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MODELING CROWD MOVEMENT IN LARGE SCALE EVENTS, THE CASE OF STORICO CARNEVALE DI IVREA

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ABSTRACT

This paper describes the analysis of a complex large scale event. The case study event, Ivrea Carnival, is peculiar because it takes place in streets and squares of a small ancient town, and not in an area designed for large scale events. Another peculiarity is that Ivrea Carnival lasts for many days, during which a large number of different kind of events occur, as music parties in squares, parades, ritual ceremony and the famous orange battle.

Numerical simulations were used to support the safety plan construction, providing in-depth comprehension of crowd movement and verification of management strategies. Among all the simulations done for the safety plan construction, three specific situations were reported in the paper to explain how numerical simulations can be used to better understand crowd dynamics (i) normal circulation of visitors in the town center, being set a maximum capacity limit in squares; (ii) entering of the parade in a crowded area; (iii) effect of the presence of movement group (e.g. families) on egress time from crowded squares.

The consequences of simulations findings on safety plan are also discussed.

INTRODUCTION

Many traditional events in Italy take place open-air in old town centers and involve a large number of people. The most relevant feature of these traditional events is that they do not occur in areas designed for large scale events, as arenas or stadium. Furthermore, these events usually include different kind of occurrences, as music party in squares, parades, ritual ceremonies. One of this traditional event is Carnival of Ivrea, that take place in the first part of year in a small town in North-West of Italy since more than a century and involves 35000 person at the same time. Another famous Italian event is Carnival of Venice, but there are also a lot of similar occurrences, all over the world, ranging from some thousand to tens thousands of people involved.

This kind of events presents a set of challenges from the perspective of evacuation safety, some of which are the same identified by Ronchi et all [4] for music festivals. (i) First of all, many people are involved, and densities can be very high in proximity of stages or areas in which a specific event (as a ritual ceremony) occurs. High people density is known as a critical factor in crowd management [2]. (ii) The largest part of attendees is familiar with the area in which event takes place, but there are also many tourists involved, that could ignore the town topography at all. The unfamiliarity with the site topography and evacuation routes potentially increases the time needed for wayfinding during evacuation in case of emergency. (iii) In these events, as in music festivals, people have not a specific location assigned (as in theater or stadium), so it is very important to set a maximum allowed density for each area in order to guarantee safe evacuation. [4] (iv) Finally, pre-evacuation behavior itself may be affected by levels of alcohol consumption and crowd euphoria [7], that are common in events as carnival and street celebrations.

Due to the recent terrorist attacks on crowd (Nice 2017, Barcelona 2017 and others) and stampedes (Torino 2017) the crowd management has becoming a relevant aspect in large events organization. Furthermore, a real threat is not needed to trigger a tragedy, as Duisburg accident in 2010 teaches. During Love Parade in Duisburg, no real threats (as a terrorist attack) neither false alarm (as in Torino) were there, but the high density of people and some operational errors leads to a large number of fatalities [3].

In response to these tragic events, a recent guideline from Italian Ministero dell'Interno (known as "Circolare Gabrielli") put the spotlight on the necessity for event organizers to work in compliance with the regulation [1]. At present, evacuation safety measures in Italy are based on two thresholds: the width of available exits related to the number of people (250 pers/0.6 m) and the people density (2 pers/m^2). For a given area with given exits, each one of these two thresholds leads to a value of maximum capacity. The maximum number of people that the area can host has to be chosen as the minimum value of capacity obtained by the two thresholds. This method has some limitations. First, it does not take into account the shape of the exits. A single ten-meters wide exit has not the same effect on egress of ten one-meter wide exits. In addition, this method is convenient when designing a new arena, but it can be too limiting when applied to pre-existing areas (as ancient town), leading to low number of people allowed to join the event.

Some guidelines, edited by regulation authorities from different countries, can be find online. As an example, the UK Office of Public Sector Information events has published in 2000 a guideline [8] aimed "to provide practical guidance to help those organising events to manage crowd safety in a systematic way." The guideline "does not specify a particular way of achieving crowd safety, but sets out a general approach" and it is applicable to "both sporting and non-sporting, at football stadia and other sports grounds, events at sites not designed for the purpose such as parks or industrial units and events in streets or built-up areas, e.g. street fairs, carnival processions, New Year celebrations". In a similar way, the Environmental Health Directorate of Australia developed the Guidelines for

Concerts, Events and Organised Gatherings, which purpose is to identify basic standards and safety measures for event organisers [5].

Evacuation drills to test evacuation plans cannot be done for occurrences that involves thousands of persons coming to the event site for the first time when the event starts. Similarly, it is not always possible to access suitable data about past edition of the event in order to observe how the crowd behaves in the real context. Evacuation modelling is a practical way to overcome these problems.
Numerical simulations can be used to both test evacuation plans and reproduce the ordinary movement of crowd inside a specific area, obtaining qualitative and quantitative information on evacuation times and space usage.

METHOD

In this study, evacuation modelling techniques was used to analyze and optimize crowd movement inside the Ivrea Carnival area. Numerical simulations were used to develop and verify the safety plan, that was submitted to the competent authority for the authorization process of 2018 Carnival edition. The first phase of the study consisted of the selection of an appropriate set of evacuation/movement scenarios. Due to the large number of events included in Carnival, it was not suitable to carry on an analysis for each one of them. For this reason, events were grouped due to their peculiarity (place in which they are hold, number of people involved, type of event), and a set of scenarios was developed for these groups. The paper focuses on the analysis of three specific scenarios.
Each scenario was analyzed by numerical simulations performed using Pathfinder 2018.1 [11]. Pathfinder is an agent based egress and human movement simulator that includes an integrated user interface and animated 3D results, developed by Thunderhead Engineering.

