Crowd and Pedestrian Dynamics: Empirical Investigation and Simulation

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Abstract

The investigation of crowd dynamics is a complex field of study, which involves different types of knowledge and skills. From the socio-psychological perspective the definition of crowd is still controversial. For this reason, we propose to analytically investigate this topic focusing on pedestrian dynamics in high-density situation. In this paper we propose a multi-disciplinary approach, which is based on observations and experimental procedures focused on proxemic behaviour of walking groups, and Multi-Agent Systems, which are useful technique to simulate what-if scenarios. The methodological approach that we propose can be synthetically represented as composed of research in vivo (observations), in vitro (experimental procedures) and in silicon (modeling and simulations).

Keywords. Crowd, Groups, Pedestrian Dynamics, Proxemics.

Introduction

The investigation of crowd dynamics is a complex field of study, which involves different types of knowledge and skills. Early interest in studying crowd behavior started from the pioneering study of Gustave Le Bon [1], who defined a crowd as a potential threat to society: as members of a crowd people display a loss of sense of self-awareness and an increase of violent behaviors. Far from this approach, the ESIM-Elaborated Social Identity Model [2] proposes a social-normative conception of collective behavior, based on the spontaneous transition from an individual to a common social identity [3]. From the socio-psychological perspective, the definition of crowd is still controversial, because of the lack of standard guidance for the empirical investigation of the phenomenon, and its variability among size and typology. For this reason, we propose to analytically investigate this topic focusing on pedestrian dynamics in high-density situations. The study of people movement dynamics, in relation with the levels of density and the physical characteristics of the environment, represents an innovative discipline that involves different knowledge areas and provides applicative results (e.g. a more efficient management of pedestrian circulation in public spaces). The multi-disciplinary approach that we propose is based on the integration between:

- Socio-Psychological perspectives about: groups[1], the basic elements which the crowd is composed of, and proxemics [4], chosen as an analytical indicator of spatial behavior dynamics within the crowd;
- Multi-Agent System simulation technique [5].

In analogy with territorial behavior in animals [6], proxemics [4] is defined as a type of nonverbal communication that conveys information about the nature of participants' relationship, by means of the dynamic regulation of interpersonal distances[2]. In situations of high density, the invasion of personal space [7] is strictly linked with crowding [8], a negative subjective state typically associated with: psycho-physiological responses of arousal and stress, cognitive performance decrements, and aggressive response.

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[1] A group can be defined as two or more people who interact for a shared goal, perceiving a membership based on a shared social identity [3].

[2] The regulation of spatial distances (intimate, personal, social, and public distances) is influenced by age, gender, culture, and personality [7].

In Computer Science, a Multi-Agent System is defined as a system in which multiple entities, called agents, interact in a shared environment, aimed to achieve some individual or collective goals [9]. The Multy-Agent System are useful approach in modeling and simulation of pedestrian and crowd dynamics [5], by means of the representation of crowd as a system of heterogeneous agents.

We propose a methodological approach that includes studies already performed (1, 4), and on-going works (2, 3):

1. Observations of proxemic behavior of walking groups, focusing on: spatial arrangement (degree of alignment and cohesion), walking speed, level of density, group size and gender;
2. Experimental investigation on size and shape of pedestrian personal space
3. Experimental investigation on the capability of group proxemic behavior to reduce the effects of crowding
4. Design what-if scenarios about pedestrian proxemic behavior by means of a simulation tool.

Group Pedestrian Behavior

Group proxemic behavior reveals the psychological relationship among the group members [10]; in motion situation, it generates typical patterns, which allow communication and spatial cohesion among members during the movement [11], in relation to the level of density[3]. At low density, group members tend to walk side by side, forming a line perpendicular to the walking direction (line-abreast pattern); as the density increases, the linear walking formation turn into a V-like pattern, with the middle individual positioned slightly behind in comparison to the lateral individuals; in situation of high density, the spatial distribution of group members leads to a river-like pattern and lane formation, characterized by the presence of a leader that coordinates the group members to cross the space [12]. To further investigate proxemic behavior of walking groups in real social context, we performed the observation of the incoming pedestrian flow to the admission test of the Faculty of Psychology at the University of Milan-Bicocca in September 1, 2011 (about two thousand students attended the test). The observation was aimed at gathering empirical data, by means of a people counting activity supported by video footages of the event[4]. The survey was focused on: percentage of groups within pedestrian flow[5]; relationship between walking speed and group size, group spatial arrangement, gender of members; level of density and level of service; lane formation and queues. Data analysis shows that more than the 65% of the incoming flow was composed of groups (77% couples, 19% triples, 4% larger groups). Moreover, a one-way analysis of variance (ANOVA) showed that the size of groups affects walking speed in situation of medium density ($p < 0{,}05$). More in detail, the differences in walking speed between singles and couples, singles and triples, couple and triples, were confirmed by a T-test analysis ($p < 0{,}01$). No significant differences in walking speed were detected in reference to spatial arrangement and gender composition ($p > 0{,}05$).

