***Post Covid*** a) calibration of pedestrian count predictive model and b) corresponding Pearson statistics between measured and predicted pedestrian flows.

It can be easily observed that the hybrid approach, both in the pre- and post-pandemic scenario, presents fairly good correlations; in fact, a Pearson correlation coefficient (P) of 0.93 (see Fig. 7 and Fig. 8) can be derived for both scenarios.

This shows that pedestrian flows are affected not only by the configuration of the network but also by the presence of particular attractors (mainly retail activities), among the several land use parameters other than population distribution (embedded in the aforementioned proximity weight). Therefore, the quantitative variables used are well correlated and the model is statistically significant.

By comparing the pre- and post-Covid conditions, both in the holiday and weekday scenarios, it can be easily seen that the approach based on a linear regression model shows similar significant agreement (correlation) with the measured data thus provided the evidence for the reliability of the proposed modelling approach.

Furthermore, as far as the linear model is concerned, it is worth to be highlighted that:

- the constant term seems to have decreased, both for the weekdays and pre-holidays days, demonstrating the reduction of "basic level" movements of pedestrian activity in the post-pandemic scenario;
- the slope of the model seems to be higher for data collected in the post-pandemic period compared with those pertaining the pre-Covid period, perhaps due to the increased preference of pedestrian to choose commercial activities located closer to their residential areas.

4 Conclusion

The pandemic emergency and the need to reduce pollution levels to improve the life of the population has seen the problem of sustainability increasingly affirm itself. Among the objectives to be achieved in order to have greener cities, one is that of promoting sustainable mobility such as the *active* or *soft* one (namely walking and cycling), thus favoring traditional transport modes with zero emissions.

With this in mind, it is necessary to design or retrofit urban infrastructures to make them safe, inclusive and comfortable for new active users. Given the ever-increasing need to design routes dedicated to vulnerable users in an urban environment, an innovative method to assess pedestrian activity has been proposed.

An exposure forecasting methodology was developed that would allow planners to take a more proactive role in pedestrian area design and in risk assessment with vehicular traffic. Although pedestrian activity and trips are characterized by high levels of uncertainty compared to those pertaining the vehicular traffic, in the past, a configurational analysis was effectively used to estimate these flows, provided that pedestrian counts were made available on a daily basis.

However, data collection using these traditional approaches can be complex and time-consuming and therefore an innovative moving observer-based survey technique was suggested. In order to gain stable pedestrian crowding data and to improve calibration of the prediction model it has been necessary to replicate pedestrian counts by moving observer approach for several working and pre-holiday days. Pedestrian counts collected in such way on several road sections has been compared with those obtained from results provided by simulations via a configurational analysis enriched with the impedance function and the presence of commercial activities that characterize the area.

A recent additional survey on pedestrian flow has provided the evidence that the proposed modelling approach is indeed still effective in capturing pedestrian activities and that a dramatic drop in walking has occurred together with a higher propensity to reach closer retail activities compared with pre-Covid scenarios.

It is believed that this methodology that requires the combined use of CENSUS data, GIS tools and of Space Syntax software, can be a valid support for administrators

to assess the risks deriving from the pandemic as well as the exposure to the road safety risk of pedestrian flows. In fact, once that the levels of pedestrian crowding are assessed, mitigation actions can be chosen such as accessibility limitations or restrictions for specific road user categories, in case of critical crowd-generating events or simply to limit collisions probability between pedestrians and vehicular traffic in urban areas. Following analysis are needed to evaluate the results of the methodology on other Italian or foreign context.

Acknowledgments. The help of Eng. Biagio Mancino in collecting pedestrian data within the post-pandemic period is gratefully acknowledged.

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