MODEL CASE STUDY

Description of the event

Ivrea Carnival takes place in the whole town center, for nine non-consecutive days. The core events, however, are concentrated in the last three days, when orange battles take place. For three hours in the afternoon, many floats cross the city carrying the "on-floats" fighters to the five squares in which the battle takes place. In these squares, "on-street" fighters wait for the float in order to start throwing oranges. At the same time, a parade formed by more or less 150 persons walks along the main streets and enters the five battle squares. When the parade approaches the square, the battle is stopped and "on-street" fighters make room to let the parade enters and cross the square. The last day, the award ceremony is hold in the main square to declare which team has won the orange battle. Many information and images of this event can be find in the official website [6].

Figure 1: Orange battle (left) and a moment of the parade (right)

In addition to parade components and orange fighters, many people come to town in order to take part in Carnival. Based on previous editions data, the maximum number of people involved in the Carnival area at the same time is about 35000. A scheme of the area involved in Carnival is reported in Figure 2.

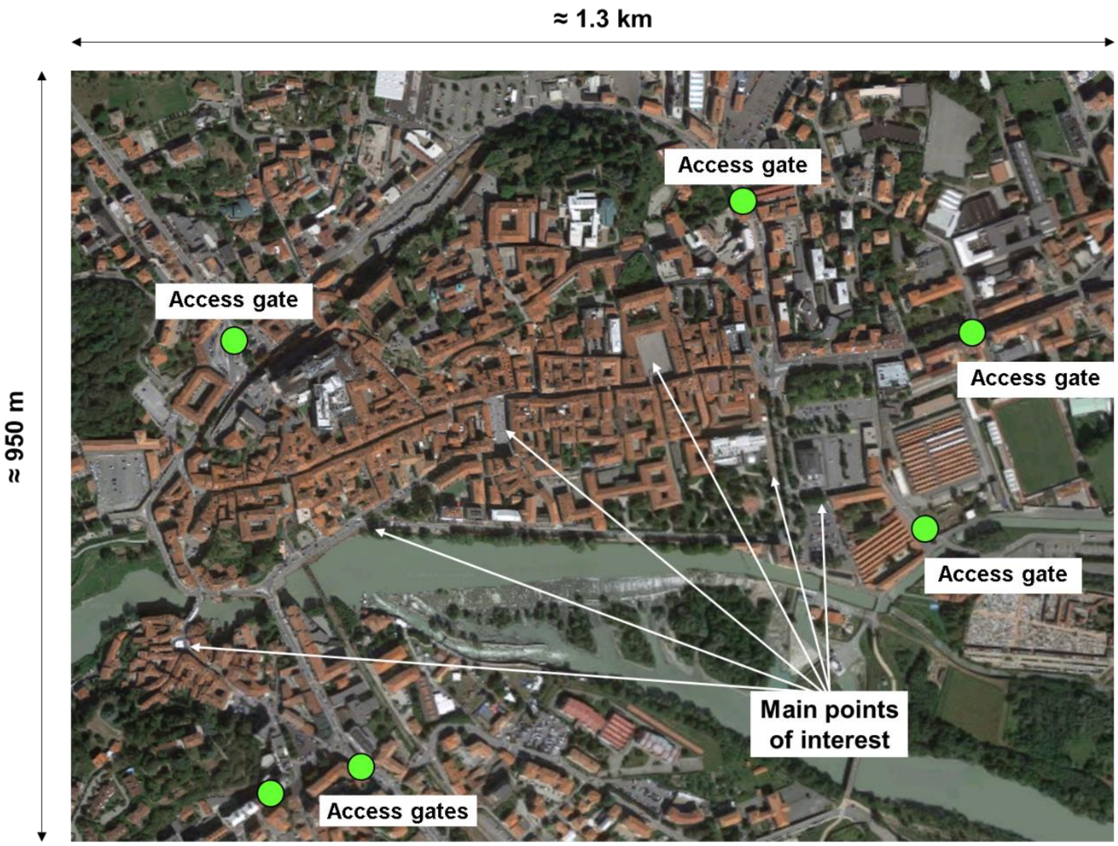

Figure 2: Overview of the event area

Simulation scenarios

A set of three scenarios has been developed in order to represent the most important moments of Carnival, from crowd management point of view.

1. Scenario 1 concerns the whole town center and reproduces the ordinary circulation of visitors between different squares and other places of interest (e.g. food and beverage facilities).
   This scenario uses the Pathfinder 2018.1 capability of set a maximum capacity value for room.
2. Scenario 2 concerns the entering of the parade into a crowded area. This scenario explores the Pathfinder 2018.1 capability of reproduce crowd movements that are not intended to egress.
3. Scenario 3 concerns the squares evacuation. This scenario reproduces both the evacuation in case of an emergency and the normal exiting of people from a square when a specific event (e.g. the award ceremony) is done.
   This scenario was developed in a number of sub-case changing the movement group settings, in order to understand how this affects results.

Model settings

Unimpeded walking speed distribution was used to represent people with different physical abilities. The distribution was assumed as uniform between minimum and maximum values. Minimum walking speed (0.4 m/s) corresponds to people with locomotion impairment due to their physical

conditions or to the slime that accumulates on streets during orange battle. Maximum walking speed (1.2 m/s) corresponds to people without locomotion impairment that walk on a regular floor.
Other inputs, as occupants behaviors and movement group settings varies depending on the scenario. These model inputs will be discussed later.
Pathfinder 2018.1 offers a set of outputs and a built-in post-processor. Depending on the analyzed scenario, results were post-processed in different way. In some cases, the standard Pathfinder post-processor were used, for example to get maps and plots. In some other cases, rough outputs were handled to get specific plots, as pie chart and frequency distribution graphs.