Pedestrian Personal Space

Personal space is traditionally defined as a circular area surrounding individuals, whose size varies depending on subject head orientation and visual mechanisms [13]. Pedestrian personal space is assumed to be different from the one in static situation, because of the need to reserve additional margins in the front zone to avoid collision with obstacles, and visual mechanism of eye convergence [14]. For these reasons, the front zone is assumed to be larger than the one in static situation, and the lateral zones are assumed to be smaller than the ones in static situation. We propose to use the “stop-distance” procedure [13], designed between subjects (60 subjects): 2

[3] Proxemic behavior of walking group is related to group size, and the features of the members among gender and age [12].

[4] The use of people tracking tools although is a useful contribution in detecting spatial movements of pedestrian within the crowd, it is not enough calibrated to recognize proxemic indicators among group members.

[5] The identification of groups in the streaming of passers-by was assessed considering verbal and non-verbal communication indicators.

groups composed of 30 subjects for each modality of the independent variable "state of movement of the subject" (subject stationary or subject walking straight ahead); the dependent variable "size" of pedestrian personal space will be deduced from the "stop-distance" requested by the subject in the moment of the perceived discomfort related to spatial invasion. The procedure will be conducted in a laboratory setting, and it will employ digital video-recording equipment for data analysis.

Group Proxemic Behavior and Crowding

Group proxemic behavior reveals the psychological relationship among members and, in static situations, it can mitigate the effects of crowding, by producing spatial boundaries that shield group members from unwanted physical interactions [8]. Starting from these assumptions, typical spatial patterns of walking groups are assumed to be an adaptive stress-reducing behavior to crowding by maintaining group cohesion, increasing inter-group distances and rising intra-group capability to communicate. In relation to the modalities of the independent variables "belonging to a group" and "state of movement of the subject" (2x2), the experimental procedure will be designed between subjects (120 subjects), with 4 groups composed of 30 subjects for each modalities. Following the standard procedure for crowding measurement [8], the subjects will be taken into a room for 30 minutes, as a short-term exposure to high-density situation (4 persons for m^2); crowding will be deduced as dependent variable, and it will be measured by means of the level of the salivary cortisol, which is an accurate indicator of endocrine activity and crowding [8, 15].

Proxemic Behavior: Modeling and Simulation

In order to support the design of what-if scenarios related to pedestrian dynamics, we use a software simulation platform, based on Multi Agent System technique, developed by CSAI [16]. The tool represents the environment of the scenario, imported as CAD file, as discretized into squared cells of 40x40 cm (the typical space occupied by a pedestrian in high density situations), in which the groups of pedestrians are driven by behavioral and perception rules. The agents are able to perceive and avoid spatial elements that represent obstacles and other agents, and to move toward their targets. The agents are also able to recognize those that belong to their group, and to behave according to proxemic behavioral parameters about: group cohesion (stay closed its group members reaching their targets), invasion of personal space (preserve a certain distance from other pedestrians, which belong to a different group). These rules are based on several behavioral rules about proxemics, which have to be calibrated starting from existing and known empirical data, and by means of the empirical results achieved by observation and experimental procedures (e.g. the typical patterns of walking group, the size of pedestrian personal space and the spatial cohesion among group members to avoid crowding).

Discussion

The innovative approach that we propose consists of a first phase of modeling and calibration by using empirical data, and a second phase of performing simulations. The results collected by means of the observation already performed, and data, which will be achieved by means of the on-going experimental procedures, will be used to improve the simulation model. In particular, a more detailed definition of the perceptive capabilities and behavioral specifications of each agent will be performed, in relation to their interpretation of the other elements in the system (e.g., agents, objects, obstacles). Although there are some objections about the simplified level of correspondence between simulations and real phenomena, we propose to use simulations as a method to study complex system from a different layer of abstraction, and as a virtual experimental laboratory to study those scenarios which are difficult to be empirically investigated (such as evacuation processes of a crowd in case of emergency). Simulations produce a series of statistical data, that can be analyzed and interpreted, and that can lead to further empirical investigations. The methodological approach that we have proposed can be synthetically represented as a "virtuous cycle" composed of three main parts: research in vivo (observations), in vitro (experimental procedures) and in silicon (modeling and simulations). The results achieved by means of empirical investigations and simulations of what-if scenarios can be useful to support the design of applicative strategies related to a more efficient management of pedestrian circulation dynamics.

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