ORDINARY CIRCULATION (SCENARIO 1)

Scenario 1 aims to reproduce the ordinary circulation of people inside the town center. Six gates are positioned at the boundary of the town, and people can access the center only through them. Occupants sources are put in the Pathfinder model in correspondence of the gates in order to simulate people arrival in the town. In Pathfinder, the movement of people is specified by "behaviors", a sequence of actions the occupant will take throughout the simulation. An important feature of behaviors is that occupants do not hang around when passing from one waypoint to the following. Occupants choose the fastest path, because current Pathfinder algorithm is the Locally Quickest, described in Technical Reference [10]. This algorithm is not completely suitable for an ordinary circulation simulation. In fact, when strolling inside a town in non-emergency conditions, people choose their path not only as the quickest but also as the more pleasant, hanging around. In order to replicate non-emergency movement in a more realistic way, authors implemented very complex behaviors, forcing agents to take longer and curvy paths. In this scenario, more than 20 different behaviors were set in order to make different groups of people move inside the city following different paths, reaching one or more points of interest and staying there for a certain amount of time. The last action of each behavior models the moment in which people left town using the same gate they used to enter. The simulation lasts for 75 minutes. Pathfinder 2018.1 offers the possibility to set a maximum capacity level for rooms. This makes it possible to reproduce a situation in which gates control strategy is operated. Maximum capacity limit is set in three squares, named Sq#1, Sq#2 and Sq#3 in Figure 3.
Results of scenario 1 are reported in Figure 3, Figure 4 and Figure 5. Figure 3 shows how the number of occupants inside specific squares or streets change over time. For what concerns squares, the effect of the maximum capacity limit is visible through the fact that curves stop their increase at a certain time.

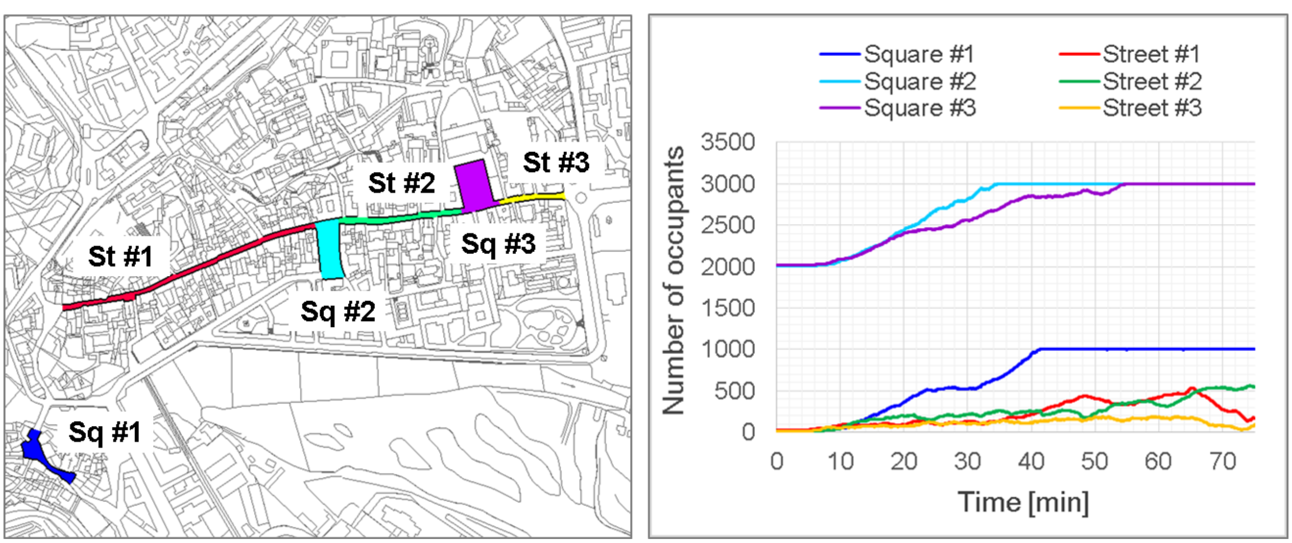

Figure 3: Number of occupants in specific squares and streets, changing over time

Figure 4 focuses on a single square. Pie graphs show the number of people entering and exiting the square, subdivided by the gate they use. People enter and exit the square at different times, depending on the behavior assigned to them. Some behaviors require to get to the square, remain there for a while and then reach another waypoint. Other behaviors do not require to reach the square, but occupants can cross it anyway, to get to another point of interest. This mix of behaviors is intended to provide a realistic simulation of crowd movement inside the square. From Figure 4, it can be seen that entering and exiting fluxes are not balanced between the four gates. The majority of people enter the square using gates A and D, and leave the square using gates B and D. Furthermore, every gate shows inequality between entering and exiting crossing. Gates A and D shows more entering than exiting, while gates B and C are crossed more time in exiting direction than in entering. This kind of graph is very useful to get information about the gates usage and operate corrections.

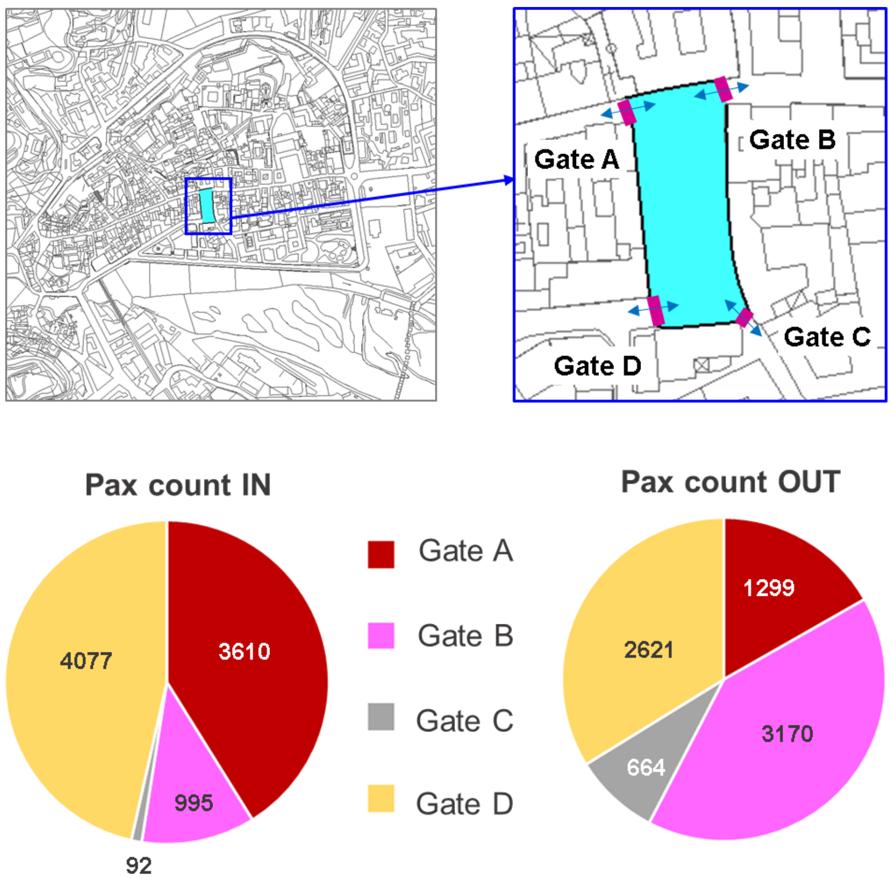

Figure 4: Square gates usage

Figure 5 shows the *accumulated usage* of the town center. *Usage* shows where occupants currently exist on the floor. A*ccumulated usage* is a time-integrated version of *Usage*, which shows how much time is spent on each area of the floor. A*ccumulated usage* is reported in two versions: in the first one, it is computed considering an influence radius equal to 2 meters, while in the second one the influence radius is equal to 5 meters. Influence radius controls the size of the area that each occupant's value has on the contour: the value is tapered from the full value where the occupant exists down to zero at this radius [9]. The default value of influence radius is 0.8 meters.

A*ccumulated usage* plots are useful to identify the area that are more used by occupants. Areas with a large number of passages and long stops are red, while areas with low number of passages and short stops are blue. The areas showing the higher a*ccumulated usage* are the same that are set as waypoints in model. These are the main attractive areas, hosting specific events, and the more travelled roads.

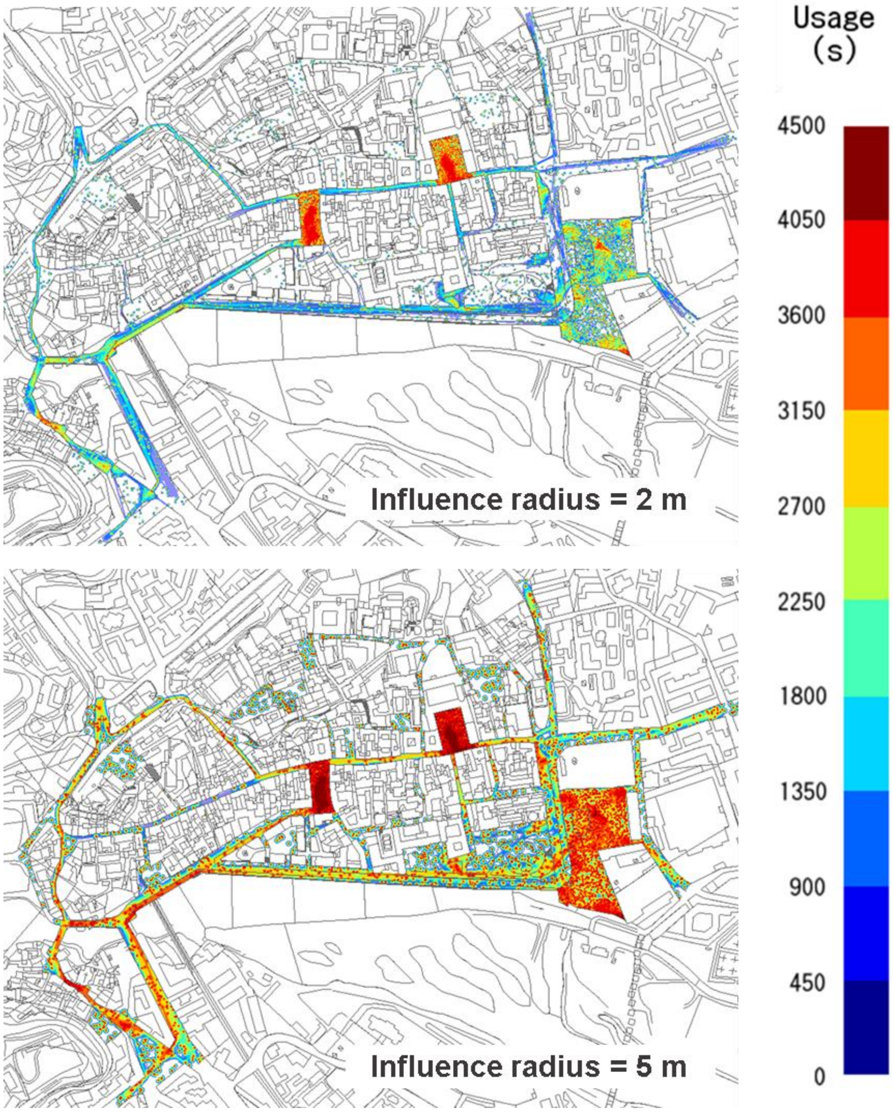

Figure 5: Accumulated usage

PARADE ACROSS A CROWDED AREA (SCENARIO 2)

Scenario 2 reproduces a parade that crosses a crowded area. The analyzed area has an uneven shape: there is a street along which three squares of different size open up. The image in the middle of Figure 6 shows the street (red) and the squares (light blue). The image on the right shows a realistic view of the area.

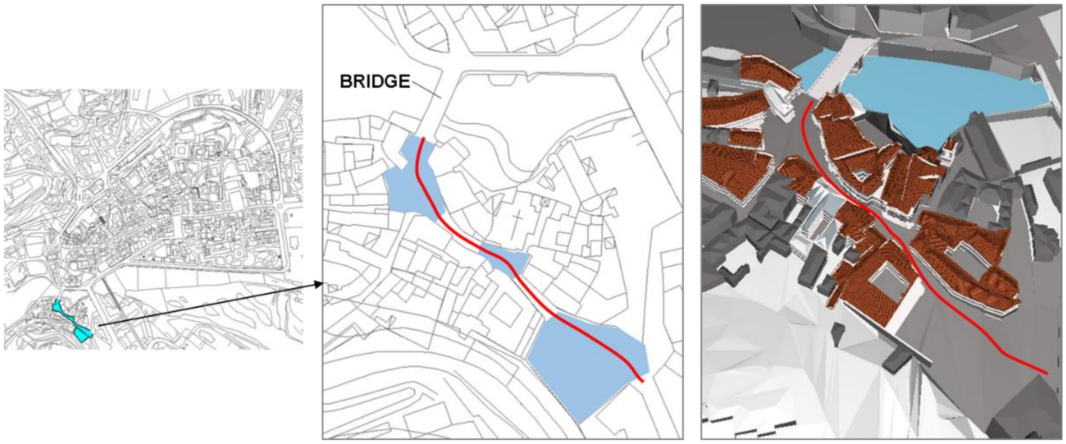

Figure 6: Top view of area of analysis for Scenario 2

Results are presented in Figure 7 by means of density plots of the area. Before the parade enters the area, density is about 2 pers/m^2. Then, crowd in the area parts in order to leave an empty aisle for the parade. At the same time, crowd assembles next to the empty aisle, in order to see the parade. Consequently, density increases to 3 pers/m^2.

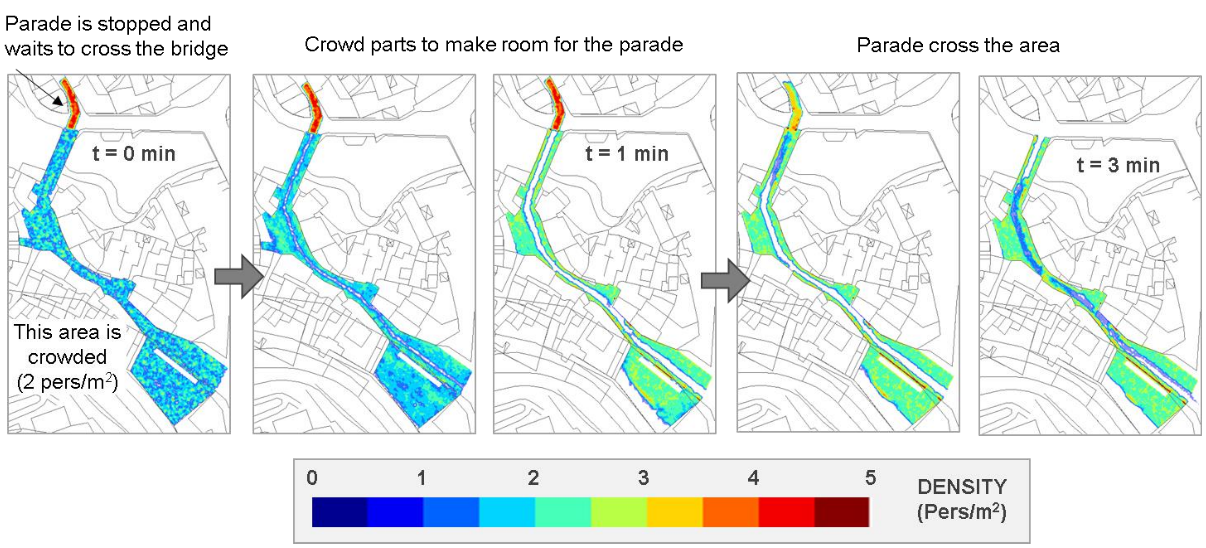

Figure 7: Density during parade crossing

EGRESS FROM A SQUARE (SCENARIO 3)

Scenario 3 reproduce the process of crowd streaming out from a square, for example when an event hold in the square ends and the audience left the area. The square taken into account is shown in Figure 8. The square has a porch on three sides and is connected to refuge areas by four means of egress (green arrows in the image). No crowd management strategies are implemented in simulation, and occupants pathways are decided by Pathfinder's algorithm.

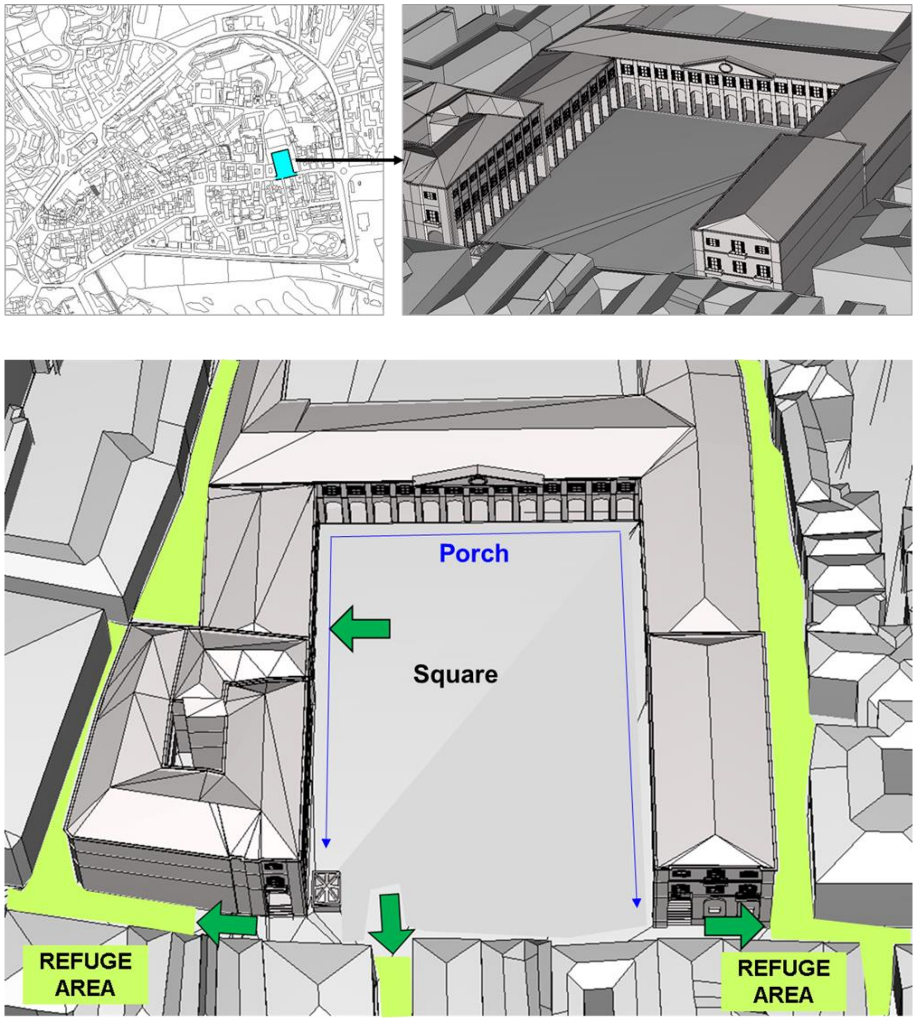

Figure 8: Square analysed in Scenario 3

Six cases are studied. Case 0 is the reference case, without movement group. Other five cases are obtained changing the movement group settings. Movement groups are used to keep occupants together during the simulation. This creates simulations that have the appearance of more realistic behavior. In this study, the initial density in the square, the percentage of occupants that are grouped and the size (number of persons) of groups are changed (see Table 1).

Table 1: Scenario 3, cases

	Scenario 3 - SETTINGS		
	Initial density	% of grouped occupants	Group size
case 0	**2 pers/m^2 (5290 occupants)**	**0%**	**-**
case 1	2 pers/m^2 (5290 occupants)	50%	4 ÷ 10 persons
case 2	2 pers/m^2 (5290 occupants)	100%	4 ÷ 10 persons
case 3	2 pers/m^2 (5290 occupants)	100%	20 ÷ 50 persons
case 4	1 pers/m^2 **(2645 occupants)**	50%	4 ÷ 10 persons
case 5	1 pers/m^2 **(2645 occupants)**	100%	20 ÷ 50 persons

Results of scenario 1 are reported in Figure 9, Figure 10 and Table 2.
Figure 9 shows the total number of occupants in square and porch over time. It can be seen that the time needed to empty the area (square and porch) is affected mainly by the initial density. Cases 0, 1, 2 and 3 consider 5290 occupants, and take at least (case 0) 15 minutes and a half to empty the square. Case 4 and 5 consider 2645 occupants, and take less than 11 minutes to empty the square. Also the presence of movement group increases the time needed to empty the square. The increase ranges from two minutes and a half to five minutes and a half. The percentage of grouped occupants and the size of group seems to not have a big impact on results.

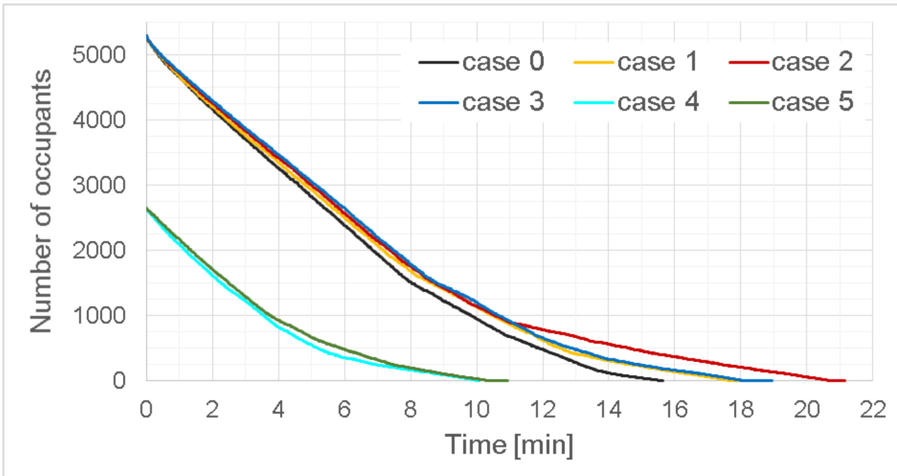

Figure 9: Number of occupants changing over time

Figure 10 shows how the *jam total time* is distributed over different ranges of time. *Jam time total* is the total amount of time the occupant spent moving at less than the *jam velocity* (equal to 0.25 m/s by default). The *jam time total* is affected mainly by initial density. In the cases in which initial density is equal to 1 pers/m^2, more than 50% of occupants stay in a jam for less than 2 minutes. In the cases in which initial density is equal to 2 pers/m^2, this percentage falls to about 22%, and people experience longer queue times. Anyway, in all cases the more frequent *jam time total* is lower than 2 minutes.

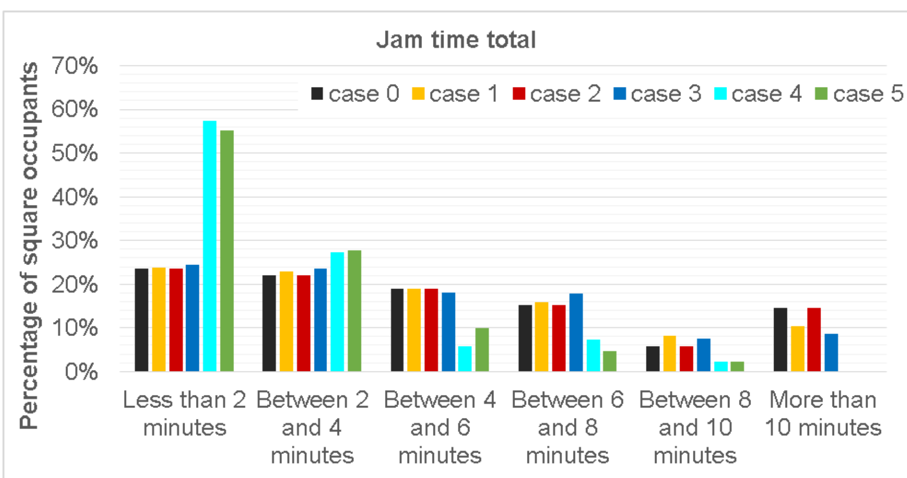

Figure 10: Jam time total distribution

Table 2 sums up the most relevant results of Figure 9 and Figure 10. Table also shows the maximum *jam time total* for each case. This is the *jam time total* of the occupants that remains stuck in jam for more time. Maximum *jam time total* shows a trend similar to the one of the time needed to empty the area.

Table 2: Scenario 3, results

	Scenario 3 - RESULTS		
	Time to empty square and porch	Max jam time total	More frequent *jam time total*
case 0	**15 min 39 sec**	**15 min 8 sec**	**Less than 2 minutes**
case 1	18 min 14 sec	17 min 4 sec	Less than 2 minutes
case 2	21 min 8 sec	21 min 8 sec	Less than 2 minutes
case 3	18 min 56 sec	17 min 19 sec	Less than 2 minutes
case 4	10 min 5 sec	9 min 40 sec	Less than 2 minutes
case 5	10 min 55 sec	9 min 46 sec	Less than 2 minutes

SAFETY PLAN

Numerical simulations was done to provide qualitative and quantitative results during the construction of safety plan for Ivrea Carnival (2018 edition). Maximum allowed occupancy of squares, number, size and position of square gates, bypass streets outside the gates were studied.

Due to simulations results, a maximum capacity value is set for main squares. Each square is delimited by gates where safety stewards monitor people entering and close gate when the maximum capacity is reached. Maximum capacity was established taking into account (i) maximum density values reached during fulfillment and emptying of squares, (ii) time to empty the square when people stream out of it, (iii) jam time distribution. In order to obtain these results, many numerical simulation, like the ones of Scenarios 1 and 3, was done, changing squares initial occupancy and gates position and size.

Many effort was done to determine the shape of maximum capacity areas. In some cases, this area corresponds to a square, while in some other cases it corresponds to a system formed by many squares and some streets. This depends on the fact that each square is different from others, having a different number of crossing streets and a different location inside the town topology. This is the case of the two central squares, named #Sq2 and #Sq3 in Figure 3. These squares hold the orange battle and are connected each other by a street, named #St2 in Figure 3, which is traveled by the parade. These two squares cannot be considered as separated, and for this reason they form a single system from the safety plan point of view.

According to safety plan, when maximum capacity is reached, visitors trying to enter the square/area are asked to quit their purpose and turn back. Nevertheless, this can lead to counter-flows and/or high crowd density beyond the gates. In order to avoid these hazardous circumstances to occur, a bypass system was implemented. Bypass are streets that are not particularly attractive to people since no events are hold, and no food/beverage facilities neither toilets are there. For this reason, this low-usage streets can be used to connect points of interest, decongesting the more attractive roads.   In order to empower the bypass system efficiency, two typologies of gates was defined: bi-directional and one-directional (Figure 11). Bi-directional gates can be used both to enter and leave the square/area. On the contrary, one-directional gates and can be used only to enter or only to exit, and so the flux of people crossing them is always one-directional. Bypass system efficiency was verified by means of a numerical simulation of ordinary circulation, like the one discussed for Scenario 1. In the specific case of the square showed in Figure 11, numerical simulations made it possible to increase the maximum capacity by 15% respect to the value calculated using Italian regulation thresholds.

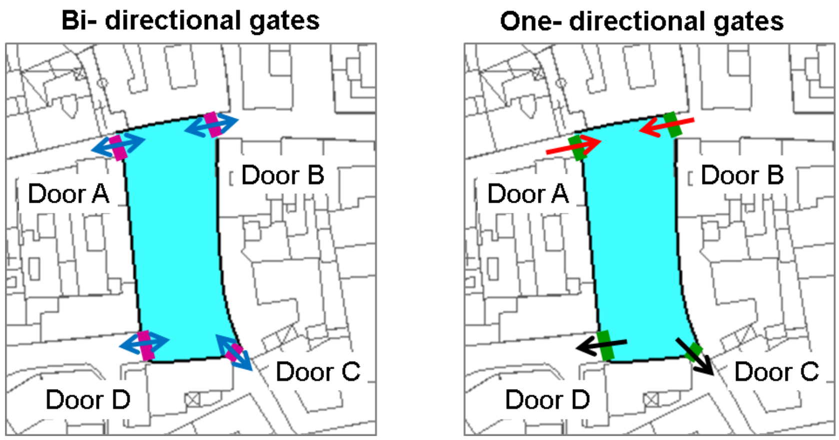

Figure 11: Typologies of gate

Figure 12 and Table 3 describe the town topology from the safety plan point of view. Figure 12 shows the pathways that connect town access gate to the main points of interest, using bypass streets. A single point of interest, named "A", includes both central squares (#Sq2 and #Sq3) for the reason discussed above. Characteristics of each point of interest are summarized in Table 3. Maximum capacity limit was not set for points "B" and "C". This is due to the fact that these areas are served by an appropriate number of large streets, therefore no critical situations are expected to happen there.

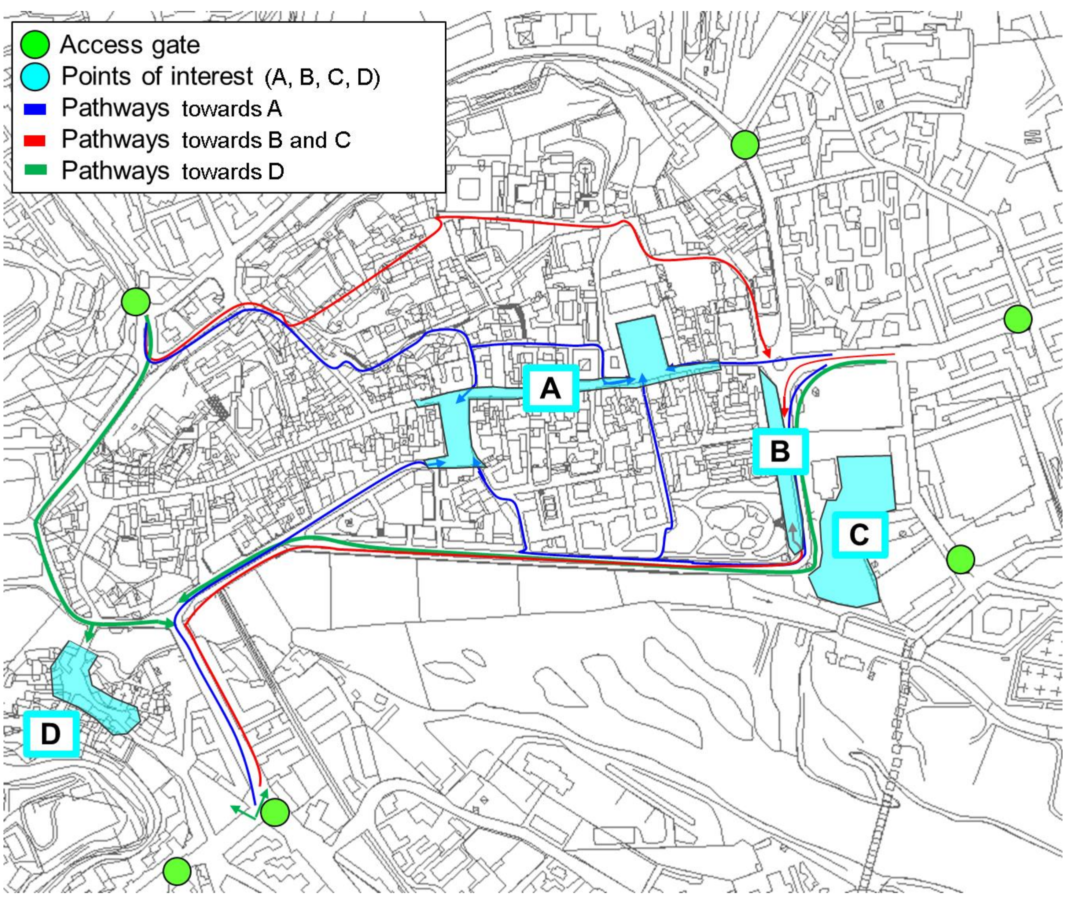

Figure 12: The town center from the safety plan point of view

Table 3: Main points of interest

	Main points of interest		
	Typology	Hold events	Maximum capacity
A	System (2 squares + some streets)	Orange battle, parade, award ceremony	14000 persons
B	Large road	Food and beverage facilities, shops	Not set
C	Square	Orange battle, parade	Not set
D	Square	Orange battle, parade	2700 persons

FUTURE RESEARCH

Evacuation models can provide useful information to event organizers and safety engineers. Nevertheless, there are some aspects that can be improved. First of all, the capability of software to reproduce the ordinary circulation of people inside a large area. The traditional approach followed by egress simulation software is not suitable to realistic reproduce a situation in which people hang around between different areas, some of which more interesting and attractive than others. Furthermore, many present egress software cannot reproduce situations in which the crowd density is high. Reproduce this situation would be useful in order to understand which measure can be implemented in the case hazardous density are reached. Finally, future research should focus on data collection on human behaviour in large scale events. This would be useful both to deeply understand crowd dynamics, and to have empirical basis for comparison of software results.

CONCLUSION

This paper analysed the peculiarity of a large scale, open-air event and the capability of numerical simulations to reproduce the realistic behaviour of the crowd. Evacuation models give qualitative and quantitative results that can be used during the safety plan building phase. Numerical simulation were used to design and verify the maximum capacity in squares and the bypass system. Furthermore, numerical simulation highlight critical aspects in site topography that need to be correct through management measures. As an example, the lack of balance between square gates was observed in numerical simulation of ordinary circulation inside the event area. Future research should focus both on software development and on data collection on human behaviour in large scale events. Software development should aim to a more realistic reproduction of ordinary movement of people and critical density situations.

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